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TEMPERATURE DEPENDENCE OF THE CRYSTAL GROWTH RATE IN POLAR GLACIERS

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B.P. 96, F-38402 St-Martin-d'Hères Cedex, France*Abstract :

In polar firn, the average cross-sectional area of grains increases linearly with time. The variation of the growth rate K with temperature is given by :

$$K = K_0 \exp - \frac{E}{RT} \quad (1)$$

where E is an apparent activation energy (≈ 0.54 eV) (1, 2). The rate of increase is nearly the same in firn and ice as long as the strain energy is small in comparison with the driving force for grain growth.

A much lower growth rate has been found in 20000 years-old ice formed during the Last Glacial Maximum in both Dome C (3) and Vostok (4) cores, two sites where ice deformation is very small. Microparticles and soluble impurities cannot affect grain growth significantly as well as variations with time of the temperature T of ice particles deposited since the last glacial age.

In the other hand, growth rate values along the 900 m Dome C ice core are very well correlated to the isotopic profile. As the isotopic content of polar snow is primarily governed by the temperature of formation of precipitation, we assume that polar ice keeps the memory of the thermal conditions during the rapid metamorphism of snow in the first 10 m of firn. The ice structure governing the diffusion of water molecules through the lattice or grain boundaries would be irreversibly modified during the rapid transformation of snow in the very initial stage of sintering. Such an approach is in agreement with the model proposed by Vassuille et al. (5) to explain the anomalous electrical and mechanical behavior of polar ice.

We propose the crystal growth rate is given by :

$$K = K_0 \exp - \frac{E_f}{RT_s} \exp - \frac{E_m}{RT} \quad (2)$$

where E_f is the formation energy of defects and E_m the activation energy of the migration of water molecules. The temperature T_s is the efficient temperature at which the ice structure is irreversibly modified near the surface of snow. Therefore, T_s is assumed equivalent to the mean annual temperature of the site.

By taking into account recent results given by Higashi et al. (6) and Goto et al. (7) on the mechanism of self diffusion in ice and on the value of 0.16 eV for E_m the formation energy of defects E_f is 0.38 eV. As the variation of $\exp(-E_m/RT)$ remains small, equation (2) gives a high sensitivity of the growth rate with T_s and this would explain the good relationship between the crystal growth rate and the past climate.

As a paleoclimate application of the model, a temperature change of about 10° C is found between the Last Glacial Maximum and the present climate for central East Antarctica, a result consistent with estimations from isotope studies. For other sites, such as Byrd in Antarctica or Camp Century and Dye 3 in Greenland, the strain energy stops grain growth and this effect becomes significant already for Holocene ice. We therefore believe that the surface temperature signal is screened by such an effect.

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