GLACIOLOGY

Creep Tests on Antarctic Glacier Ice

The strain rate of polycrystalline ice is known to depend on the applied stress, the temperature and the orientation of crystals in the specimen. From laboratory creep tests on randomly oriented ice, Glen[1] derived the simple flow law

$$\dot{\varepsilon} = k\sigma^n$$

where $\dot{\varepsilon}$ is the strain rate, σ is the stress, and k is constant for a given temperature. Other workers have confirmed the validity of this relationship for the stress range 2–15 bars. From observed minimum strain-rates Glen[1] deduced $n = 3 \cdot 17$; but he considered that a value of 4·2 derived from analysed quasi-viscous creep-rates was a more correct one for randomly oriented ice. Some observations on glacier tunnel deformation tend to confirm Glen's higher value for the exponent[2], whilst the closure of a bore-hole in the Greenland ice-cap gave an exponent of 3·77[3]. Other laboratory tests on glacier and commercial ice of high density gave figures ranging from 2·42 to 3·53 with a mean of 2·96[4]. Weertman's dislocation climb theory[5] calls for a dependence on stress to the power 4·5. Below a stress of 1 bar the flow mechanism is different and there is an approximation to viscous behaviour, with an exponent of about 1·5 applying.

As part of the International Geophysical Year work of the Australian National Antarctic Research Expeditions I, as the latter's glaciologist, conducted compression creep tests in the stress range 2–15 bars on randomly oriented antarctic ice at a temperature of —30°C. This ice is characterized by the inclusion of air under pressure in small (about 0·6 mm. diameter) bubbles, the density of the ice tested being approximately 0·87 gm./cm.[3]. The exponent n for flow of this ice was found to be 4·2, suggesting that the cellular structure does not significantly alter the power in the relation between strain rate and stress.

Glen[1] also gave a relationship between strain-rate and temperature for a stress of 6 bars in the temperature range —1.5 to —13°C., assuming that the following equation holds :

$$\dot{\varepsilon} = A \exp\left(\frac{-Q}{RT}\right)$$

where A is a constant for a given stress, R the gas constant, Q the heat of activation and T the absolute temperature. Extrapolation of Glen's inverse linear relationship indicates that the value of the coefficient k in the flow law would be about 2×10^{-5} at —30°C., and Steinemann's[6] quasi-viscous creep-rates at a stress of 6 bars seem to confirm this figure. My results give $k = 5 \times 10^{-4}$ at —30°C., more than an order of magnitude larger. This indicates that the presence of numerous small air bubbles leads to easier deformation at a given stress and temperature. Under a stress of 6 bars the strain-rate of the bubbly ice at —30°C. was equal to the strain rate of the ice used by Glen at —10°C.

Full details of the tests are given in an A.N.A.R.E. Interim Report to be published by the Antarctic Division, Department of External Affairs, Australia.

I gratefully acknowledge the help of the Commonwealth Aeronautical Research Laboratories, Melbourne, in lending a creep machine and thank Peters Ice Cream Ltd. for the use of a cold room.

MALCOLM MELLOR

Meteorology Department,
University of Melbourne.

[1] Glen, J. W., *Proc. Roy. Soc.*, A, **228**, 519 (1955).
[2] Nye, J. F., *Proc. Roy. Soc.*, A, **239**, 113 (1957).
[3] Hansen, B. L., and Landauer, J. K., Symposium de Chamonix, Physique du mouvement de la glace, International Union of Geodesy and Geophysics, International Association of Scientific Hydrology, Gentbrugge (1958).
[4] Butkovich, T. R., and Landauer, J. K., Symposium de Chamonix (1958).
[5] Weertman, J., *J. App. Phys.*, **28**, 362 (1957).
[6] Steinemann, S., Symposium de Chamonix, etc. (1958).

METEOROLOGY

Nitrogen Content of Rain Water collected in the Humid Central Congo Basin

It has been frequently assumed that in equatorial regions rain-water nitrogen was an important entry in the balance sheet of this element, and a great deal of speculation about this appears in the literature.

From April 1958 until March 1959 inclusive, rain water was collected in Yangambi, in standard rain-gauges, and systematically analysed for inorganic nitrogen. During the first four months, analyses were made after each separate downpour, later only once a month, the collected water being kept in stoppered bottles to which mercuric chloride had been added in order to prevent microbiological action.

Ammonia nitrogen was determined by Nessler reagent on a distillate, using ammonia-free water and 5N sodium hydroxide. Nitrate nitrogen was determined on the distillation residue (Devarda's alloy, distillation, Nesslerizing of the distillate) whereas nitrous nitrogen was determined colorimetrically by Griess's method. This last determination was made only during the first few months.

During the period under observation a total rainfall of 1·546 mm. was collected. This is lower than the mean total average for the area which is 1·842 mm. The total amount of nitrogen brought down by this rain amounts to 5·371 kgm. per hectare, 3·167 kgm. of it being ammonia nitrogen. Nitrous nitrogen did not exceed 3 per cent of the nitric nitrogen.

These amounts are very small, and as ammonia originates mainly in the soil itself (there are no industries near the site of collection), the net amount of inorganic nitrogen gained is of doubtful significance for agriculture and for the nitrogen balance of the arable soil.

Table 1 gives the results obtained on separate downpours during the months of May and June.

TABLE 1

Date	Rainfall (mm.)	Nitrogen p.p.m. as	
		nitrate and nitrite	ammonia
5–5–1958	9·2	0·07	0·50
12–5–1958	25·3	0·13	0·51
16–5–1958	17·0	0·15	0·60
21–5–1958	6·9	0·42	1·18
22–5–1958	1·1	0·56	0·78
25–5–1958	35·6	0·03	0·03
2–6–1958	20·0	0·24	0·43
6–6–1958	4·5	0·33	0·86
7–6–1958	9·7	0·12	0·39
10–6–1958	43·7	0·09	0·06
12–6–1958	3·1	0·25	0·42
21–6–1958	29·6	0·15	0·11
28–6–1958	11·6	0·20	0·18
29–6–1958	6·9	0·27	0·62

It will be noted that there is some connexion between quantity of water collected and its nitrogen content : the smaller the downpour, the higher the concentration, especially of ammonia.