Ice movement and mass balance at the Allan Hills Icefield

LUDOLF SCHULTZ

Max-Planck-Institut für Chemie
Mainz, Germany

JOHN O. ANNEXSTAD

Bemidji State University
Bemidji, Minnesota 56601

GEORG DELISLE

Bundesanstalt für Geowissenschaften und Rohstoffe
Hannover, Germany

The Allan Hills Icefield in Victoria Land has so far yielded more than 1,700 meteorite specimens. In an attempt to provide a quantitative measure of ablation and ice flow, a triangulation network across the icefield was established in 1978 (see figure 1). Two baseline stations are located on bedrock of the Allan Hills. Eighteen additional stations define a grid which extends 13 kilometers westward and across the area with the high meteorite concentration. The grid was remeasured in 1979 (Nishio and Annexstad 1980) and 1981 (Schultz and Annexstad 1984) and revisited during the 1988–1989 austral summer. In addition, a radio echo sounding survey from the Allan Hills Icefield to the Mid Western Icefield* was carried out in 1988-1989 to determine bedrock topography (Delisle, Sievers, and Schultz 1989; Delisle and Sievers in press).

In 1981 and 1988, the angles within the network were measured with a precision theodolite (Wild T2). An infrared distance meter (Wild DI4L) was used to measure distances between grid points. This technique and the long lapse of the 7 years between the two measurements made it possible to determine direction and horizontal velocity of the ice flow with much higher precision than at any previous time (e.g., uncertainties of the ice velocity and direction of the most westerly station are ± 8 centimeters per year and 8°, respectively.)

Ablation rates are obtained by comparing the heights of a stake measured in different years. The mean annual ablation rate, measured in 1988, of about 4.5 centimeters per year is comparable to those measured in previous years (Annexstad and Annexstad 1989). There is, however, a wide diversity between individual stations, and there are indications that the annual ablation may take place on a few days with high temperatures (Delisle and Sievers in press).

The horizontal ice movement of the individual stations is given in figure 1. At the most westerly stations, the ice moves about 60 centimeters per year in an almost northern direction, roughly parallel to the ice stream between the Allan Hills and

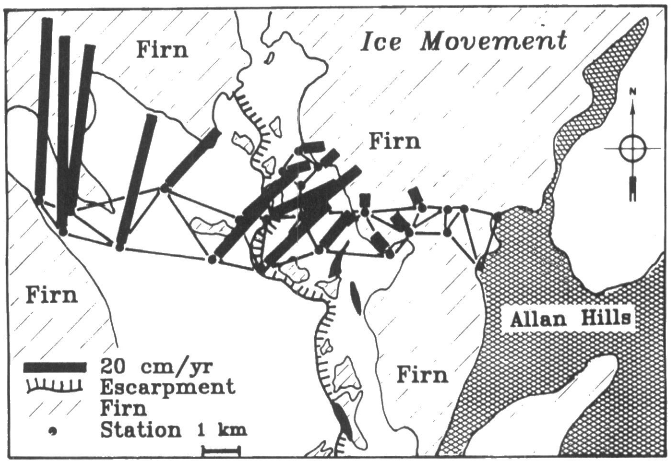

Figure 1. Direction and horizontal ice velocity of ice as measured along the triangulation grid across the Allan Hills Icefield. (km denotes kilometer. cm/yr denotes centimeters per year.)

the Near Western Icefield which advances northwards in a more than 1,200-meter deep depression toward the Mawson Glacier (Delisle et al. 1989; Delisle and Sievers in press). Close to the escarpment the flow of ice is in a northeast direction. The ice velocity drops here to about 25 centimeters per yer. East of the escarpment, a small valley has developed. Most of the meteorites are found here and ice velocities drop to less than 8 centimeters per year. From the radio-echo sounding data, it is known that this valley is not caused by bedrock topography. Meteorological processes seem to be a likely explanation (Cresswell 1988).

It should be noted that meteorites found on icefields west of the south-north ice stream will never be transported to the Allan Hills Icefield. It is suggested that a minor portion of the ice of the south-north ice stream flows onto the high plateau of the Allan Hills Icefield and, finally, drops into the high ablation zone to the east of the escarpment (figure 1) and deposits there meteorites.

In an attempt to model the ice flow of the high plateau of the Allan Hills Icefield, we have used the following models:

- Case a: A 2-D-ice sheet with a thickness of 400 meters (alternatively 300 meters and 500 meters) and a length of 5 kilometers (figure 2, block a) is exposed at its surface to a constant ablation rate of 5 centimeters per year from $x=0.5$ kilometers to 5 kilometers.
- Case b: A linearly increasing ablation rate from a value of 3.5 centimeters per year at $x=0.5$ kilometer to 5.2 centimeters per year at $x=5$ kilometers is used. The underlying assumption in latter case is that of an ablation rate dependence on the effectiveness of the foȟn wind, which should increase with drop of elevation.

An ice thickness of 400 meters corresponds roughly with the measured value at the western border of the Allan Hills Icefield. The change of surface elevation and the shear stress within the ice are each calculated as a function of time; the horizontal and vertical ice velocities are each calculated as function of depth and the internal temperature field in the ice body. Subice topography, as measured at the Allan Hills, is not included in this model. We take advantage of the fact that the dominant driving force of ice movement is given by surface slope.

Our ice velocity measurements suggest that about 90 percent of the mass loss from the high plateau of the Allan Hills Icefield

* The designations "Far Western Icefield," "Mid Western Icefield," "Near Western Icefield," and "Main Icefield" are not official names, but the features are distinct geographic units.

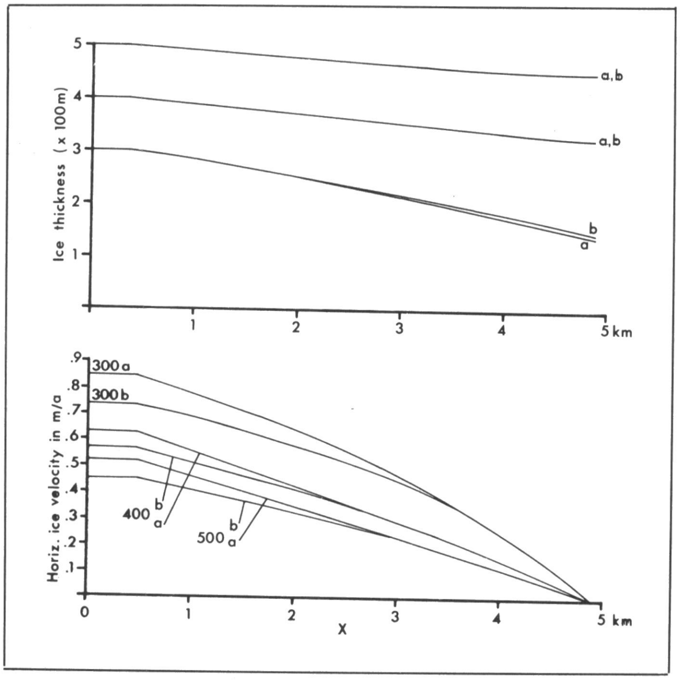

Figure 2. A. Numerical model on ice flow in 2-D for a 5-kilometer long and 400-meter (alternatively 300-meter and 500-meter) thick ice slab exposed to ablation at the ice surface. Shown is the calculated elevation drop, which for a 400-meter or 500-meter thick ice sheet is the same within ± 1.5 meter for constant (A) and linearly increasing (B) ablation. Ablation loss is 225 cubic meters per year per 1-meter slab width (A) or 196 cubic meters per year (B). Integration of horizontal velocity over height shows that in both cases mass losses by ablation are compensated. Horizontal ice flow in the case of a 300-meter thick ice sheet, however, is unable to adjust within 5,000 years to make up the ablation losses. As a consequence, surface slope steadily steepens within this time period. B. Horizontal velocity distribution for all cases. (km denotes kilometer. m/a denotes meters per year. m denotes meter.)

is due to ablation and only 10 percent due to ice flowing across the escarpment. We believe, therefore, that our model describes in a good approximation the actual mass transfer and mass balance on the high plateau.

We make use of ice-rheological parameters and basic equations given in Nye (1952) and Paterson (1981) and a computer code as described in Delisle (1989). Ice-rheological parameters have been calculated for a mean annual temperature at the ice surface of −25 °C and a heat flow value of 60 milliwatts per square meter from below.

The left side of the model ice sheet resembles in nature the boundary between the Allan Hills Icefield and the ice stream to the west. This is equivalent to the assumption of an unchanged ice level of the ice stream at least during the last few thousand years. The consequences of an ice level changing in time are pointed out below.

The calculations show a quasi-stationary ice slope profile develops for an initially 400-meter thick ice sheet within about 2,200 years. Ice flowing from the ice stream towards the east (to right hand side in figure 2) is balanced by the ablation losses. The calculated total drop of ice level for case a is 76 meters (case b: 74 meters), which compares well with the measured drop of about 75 meters in the field (Delisle and Sievers in press). The ice velocity given by the model are in general agreement with the measured values (compare figure 1 and figure 2, block b).

Given a 500-meter thick ice sheet (which on the basis of our calculations would acquire equilibrium within about 1,600 years) total drop of ice surface for case a would only be 51 meters (case b: 49 meters). Alternatively, a 300-meter thick ice sheet would not reach equilibrium even after 5,000 years despite an elevation drop of then more than 160 meters for case a (case b: 150 meters) acquired at that time (figure 2, block a).

The results of our analysis are compatible with the assumption of essentially unchanged ablation rates on the Allan Hills Icefield for at least 2,500 years and confirm the dependence of the ice budget of the Allan Hills Icefield on the ice level of the ice stream to the west and—equally important—on the ablation rate.

A only modest ice level rise of the ice stream would effectively decrease horizontal ice velocities and decrease surface slope on the icefield at the same time (see figure 2). This is seemingly a contradiction, but one has to keep in mind that a thicker ice sheet— due to the larger mass involved—can compensate mass losses more effectively by compressive ice flow. One might speculate that a reduced ice slope might cause less ablation due to decreasing fhn winds, whose force depends on slope. Fewer meteorites would then be uncovered across the icefield. Presumably an ice fall would develop at the escarpment to the east. A fall of the ice level of the ice stream (i.e., 300 meters), however, would even increase surface slope and horizontal ice flow. Nevertheless, ice would then eventually be unable to move across the escarpment. The effectiveness of the Allan Hills meteorite trap would even increase as it would develop into the same trap type as exists at Lewis Cliff today.

With the results of this model in mind one wonders through what changes the Allan Hills meteorite trap might have gone during the climatic changes of the last 1 million years.

References

Annexstad, J.O., and K.M. Annexstad. 1989. Extension of the Allan Hills triangulation network system. *Smithsonian Contributions to the Earth Sciences*, 28, 17–22.

Cresswell, R.G. 1988. Meteorite concentrations in Antarctica: Sites of katabatic ablation? *Geophysical Research Letters*, 15, 342–345.

Delisle, G. 1989. Genesis of subglacial channels in northern Europe during glacial stages. *BGR-Report*, Archiv Nr.: 105 505, Hannover. (In German)

Delisle, G., and J. Sievers. In press. Subice Topography and Meteorite Finds near the Allan Hills and the Near Western Icefield, Victoria Land, Antarctica. *Journal of Geophysicl Research*.

Delisle, G., J. Sievers, and L. Schultz. 1989. Radio-echo sounding Survey across the Allan Hills Icefield. *Antarctic Journal of the U.S.*, 24(5), 50–52.

Nishio, F., and J.O. Annexstad. 1980. Studies on the Ice Flow in the Bare Ice Area near the Allan Hills in Victoria Land, Antarctica. *Memoirs of the National Institute of Polar Research (Japan)*. Special Issue, 17, 1–13.

Nye, J.F. 1952. The mechanics of glacier flow. *Journal of Glaciology*, 2, 82–93.

Paterson, W.S.B. 1981. *The physics of glaciers*, (2nd edition). Oxford: Pergamon Press.

Schultz, L., and J.O. Annexstad. 1984. Ablation and ice movement at the Allan Hills Icefield between 1978 and 1981. *Smithsonian Contributions to the Earth Sciences*, 26, 17–22.