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Rheology of ice in polar ice sheets

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In polar ice sheets ice flows at the strain rate of 10^{-10} to 10^{-14} s^{-1} and its deformation mechanisms have been considered to be dislocation creep and diffusion creep (Goodman et al 1981, Duval et al 1983). Recently Goldsby and Kohlstedt, (1997, 2001) presented the new hypothesis based on their experimental study that grain boundary sliding contributes significantly in glaciers and ice sheets. The constitutive law for the flow of polycrystalline ice is still under debate (Duval and Montagnat, 2002, Goldsby and Kohlstedt, 2002, Peltier et al, 2000). The crucial problem is the understanding of the ice flow under the small gravitationally applied shear stresses, which are not directly accessible to tests in the laboratory and may not obey the conventional Glen's flow law (1955) nor Goldsby & Kohlstedt's flow law. One question is whether or not, at the low levels of differential stress realized in the flow of large continental ice sheets, the processes that are expected to control the strain rate is dislocation creep or grain boundary sliding.

On the other hand, as in other geological materials, the microstructure of polar ice evolves over centuries and millennia under the action of continual deformation and thermally activated processes like dynamic recovery and recrystallization. During several decades glaciologists have believed that three thermally activated processes should control the micro structural evolution of polar ice throughout the ice sheet, which states that the microstructure of polar ice in the upper layers of an ice sheet should evolve under the regime of normal grain growth , being counterbalanced after some hundreds of meters depth by grain splitting via polygonization, while in the deepest hundreds of meters of the ice sheet, where the ice temperature raises above -10C the microstructure evolution should be dominated by dynamic recrystallization with nucleation of new grains. On the contrary, recent successes of deep ice sheet drillings brought us the knowledge that (1) subgrain boundaries are present along the entire core, apparently independent on depth, temperature, grain size or impurity content, (2) the basic microstructural features and patterns related to deformation and recrystallization seem to be similar or are the same in polar ice sheets, (3) the characteristic texture (fabric) due to dislocation glide generally develops with depth (Azuma et al 1999, Kipfstuhl et al 2006). These facts break the old concept about the microstructure evolution stated above and give some hints on the dominant deformation mechanism in ice sheets. I review the recent progress of ice rheology.