CORRESPONDENCE

The Editor,

Journal of Glaciology

SIR, *Melting at the ice–water interface, "Little America" station*

In a recent article, Shumskiy and Zotikov (1963) re-interpreted the ice regime figures I observed at "Little America" station in 1957 and 1958 (Crary, 1961), obtaining a value of annual melting from the ice–water interface of 29·7 cm., compared with my original value of 80 cm. Although in later reports based on ice regime inland from "Little America" station (Crary and others, 1962) and direct measurements in 1961 (Crary and Chapman, 1963), my original value was reduced to about 60 cm., the difference from that obtained by Shumskiy and Zotikov warrants an examination of their figures. I refer only to values deduced from the regime equation rather than from the temperature profile, since their interpretation of the latter is based on assumptions of accumulation and melt values inland which are difficult to verify without direct measurements. In retrospect, the value of 60 cm. bottom melt in my original equation fits the temperature profile much better than 80 cm., the latter being based mainly on temperature gradients.

Shumskiy and Zotikov assume there is no change in density with distance or time, i.e. $\partial\rho/\partial x = 0$ and $\partial\rho/\partial t = 0$, which, with the x-axis taken at sea-level is not at all realistic. If, on the other hand, the x-axis is taken at the shelf surface, the assumptions mean that the density profile is invariant with time and distance, and any change in the shelf thickness would result from changes in the thickness of constant-density ice in the lower part of the column. This would be the case if the thickness changes were due to melting only, but these changes are due also to ice creep and variations in the density profiles. The only field data available are the ice thickness–elevation relations in this area, given in figure 12 of Crary (1961) and figure 14 of Crary and others (1962). Over large areas of the Ross Ice Shelf the ratio of changes of total thickness of the ice shelf H with those in elevation above sea-level h, dH/dh, is about 9, while in the "Little America" area the value is close to 6, and this latter figure was used in my calculations of ice regime.

For the mass balance, assuming no change in density profile with distance or time, and ice shelf equilibrium, Shumskiy and Zotikov show annual accumulation of $+23\cdot7$ g. cm.$^{-2}$, strain of $-45\cdot8$ g. cm.$^{-2}$ and supply by movement of $+49\cdot2$ g. cm.$^{-2}$, leaving $-27\cdot1$ g. cm.$^{-2}$ for bottom melt. I agree generally with their accumulation and strain values but not the supply of ice by movement. This was determined by $u\left(\frac{\rho_w}{\rho_w - \rho}\right)_b \rho_s \tan\alpha$ where u is the annual forward movement of the ice sheet, 255 m.; ρ_w the density of water, $1\cdot028$ g. cm.$^{-3}$; ρ_s the density of surface snow, $0\cdot354$ g. cm.$^{-3}$; ρ_b the density of ice at the bottom, $0\cdot913$ g. cm.$^{-3}$, and $\tan\alpha$ the surface slope with reference to sea-level, $6\cdot1\times10^{-4}$. I contend that the contribution by movement should be represented by $6u\bar{\rho}\tan\alpha$ where $\bar{\rho}$ is the average density of the ice column, $0\cdot849$ g. cm.$^{-3}$. Substituting values in this relation gives 79 g., which with the values of accumulation and strain above shows a balance of 57 g. annual bottom melt.

In translating the regime to rates of annual thinning of the ice shelf, Shumskiy and Zotikov give accumulation of $66\cdot9$ cm., thinning due to extension of $50\cdot2$ cm., thinning due to densification of $50\cdot5$ cm., and supply of ice by movement of $63\cdot5$ cm., leaving $29\cdot7$ cm. for bottom melt. Again I agree generally with the accumulation and extension values, but contend that neither the densification nor supply by movement are realistic. The formula given by Shumskiy and Zotikov for densification is $w_s \frac{\rho_b - \rho_s}{\rho_b}$ where w_s is the annual vertical movement of the ice at the surface relative to sea-level, $-82\cdot5$ cm., and the densities are as given above. I would prefer a densification determined by $\frac{a_s}{\rho_s}\frac{\bar{\rho} - \rho_s}{\bar{\rho}}$ where a_s is the annual accumulation, $23\cdot7$ g. cm.$^{-2}$ yr.$^{-1}$. This gives 39 cm. instead of $50\cdot5$ cm. Shumskiy and Zotikov contend that my original value of regime omitted the densification but in fact, by using 24 cm. of ice for annual accumulation, I included 43 cm. of densification. For supply of ice by movement, Shumskiy and Zotikov give $u(\tan\alpha - \tan\beta)$, but the values of $\tan\beta$, the bottom slope referred to sea-level, was not given. This should be $-5\tan\alpha$ in order to make the thickness–elevation ratio equal to 6 as obtained from field measurements. Using this value of $\tan\beta$ in the above equation

gives 93 cm. instead of 63·5 cm. obtained by Shumskiy and Zotikov. Using these new values, the annual bottom melt would be about 67 cm.

It is interesting to note that if the density profile relative to the surface is invariant, making dH/dh about 9, then the bottom melting as calculated above would be about 113 cm.

The remeasurements made at "Little America" station in 1961 confirmed the order of annual change in elevation of the moving ice sheet: 63 cm. decrease over a 4·2 yr. period or 15 cm. yr.$^{-1}$, and the absolute velocity: 309 m. yr.$^{-1}$. These two directly measured values strengthen the contention of ice shelf equilibrium and hence the deduced annual bottom melting of about 60 cm. It is hoped that in the future added drill holes can be made for other vertical temperature profiles, particularly along the ice-shelf flow lines. It would be interesting also to have comparative regime figures for such ice shelves as Larsen, West or Amery where the higher annual temperatures should result in considerable difference in the strain values, net accumulation and perhaps in bottom melting. In the overall regime figures for Antarctica, as Shumskiy and Zotikov point out, the shelf bottom melting is an important factor, and more observations, indirect or direct, would be most helpful.

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SIR, *Long-term ice flow study*

This notice is submitted in order to place in a permanent, accessible form the record of an ice flow experiment whose completion is not expected until many years hence when the present generation of glaciologists will have passed away. Site of this experiment is the Blue Glacier on the northern flanks of Mt. Olympus, located on the Olympic Peninsula of western Washington State, U.S.A. (lat. 47° 48′ N., long. 123° 42′ W.).

On 9–10 September 1963, 32 markers were placed on the firn surface of the two Blue Glacier accumulation basins. Details of the marker construction and placement are shown in Figure 1. Their locations are shown on the sketch map of the accumulation zone of Blue Glacier in Figure 2. The markers are numbered 1 through 19 (s = 37 cm.), and 21 through 33 (s = 56 cm.). Marker No. 20

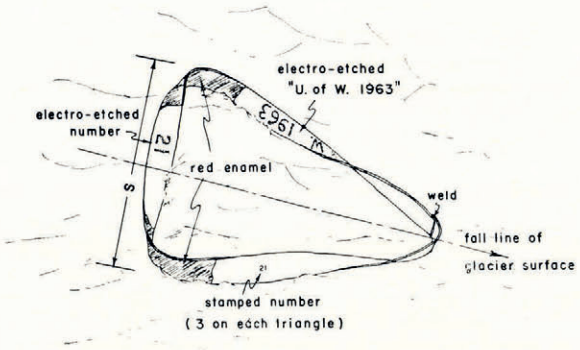

Fig. 1. Blue Glacier long-term ice flow marker. See text for further details