CORRESPONDENCE

The Editor,

Journal of Glaciology

Sir, *Regime of the Ross Ice Shelf, "Little America" station*

In a letter to you, Crary (1964) has discussed our calculation of the regime of the Ross Ice Shelf (Shumskiy and Zotikov, 1963[b]), and disagreed with part of it. The main difference between Crary's conclusion and ours arises from our assumption that ice density is constant along the horizontal x-axis in the direction of ice movement. Crary's data which we used did not include information on this density gradient and so we assumed $\partial\rho/\partial x = 0$.

We subsequently found that the density gradient could be evaluated using Crary's value for the tangents of the angles of bottom slope (β) and surface slope (α):

$$\tan\beta = -5\tan\alpha = -3\cdot 05 \times 10^{-3}.$$

From the equation of hydrostatic equilibrium, equation (5) in Shumskiy and Zotikov (1963[a]), it follows that

$$\int_{z_s}^{z_b} \frac{\partial\rho}{\partial x} dz = \rho_s \tan\alpha + (\rho_w - \rho)_b \tan\beta = -1\cdot 35 \times 10^{-4}\ \text{g. cm.}^{-3}.$$

Thus, due to melting of the dense bottom ice, the average ice-shelf density is appreciably decreasing towards the edge, and this completely changes the result of the calculation. Because of this the ice-shelf bottom slope is also $1\cdot 6$ times steeper than in the case of constant density.

Substituting the observed value for the density gradient into equation (10) in Shumskiy and Zotikov (1963[a]), we obtain results that are as follows: bottom melting rate $a_b = -57\cdot 8$ g. cm.$^{-2}$ yr.$^{-1}$, $a_b/\rho_b = -63\cdot 3$ cm.yr.$^{-1}$, supply of ice by movement

$$u\left[\rho_s \tan\alpha - \rho_b \tan\beta - \int_{z_s}^{z_b} \frac{\partial\rho}{\partial x} dz\right] = u\left[\frac{\rho_w}{\rho_w - \rho}\right]_b \left[\rho_s \tan\alpha - \int_{z_s}^{z_b} \frac{\partial\rho}{\partial x} dz\right] = 79\cdot 9\ \text{g. cm.}^{-2}\ \text{yr.}^{-1},$$

and $u(\tan\alpha - \tan\beta) = 93\cdot 4$ cm. yr.$^{-1}$. The small differences from Crary's results are due to the fact that Crary used the average density in his approximate formulae.

In connection with this some results of thermal regime calculations in our previous papers ought also to be changed. Calculated temperature values obtained using the changed values of the bottom melting rate and of the Pecle number ($Pe = 7\cdot 55$) are shown in Table I.

Table I. Recalculated Temperature Distribution in the Ross Ice Shelf at "Little America" Station

Depth	m.	25·7	51·4	77·1	103	128·5	154	180	206	231
Temperature	°C.	−23·2	−23·1	−22·9	−22·6	−21·8	−20·7	−18·6	−15·4	−9·8

Our attempt to evaluate changes of bottom melting rate with distance from the ice shelf edge was based on the assumption of constant water temperature under the ice shelf. New data by Zumberge (1964) are contrary to this assumption, showing a much greater gradient of bottom melting rate.

We cannot agree with Crary's other comments. Our assumption that density is constant with time ($\partial\rho/\partial t = 0$), is the necessary condition for a steady state, as found by Crary, and discussion about an ice shelf changing its thickness only as a result of bottom melting and without ice creep and density gradients has no relation to the case we considered.

Our method of calculation is based on integration of the continuity equation having regard to the real boundary conditions at the surface and bottom of an ice shelf (Shumskiy and Zotikov, 1963[a]).

The two equations used take into account all possible changes in a steady ice shelf, considered as a continuum, at a given point. They are:
for mass changes

$$\overset{1}{a_s} + \overset{2}{a_b} + u\left[\overset{3}{\rho_s \tan\alpha} - \overset{4}{\rho_b \tan\beta} - \overset{5}{\int_{z_s}^{z_b} \frac{\partial \rho}{\partial x}\, dz}\right] - \overset{6}{\left[\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right] \int_{z_s}^{z_b} \rho\, dz} = 0$$

$$23{\cdot}7 - 57{\cdot}8 + 5{\cdot}5 + 71{\cdot}0 + 3{\cdot}4 - 45{\cdot}8 = 0 \text{ g. cm.}^{-2}\text{ yr.}^{-1}$$

for thickness changes

$$\overset{1}{\frac{a_s}{\rho_s}} + \overset{2}{\frac{a_b}{\rho_b}} + u\left[\overset{3}{\tan\alpha} - \overset{4}{\tan\beta} - \overset{5}{\frac{1}{\rho_b}\int_{z_s}^{z_b} \frac{\partial \rho}{\partial x}\, dz}\right] - \overset{6}{\frac{1}{\rho_b}\left[\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right] \int_{z_s}^{z_b} \rho\, dz} - \overset{7}{\frac{\rho_b - \rho_s}{\rho_b} w_s} = 0$$

$$66{\cdot}9 - 63{\cdot}3 + 15{\cdot}6 + 77{\cdot}8 + 3{\cdot}7 - 50{\cdot}2 - 50{\cdot}5 = 0 \text{ cm. yr.}^{-1}$$

Every term of the equation has a number placed above it and also has its value at the particular point on the Ross Ice Shelf given beneath it. Each term in the first equation corresponds to the term with the same number in the second equation, except that there is no term No. 7 in the first equation because this term of the second equation expresses the rate of total ice thickness decrease due to densification of ice without change of mass.

Crary does not consider mass and thickness changes due to movement and density gradient (term No. 5 in both equations) and prefers to determine the rate of thinning due to densification as $\frac{a_s}{\rho_s}\frac{\bar{\rho}-\rho_s}{\bar{\rho}} = 39$ cm. yr.$^{-1}$. But the ice-shelf thinning due to densification is the sum of the thinning of all its individual strata. Our method may be applied to any layer within the ice shelf, or to the sum of layers, whereas Crary's method is not applicable to inner layers because of his use of the factor a_s/ρ_s, and it underestimates vertical density gradient because $\bar{\rho}$ replaces ρ_b.

Soviet Committee on Antarctic Research,
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24 August 1964

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Sir,

Movement of stones under snow cover

Movement of loose stones over bedrock surfaces below a cover of snow, such as described from Mount Twynam (Costin and others, 1964), is characteristic of the area adjacent to the glacier Østerdalsisen, in Norway (lat. 66° 31′ N., long. 14° 06′ E.). Stones are moved down slope on the bare rock which lies