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The effect of deformation mechanisms for ice sheet dynamics

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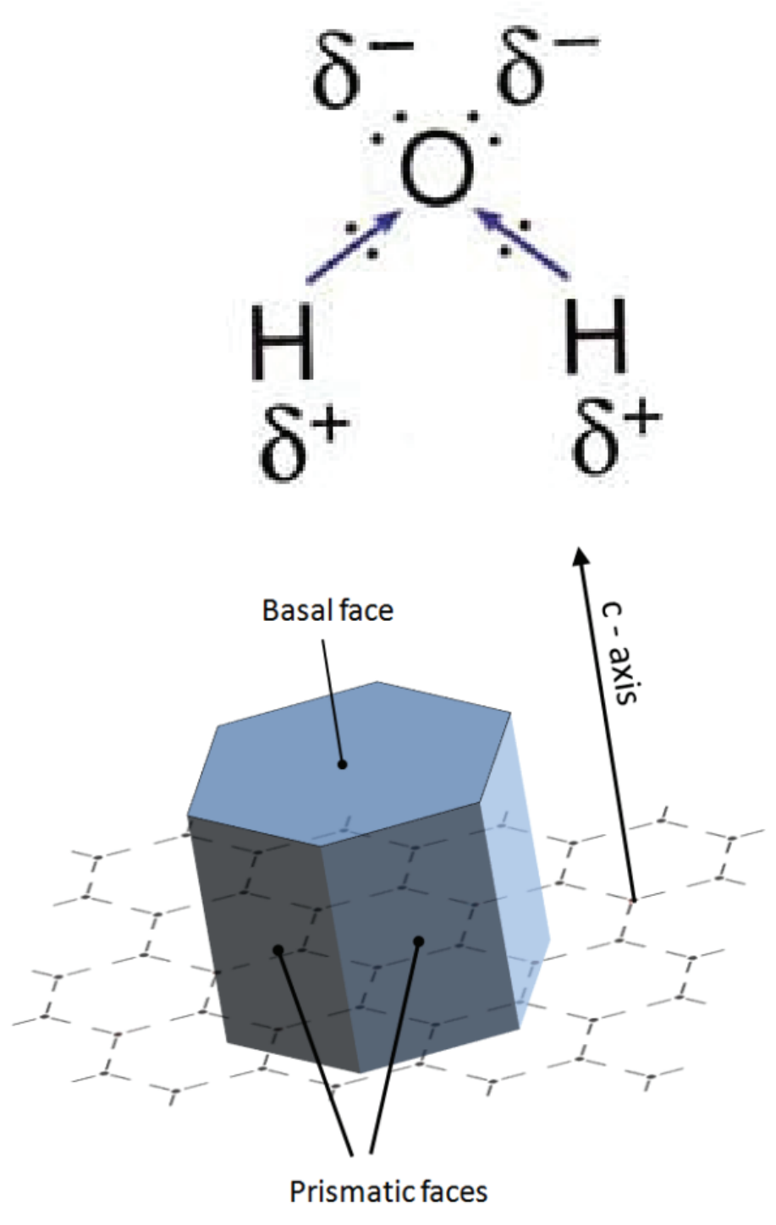
Objectives:

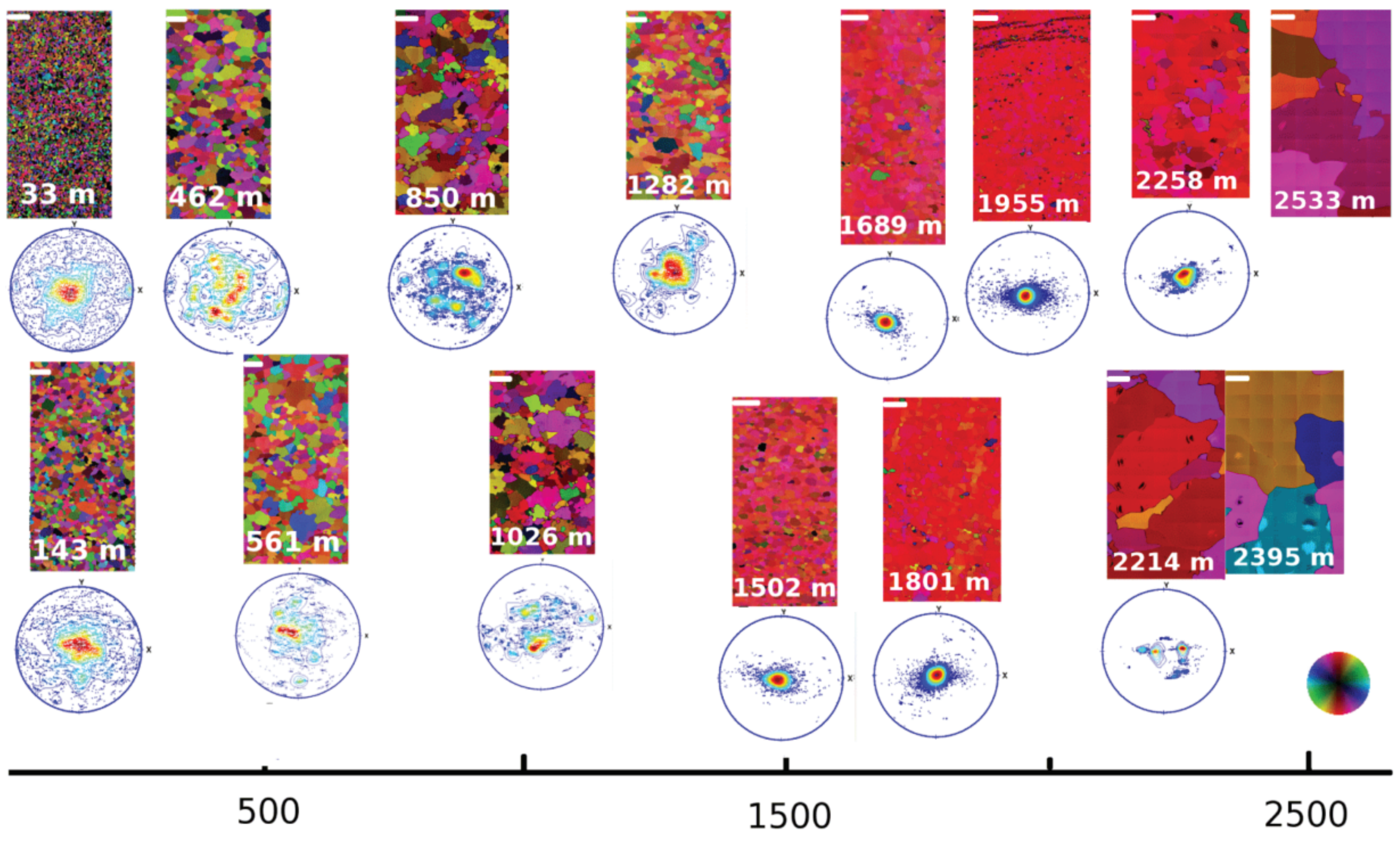
To improve our understanding of dynamical processes in polar ice sheets by microstructural analysis of ice core samples and modelling of flow behaviour. One of these microstructural analysis techniques is electron backscattered diffraction (EBSD). EBSD produces high resolution maps that show the crystal orientation of ice crystals. By analyzing these maps we can determine the slip systems that are active in the Greenland and Antactic ice sheets. Understanding these deformation mechanisms will improve ice sheet modelling and predicting the contribution of melting ice sheets to sea level rise in the future.



The crystal structure of ice:

A single water molecule has a three-dimensional structure which can be described by a tetrahedron. The centre of the tetrahedron is occupied by an oxygen atom and the four corners are occupied by two hydrogen atoms and two ion pairs.

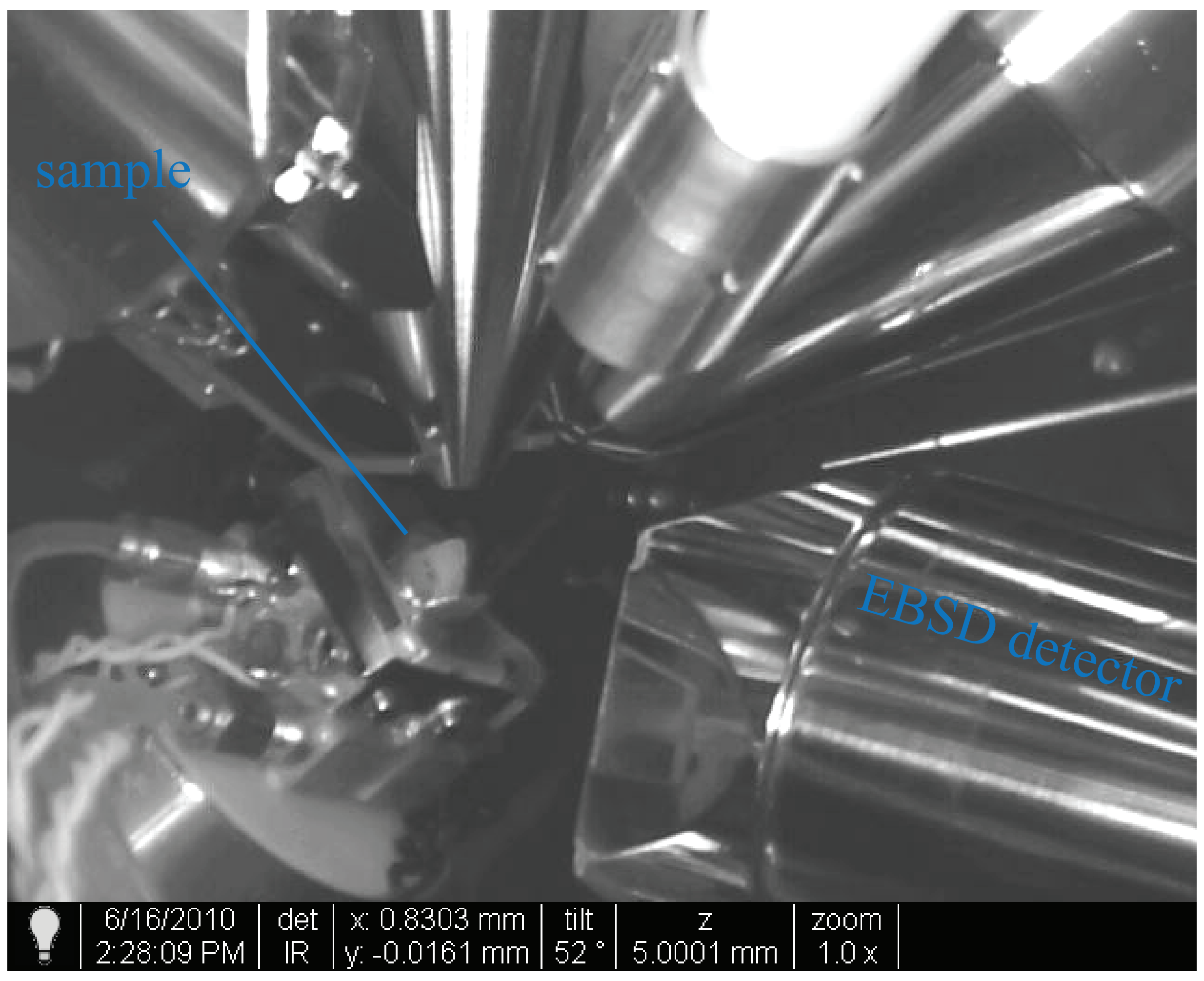
The tetrahedrons form planes or sheets, known as the basal plane. The axis orthogonal to this basal plane is the c-axis and is the optical axis of the crystal structure. When responding to stress, the ice deforms by dislocation glide along the basal plane. The minimum stress needed to deform the ice along the basal plane is ~60 times less than is needed to deform the ice along one of the non-basal planes. This makes the single ice crystal highly anisotropic. Image from Maijwee (2008).



Microstructure along ice cores:

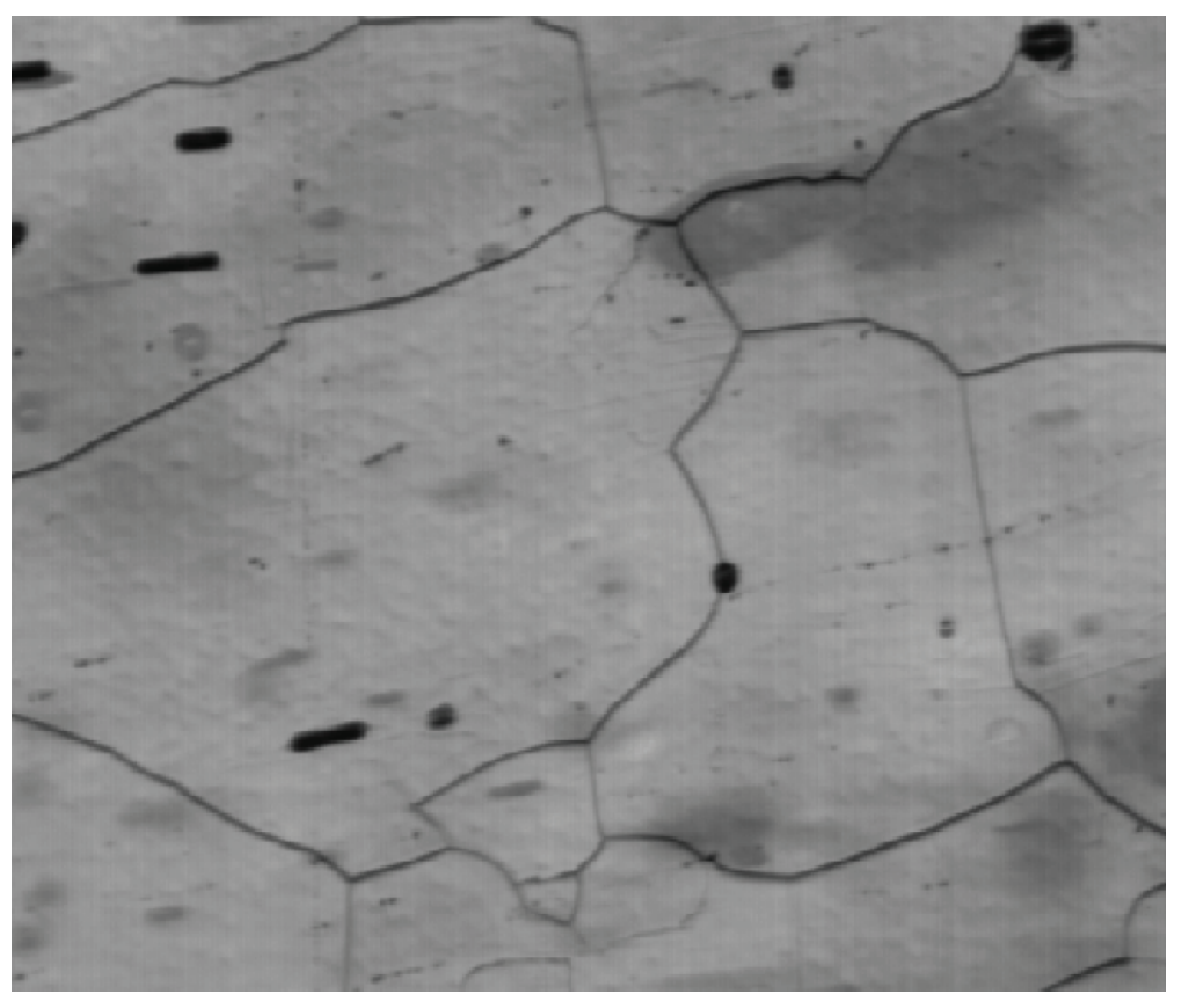
The evolution of the microstructure with depth along the NEEM ice core (Greenland) shows that grain size is increasing with depth by 2-3 orders of magnitude. Also, the crystallographic prefered orientation (CPO) is getting stronger with depth as is shown by the pole figures in the figure above. This alignment of the c-axes around the vertical makes the deformation in the horizontal direction easier (along the basal plane).

Image from Montagnat et al. (2014).

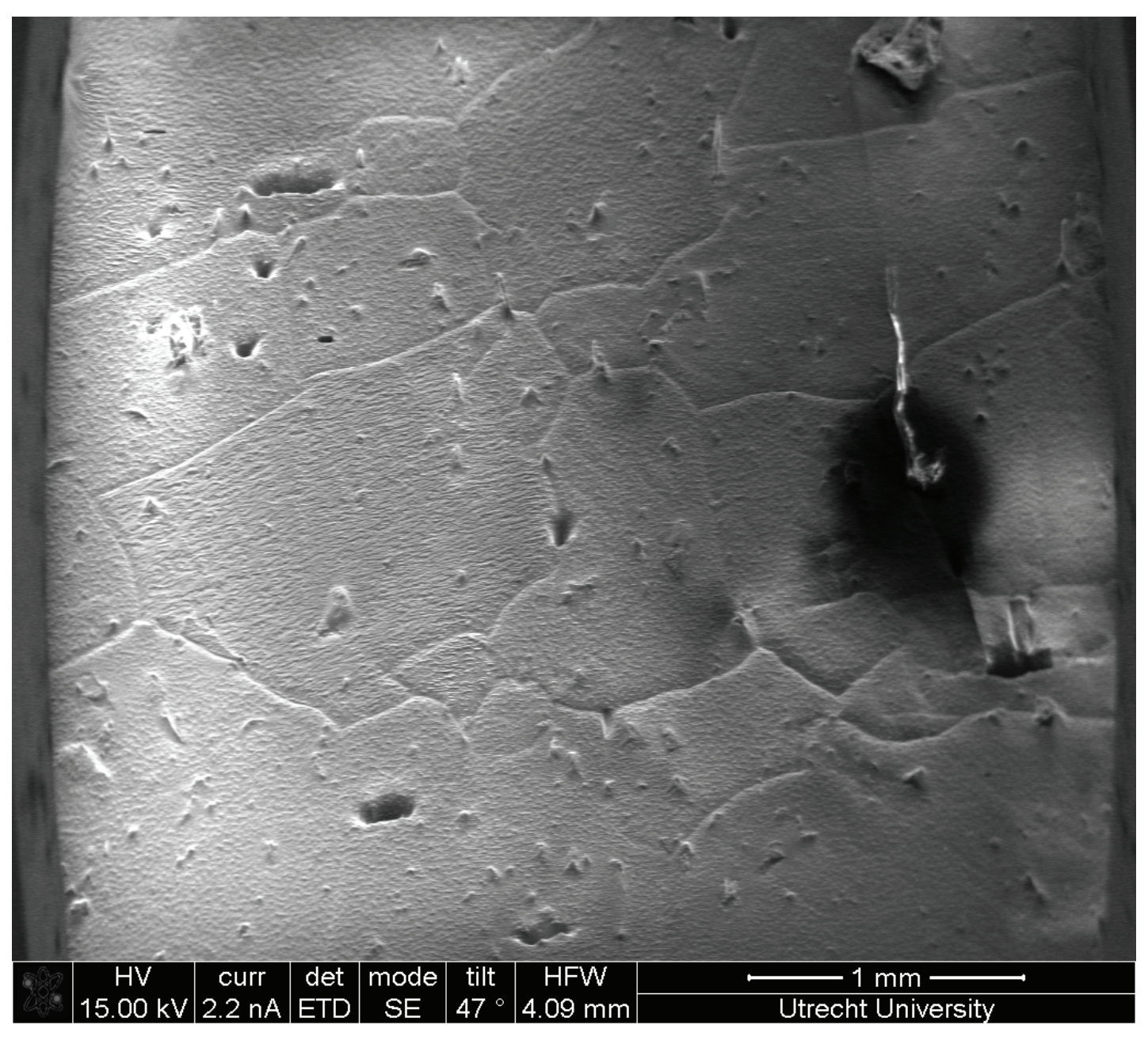


SEM-EBSD measurements:

By studying the ice core samples in a scanning electron microscope (SEM) equiped with an EBSD detector we get a high resolution map of the crystal orientation of the different grains in the sample. The figure above shows an ice core sample and an EBSD detector in the SEM.



Light microscope image

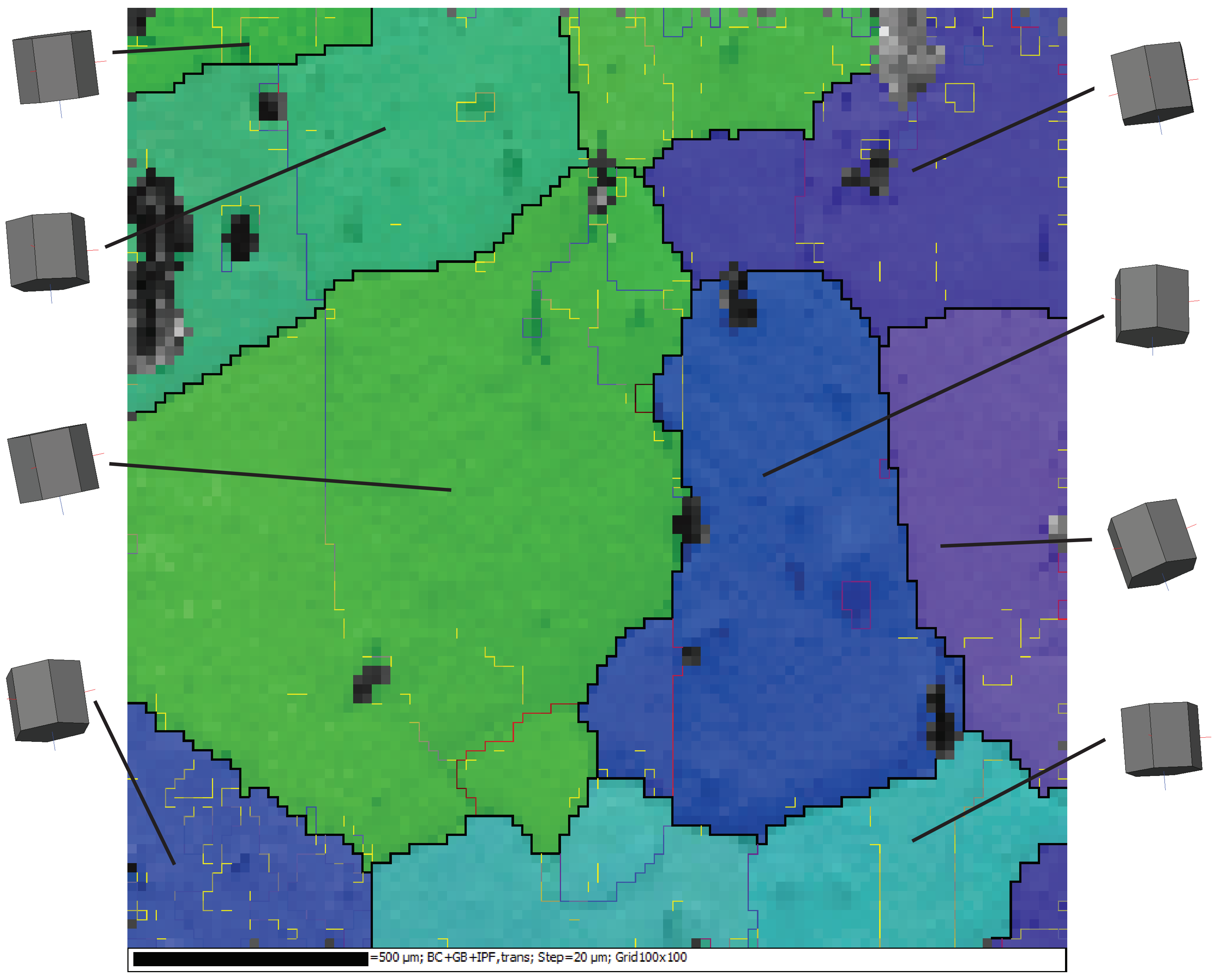


SEM image

EBSD map:

The figure on the right shows the EBSD map of a NEEM ice core sample at ~1767 depth. The corresponding light microscope image and the SEM image are shown above.

The 3D crystallographic projections next to the image show a vertical clustering of the c-axis for the eight different grains which are given different colours in the image. There is a strong texture as all the grains have a similar orientation. The boundaries between the crystals have different misorientations which affects the properties of the ice.



EBSD map showing crystal orientation and boundaries between crystal (lines: yellow 0°-0,7°; red 0,7°-2,0°; blue 2,0°-5,0°; black <10.0° misorientation). The top of the ice core is the top of the image.

references:
- Maaijwee, 2008, The importance of implementing a grain size sensitive rheology in terrestrial ice sheet modeling (unpublished).
- Weikusat et al, 2010, Cryogenic EBSD on ice: preserving a stable surface in a low pressure SEM. Journal of Microscopy, 242, 295-310.
- Montagnat et al, 2014, Fabric along the NEEM ice core, Greenland, and its comparison with GRIP and NGRIP ice cores. The Cryoshere, 8, 1129-1138.