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Dominant processes for microstructure evolution in polar ice

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The microstructure of polycrystalline polar ice is affected by many recrystallization processes, which can occur simultaneously as well as in succession. The size and shape of individual grains, the orientation of c-axes and the occurrence of sub-grain boundaries are all influenced by a number of agents, including stress, strain, impurity content, and temperature within the ice.

To interpret the structures found in ice core data with respect to the generating deformation mechanisms, it is necessary to better understand the feedback between microstructure and rheology of the ice. A better knowledge of ice rheology is also required for improving macroscopic ice flow models and producing realistic projections of the mass balance of ice sheets.

The analysis of microstructural data of deep ice cores within the last decades contributed significantly to the understanding of recrystallization processes. The review paper by Faria et al. (in preparation) revisits some historic results: The analysis of grain sizes and c-axis orientation distributions with depth of the Byrd deep ice core, Antarctica, suggested that microstructural evolution could be characterized by three main depth ranges of the ice core, defined by their predominant recrystallization regimes. A generalization of these results gave rise to the tripartite paradigm of polar ice microstructure, also called the “three-stage model”:

(1) In the upper part Normal Grain Growth (NGG) dominates the evolution of the microstructure, leading to steady increase of the average grain size with age/depth. (2) In the central part the NGG is balanced by rotation recrystallization (sometimes also called “polygonisation”), which describes splitting of grains along sub-grain boundaries and consequently leads to a stationary average grain size. (3) In the lower (and warmer) parts of the ice core strain-induced boundary migration including nucleation of new grains was thought to be the dominant factor, resulting in larger average grain sizes and a bulk anisotropy often characterized by multiple maxima in the c-axis orientation distribution.

However, some information from ice cores reported in the literature and recent studies show that this three-stage model is not always valid (Faria et al. in preparation). For example, data from the EDML ice core indicate that here dynamic recrystallization is equally present at all depths starting from firn depth on. This has been observed in studies on subgrain boundary occurrence and grain shape analysis as well as classical grain size curves (Kipfstuhl et al. 2009; Weikusat et al., 2009).

Here we will discuss these issues and present a qualitative analysis of these relations.

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