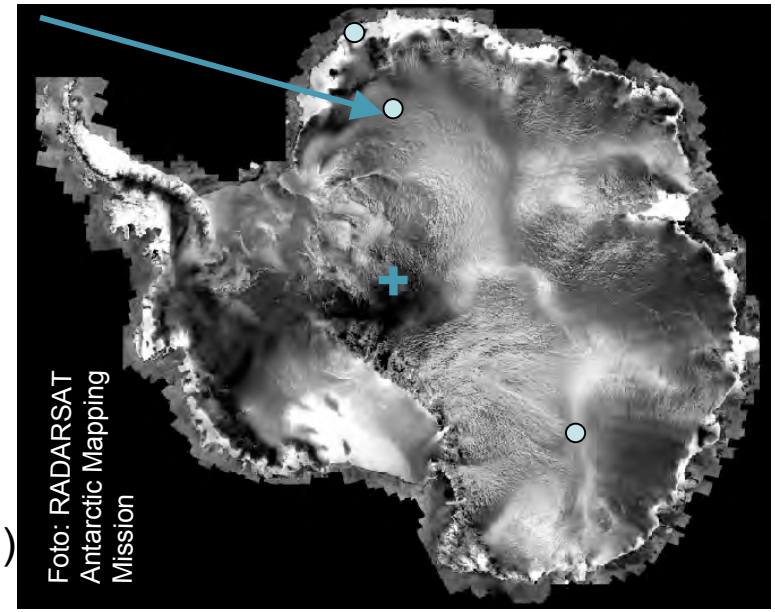
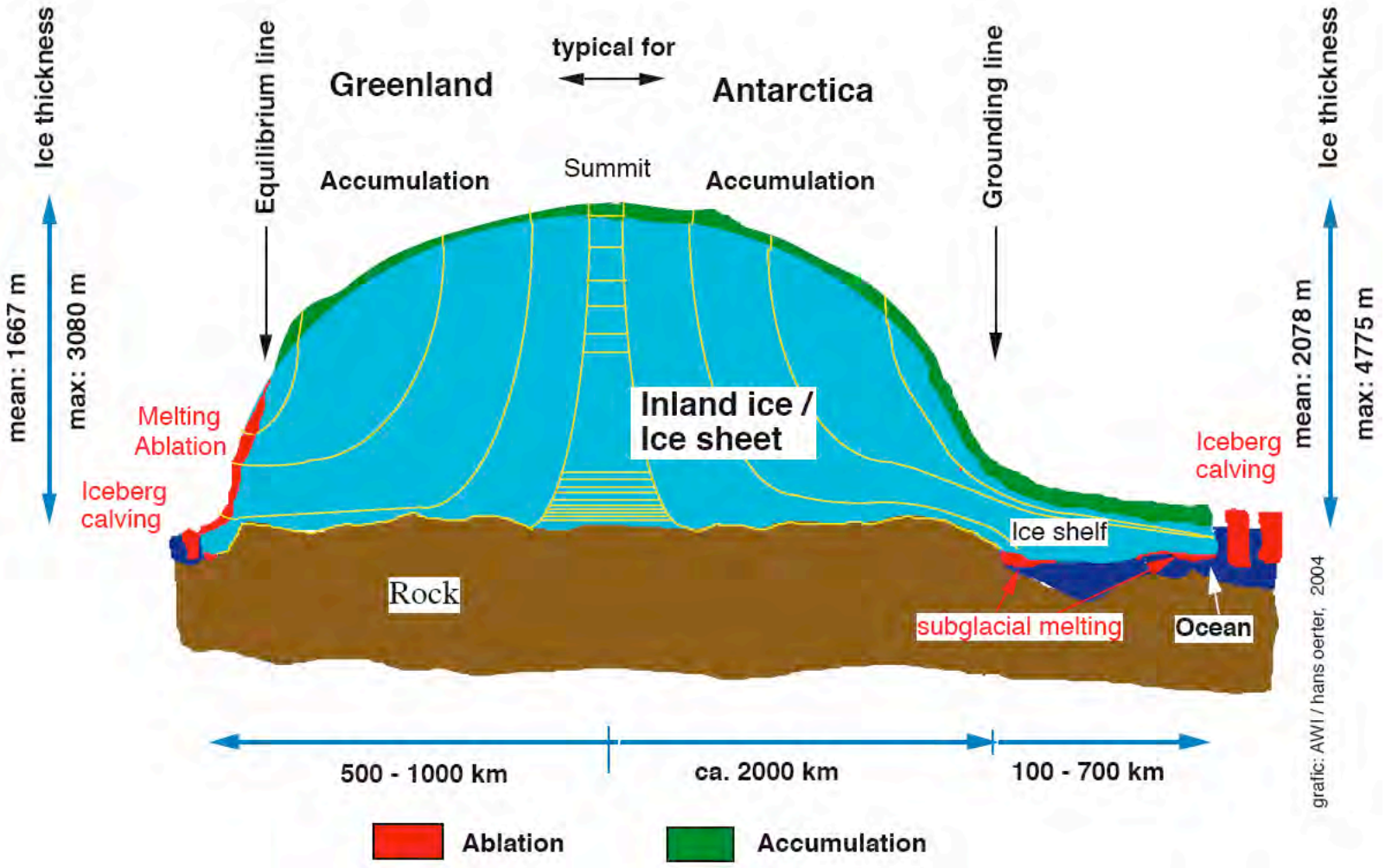
Characterization of subgrain boundary types in polar ice (EPICA-DML ice core)

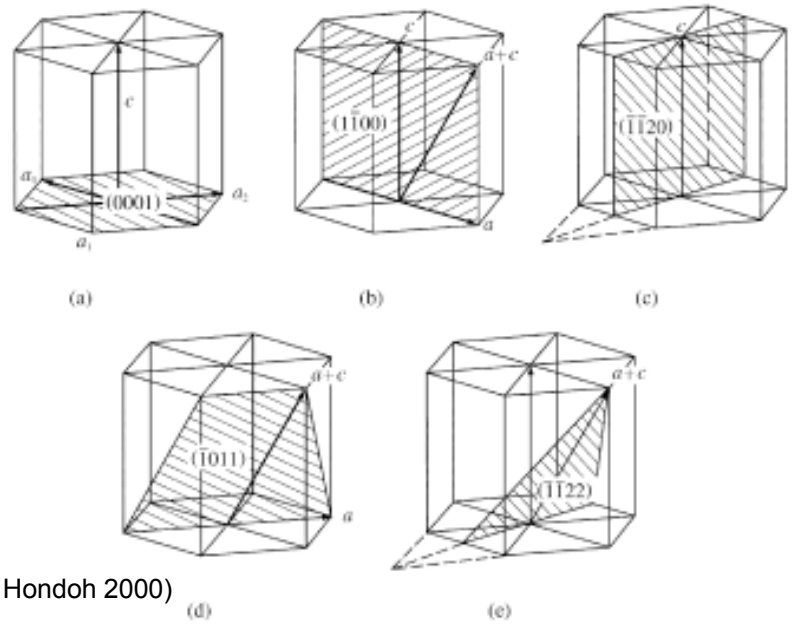
Ilka Weikusat[1],
Atsushi Miyamoto[2], Martyn R. Drury[3],
Sepp Kipfstuhl[1], Sérgio H. Faria[4],
Gill M. Pennock[3], and Nobuhiko Azuma[5]

[1]Alfred-Wegener-Institut für Polar- und Meeresforschung (Bremerhaven, Germany)
[2]Institute of Low Temperature Science (Sapporo, Japan)
[3]Utrecht University (The Netherlands)
[4]University of Göttingen (Germany)
[5]Nagaoka University of Technology (Japan)



Schematic Cross section through an ice sheet



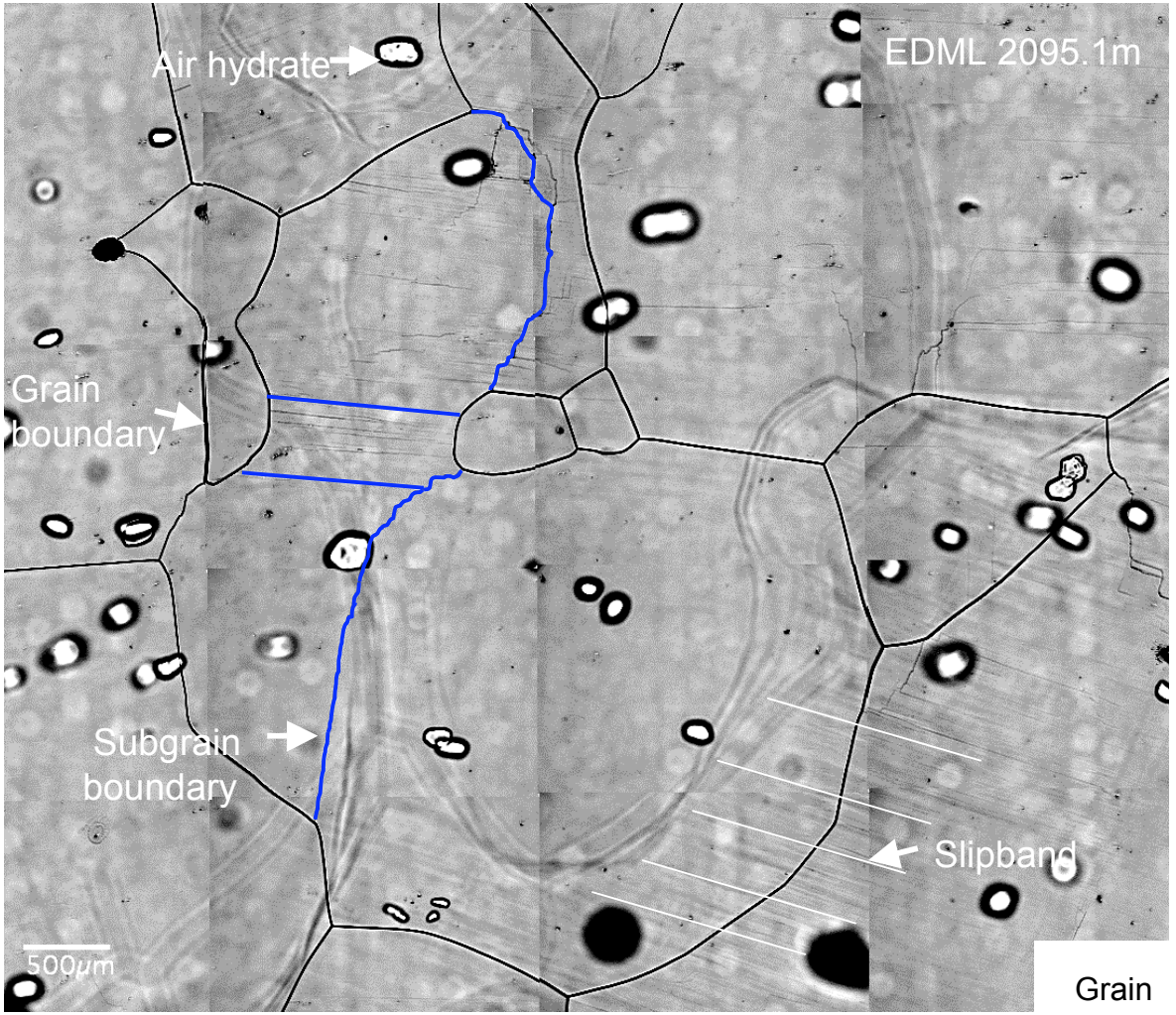


(from Hondoh 2000)

Glide on non-basal planes ≈60x harder!

But needed for deformation compatibility

Glide systems in ice



Microstructure Mapping (μSM)

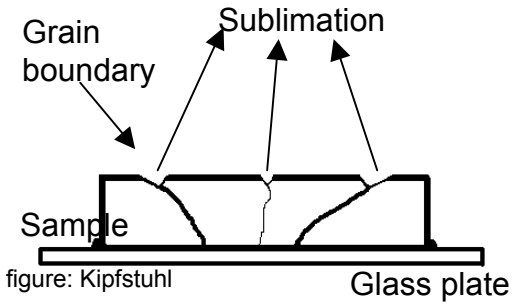
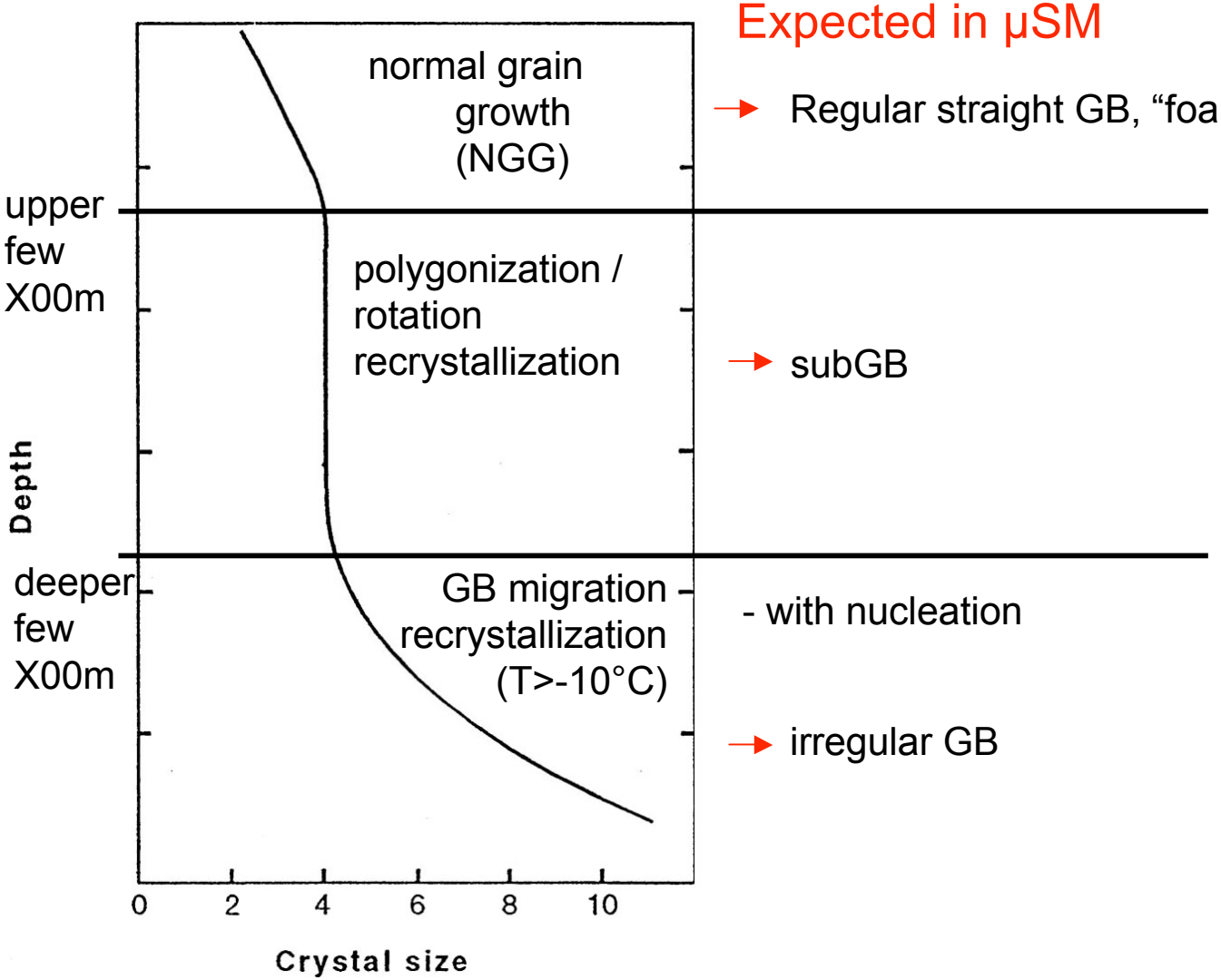


figure: Kipfstuhl

Literature - recrystallization regimes in ice sheets



modified after: De La Chapelle et al. 1998

Expected in µSM

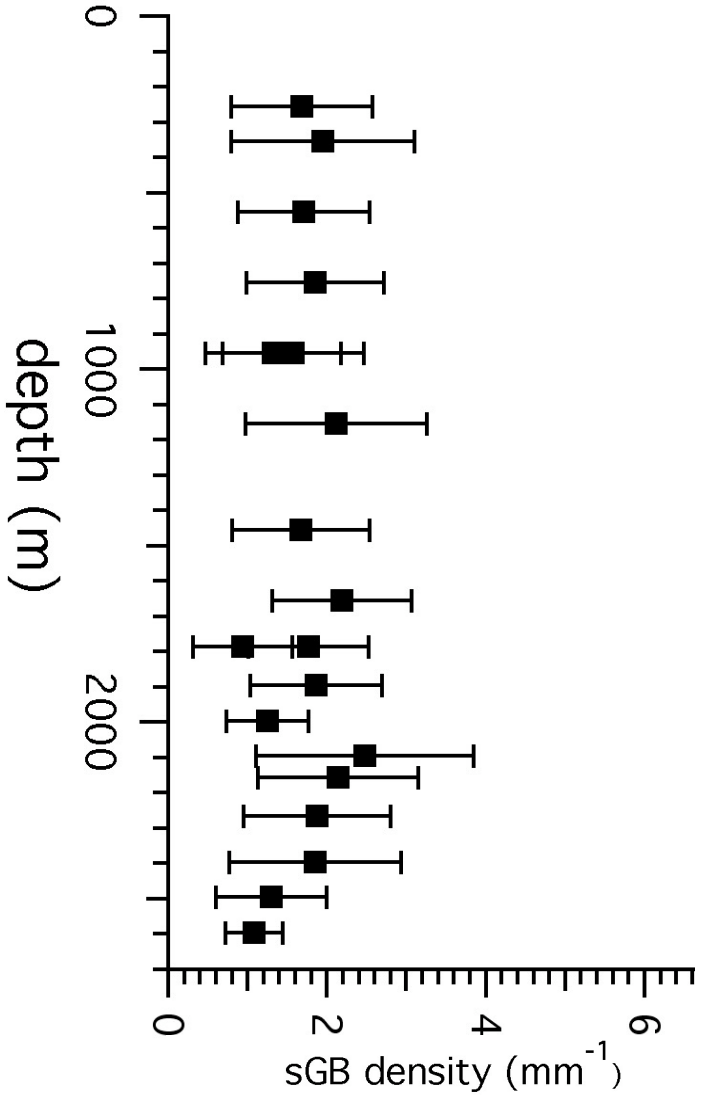
→ Regular straight GB, “foam texture”

→ subGB

- with nucleation

→ irregular GB

but, ice core data (EDML) do not show a "subGB depth range"



subGB density:

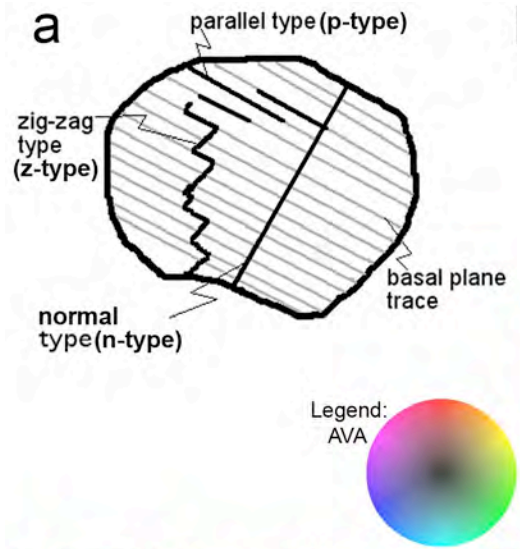
$$\rho_{subGB} = \frac{L_{subGB}}{A}$$

L : total subGB length
A : area

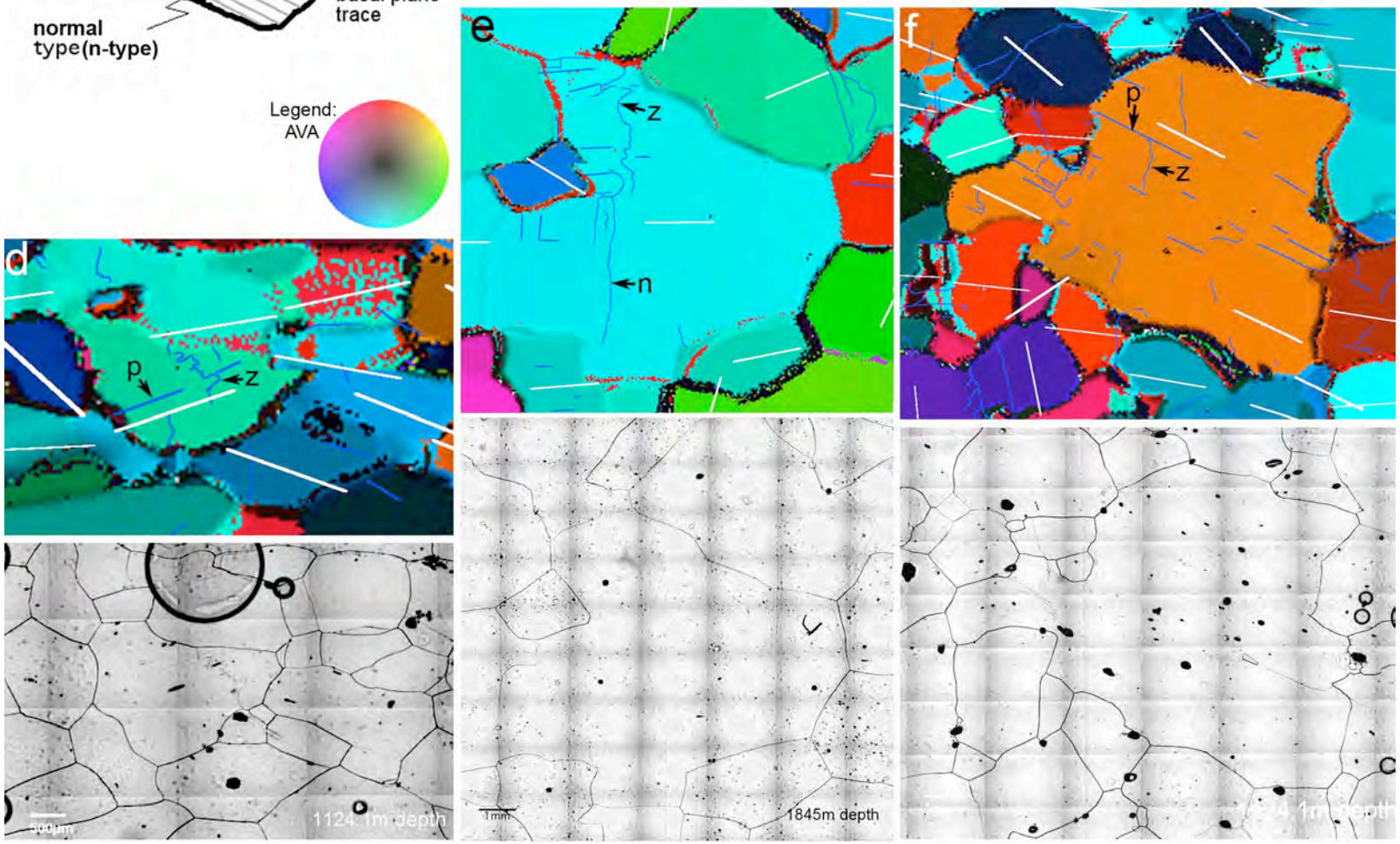
... (and neither do other parameters support the three recrystallization regimes)

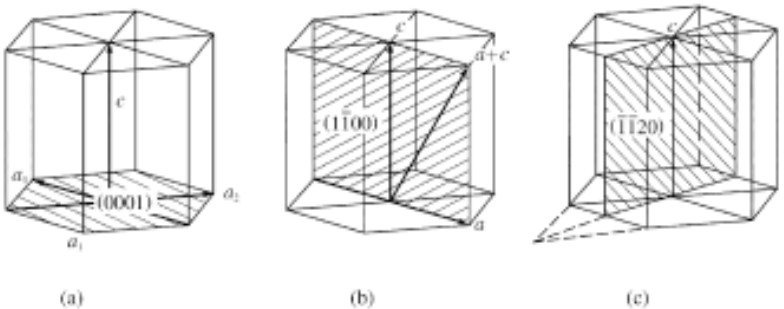
Weikusat et al. 2009, J. Glaciol.

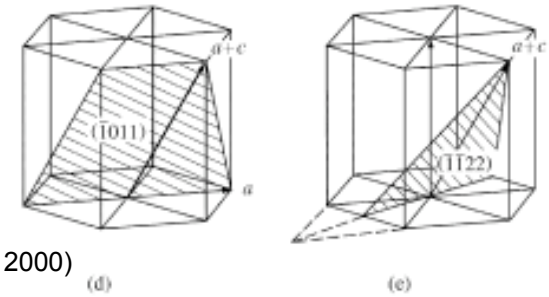
subGB types (morphologic)



Weikusat et al. 2009, J. Glac.







(from Hondoh 2000)

Glide on non-basal planes ≈60x harder!

But needed for deformation compatibility

Glide systems in ice

$$\dot{\varepsilon} = B \cdot \exp(-Q/RT) \cdot \sigma^n$$

T = absolute temperature
R = gas constant
B, n, Q = constants

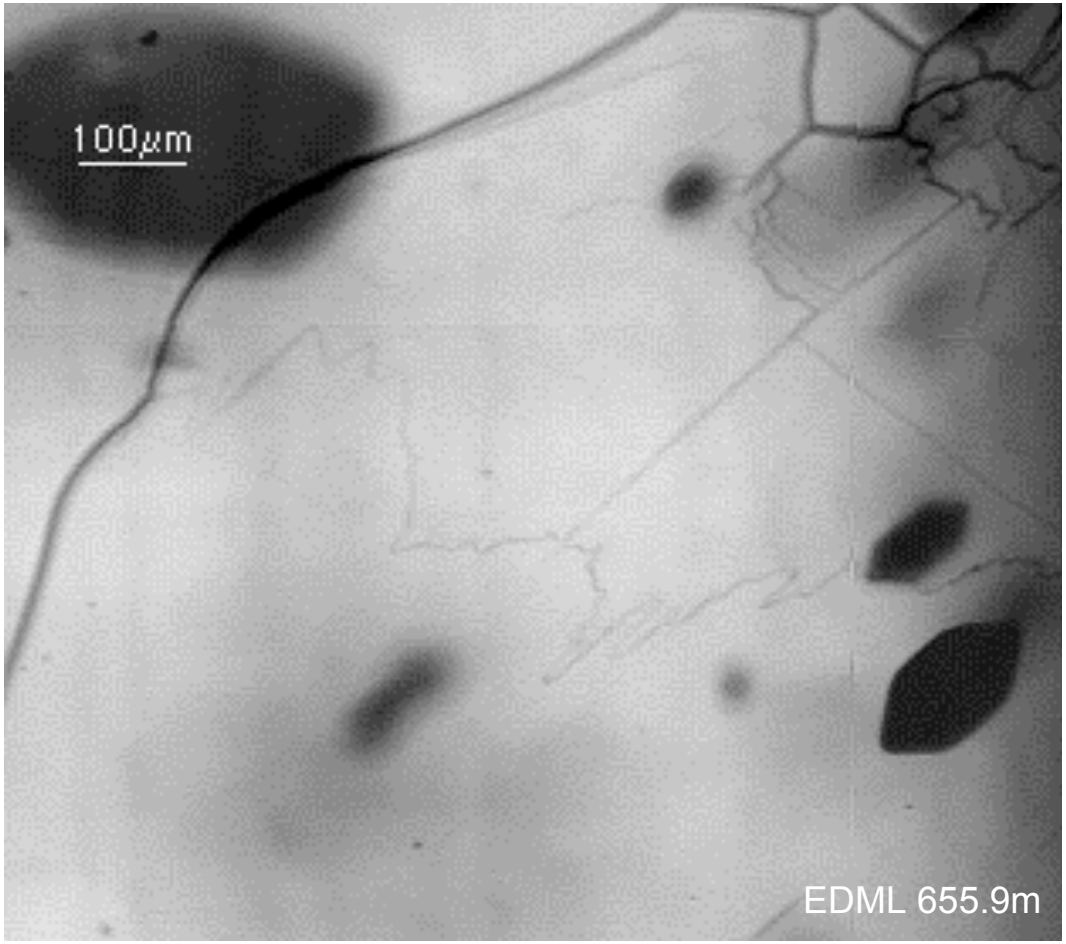
Flow law used in ice sheet modelling

Table 1: Rate-limiting processes for Equ. 1

	σ (MPa)	n	rate-limiting process
creep test σ-range:	~0.1 to 1	≈3	activation of non-basal slip systems
Ice sheet σ-range:	~0.1	≈2	?

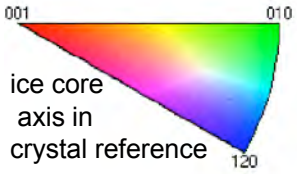
(after Montagnat and Duval, 2004)

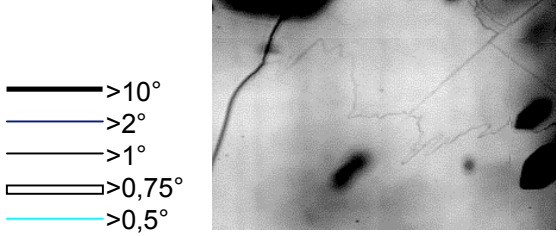
μSM

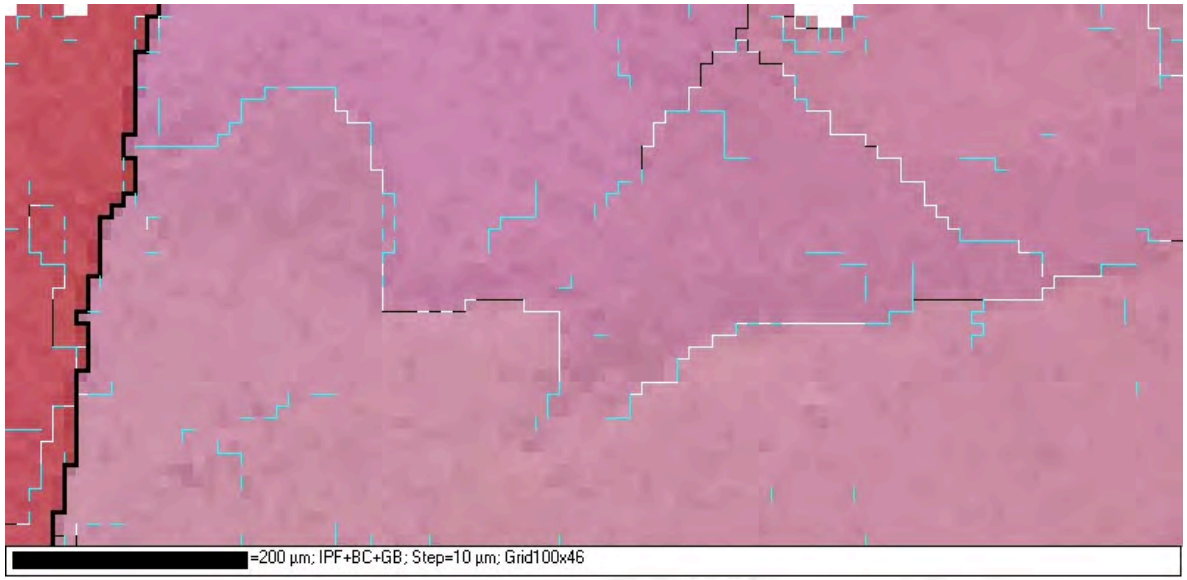


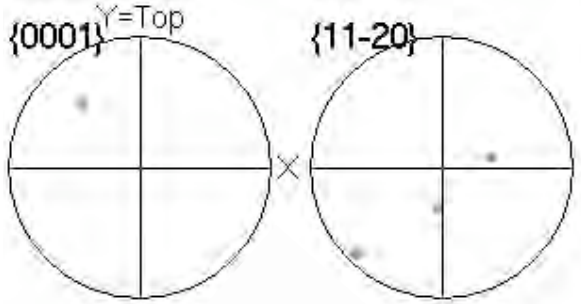
subGB types (morphologic)

subGB types (structural)



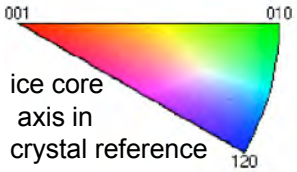


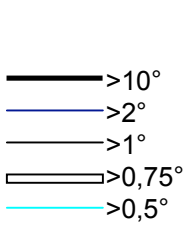


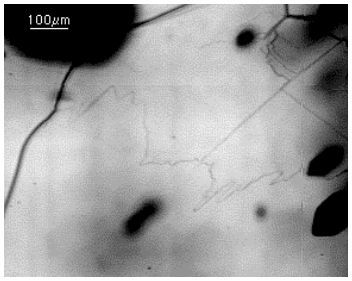


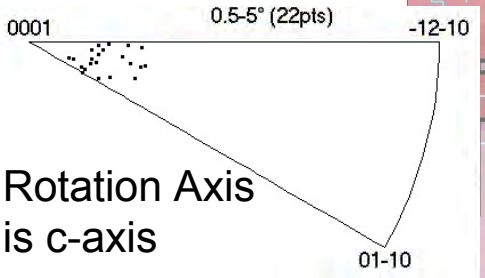
EBSD data

subGB types (structural)

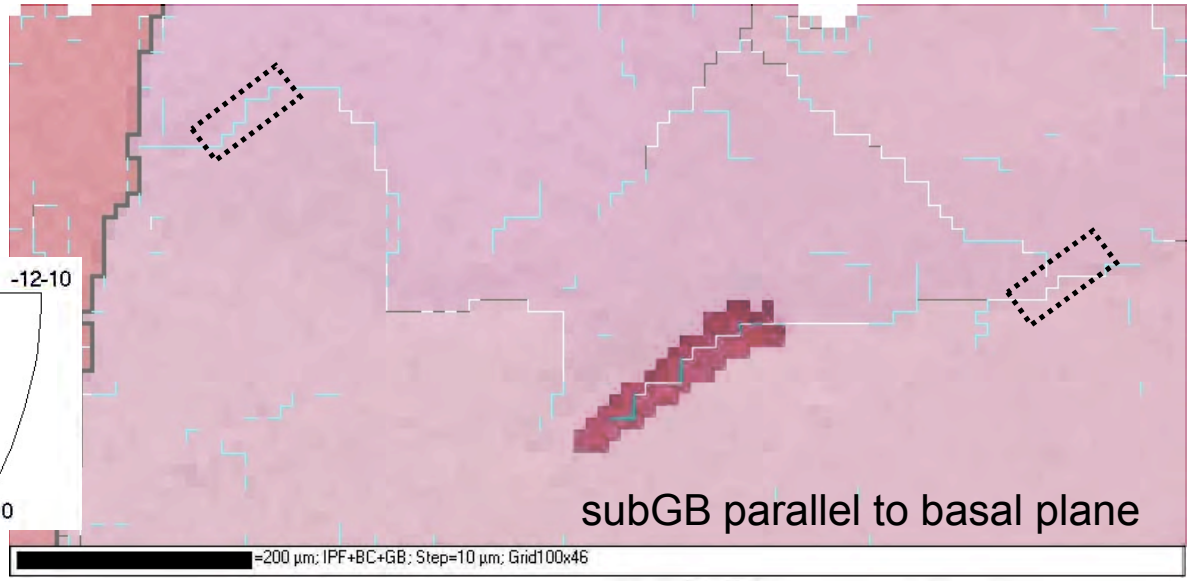




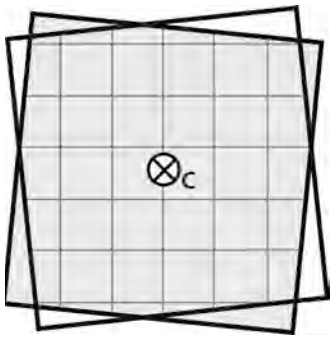


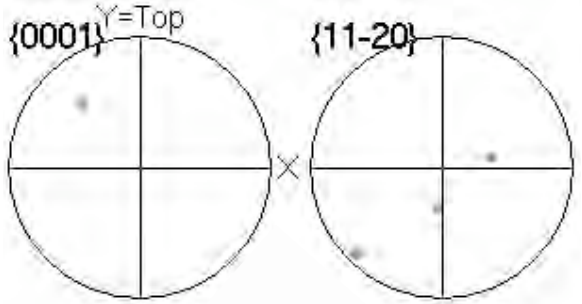


Rotation Axis
is c-axis



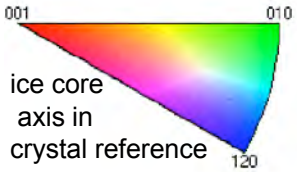
subGB || basal plane
+
Rot. Axis ⊥ basal plane
=
Twist boundary with sets of screw dislocations on basal (b=a)

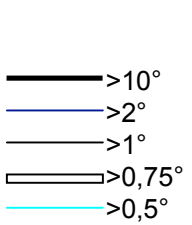


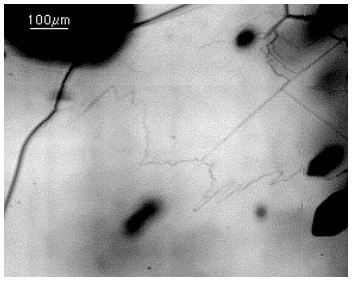


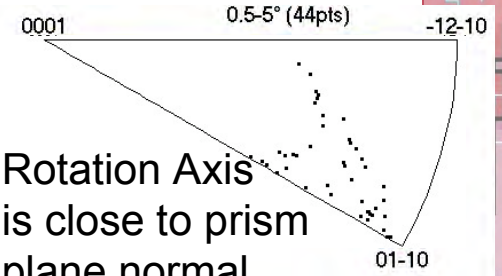
EBSD data

subGB types (structural)

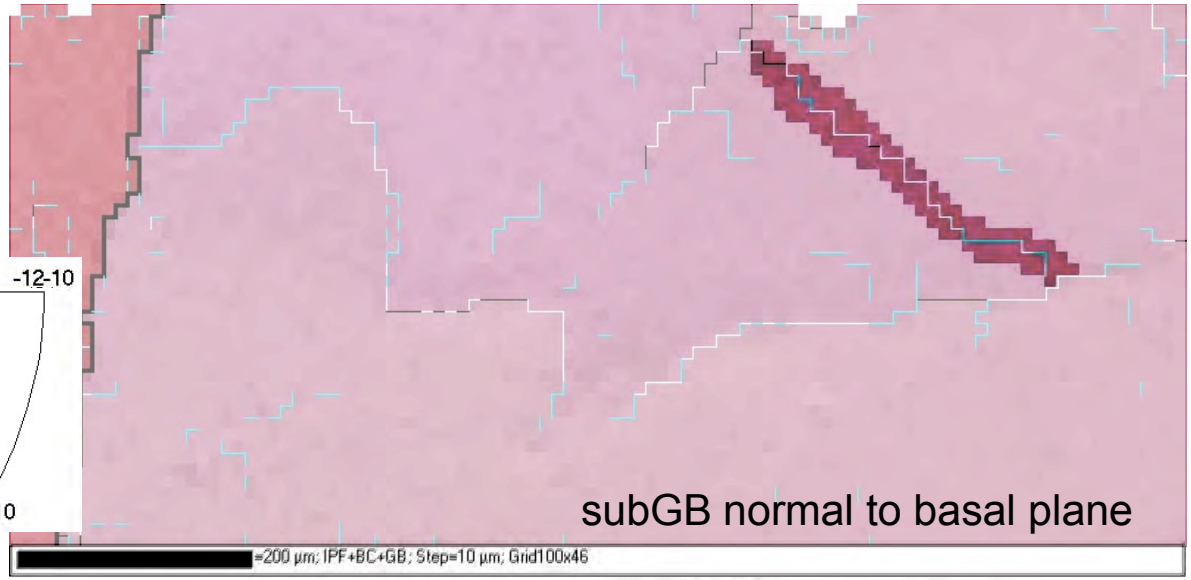




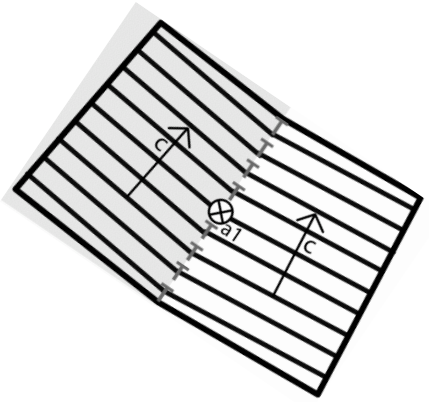


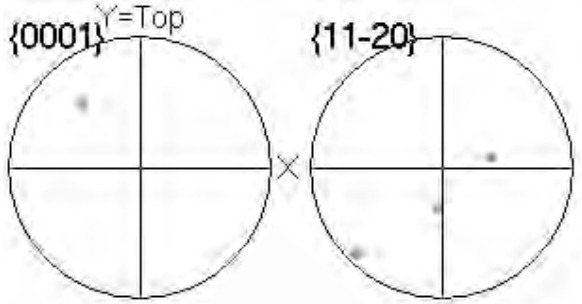


Rotation Axis is close to prism plane normal



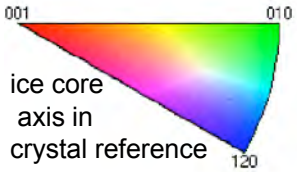
sGB ⊥ basal plane
+
Rot. Axis || basal plane
=
Tilt boundary with edge dislocations on basal (b=a)



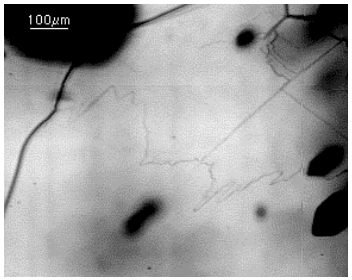


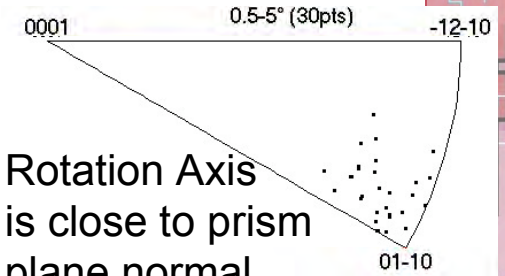
EBSD data

subGB types (structural)

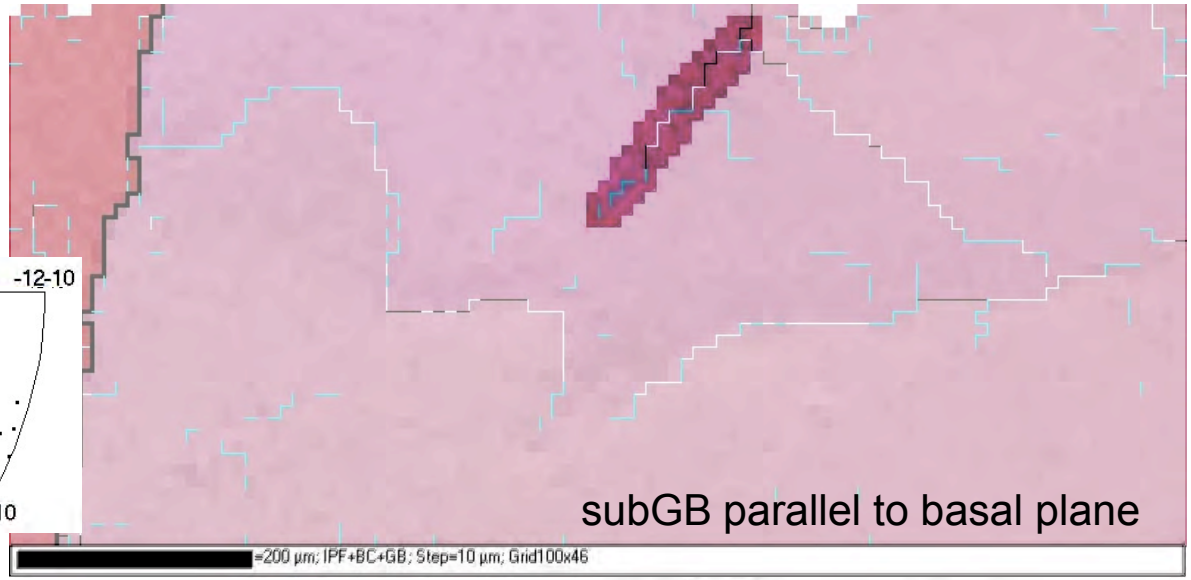


>10°
>2°
>1°
>0,75°
>0,5°

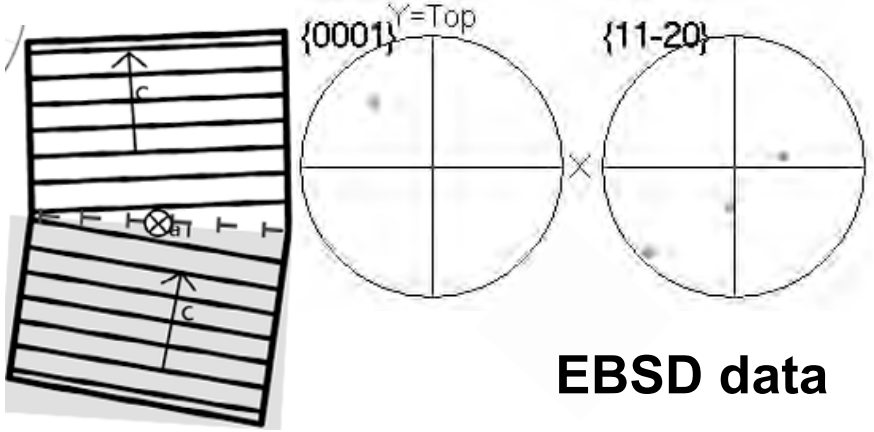




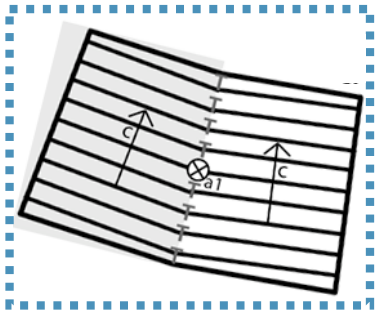
Rotation Axis is close to prism plane normal



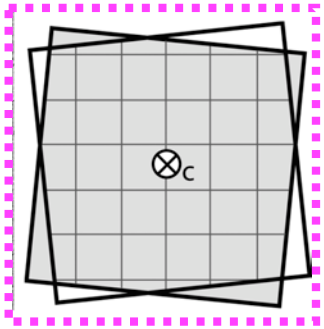
sGB || basal plane
+
Rot. Axis || basal plane
=
Tilt boundary with edge dislocations on non-basal (b=c or b=c+a)



EBSD data

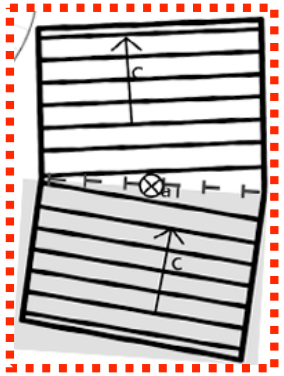


Basal tilt boundary
Burgers vector = a



Basal twist boundary
Burgers vectors = a

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



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

Weikusat et al. 2010, submitted to J. Glac.

X-ray Laue diffraction Data

- Three recrystallization regimes have to be reconsidered
- 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.
ilka.weikusat@awi.de

References

- Hondoh, T. Hondoh, T. (ed.) Nature and behaviour of dislocations in ice Physics of Ice Core Records, Hokkaido University Press, 2000, 3-24
- Weikusat, I.; Kipfstuhl, S.; Faria, S. H.; Azuma, N. & Miyamoto, A. Subgrain boundaries and related microstructural features in EPICA-Dronning Maud Land (EDML) deep ice core J. Glaciol., 2009, 55, 461-472
- Montagnat, M. & Duval, P. Dislocations in ice and deformation mechanisms: from single crystals to polar ice Deffect and Diffusion Forum, Scitec Pub., 2004, 229, 43-54
- De La Chapelle, S.; Castelnau, O.; Lipenkov, V. & Duval, P. Dynamic recrystallization and texture development in ice as revealed by the study of deep ice cores in Antarctica and Greenland J. Geophys. Res., 1998, 103, 5.091-5,106
- Weikusat, I., Miyamoto, A., Faria, S. H., Kipfstuhl, S., Azuma, N., Hondoh, T.(2010).Subgrain boundaries in Antarctic ice quantified by X-ray Laue diffraction, J. Glaciol. [SUBMITTED]