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Glacier sliding, regelation water flow and development of basal ice

Recent theoretical modelling by Lliboutry (1993) has suggested that standard models of glacier sliding by regelation are flawed. Lliboutry's analysis predicts that melting of ice in response to flow obstruction by bed protuberances will occur in an ice layer of thickness h_w through which meltwater will be mobile in the vein capillary network. This contradicts the common assumption that regelation water flow is in a basal film at the ice–bed interface (e.g. Robin, 1976). Modelling of basal sliding is central to glaciology and bears upon the climatic interpretation of ice cores and the modelling of ice-sheet behaviour, so it is important to be able to test rival models. Lliboutry has called for field observations of h_w to constrain his model but he has recognized problems in identifying h_w in the field.

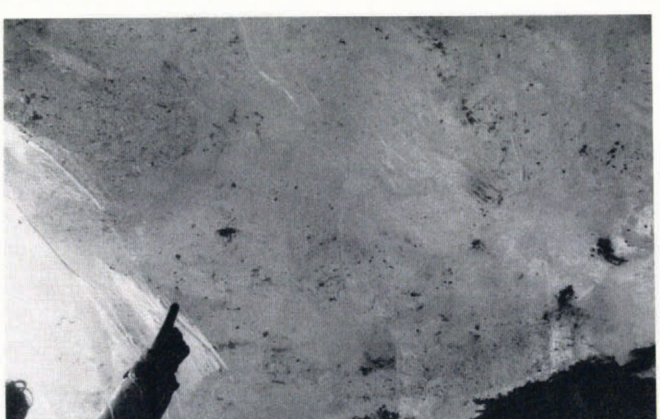

Fig. 1. Photograph showing basal ice with dispersed aggregates of fine-grained debris at the ice-sheet margin near Kangerlussuaq, Greenland. The field of view is about 3 m × 2 m. Particle-size distribution within the debris aggregates is dominated by clay and silt (78% by weight < 63 μm, 5% by weight > 250 μm). Aggregates range in size from single particles to about 9 cm. All the debris occurs at crystal boundaries. More details have been given by Knight and others (1994). This ice facies has previously been referrred to as "clotted ice" (Sugden and others, 1987) but is probably equivalent to Lawson's (1979) "dispersed" facies.

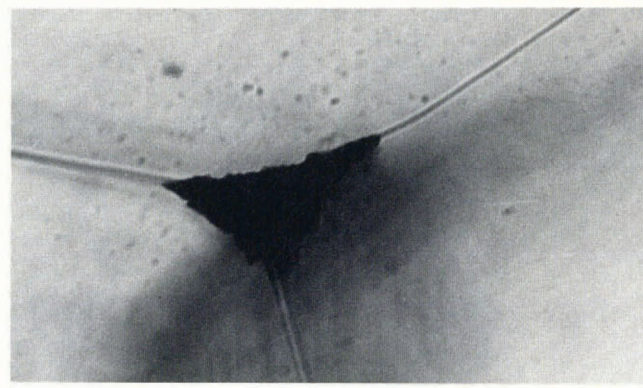

Fig. 2. Photograph showing fine-grained debris at a three-grain boundary in the vein network of polycrystalline ice created in the laboratory. The field of view is ~800 μm × ~450 μm. Particle sizes in the vein range from 30 to 60 μm, and were selectively entrained into the ice through the vein network from a reservoir of particles ranging from 30 to 250 μm. Full details of the experimental procedure will be published separately.

We suggest that observations of the dispersed facies of the basal layer (Lawson, 1979), which is accessible at some glacier margins (Lawson, 1979; Sugden and others, 1987) (Fig. 1), could provide the modelling constraint that Lliboutry has called for and a test of his theory. The formation of the dispersed facies has previously been attributed to regelation sliding across a rough bed (Lawson, 1979; Sugden and others, 1987) and we have previously suggested (Knight, 1987), in a development of an earlier model by Lliboutry (1986), that water squeezed away from the bed into the vein network adjacent to bed obstacles could import fine debris with it. Models of water and solute pumping through the vein network (Mader, 1992) are easily extended to include mobilization of fine debris.

We have carried out a series of experiments in the low-temperature laboratory that demonstrate both debris transport through the vein network of polycrystalline ice and entrainment of debris into the vein network from beneath the ice in response to a pressure gradient (Fig. 2). The selective entrainment of fine debris by grain-boundary mechanisms such as those that we have reproduced, or entrainment by theoretically conven-

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tional bump-related regelation and the subsequent redistribution of the debris through the vein network by recrystallization processes combined with the water flow predicted by Lliboutry's model, could account for the detailed characteristics of the dispersed facies reported (Knight and others, 1994) from the margin of the Greenland ice sheet. Our experiments confirm that selective dispersal of fine-grained debris in polycrystalline ice results from the constraint of temperature-dependent (Mader, 1992) vein diameters. The gradual transition from "basal" to "englacial" characteristics of features such as bubble distribution at the top of the dispersed facies follows from the progressive vertical decrease in vein-meltwater flow implicit in Lliboutry's theory. A clearly delineated boundary at the top of the layer h_w would not be expected. The ambiguous isotopic signature of the dispersed facies (Sugden and others, 1987) can be explained not only by isotopic exchange with the mineral component (Souchez and others, 1990) but also by the sub-crystalline scale of melting, refreezing and water transfer within the capillary system. If Lliboutry's zone h_w does exist, then the dispersed facies may be a visible consequence of it.

In order to use field exposures of the dispersed facies to calibrate h_w, account must be taken of diagenetic flow-related thickness variation within the layer (Boulton, 1975; Knight and others, 1994). Nevertheless, estimates of h_w sufficiently accurate to test and constrain Lliboutry's model should be possible on the basis of field observations at ice-margin sites and from deep cores.

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