Deformation and recrystallization microstructures in the EPICA-DML ice core

Subgrain boundaries

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AWI

Why are subgrain boundaries (sGB) interesting?

Motivation

EBSD Example 1

EBSD Example 2

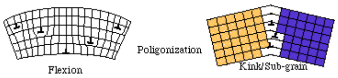
X-ray Laue Example 1

X-ray Laue Example 2

Statistics

Summary

- Ice deforms mainly with dislocation creep and thus recovery (forming sGB) plays an important role



from: Jessell & Bons 2000

- Rotation recrystallization is supposed to dominate in large depth regions of ice sheets

- Orientation of boundary plane and rotation axis across boundary can give insight into activity of dislocation types

Morphological characterization of sGB

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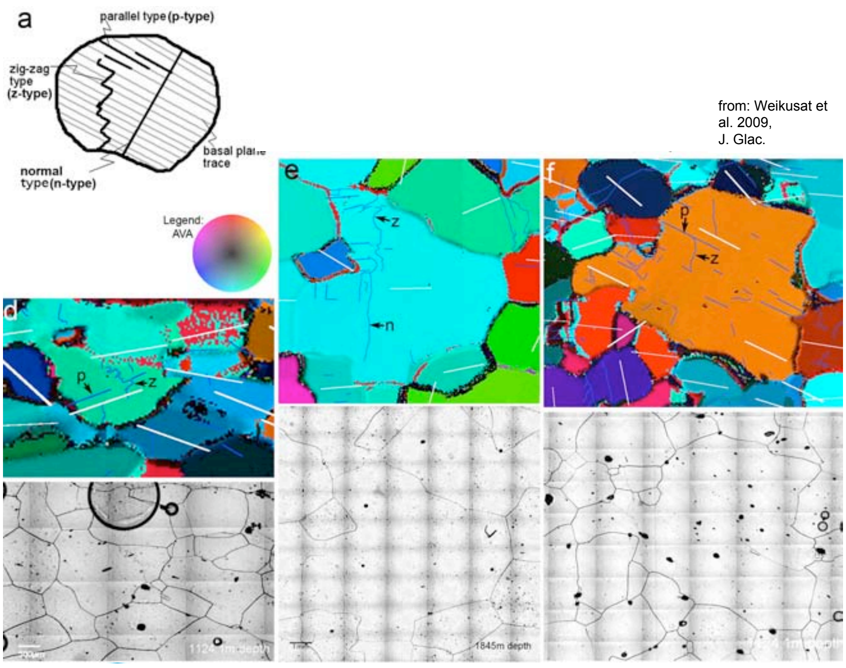

from: Weikusat et al. 2009, J. Glac.

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1. by shape with etched sublimation features in light microscopy
2. in combination with c-axes orientation (optical fabric measurements)

P-type

Z- and n-type

Description of sGB: Boundary plane + Misorientation

Description of Misorientation: Rotation Axis + misorientation angle

Sublimation grooves in µS-mapping

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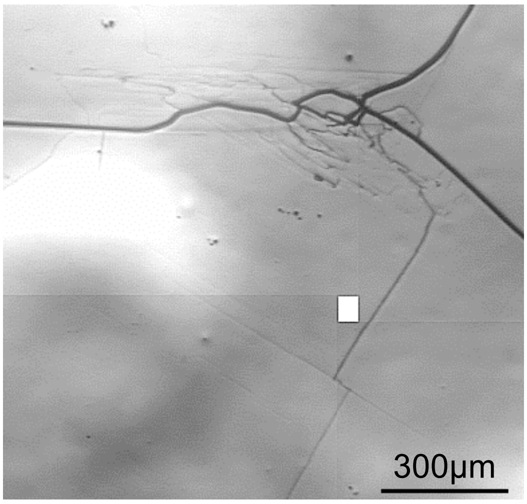
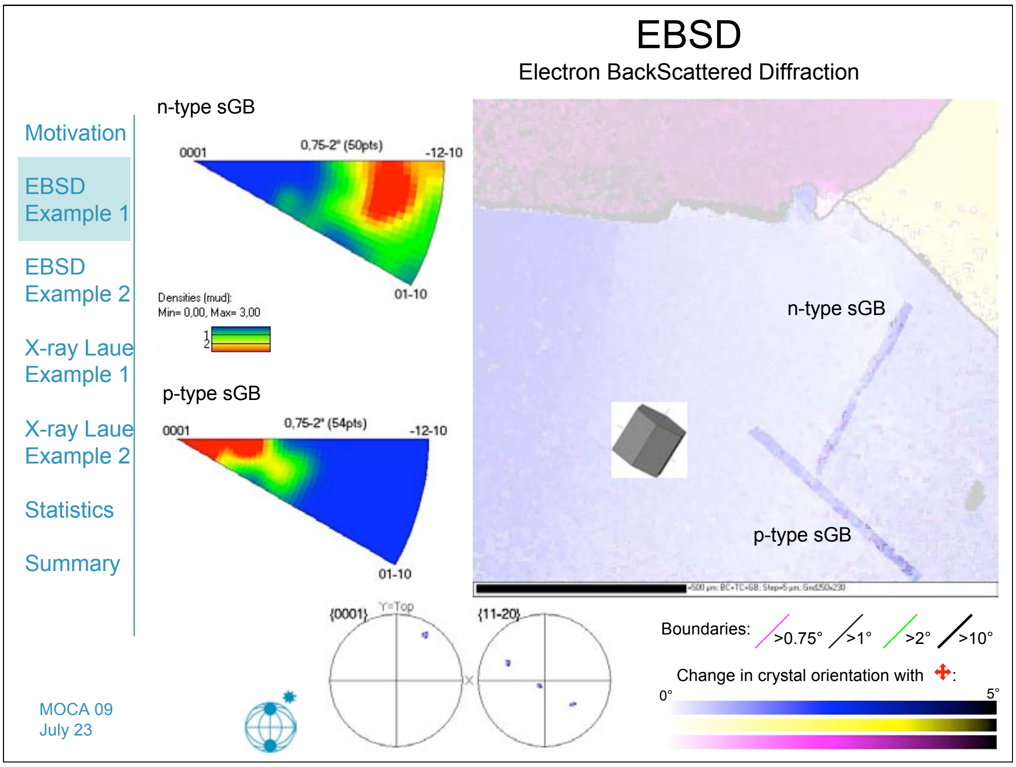


grooving under sublimation due to thermal etching

Visualization of µS using light microscope

Large samples can be scanned and mapped (default sample size 10x5cm)

No quantitative information on crystallographic orientation



Same area: Crystallographic orientation from EBSPs

EBSD: introduced by Baker this morning

Texture component map (change in orientation with reference point) and misorientation boundaries between neighbouring pixels reveal same sGB as µS-mapping

Bulging close to triple junction

Misorientation gradient

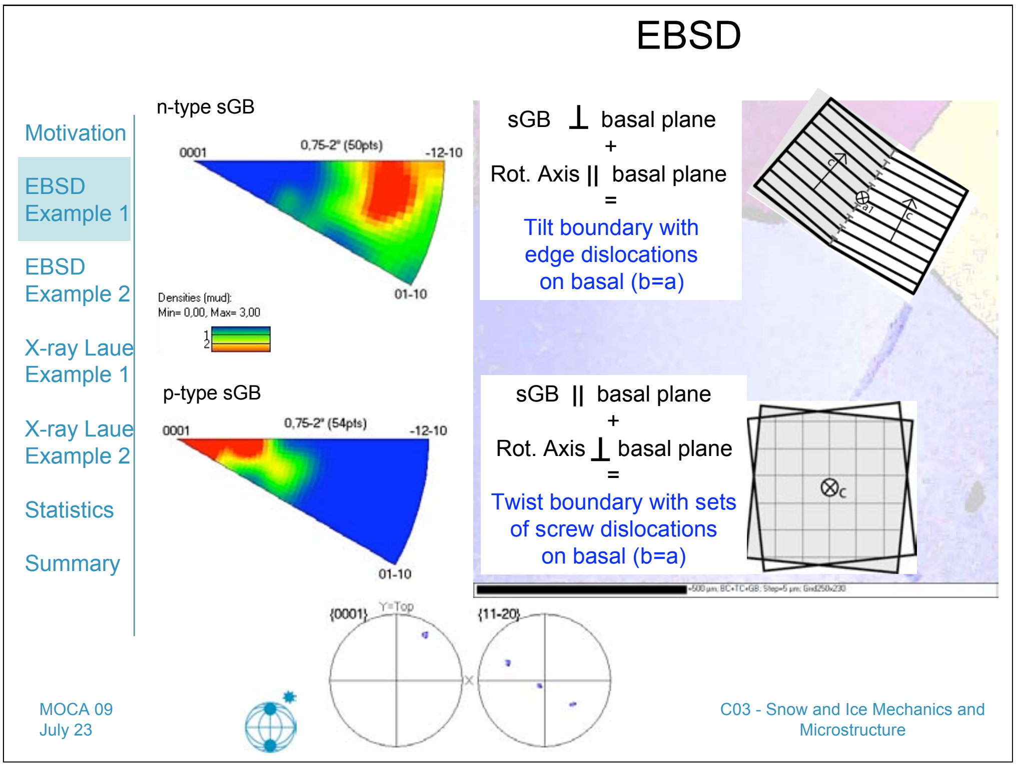
Focus on blue grain: overall orientation (3D & PoleFigure~Schmidt diagram (crystal axes in sample CoordSystem))

Subset of data along sGB +- normal to basal plane: RotAxes in inverse pole figure (RotAxes in crystal CoordSystem) -> RotAxes scatter around a-axis

Subset of data along sGB +- parallel to basal plane: RotAxes in inverse pole figure -> RotAxes scatter around c-axis

(SP5n 2K3x3) 98.5% indexing after reanalysis

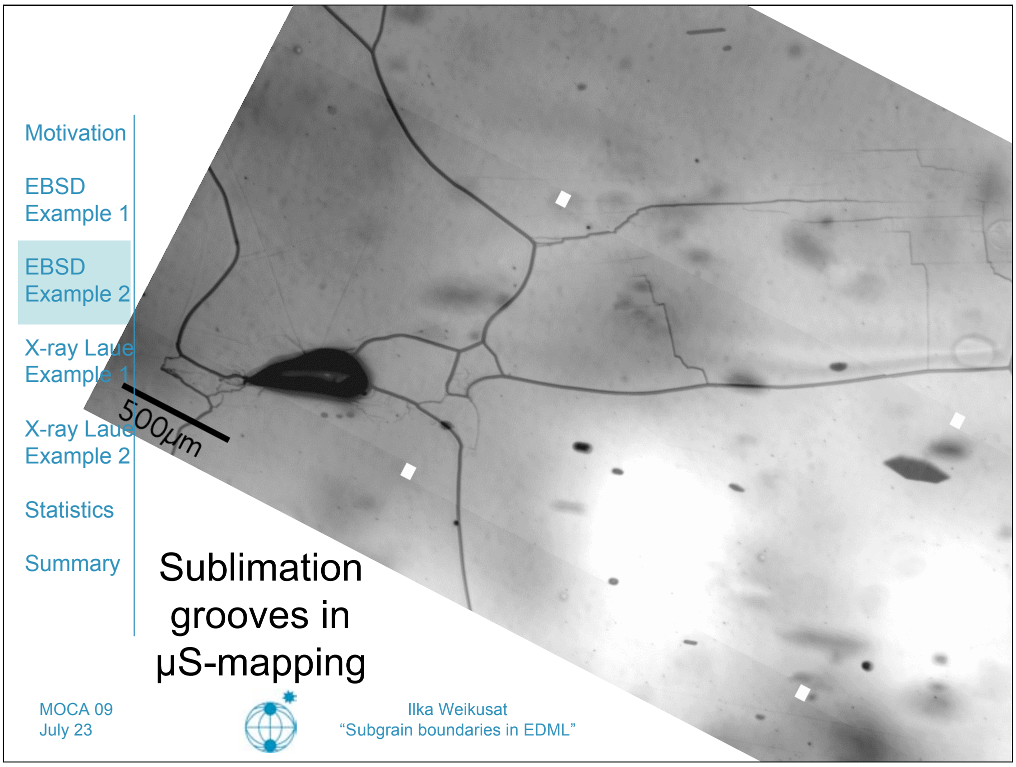
Mud=multiples of uniform density



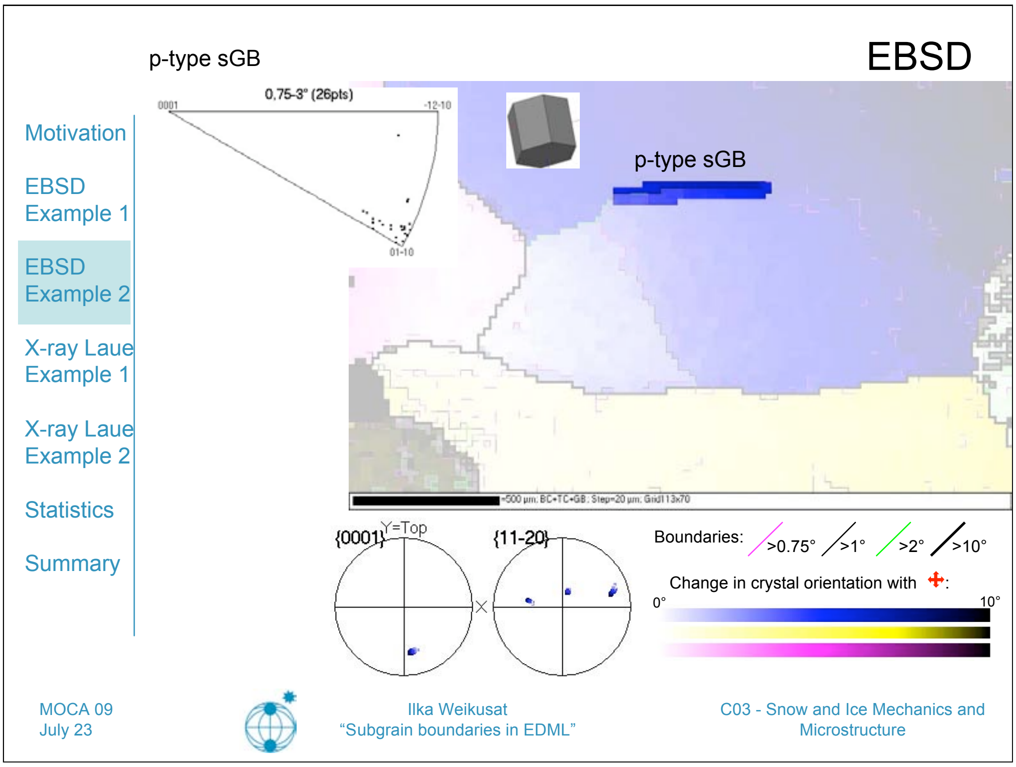
Assumption: sGB steep in 3rdDimension of sample (close to perpendicular to section surface)

Assumption: dominance of basal dislocations (see talk Hondoh 30 min ago)

1. RotAxis a lying in basal plane & sGB plane perp. To basal plane (RotAxis lying in sGB plane) -> basal tilt boundary
2. RotAxis c perp. To basal plane & sGB plane || to basal plane (RotAxis perp. To sGB) -> basal twist boundary



Another example



Texture component map

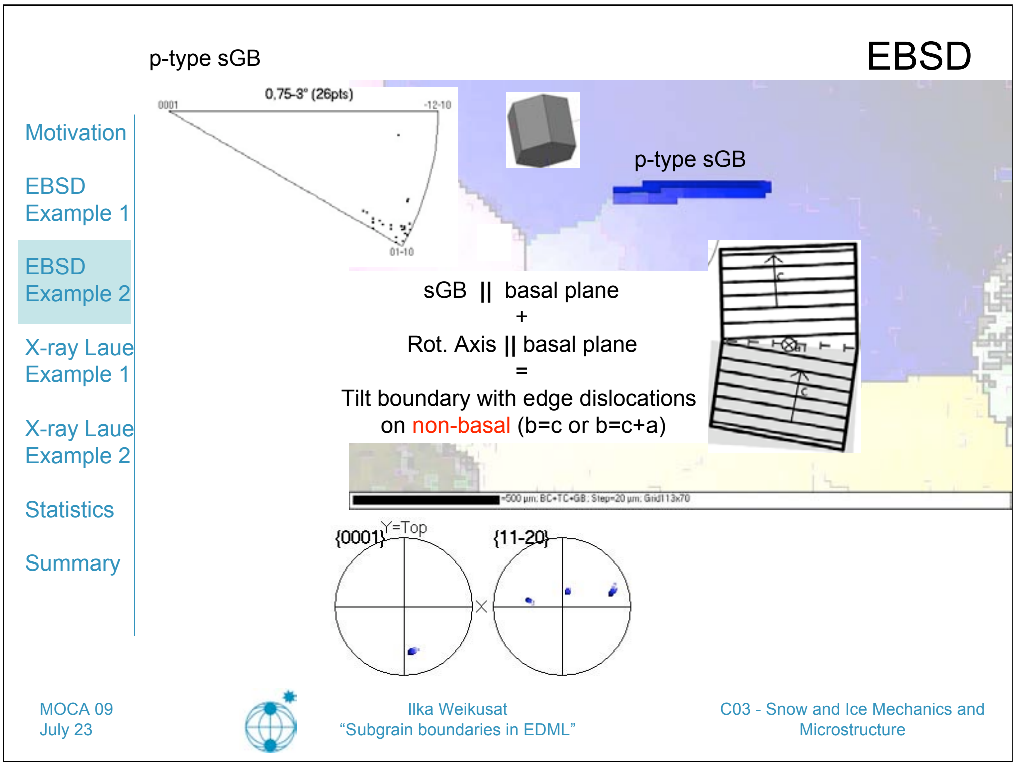
Focus on blue grain

Overall crystal orientation

Again: p-type sGB +- parallel to basal plane (3D & PolFigure)

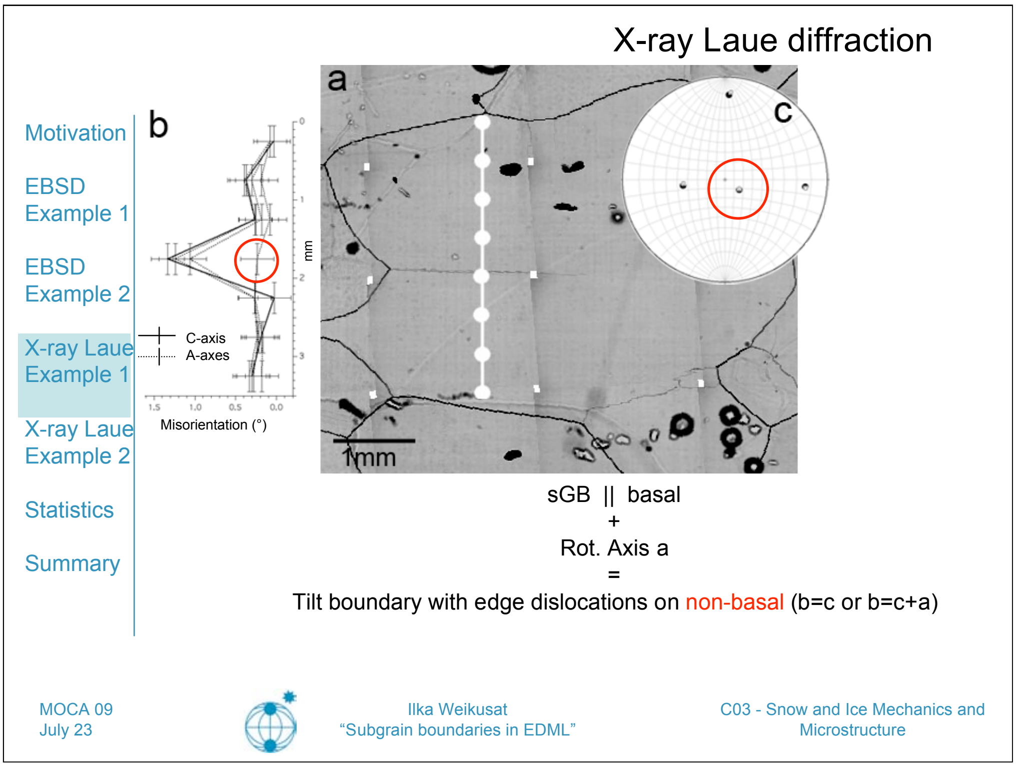
Inverse pole figure with RotAxes: cluster around prism-plane-normal -> RotAxis is in basal plane

2(Sp5n) 2K3x3, 96.8% indexing (reanalyzed)



RotAxis AND sGB plane || to basal plane cannot be explained with basal dislocations

RotAxis lying in sGB plane -> tilt boundary



Same result found with X-ray Laue diffraction (oldest crystallographic method can be applied to polycrystalline ice, because of large grain sizes compared to other materials)

Semi-automatic method: line scan

Standard sample size can be used, but spatial resolution much lower (x-ray beam 200µm)

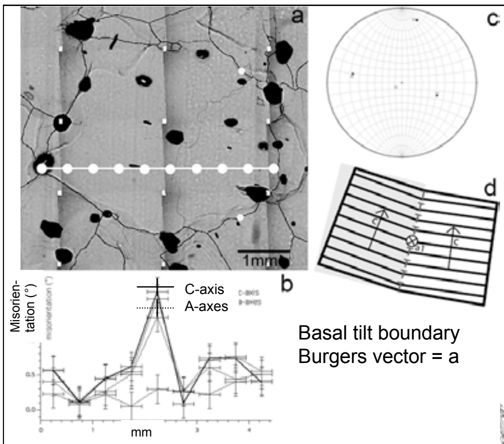
Misorientation of c- and a-axes separately and dispersion in PoleFigure reveals RotAxis across sGB: a-axis

sGB trace obtained from µS-mapping in light microscopy

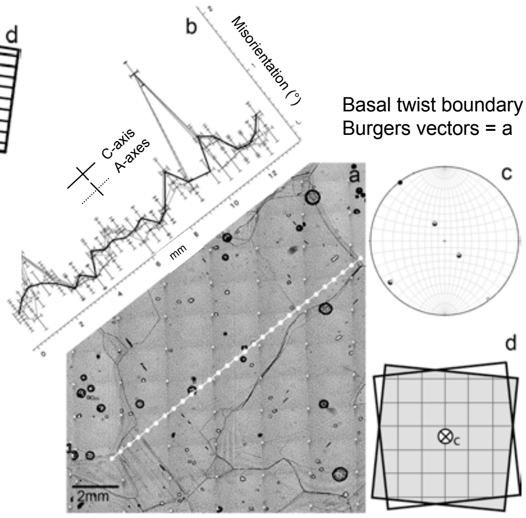
RotAxis AND sGB plane || to basal plane cannot be explained with basal dislocations

RotAxis lying in sGB plane -> tilt boundary

X-ray Laue diffraction



Basal tilt boundary
Burgers vector = a



Basal twist boundary
Burgers vectors = a

Example 2

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Basal tilt and twist boundaries also found in Laue

X-ray Laue diffraction

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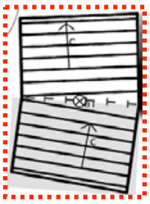
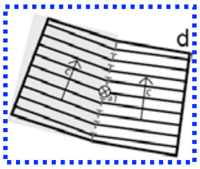
Non-basal tilt boundary
Burgers vector = c or c+a

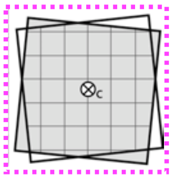




Basal tilt boundary
Burgers vector = a

basal plane: $N_{sGB} = 165$; [%]	*rotation axis:* a-axes	c-axes	arbitrary
normal (n and z-type)	39	0	9
parallel (p-type)	27	7	9
no particular	4	1	5

Basal twist boundary
Burgers vectors = a



As standard size samples can be used with X-ray Laue, small (soft) statistic is available

Table: classification of sGB using arrangement of trace with basal plane (lines) and rotation axes describing the misorientation across sGB (columns)

Non-basal tilt boundaries are more common among p-type sGB (parallel to basal plane)

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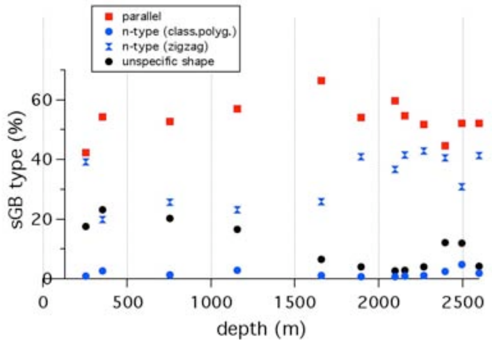

from: Weikusat et al. 2009, J. Glac.

$N_{sGB} = 165$; [%]	*rotation axis:* a-axes	c-axes	arbitrary
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Statistics from sublimation features in µS-mapping (light microscopy): p-type sGB most frequent one in EDML

Relevance: discussion on rate-limiting processes, which determine the stress exponent n in Glen's flow law

1. n~3 in fast deformation (creep experiments) due to activation of non-basal slip systems
2. n~2 in slow deformation (ice sheet) process unknown

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Subgrain boundaries identified as

- Tilt boundary comprised of
  edge dislocations in basal plane (b=a)

- Twist boundary comprised of sets of
  screw dislocations in basal plane (b=a)

- Tilt boundary comprised of
  edge dislocations in NON-basal plane (b=c or b=c+a)

Surprising: Non-basal tilt boundaries are quite common


Thank you.