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# THE ROLE OF DEBRIS-RICH ICE IN FLOW NEAR THE MARGINS OF GLACIERS

## (Abstract)

by

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## ABSTRACT

The margins of many ice sheets and ice caps are marked by the presence of alternating layers of debris-laden and clean ice. The role of this ice in flow and sediment transport near the margins of glaciers has been the subject of considerable controversy between glacial geologists and glaciologists for over three decades.

Glacial geologists (Goldthwait, 1951, 1960, 1971, 1975; Bishop, 1957; Souchez, 1967, Boulton, 1970, 1972; Hambrey, 1976) commonly refer to the debris-bearing ice bands as "thrust planes" or "shear planes", apparently seeing them as reverse faults which transport rock debris from the glacier bed to the surface in a "conveyor-belt-like" manner (Goldthwait, 1975, p. 192). As supporting evidence for the shear-plane mechanism, glacial geologists have offered only qualitative observations and none seem to have actually observed it in action. Glaciologists on the other hand, particularly Weertman (1961), Hooke (1968; 1973), and Hooke and Hudleston (1978), have objected to this concept on physical grounds and have presented convincing arguments for doubting that it is mechanically sound. In spite of the controversy surrounding it, the shear-plane mechanism has gained wide acceptance among geologists and physical geographers and has been perpetuated in recent years through a number of popular introductory geology and physical geography textbooks (e.g. Embleton and King, 1975; Judson, Deffeyes, and Hargraves, 1976; Leet, Judson, and Kauffman, 1978; Press and Siever, 1982; Hamblin; 1982).

### Testing the shear-plane hypothesis

The basic rationale requiring faulting in the shear-plane model was the notion that a stagnant wedge of ice exists at the margin of many polar glaciers and that this wedge is overridden by the active, main body of the glacier along discrete thrust planes. A quantitative test of the shear-plane hypothesis requires a thorough understanding of the rheology of debris-laden ice, as layers of this ice are envisioned as the zones of weakness along which faulting occurs. Consequently, field investigations were conducted on the Barnes Ice Cap, Baffin Island, N.W.T., Canada, where a 20 m tunnel was excavated into the glacier margin in a zone marked by alternate layers of clean and debris-laden ice. In one wall of the tunnel, eight square-strain nets were set by freezing wooden pegs into the glacier. Over a two-year period, the lengths of the sides and diagonals of these nets were measured, using the technique and measuring instrument described by Hooke (1973). Lengths were recorded to the nearest 0.1 mm and reproducible to about ±0.3 mm. The median error in measurement, calculated by the method of Hooke (1973), was 0.4 mm.

For each tunnel strain net, the principal strain rates $\dot{\epsilon}_1$ and $\dot{\epsilon}_2$ were calculated using the relationships of Nye (1959). Adjustments to remove effects of tunnel closure were made, using the method of Hooke (1973). Results are presented. It can be seen that the ice in this area near the margin of the glacier is not stagnant and that the magnitude of the principal strain rates increase from the front to the rear of the tunnel, as might be expected.

In order that more detailed measurements could be made, strain net #8 was subdivided into three roughly rectangular subnets, corresponding to dirt-laden and relatively clean ice bands. Variations in principal strain rates in these subnets show that differential flow occurs in inter-layered clean and debris-rich ice. However, absolutely no evidence was found for fault-type displacements.

In addition, five rectangular blocks of oriented glacier ice were tested in unconfined uniaxial compression in the field. Three of the samples were taken from the subnets within strain net 8; the remaining two samples were collected from within net 2. The samples measured approximately 150 mm by 100 mm by 50 mm, with layering dipping about 45° from the top face. After cutting and shaping samples, they were next weighed, measured with a steel tape to ±0.2 mm, wrapped in plastic to minimize sublimation, and placed in the testing machine.

The compression apparatus was similar to that used by Colbeck and Evans (1973) and was located in an alcove about 75 mm from the entrance of a 125 m tunnel excavated for glaciological research in 1970 (Hooke, 1973). A baffle over the alcove entrance held temperature fluctuations during tests to a minimum - generally less than 0.3°C. Deformation was measured by three dial micrometers which were accurate to 2.54 µm. Three micrometers were used in order to determine the exact motion of the upper platen.

Tilting was held to less than 0.1 percent by placing movable dead weights on the upper platen. Temperature was measured with a mercury thermometer which could be read to ±0.2°C. During tests, dial micrometers and the thermometer were read at 1– to 3–hour intervals during the day, with a 7– to 8–hour gap in readings during the night. The techniques of Baker (1978, 1979, 1981, 1982) were used to determine minimum octahedral strain rates, crystal fabric, grain size, and volume-fraction particulate. Effective strain rates were calculated (Nye, 1953), to facilitate direct comparison between the compression experiments and the tunnel strain nets.

Effective strain rates from these experiments compare favorably with the results from the tunnel strain nets.

In conclusion, these data indicate that near glacier margins, where inter-layered clean and debris-rich ice exists, differential deformation – a form of shear – can occur. However, this is a form of plastic rather than brittle strain and is the typical response of most materials to an applied stress at temperatures close to their melting points (within 90% of the homologous temperature); the layers of debris-laden ice are not active fault planes.