10th International Workshop on Modeling of Mantle Convection and Lithospheric Dynamics

September 2-7, 2007, Carry-le-Rouet, France

Abstract

Rheology of ice in glaciers and polar ice sheets: experimental results and modelling

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The slow motion of polar ice sheets is governed by the viscous deformation of anisotropic ices. Strain rates and temperature are respectively between 10^{-9} and 10^{-13} s^{-1} and between -57°C and the ice melting point. The viscoplastic deformation induces the development of lattice preferred orientation (textures) giving a non-random orientation of the *c*-axes in the largest part of ice sheets. Initially isotropic ice formed after the transformation of snow into ice becomes anisotropic as textures develop. But, recrystallization textures associated with dynamic recrystallization are also found near the bottom where temperature is the highest. Up to now, numerical models describing the flow of ice sheets have not accounted for the evolution with depth of the anisotropy of such ices.

Several approaches are used to simulate the behavior of anisotropic ice. Micro-macro models consider a representative volume of ice as an aggregate of grains, a polycrystal and, assuming that the behavior of the grain is known (the micro-scale), these models give the macroscopic behavior of the aggregate by a homogenization procedure. The computation of the mechanical behavior of anisotropic polycrystalline ice using a *self-consistent* approach is nowadays a standard approach. These models consist in regarding each crystal of the polycrystal as an inclusion embedded in an infinite homogeneous equivalent medium whose the

behavior represents that of the polycrystal. A good prediction of the mechanical behavior of anisotropic ices is obtained on condition that stress and strain rates fluctuations within grains are introduced in such models.

Single crystals undergo plastic deformation as soon as there is a component of shear stress on the basal plane. Basal slip is observed for shear stresses in the basal plane lower than 0.02 MPa and takes place from the motion of basal dislocations with the $a/3 < 11\bar{2}0 >$ Burgers vector. Non-basal slip associated with the cross slip of basal screw dislocations is invoked for the multiplication of dislocations. But, its contribution to the deformation of the ice crystal is very small. Due to the low lattice friction, dislocations glide cooperatively and long-range internal stresses develop with deformation. The plastic deformation takes place through isolated bursts or dislocation avalanches as soon as diffusion processes are not significant.

At the both scales of the ice crystal and the polycrystal, the deformation is highly heterogeneous. This behavior is associated with the anisotropy of the ice crystal and the mismatch of slip at grain boundaries for the polycrystal.

After an introduction on the deformation conditions in glaciers and polar ice sheets, I will describe the creep behavior of the ice crystal and the polycrystal with emphasis put on physical processes which produce and control the deformation. The development of textures and recrystallization processes will be specially discussed. Micro-macro self-consistent models used to simulate the deformation of anisotropic polycrystals will be shortly described. Finally, an overview of the flow of polar ice sheets will be given. Variation of the ice viscosity in glaciers and ice sheets will be given. These data could be useful when looking for the behavior of ice in Europa.
