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EBSD analysis of subgrain boundaries and dislocation slip systems in Antarctic and Greenland ice

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Ice has a very high plastic anisotropy with easy dislocation glide on basal planes while glide on non-basal planes is much harder. Basal glide involves dislocations with Burgers vector b=<a>, while glide on non-basal planes can involve dislocations with b=<a>, b=[c] and b=<c+a>. During natural ductile flow of polar ice sheets most of the deformation is expected to occur by basal slip accommodated by other processes including non-basal slip and grain boundary processes, however the importance of different accommodating processes is controversial. The recent application of micro-diffraction analysis methods to ice such as X-ray Laue diffraction [1] and electron backscattered diffraction (EBSD) [2] has demonstrated that subgrain boundaries indicative of non-basal slip are present in naturally deformed ice, although, so far the available data sets are limited. In this study we present an analysis of a large number of subgrain boundaries in ice core samples from one depth level from two deep ice cores, from Antarctica (EPICA-DML deep ice core at 656 m depth) and from the Greenland (NEEM deep ice core at 719 m depth).

EBSD provides information for the characterization of subgrain boundary types and on the dislocations that are likely to be present along the boundary. EBSD analyses, in combination with light microscopy measurements, are presented and interpreted in terms of the dislocation slip systems [3]. The most common subgrain boundaries are indicative of basal <a> slip, with an almost equal occurrence of subgrain boundaries indicative of prism [c] or <c+a> slip on prism and/or pyramidal planes. A few subgrain boundaries are indicative of prism <a> slip or slip of <a> screw dislocations on the basal plane. In addition to these classical polygonization processes that involve recovery of dislocations into boundaries, alternative mechanisms are discussed for the formation of subgrain boundaries that are not related to the crystallography of the host grain.

The finding that subgrain boundaries indicative of non-basal slip are as frequent as those indicating basal slip, is surprising. Our evidence of frequent non-basal slip in naturally deformed polar ice core samples has important implications for discussions of crystal plasticity descriptions for ice, on rate-controlling processes which accommodate basal glide and on subsequent discussions of anisotropic ice flow descriptions of large ice masses, with the wider perspective of sea-level evolution.

[1] doi: 10.3189/002214311795306628
[2] doi: 10.1111/j.1365-2818.2010.03471.x
[3] doi: 10.5194/se-8-883-2017

Significance statement

The potential significance of non-basal dislocations in natural ice shown for the first time in 2011 [1] is confirmed by this study on a large number of subgrain boundaries in ice core samples from both poles' ice sheets.

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