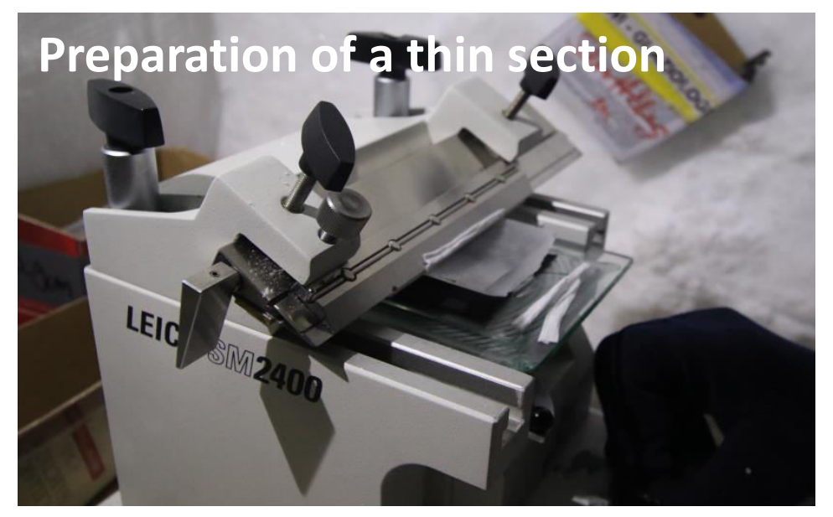
An analysis of the influence of deformation and recrystallisation on microstructures of the EastGRIP ice core

Nicolas Stoll[1], Johanna Kerch[1], Ina Kleitz[1], Jan Eichler[1], Wataru Shigeyama[3,4], Tomoyuki Homma[5], Daniela Jansen[1], Maddalena Bayer-Giraldi[1], Ernst-Jan Kuiper[1,6], Julien Westhoff[1,7], Tomotaka Saruya[5], Sérgio Henrique Faria[5,8,9], Sepp Kipfstuhl[1], Dorthe Dahl-Jensen[7], Ilka Weikusat[1,2]

EastGRIP Overview

EastGRIP is the first deep ice core through one of our Earth's ice sheets partly motivated by ice dynamics' research. It is drilled downstream of the onset of the largest ice stream in Greenland, the *North East Greenland Ice Stream (NEGIS)*. The two main findings regarding CPO (c-axes fabric) pattern are 1) a rapid evolution of c-axes anisotropy and 2) partly novel characteristics of the CPO patterns themselves. To gain a better understanding of the dominating deformation mechanisms of *NEGIS*, different approaches considering different length scales were chosen (1700m versus 0.55m and 0.09m scale), including several case studies.

Cutting of the EastGRIP ice core

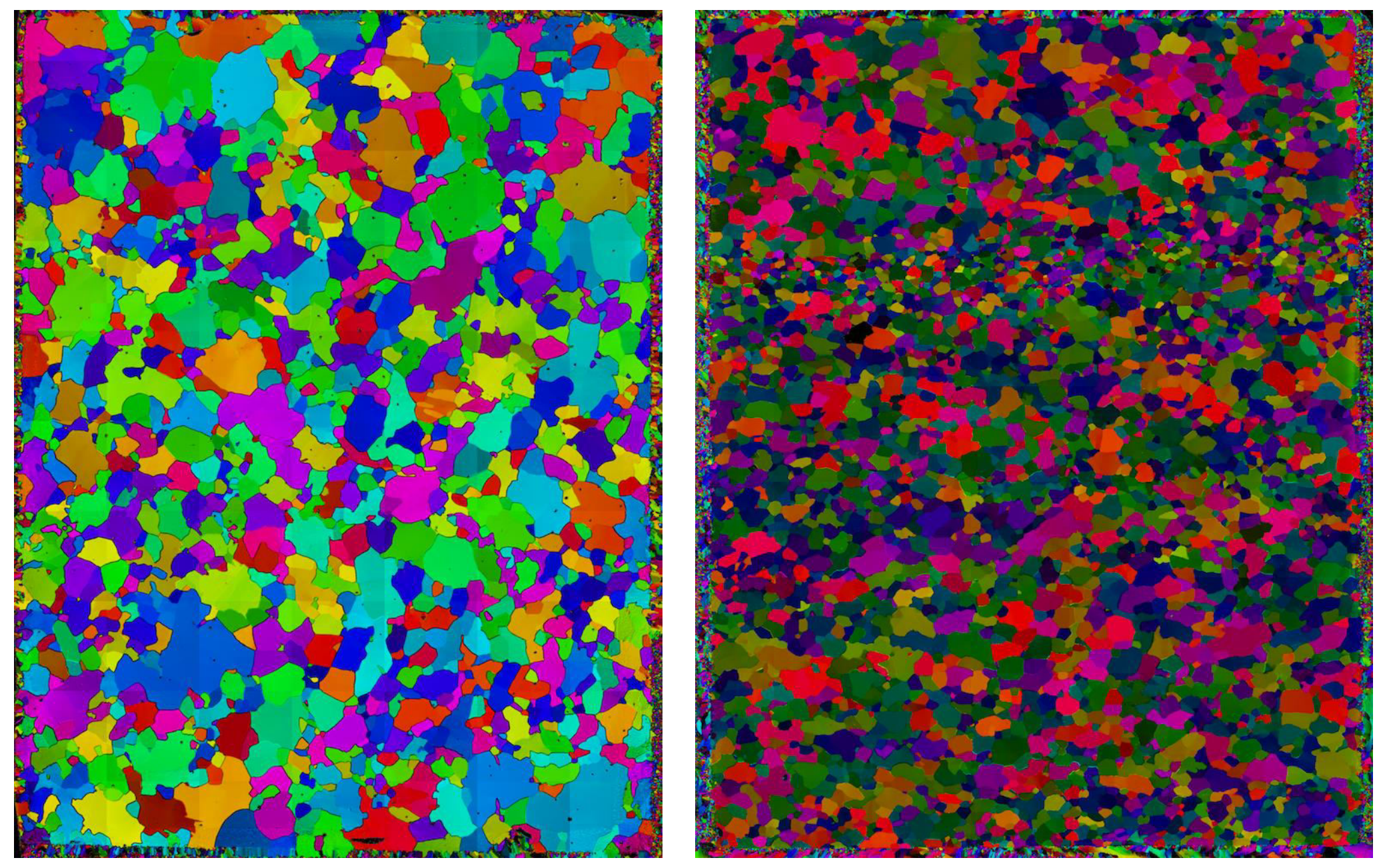


Preparation of a thin section

High-resolution images (5 to 20µm/pix), derived with a Large Area Scan Macroscope (*LASM*), enable detailed investigations of grain shape, grain boundaries and sub-grain boundaries and therefore the possibility to find distinct features from deformation and recrystallisation in the microstructure.

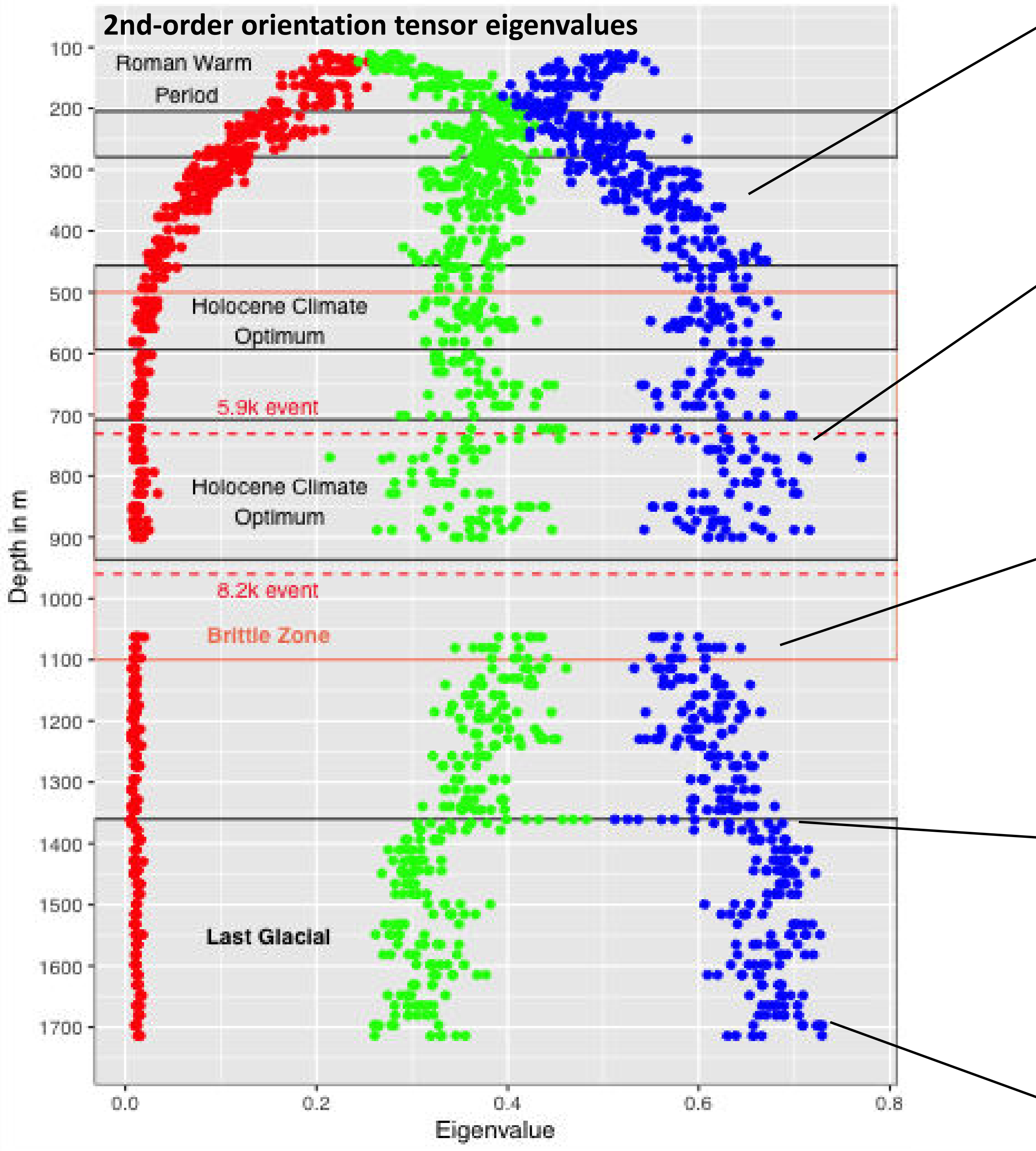
Several grain-parameters were investigated, e.g. perimeter ratio and grain size, indicating the frequent occurrence of unusual irregular grains compared to lower dynamic sites [1]. Grains usually show irregular, circular or rectangular shapes rather than elongated shapes. Characteristic are also amoeboid grain shapes and sutured grain boundaries, typical features of grain boundary migration. Furthermore, layering, "sandwiched grains" and strong gradients in grain size over only a few centimetres can be observed in various depth ranges.

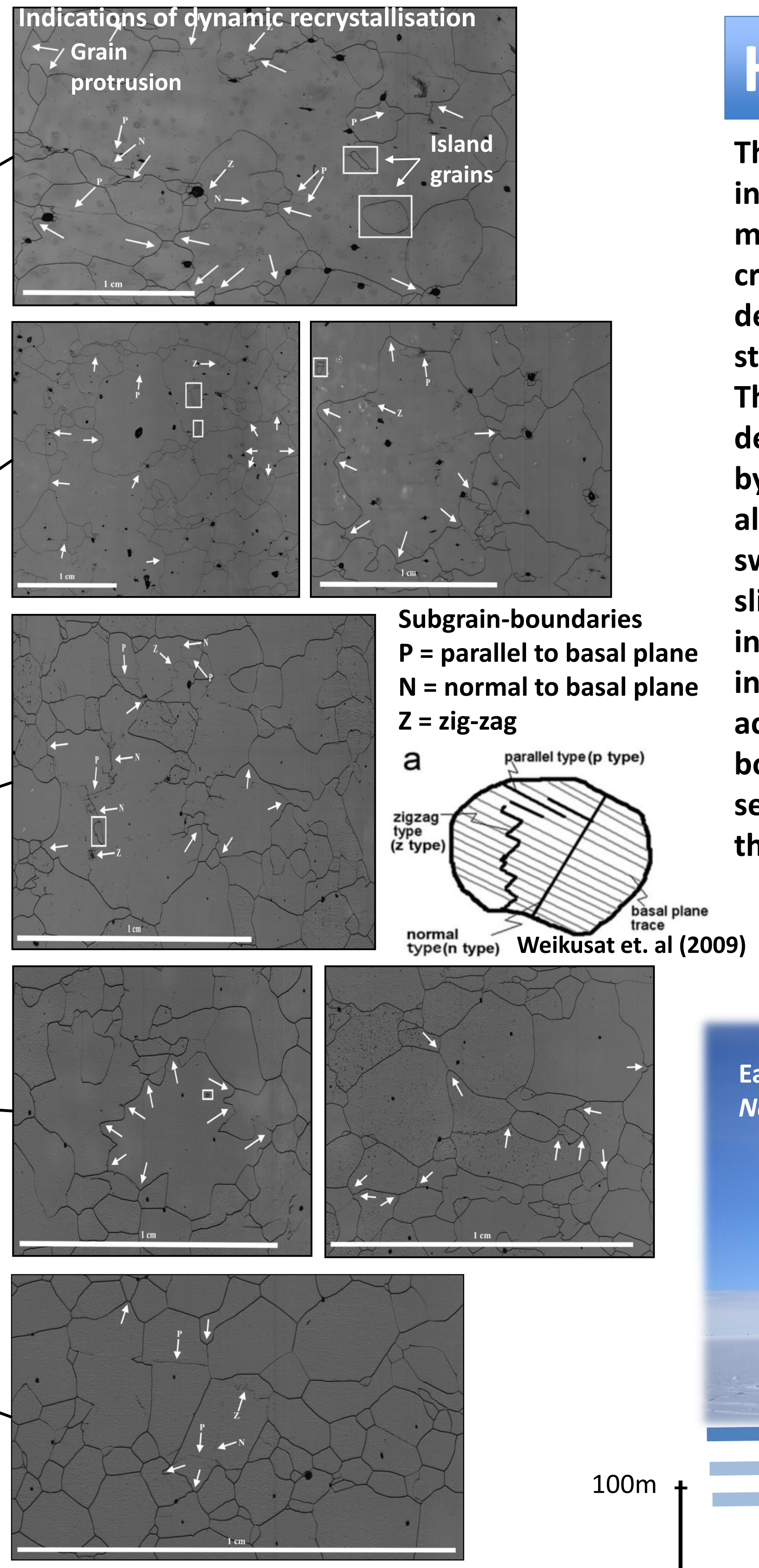
Fabric examples



Colour code for fabric trend images: the centre corresponds to the vertical ice-core axis

Results of fabric analysis

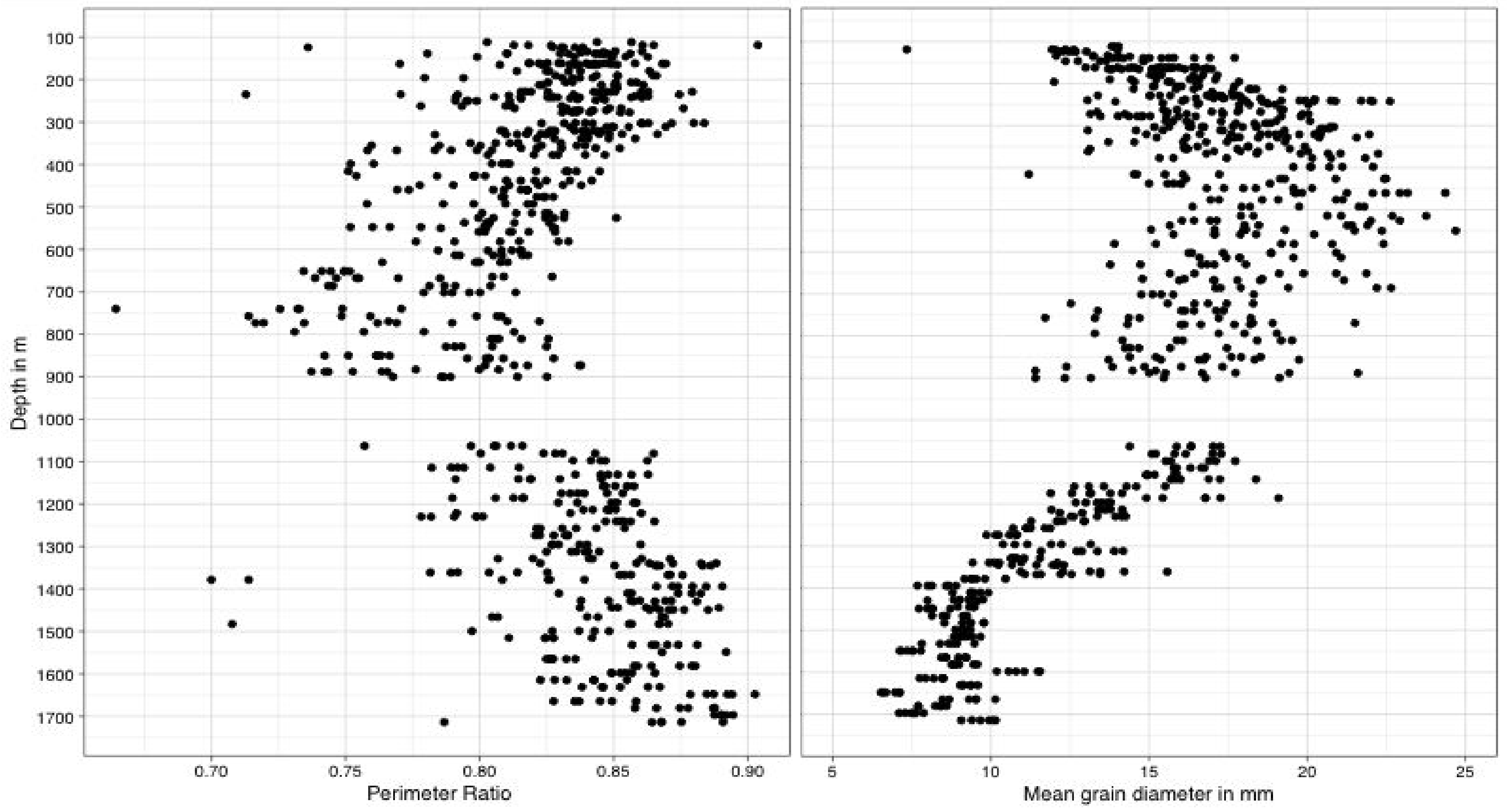




Subgrain-boundaries
P = parallel to basal plane
N = normal to basal plane
Z = zig-zag

Weikusat et. al (2009)

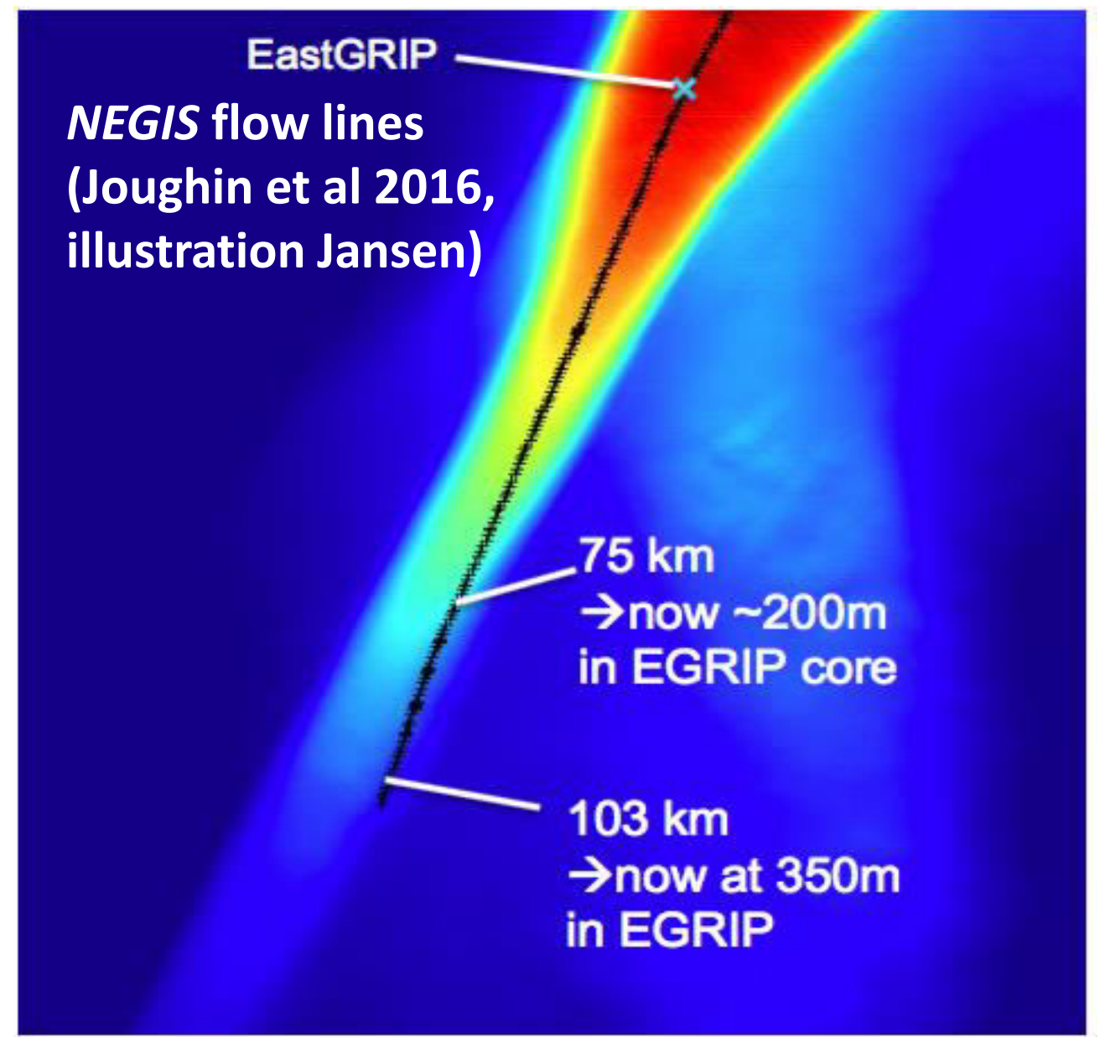
Perimeter Ratio and Grain Size



Perimeter Ratio = measure for grain irregularity [1]

Hypothesis for novel Type I crossed girdle

The results from our combined microstructure and fabric investigations show a CPO evolution from a broad single maximum (118m) towards symmetric and asymmetric type I crossed girdles (195-296m). Below an intermediate transition depth, a classic girdle starts to develop and reaches full strength in a depth of 500m. Therefore, we propose the hypothesis of dynamically changing deformation modes in the upper 500m of *NEGIS*, accompanied by an early onset of syntectonic dynamic recrystallisation, as already stated for quartz [2]. On a scale of 100m, deformation switches back and forth between coaxial deformation (basal slip dominant) and progressive simple shear. This is due to an increasing rotational component of strain path or an increasing strain in simple shear. These processes are accompanied by 1) the elimination of locked up grains by grain boundary migration and 2) partially reorientated grains by selective recrystallisation [3, 4], resulting in a CPO found for the first time in ice: the type I crossed girdle.



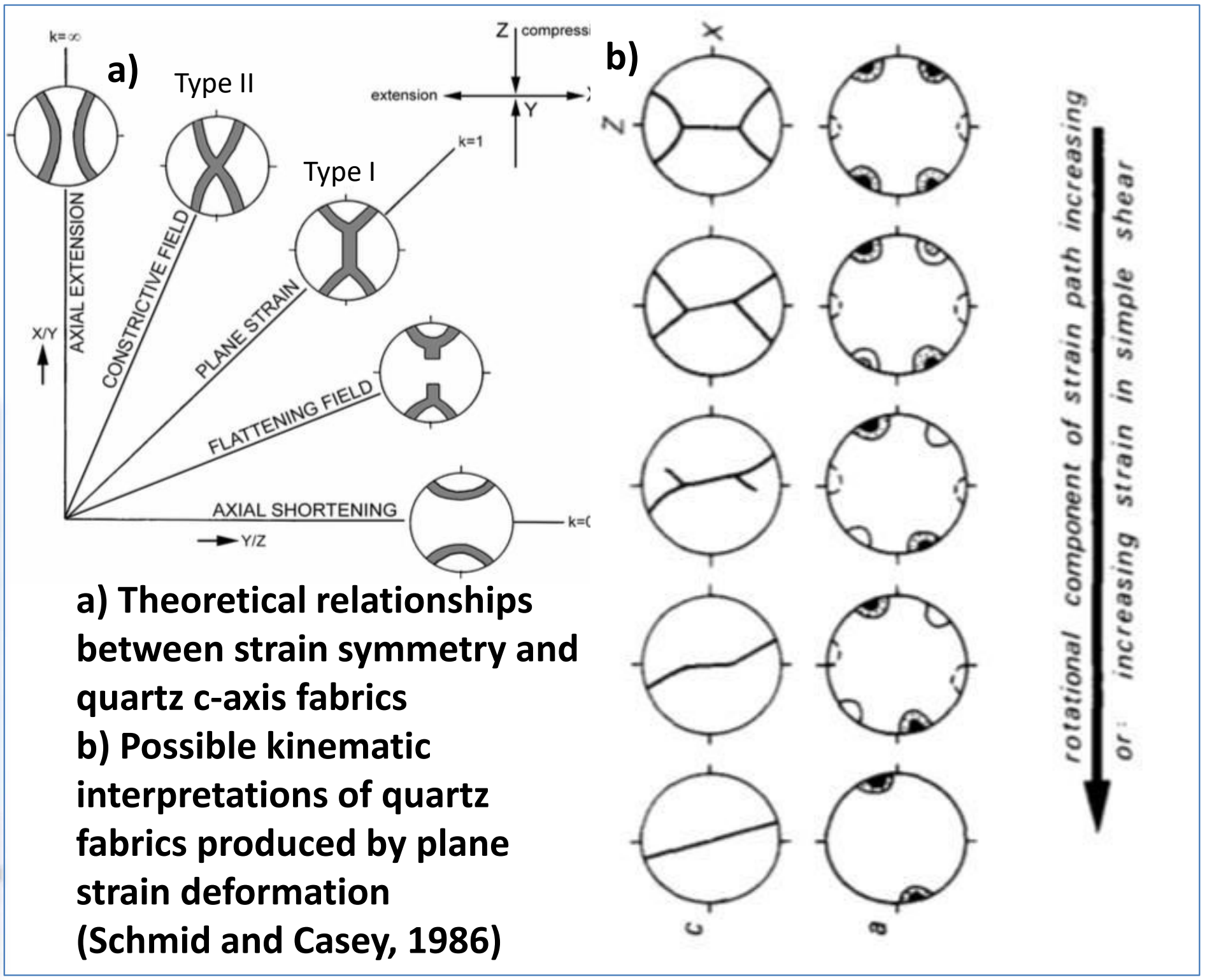
EastGRIP

NEGIS flow lines (Joughin et al 2016, illustration Jansen)

75 km →now ~200m in EGRIP core

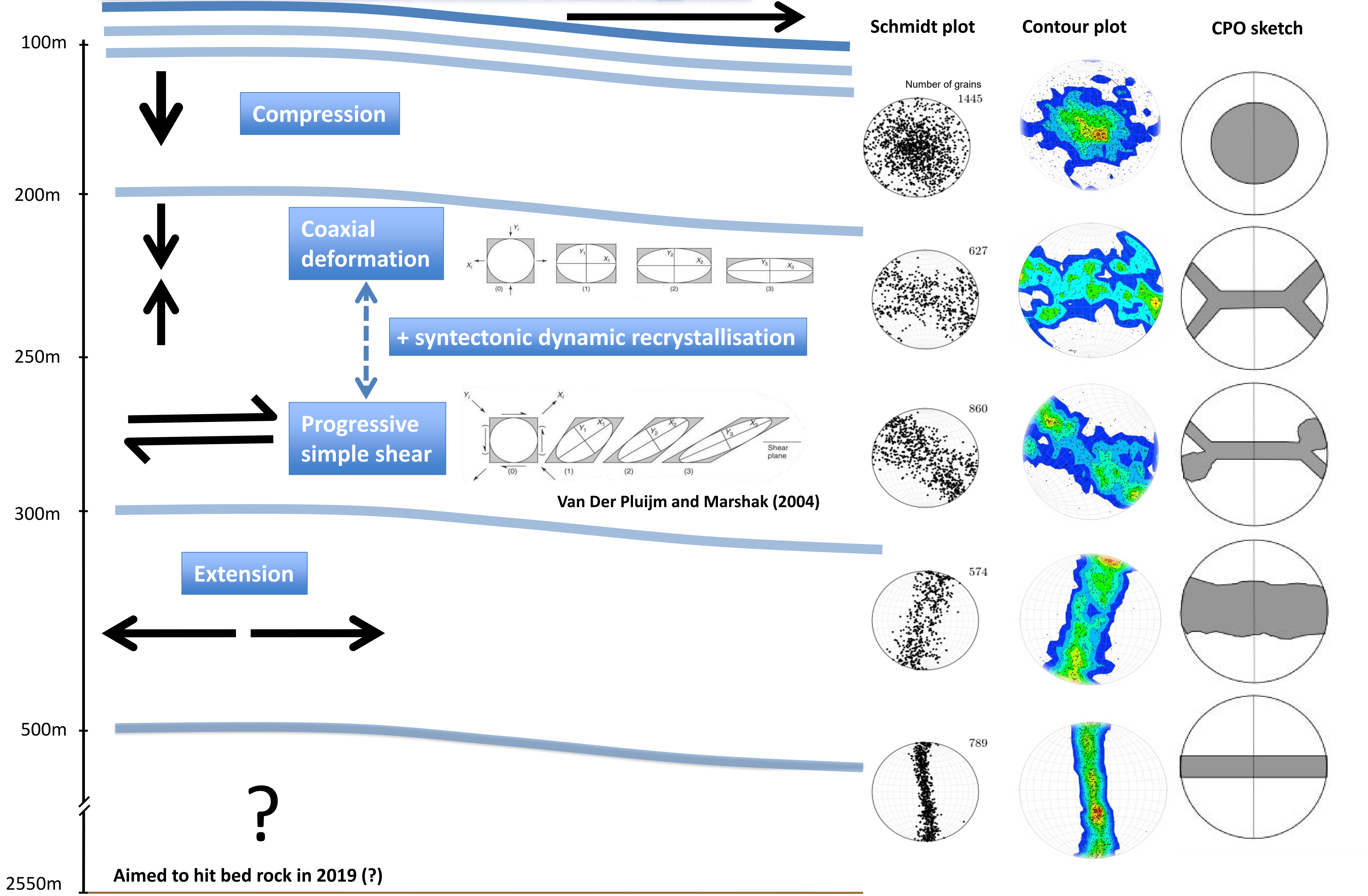
103 km →now at 350m in EGRIP

Excursion into Quartz



a) Theoretical relationships between strain symmetry and quartz c-axis fabrics
b) Possible kinematic interpretations of quartz fabrics produced by plane strain deformation
(Schmid and Casey, 1986)

EastGRIP camp located on the
North East Greenland Ice Stream



Flow direction

Compression

Coaxial deformation

+ syntectonic dynamic recrystallisation

Progressive simple shear

Van Der Pluijm and Marshak (2004)

Extension

?

Aimed to hit bed rock in 2019 (?)

References
[1] Weikusat et al. (2009), J. Glaciol., Vol. 55.
[2] Schmid and Casey (1986), Geophysical Monograph, Vol. 36, doi:10.1029/GM036p0263
[3] Behrmann and Platt (1982), Earth and Planetary Science Letters, Vol. 59
[4] Law (1986), Journal of Structural Geology, Vol. 8, No. 5

Last processing crew of 2018, final drill depth: 1750m
Photo credit: S. H. Faria

[1] *Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany*
[2] *Department of Geosciences, Eberhard Karls University, Tübingen, Germany*
[3] *Department of Polar Science, SOKENDAI | The Graduate University for Advanced Studies, Tokyo, Japan*
[4] *National Institute of Polar Research, Tokyo, Japan*
[5] *Nagaoka University of Technology, Nagaoka, Japan*
[6] *Utrecht University, Utrecht, Netherlands*
[7] *Centre for Ice and Climate, Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
[8] *Basque Centre for Climate Change (BC3), Bilbao, Spain*
[9] *Ikerbasque Basque Foundation for Science, Spain*

Contact: Nicolas Stoll
nicolas.stoll@awi.de
Am Handelshafen 12
27570 Bremerhaven