High resolution deformation microstructures in ice: grain-boundary morphology and subgrain boundaries in samples from creep tests and an Antarctic ice core

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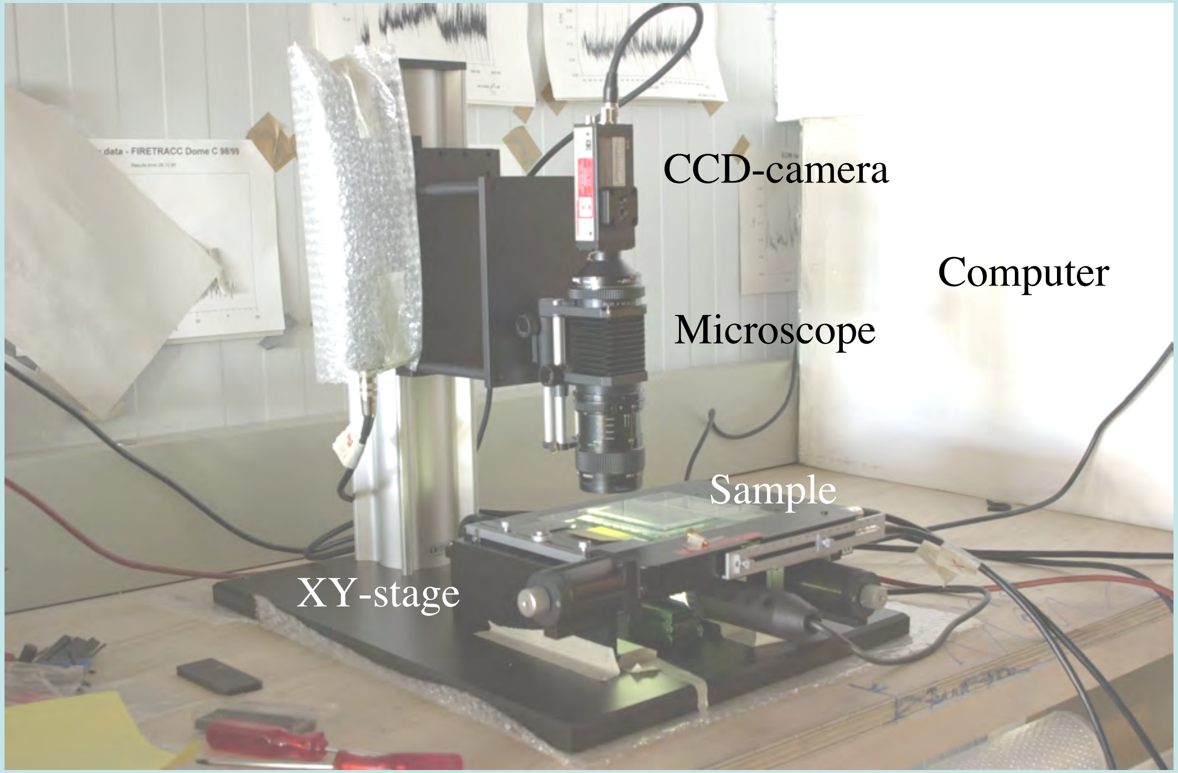
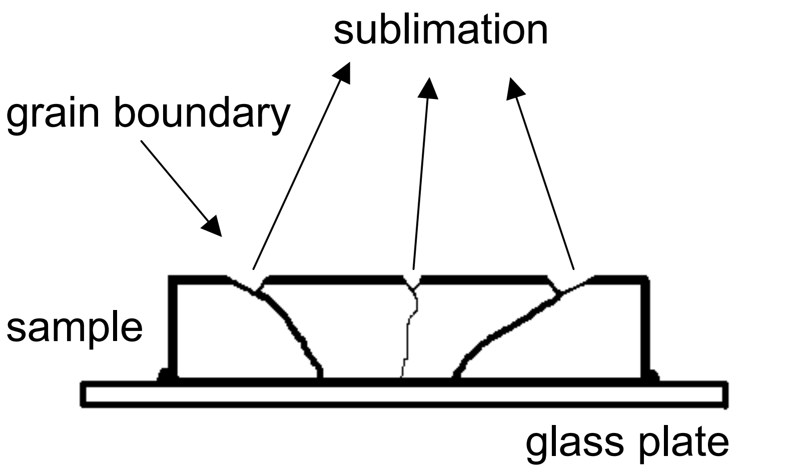


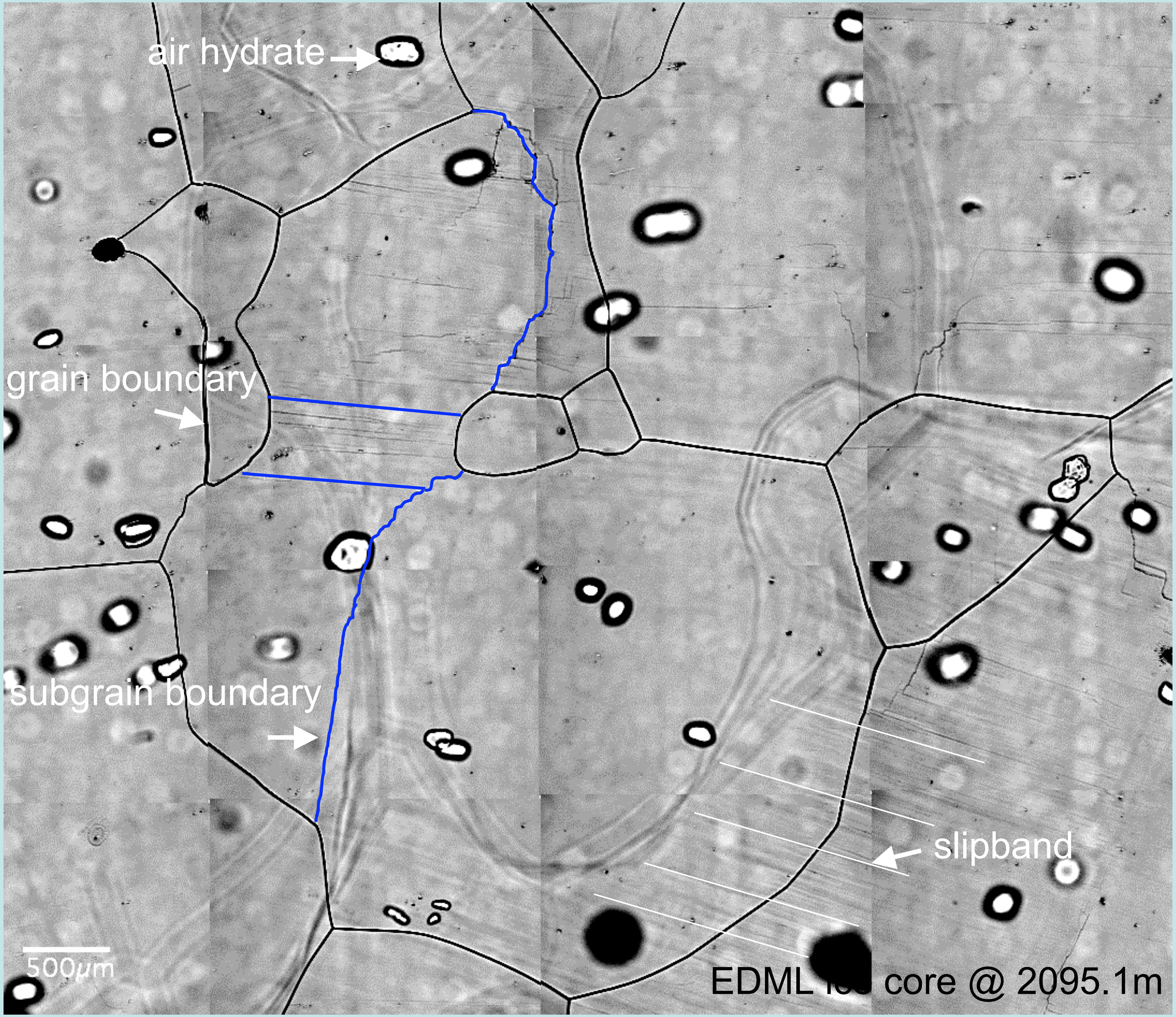
Detour:

µS-Mapping validation

Microstructure Mapping



picture: Kipfstuhl



Detour:

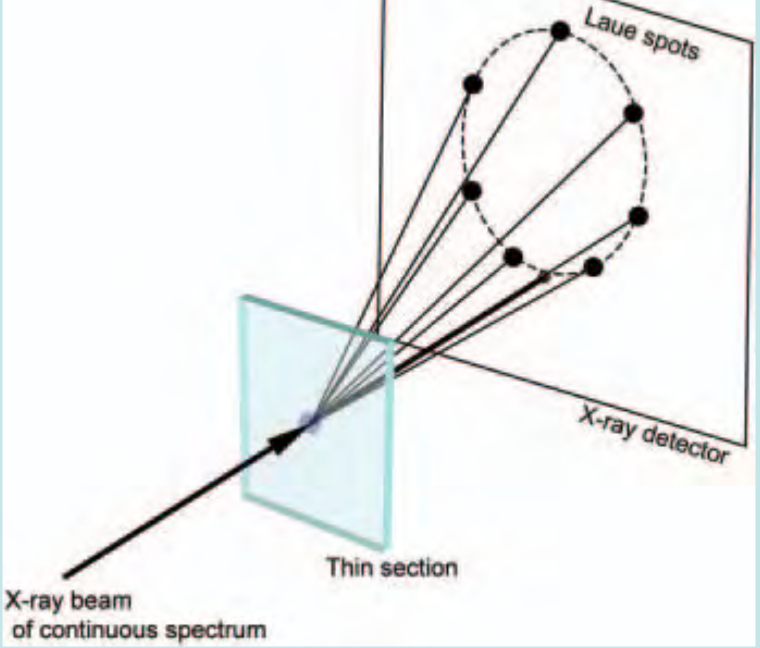
µS-Mapping validation

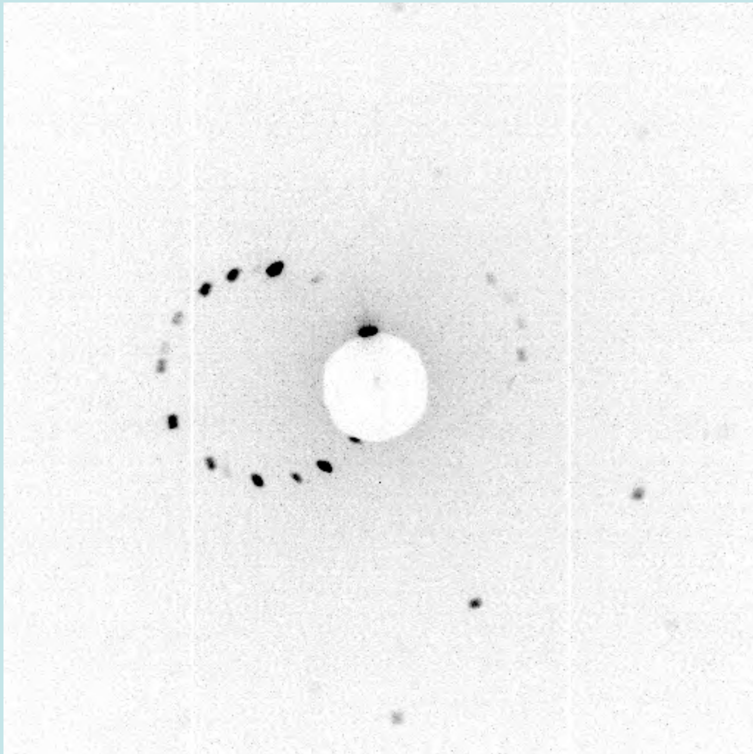
X-ray Laue diffraction

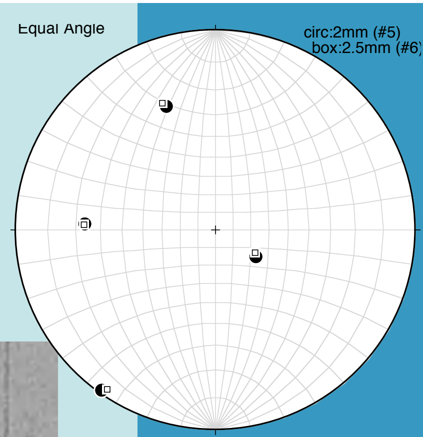
Detour:

µS-Mapping validation

picture:
Miyamoto et al. 2005



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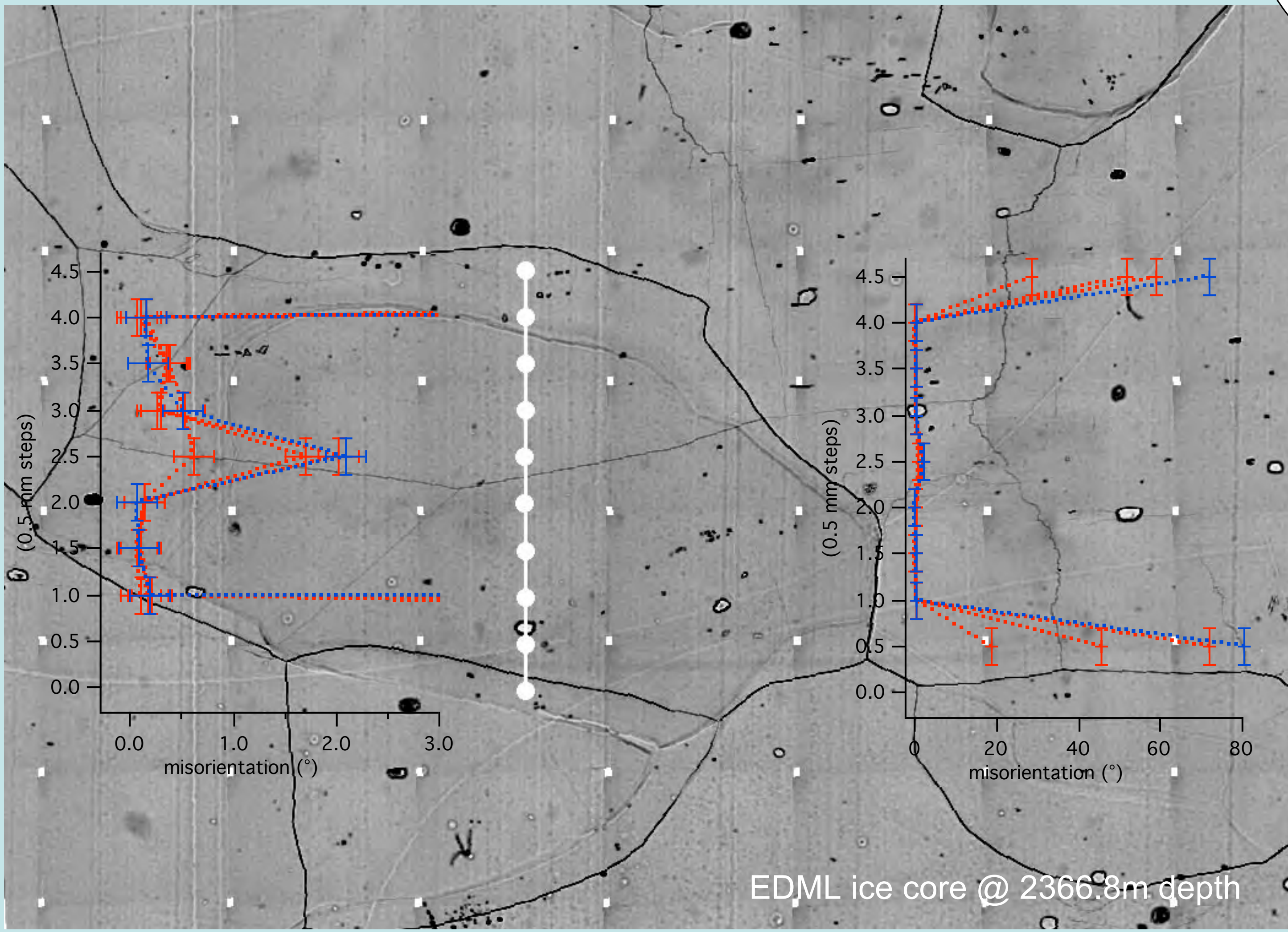
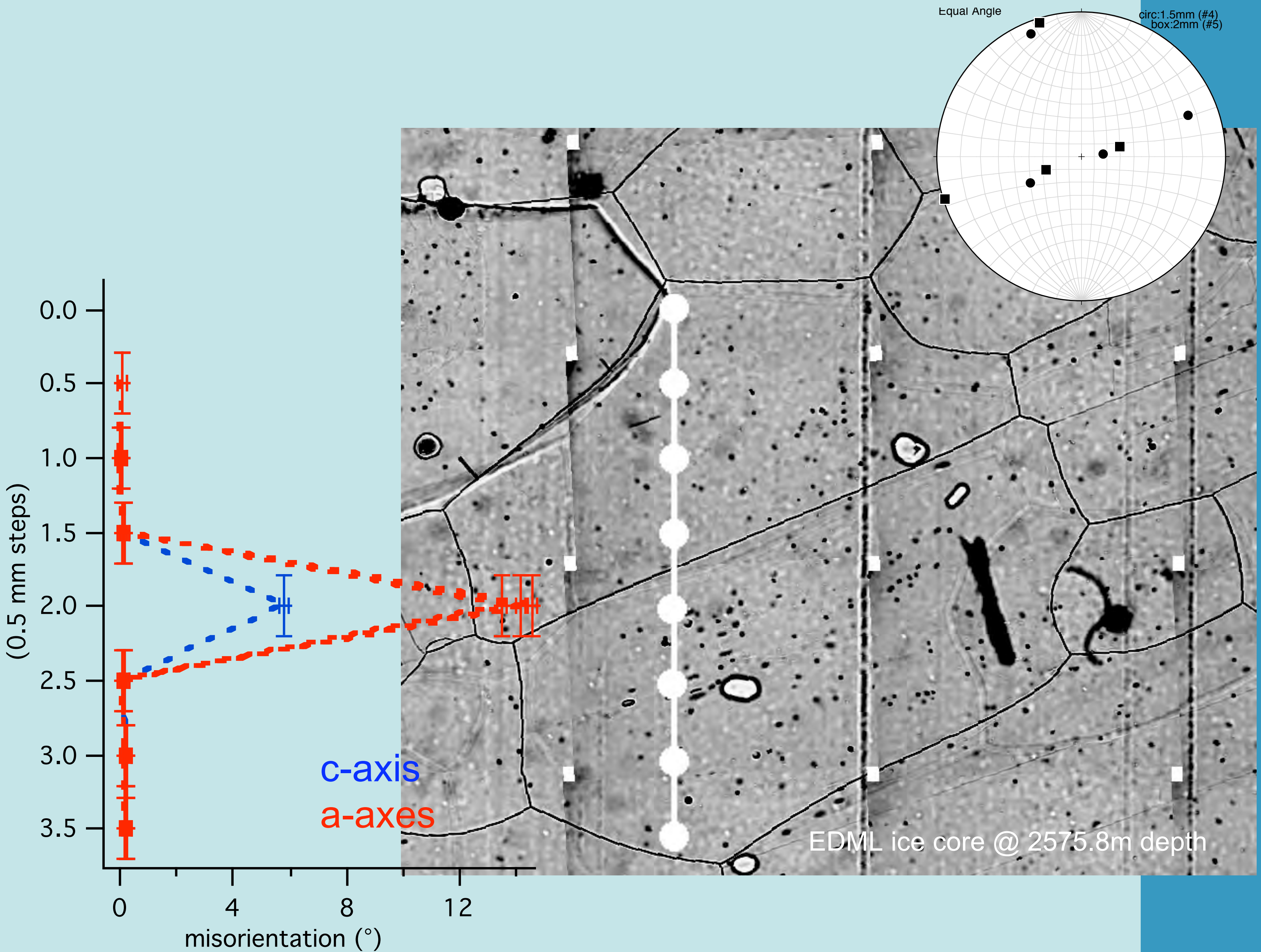
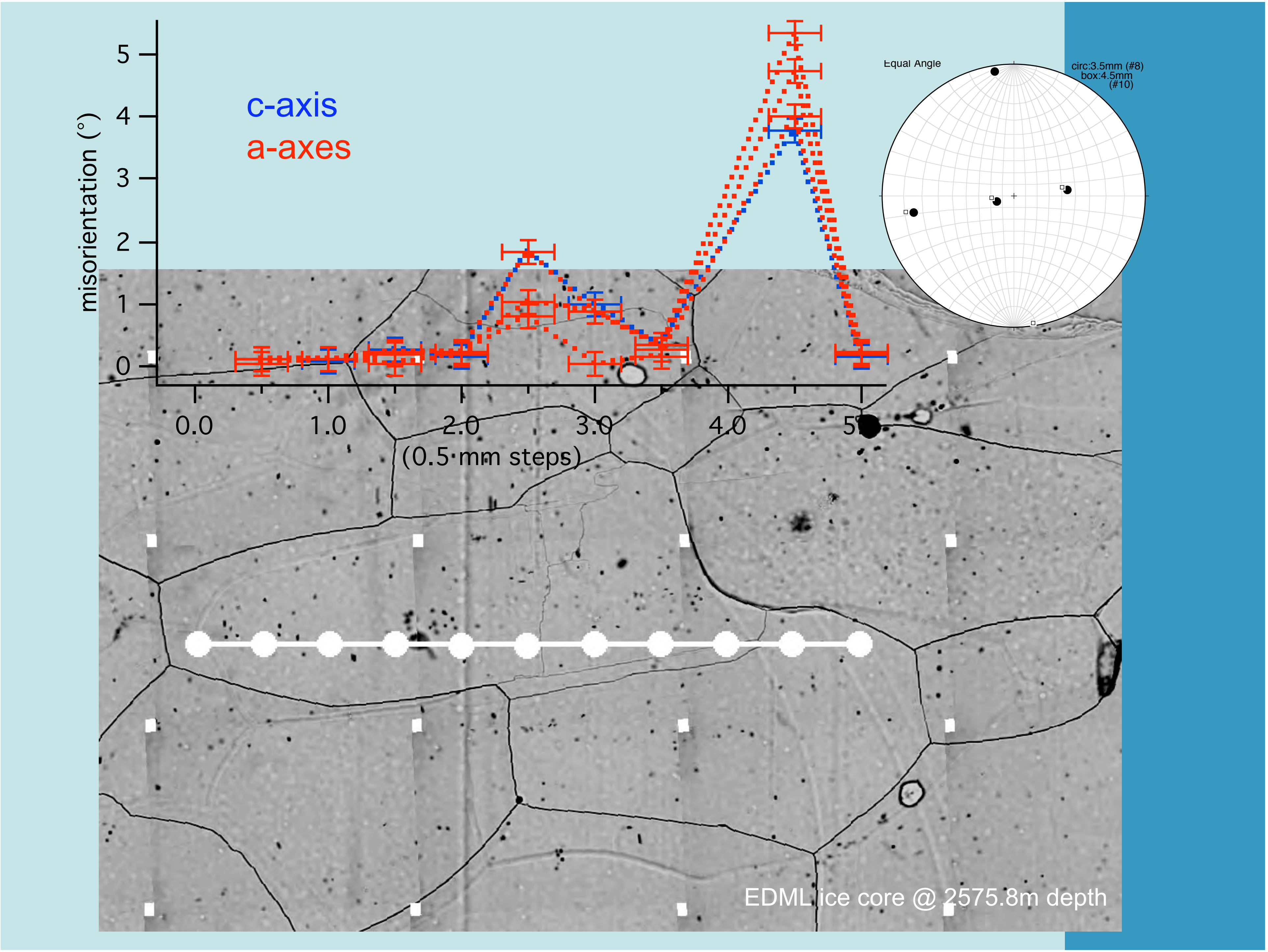
box:2.5mm (#6)

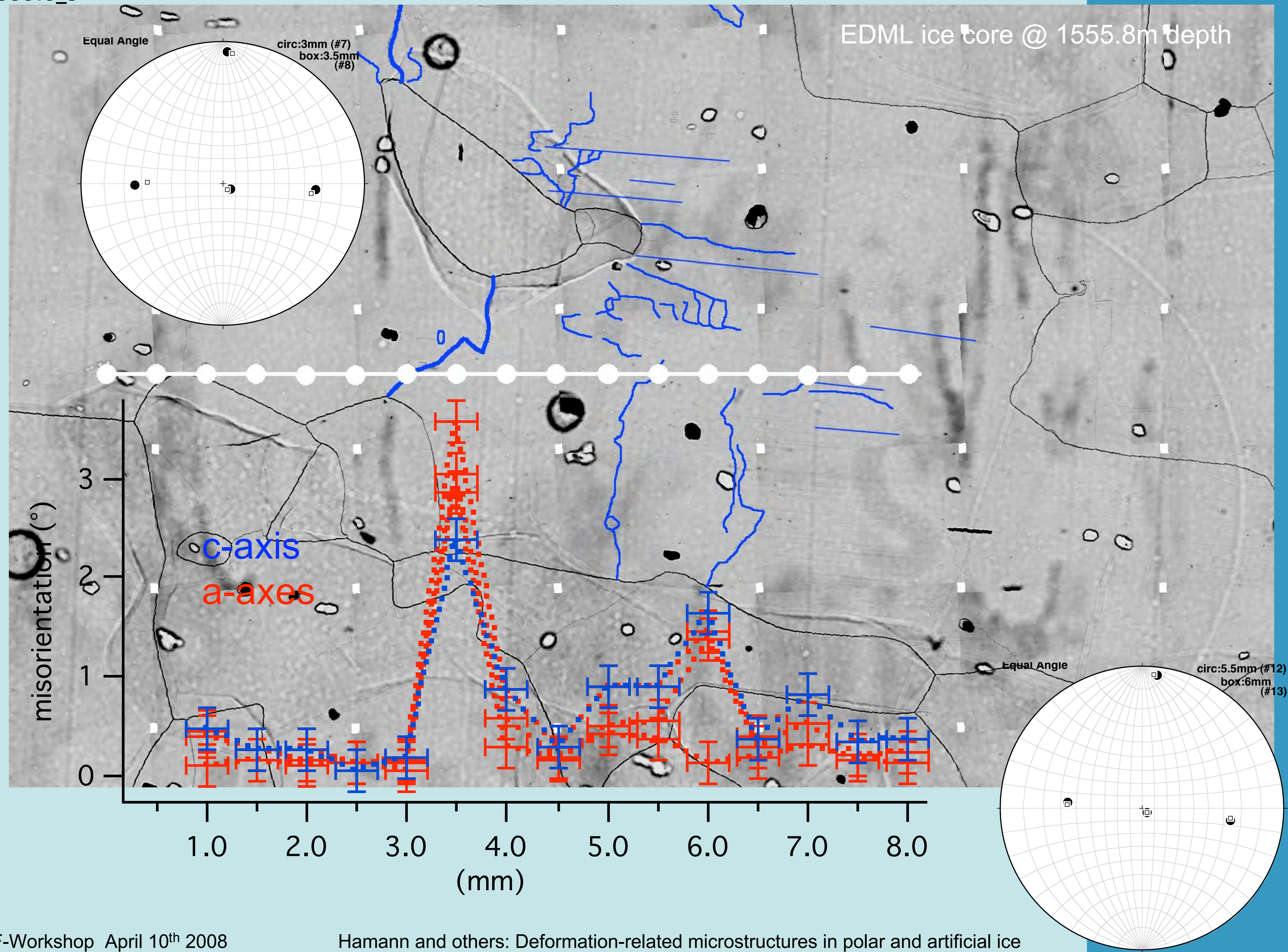

(0.5 mm steps)
misorientation (°)
0.0
1.0
2.0
3.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
20
40
60
80
EDML ice core @ 2366.8m depth


Equal Angle
circ:1.5mm (#4)
box:2mm (#5)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
(0.5 mm steps)
0
4
8
12
misorientation (°)
c-axis
a-axes
EDML ice core @ 2575.8m depth

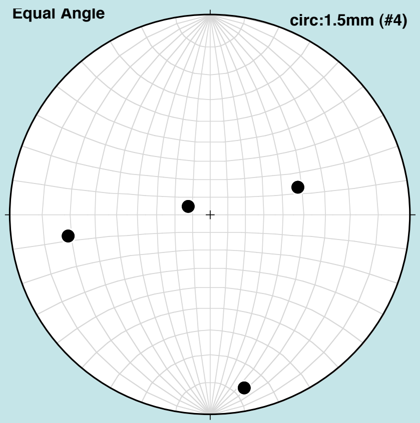


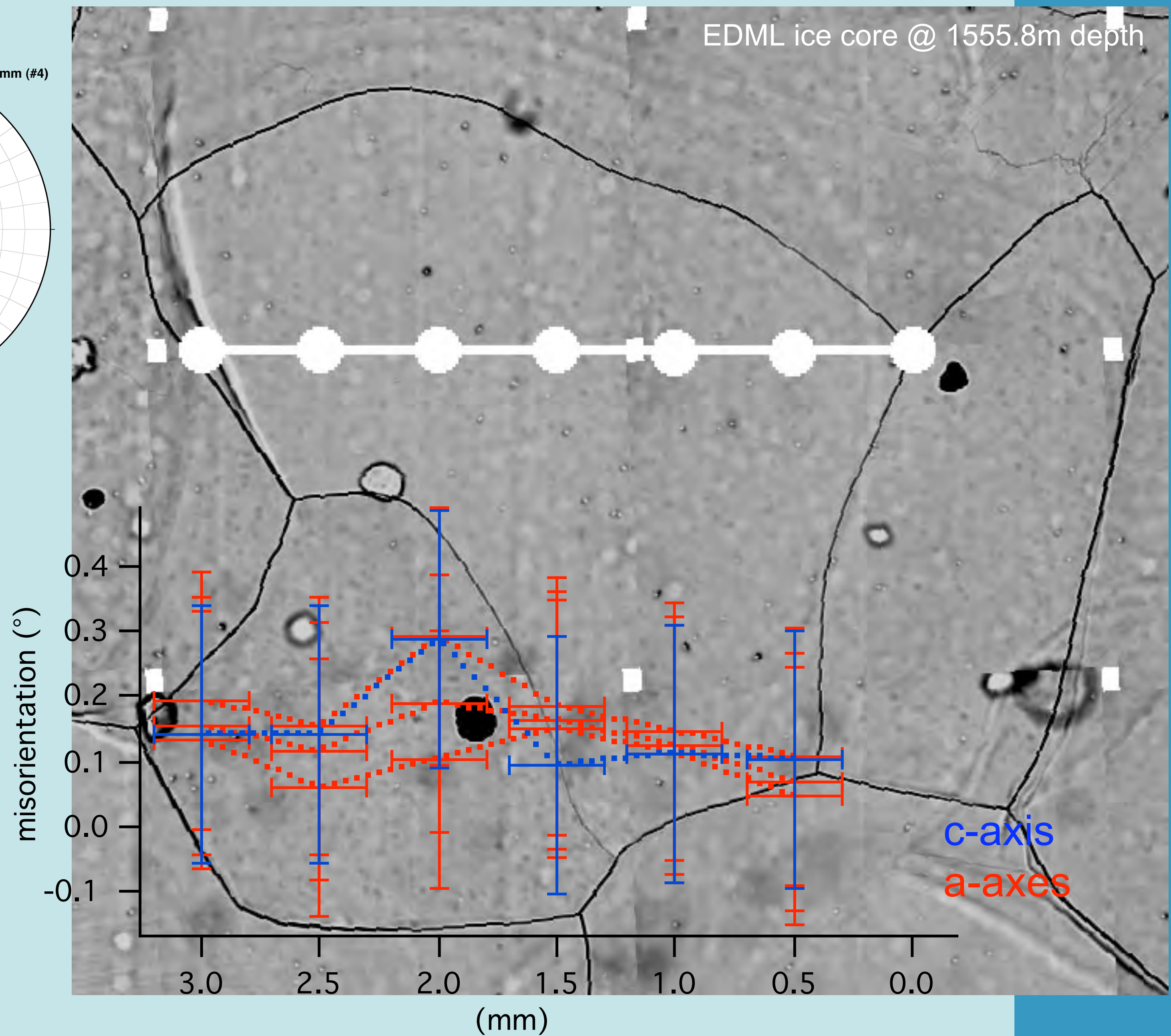
c-axis
a-axes
misorientation (°)
0
1
2
3
4
5
0.0
1.0
2.0
3.0
4.0
5.0
(0.5 mm steps)
Equal Angle
circ:3.5mm (#8)
box:4.5mm
(#10)
EDML ice core @ 2575.8m depth

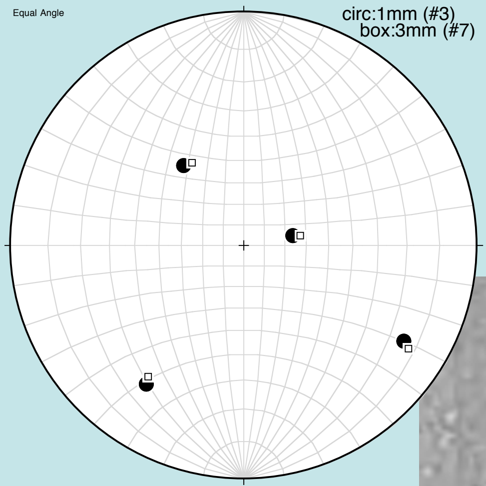
1555.8_3

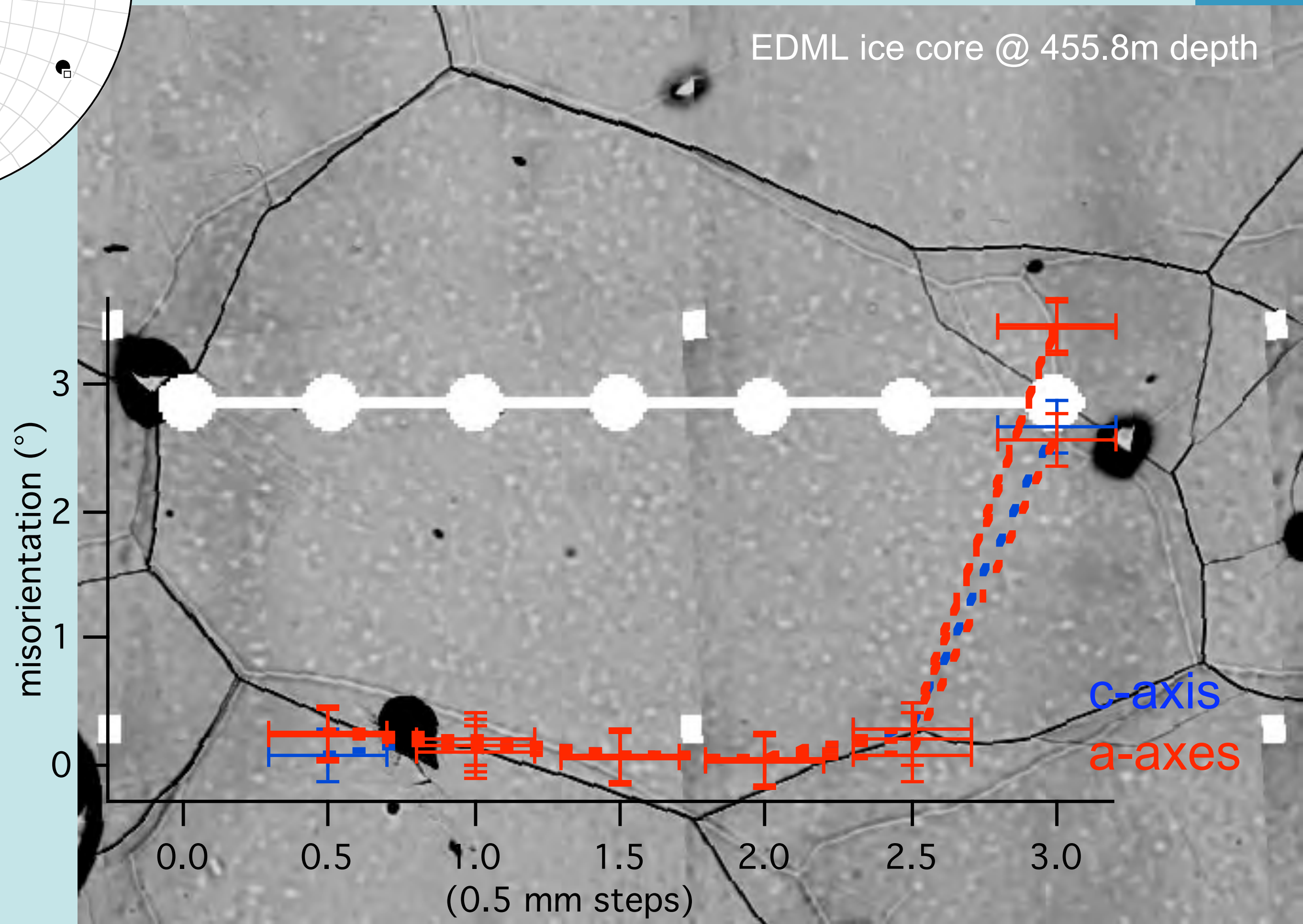


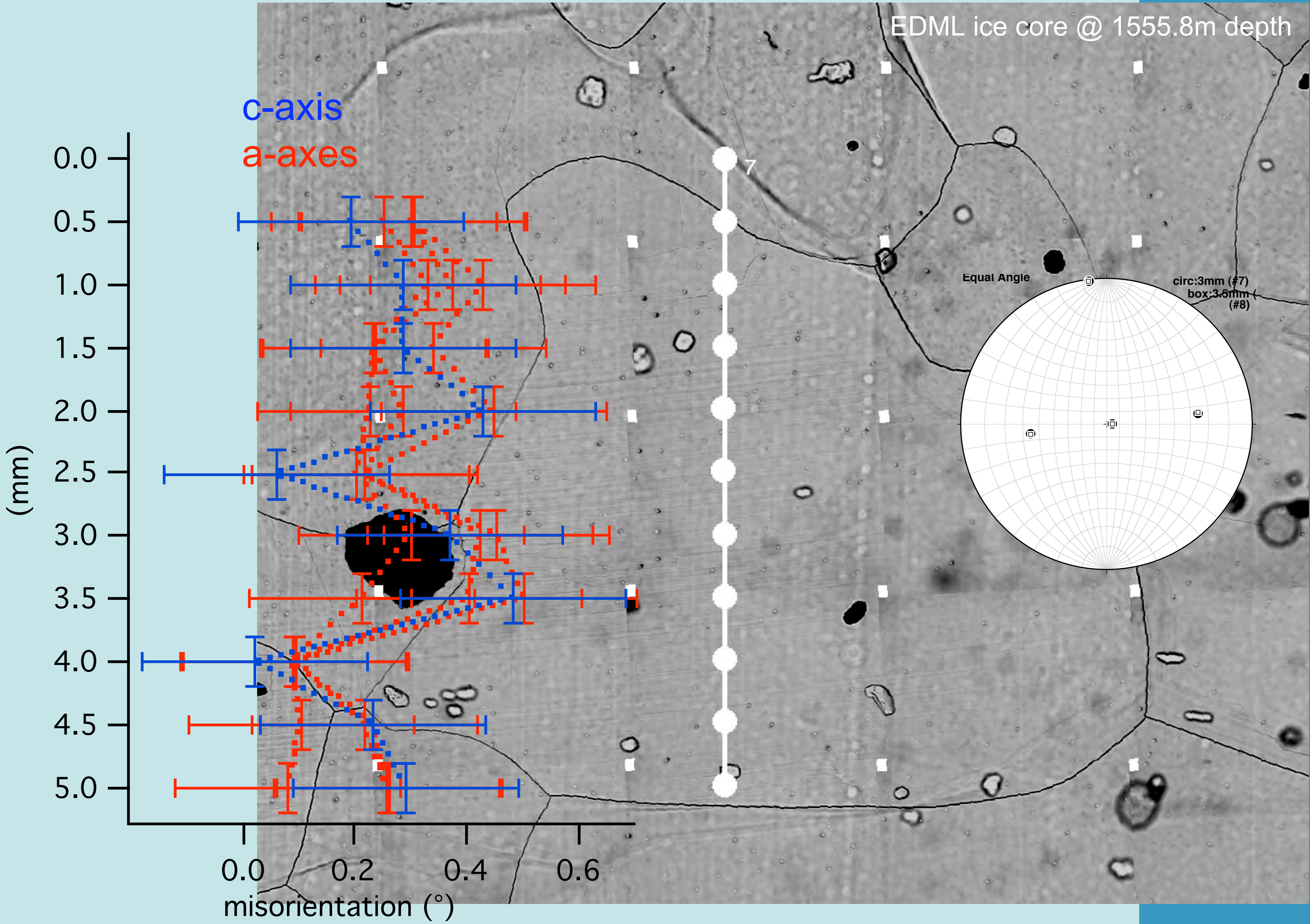
EDML ice core @ 1555.8m depth
Equal Angle
circ:3mm (#7)
box:3.5mm (#8)
Equal Angle
circ:5.5mm (#12)
box:6mm (#13)
c-axis
a-axes
misorientation (°)
0
1
2
3
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
(mm)


Equal Angle
circ:1.5mm (#4)


EDML ice core @ 1555.8m depth
misorientation (°)
0.4
0.3
0.2
0.1
0.0
-0.1
3.0
2.5
2.0
1.5
1.0
0.5
0.0
(mm)
c-axis
a-axes


Equal Angle
circ:1mm (#3)
box:3mm (#7)


EDML ice core @ 455.8m depth
misorientation (°)
0
1
2
3
0.0
0.5
1.0
1.5
2.0
2.5
3.0
(0.5 mm steps)
c-axis
a-axes



EDML ice core @ 1555.8m depth
c-axis
a-axes
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
(mm)
0.0
0.2
0.4
0.6
misorientation (°)
7
Equal Angle
circ:3mm (#7)
box:3.5mm (#8)

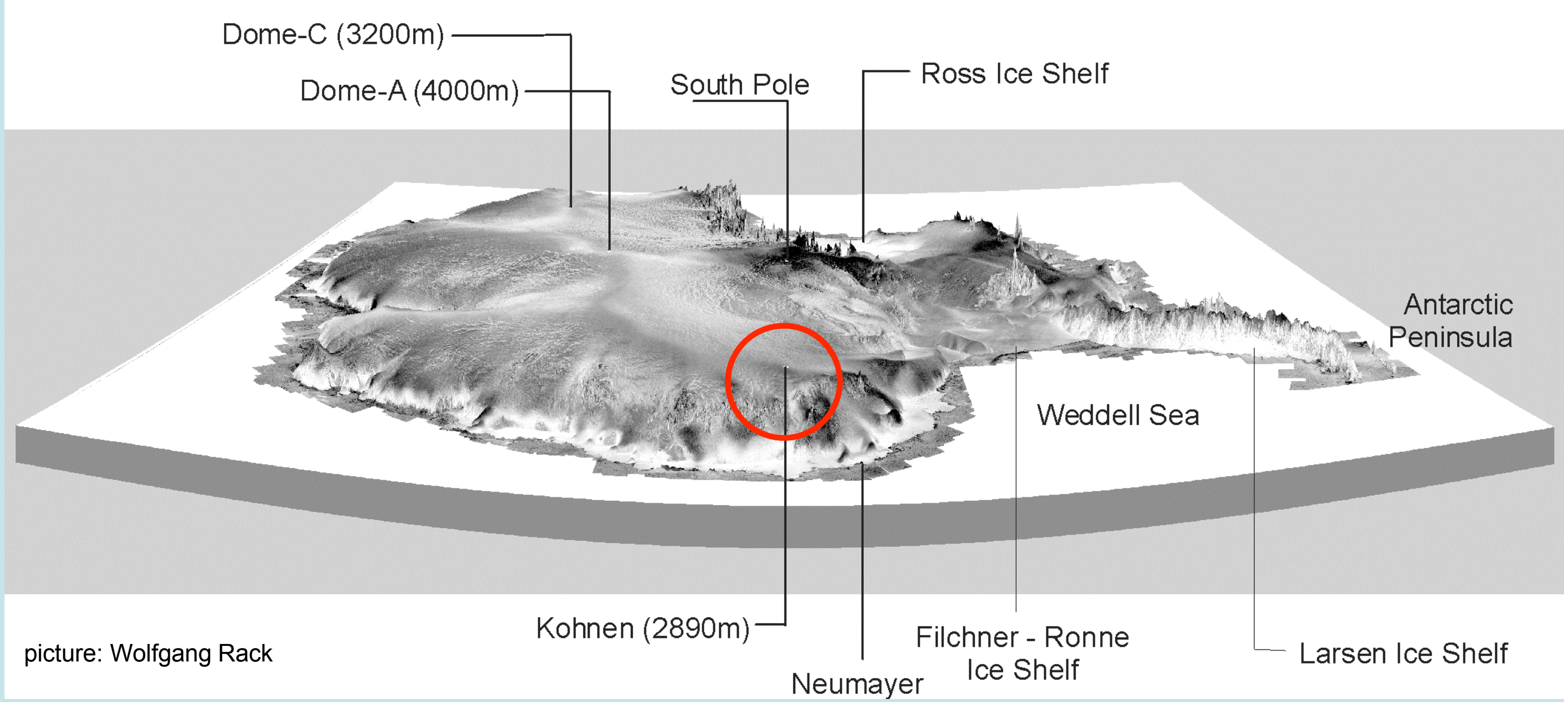
- Measured samples: 15
- Measured grains: 83
- Measured sGB: 235

- Shallow sublimation groove (“sGB”)

misorientation frequencies (rough figures!!)

	c-axes	*a-axes (max. mis.)*
– <0.5°:	40%	34%
– 0.5-1°:	28%	32%
– 1-2°:	17%	22%
– 2-3°:	8%	6%
– 3-4°:	5%	4%
– 4-5°:	1%	1%

EPICA Dronning Maud Land drilling location



picture: Wolfgang Rack

SAMPLES

- EDML
- Creep tests

µS-MAPPING

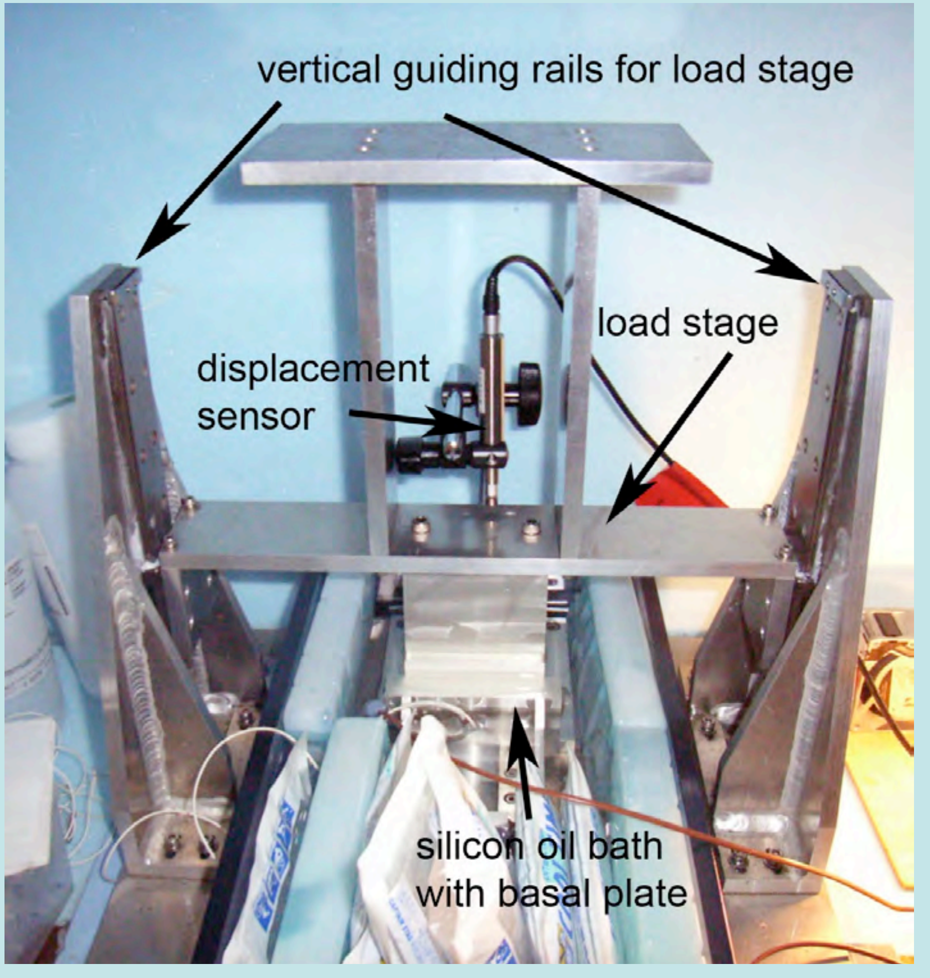
- GB morphology
- sGB
- Interaction of GB and sGB
- sGB-types

X-ray LAUE

- sGB-types

SUMMARY

Deformation Experiments



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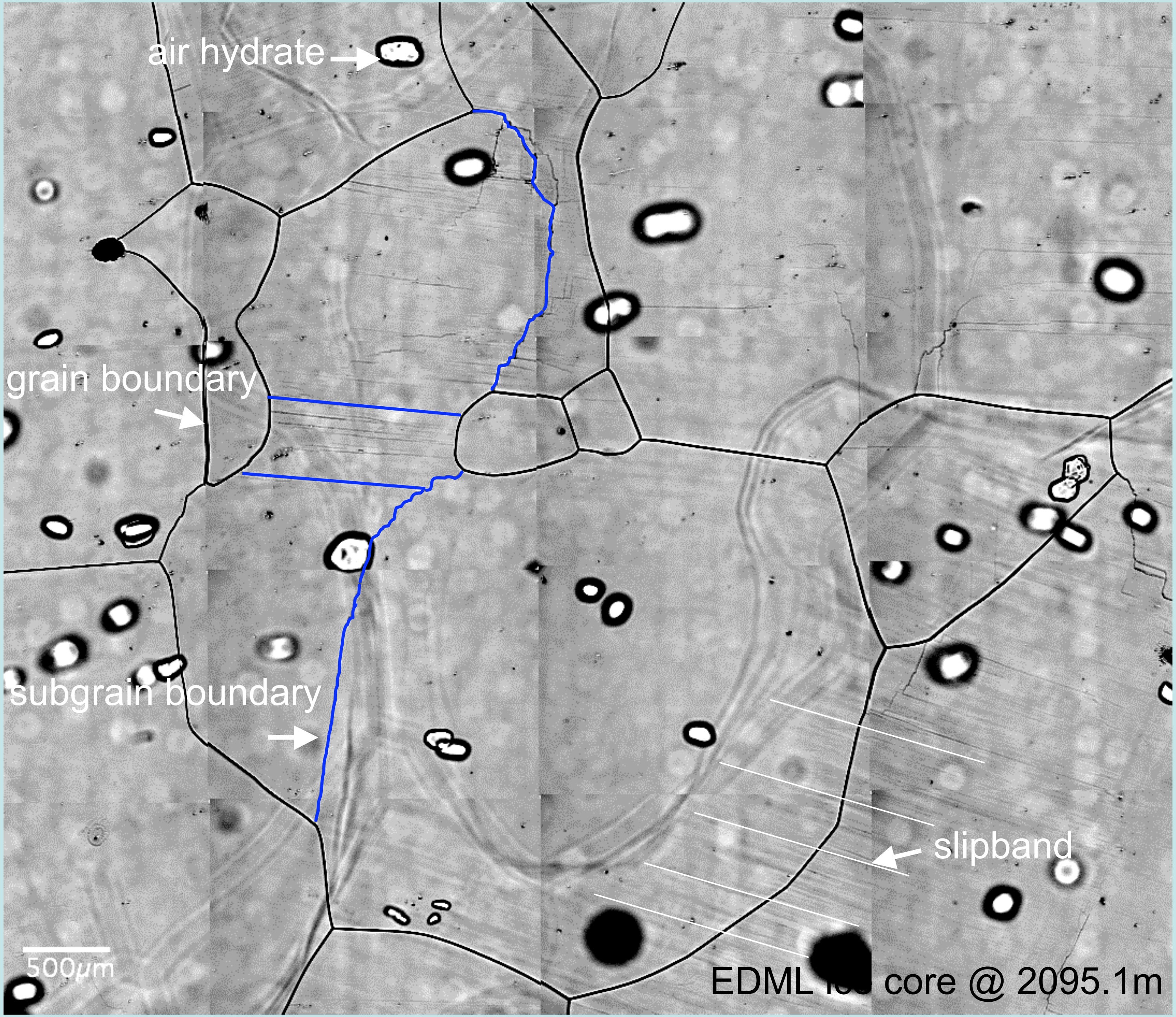

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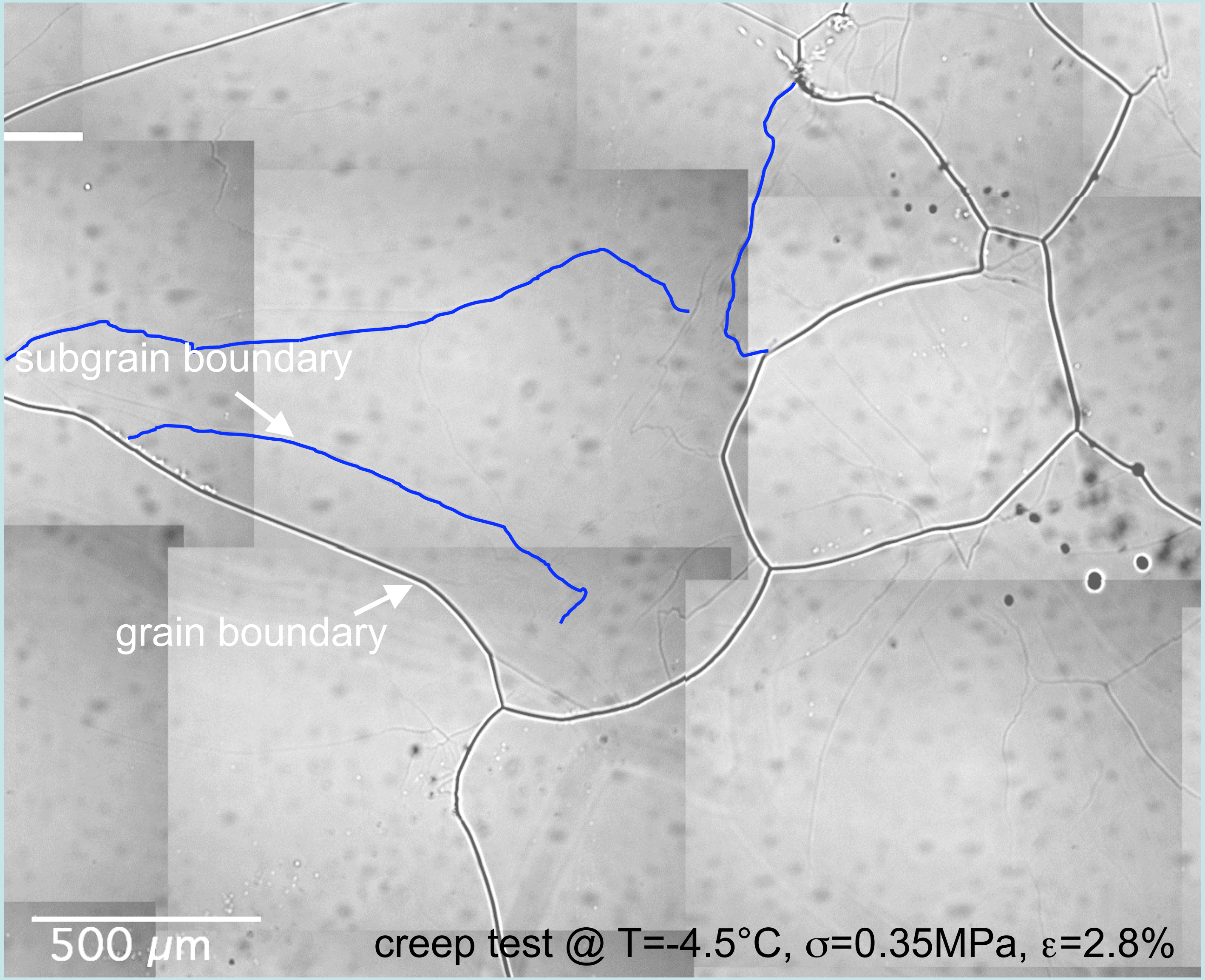
Microstructure Mapping



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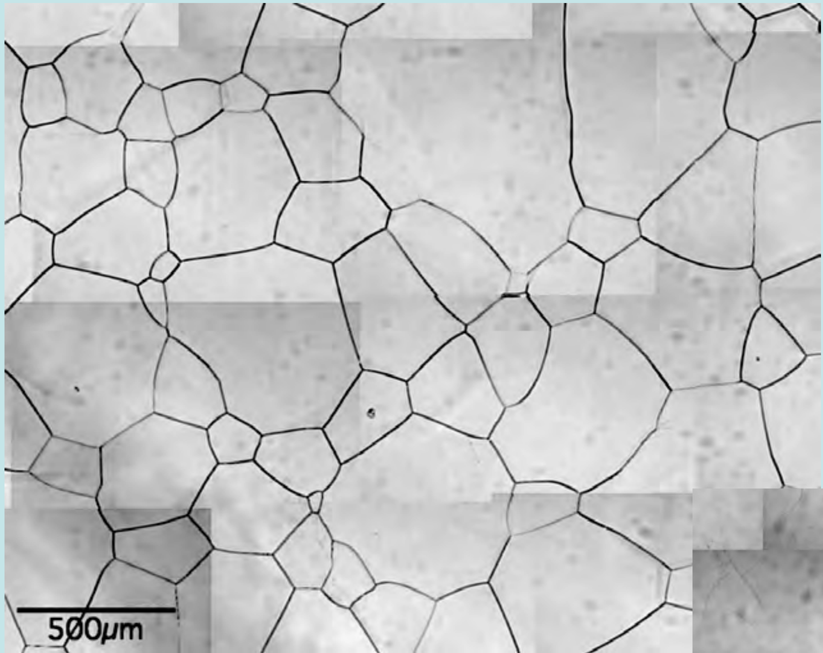
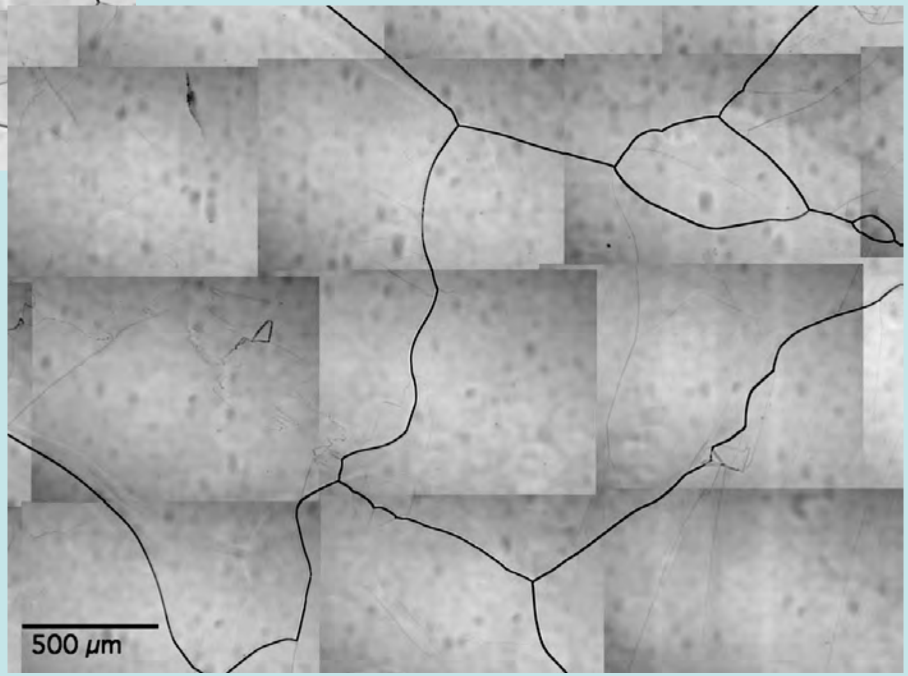
Grain-boundary morphology



initial
sample

creep test @
T=-4.9°C,
σ=0.52MPa,
ε=3.6%



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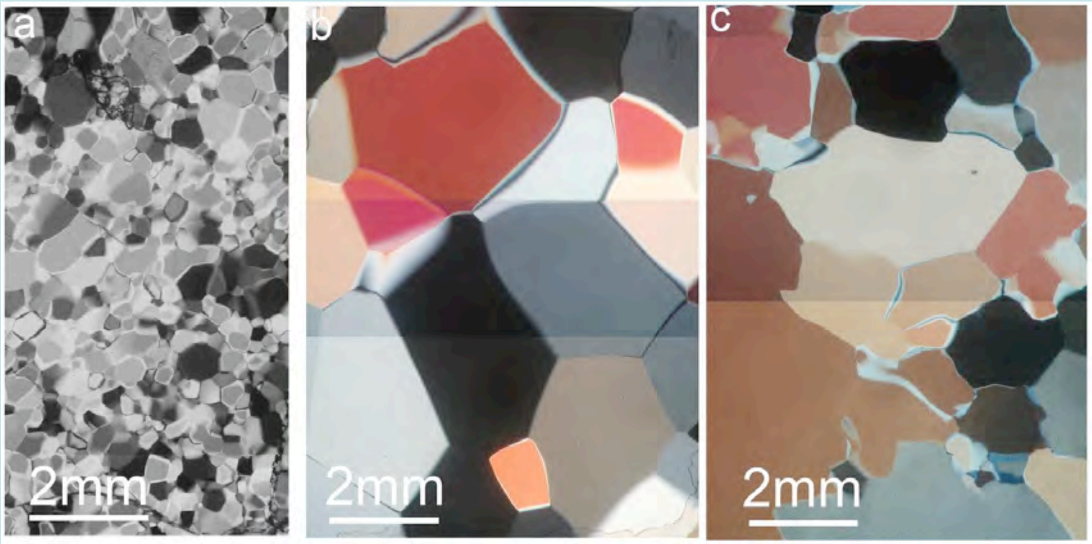
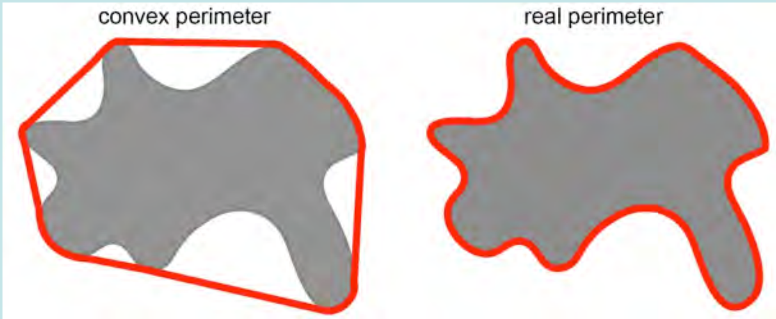
Grain-boundary morphology



Initial sample

Annealing @ T=-4.9°C, time=3d

Creep test @ σ=0.52MPa, ε=3.6%



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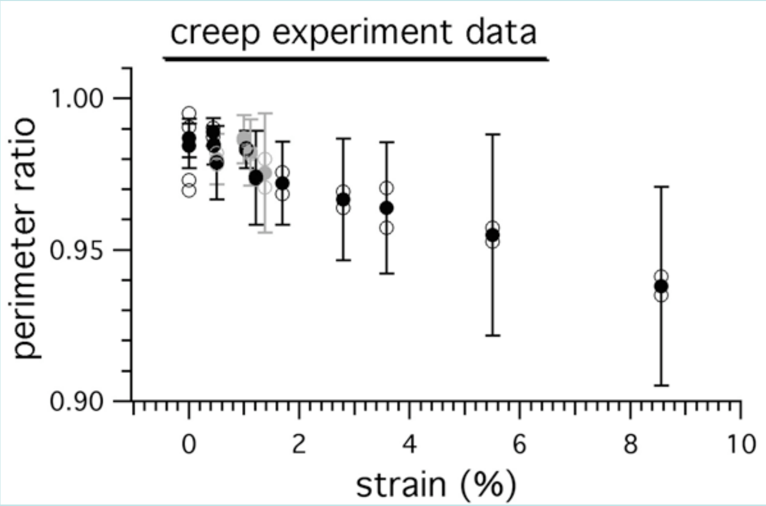
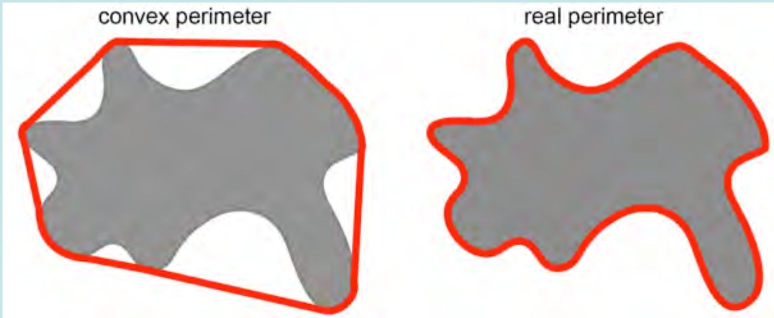
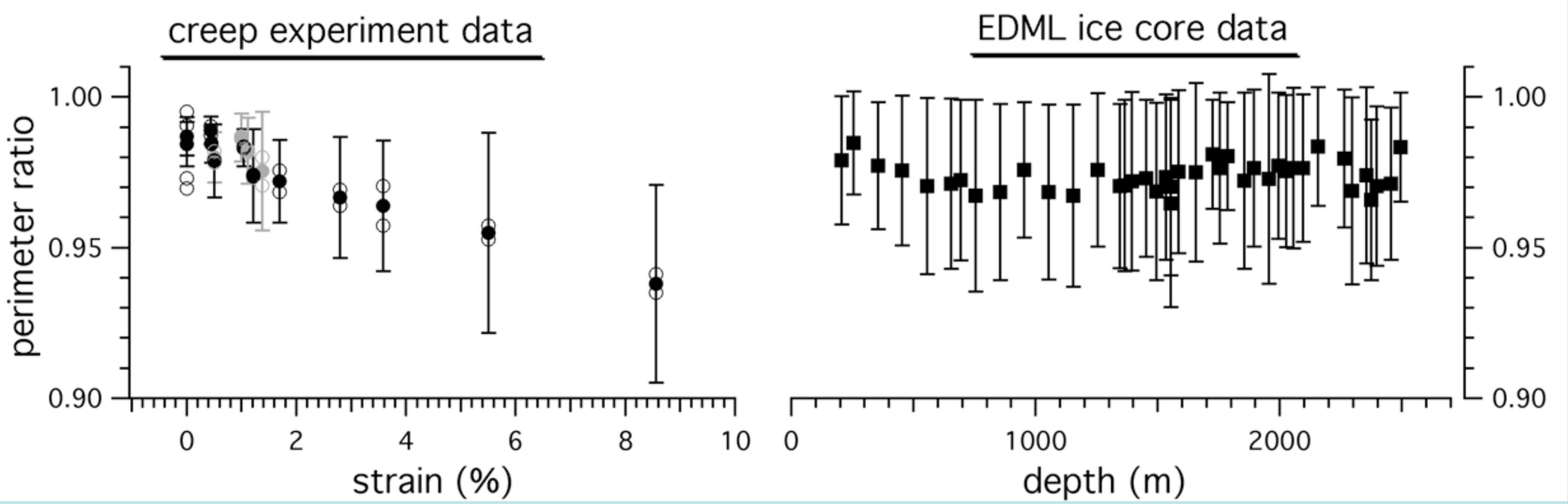
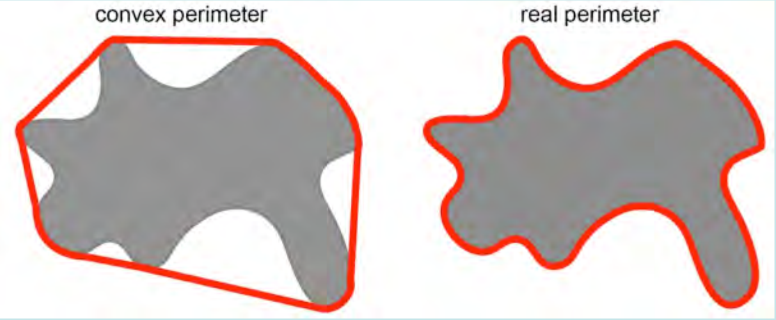




Grain-boundary morphology





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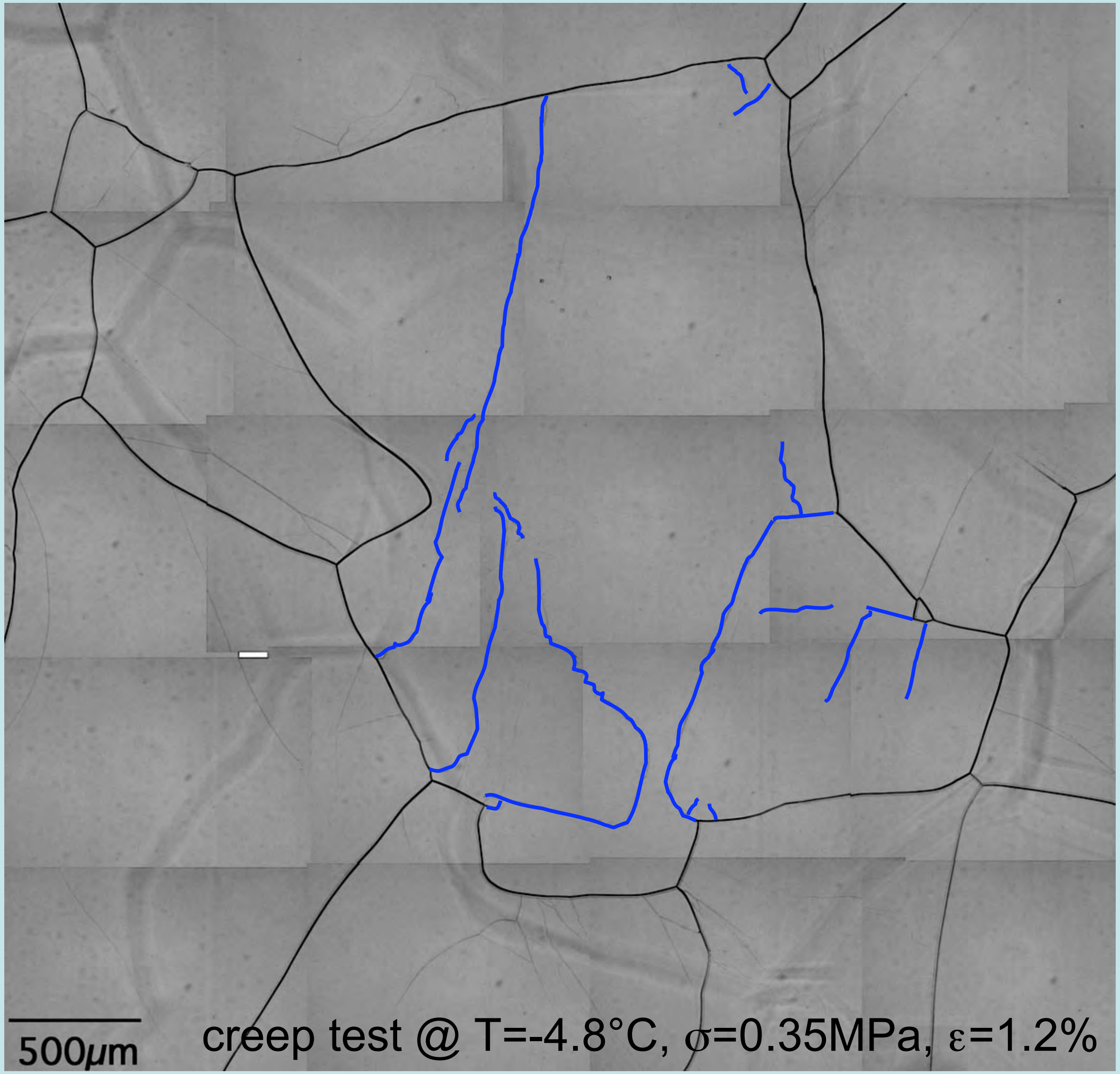
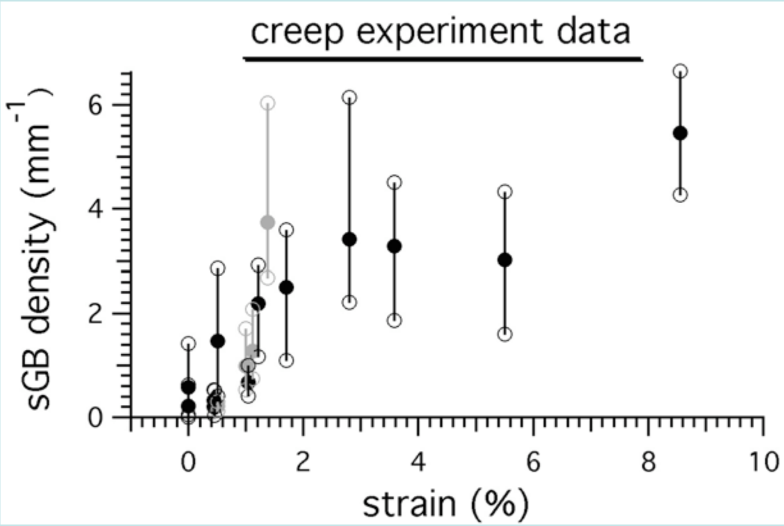
Subgrain-boundary



Subgrain-boundary density



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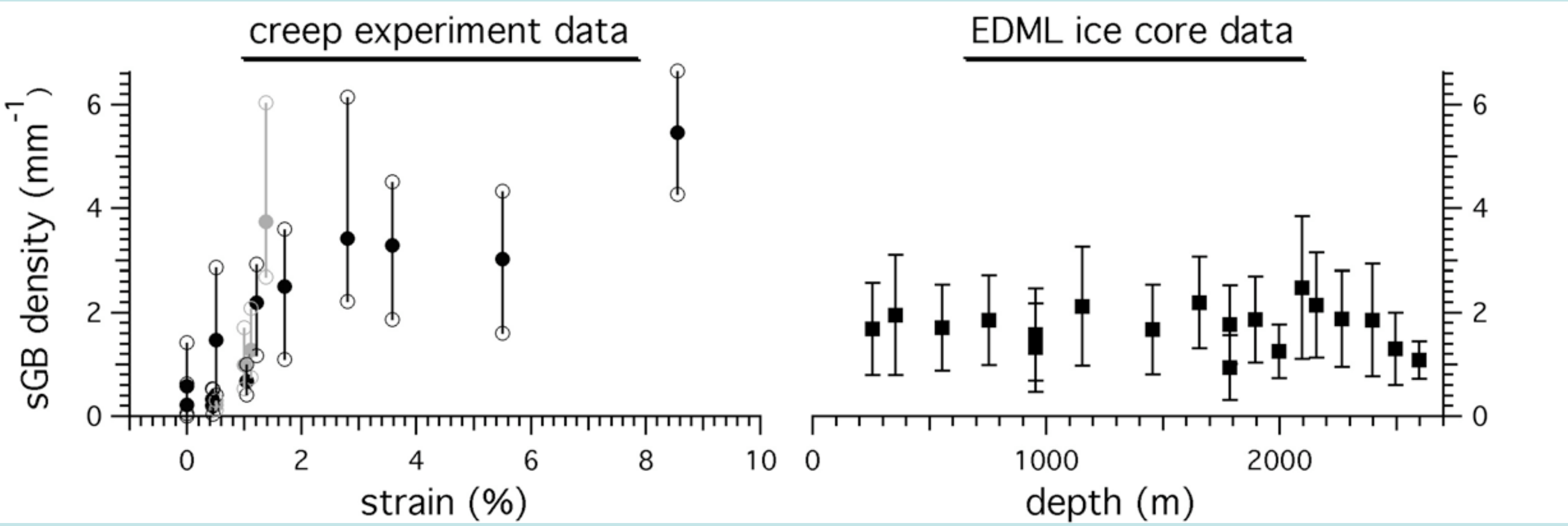
Subgrain-boundary density



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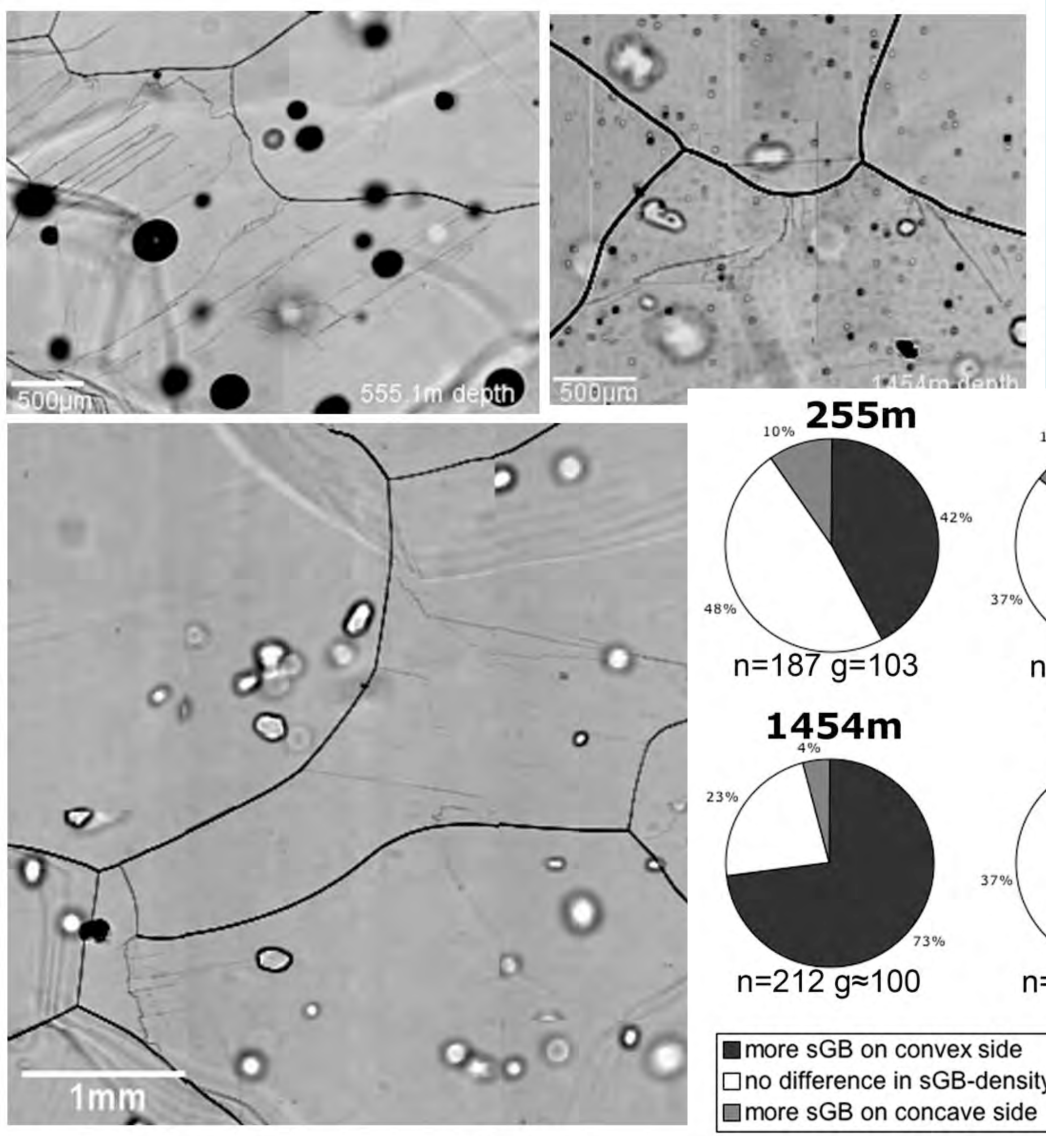
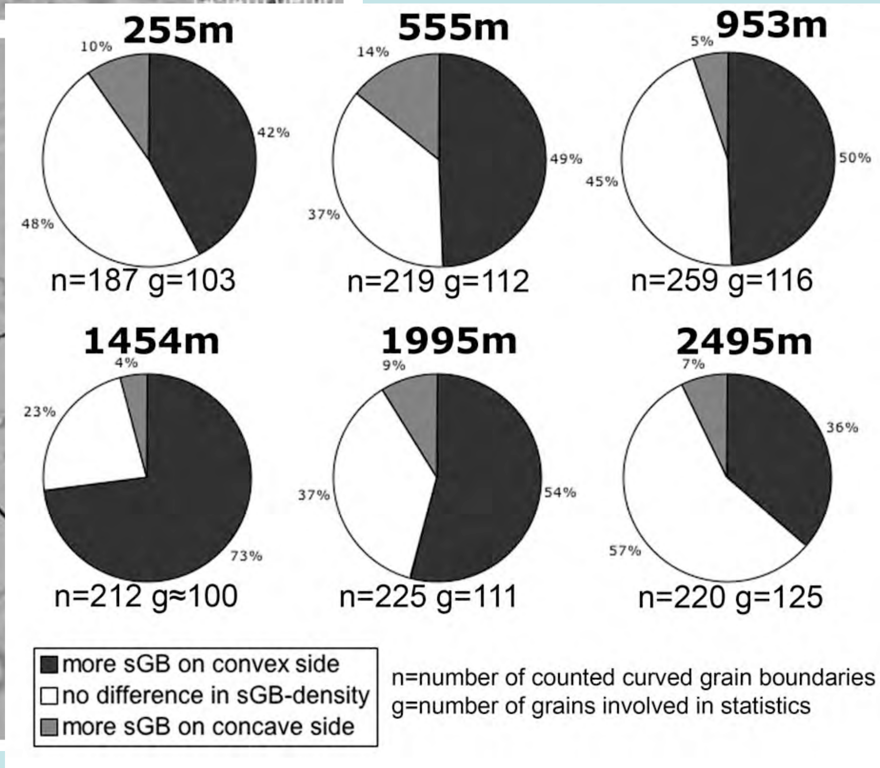
Interaction of grain boundary and subgrain boundaries





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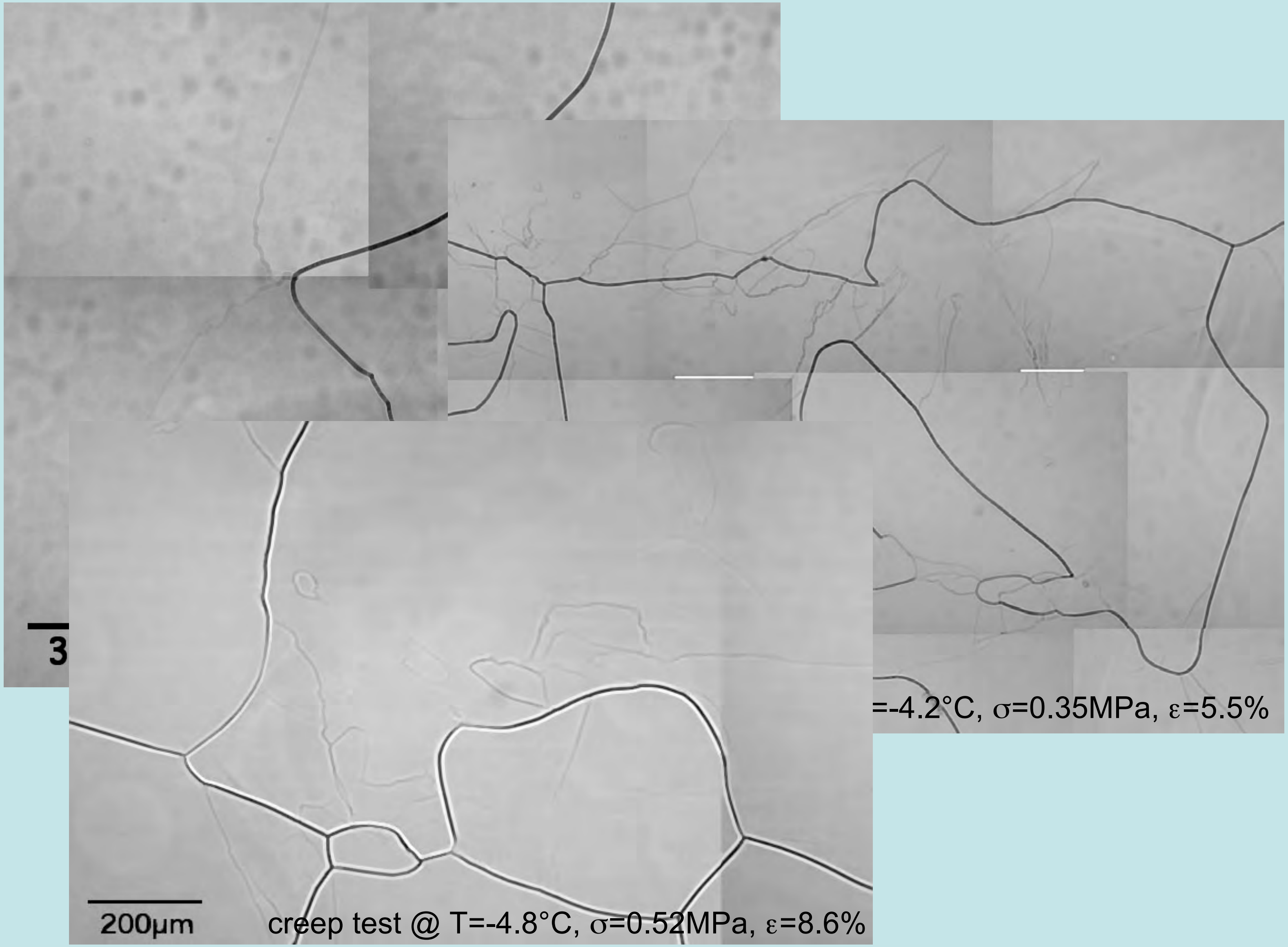
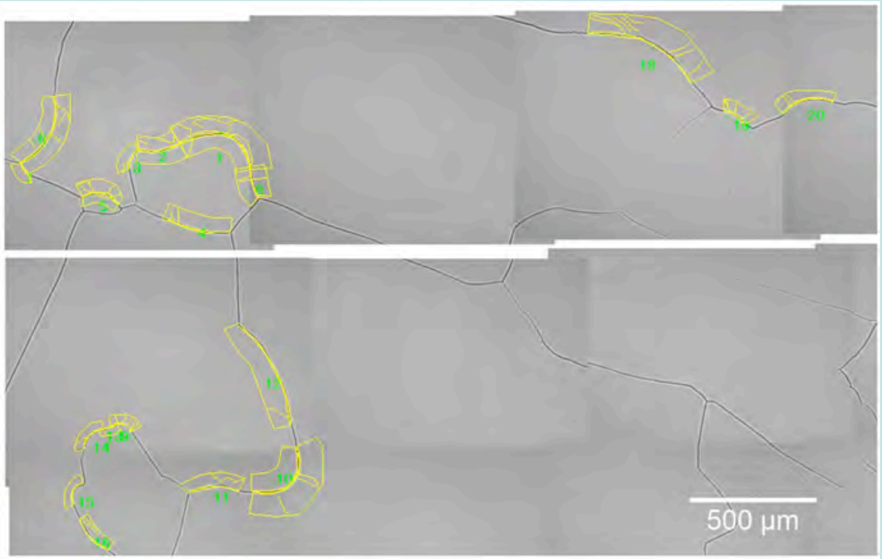
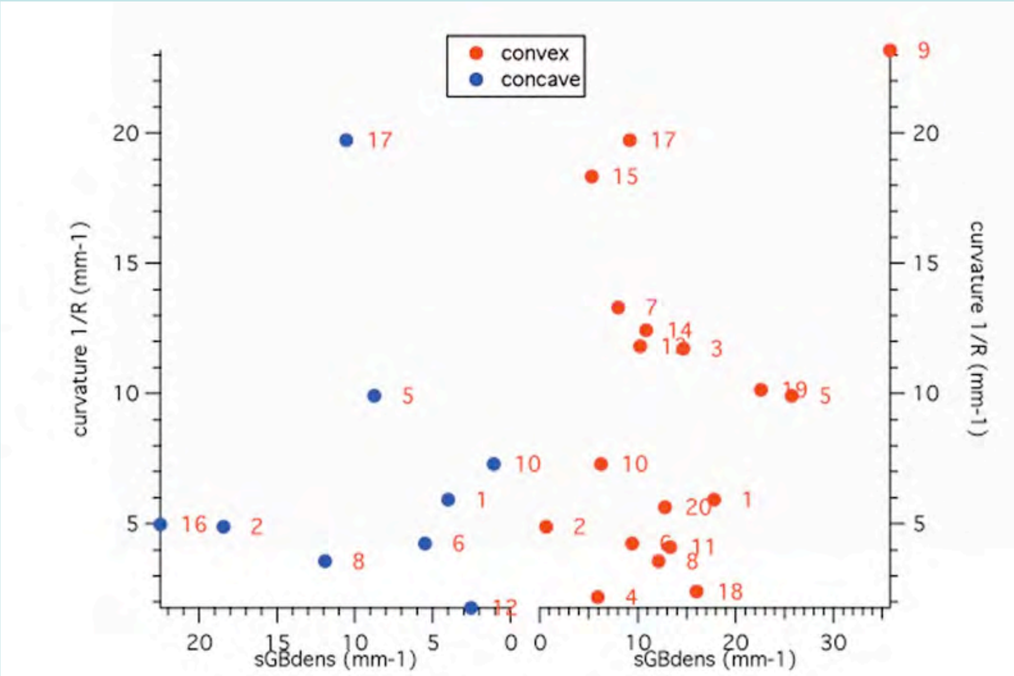


Interaction of grain boundary and subgrain boundaries



creep test @ T=-4.8°C, σ=0.52MPa, ε=8.6%



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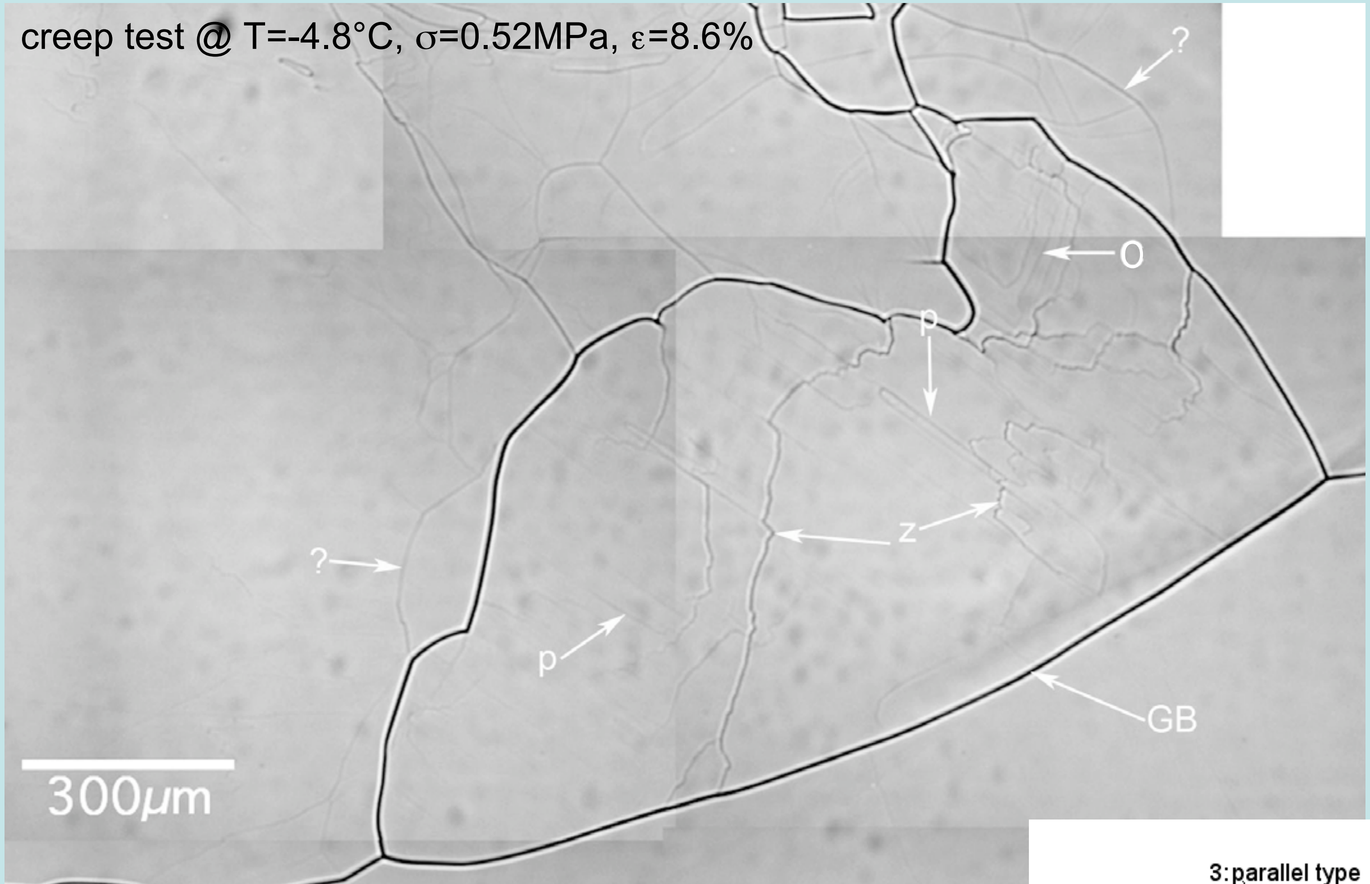
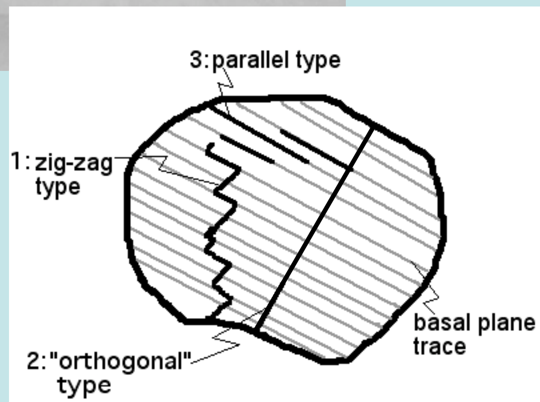
Subgrain-boundary types





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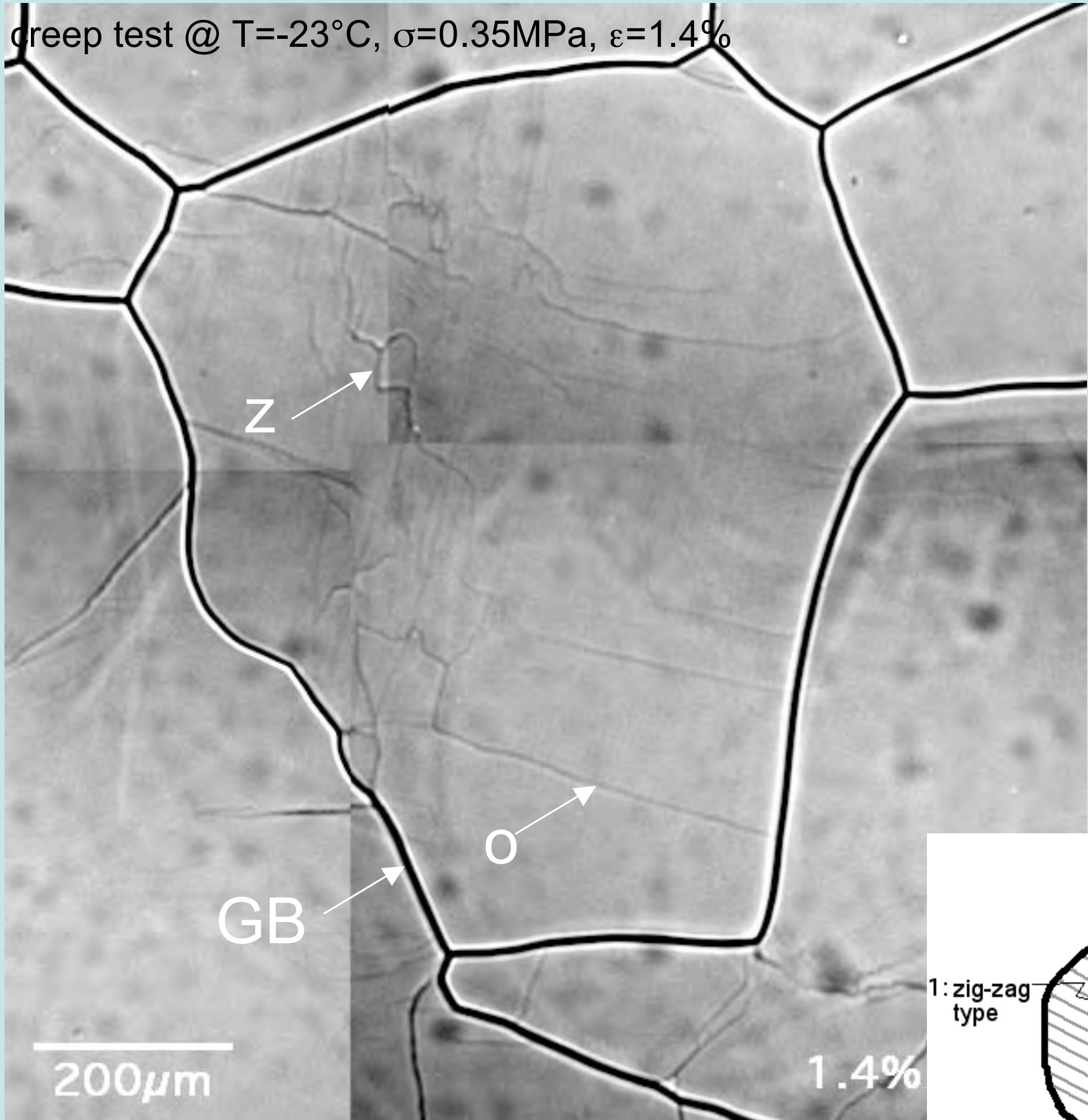
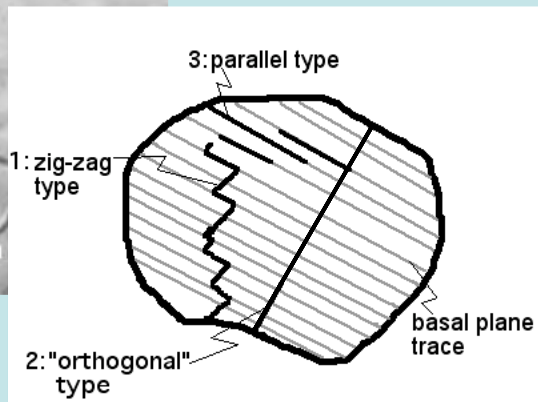
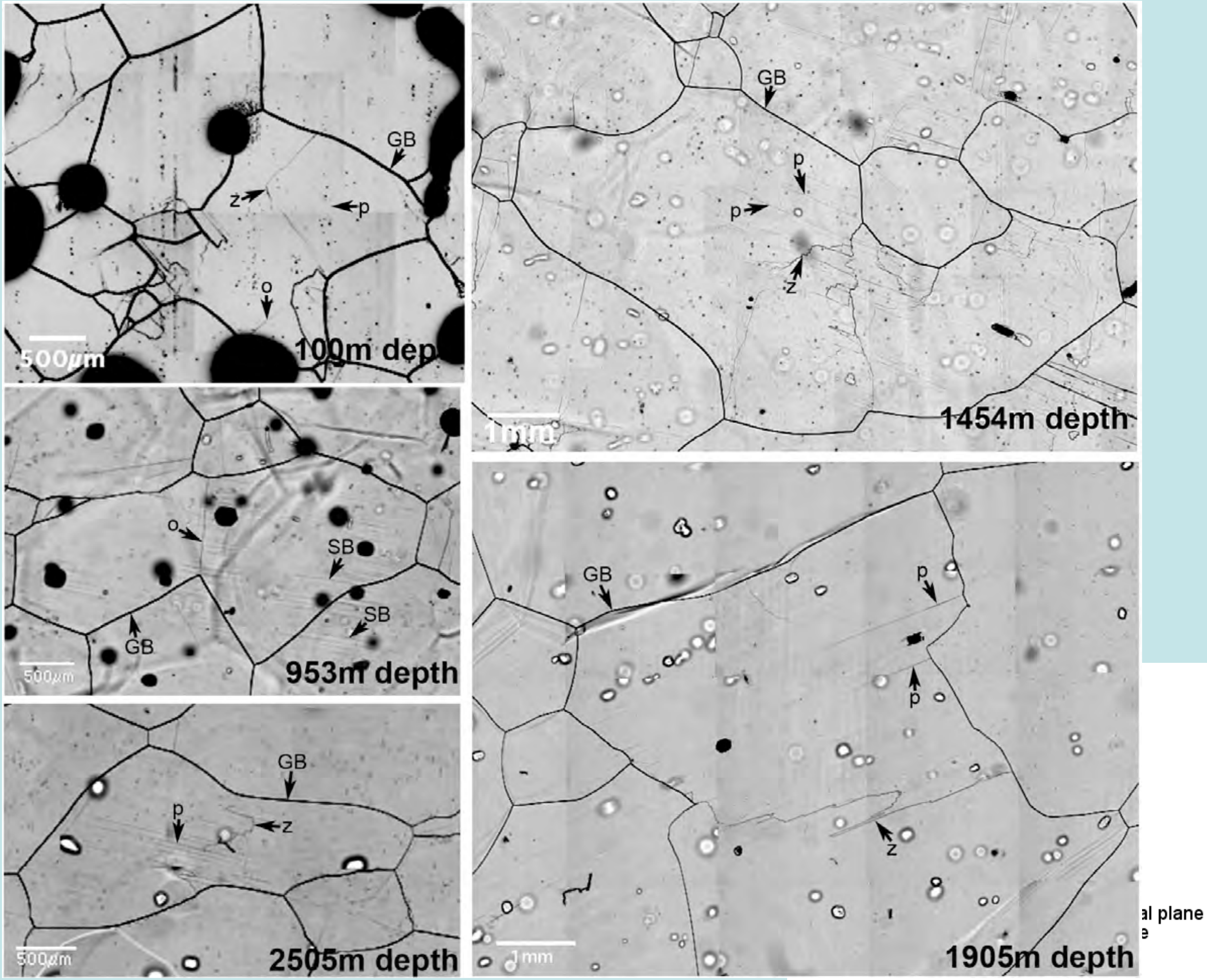
Subgrain-boundary types





Subgrain-boundary types



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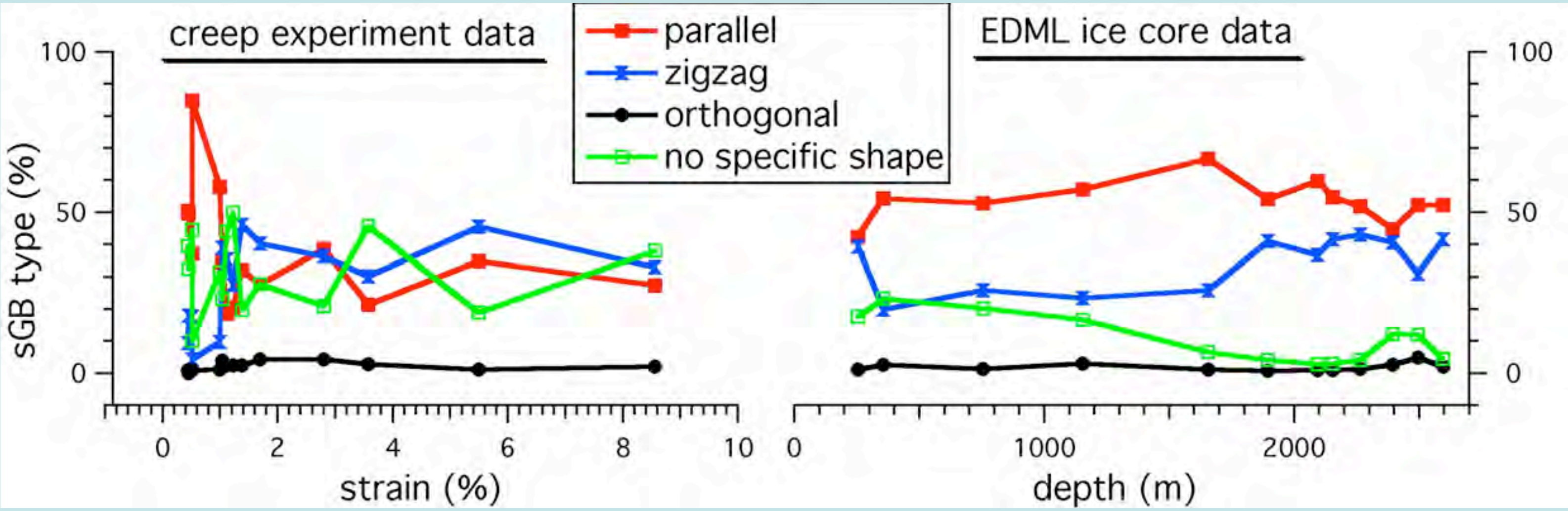
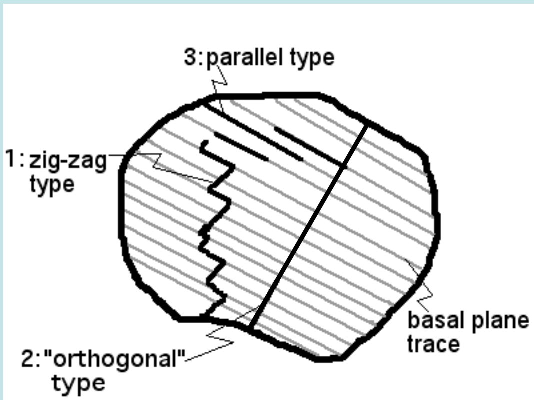
Subgrain-boundary types





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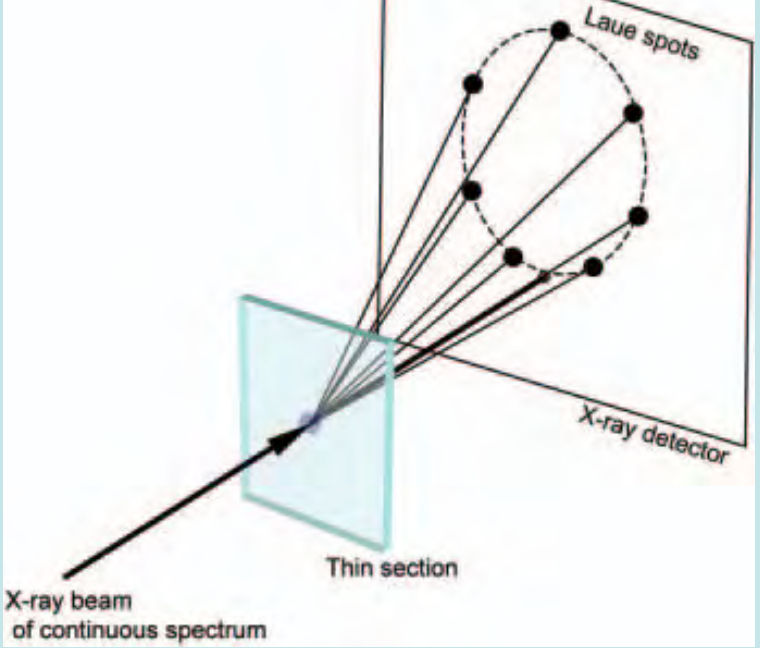
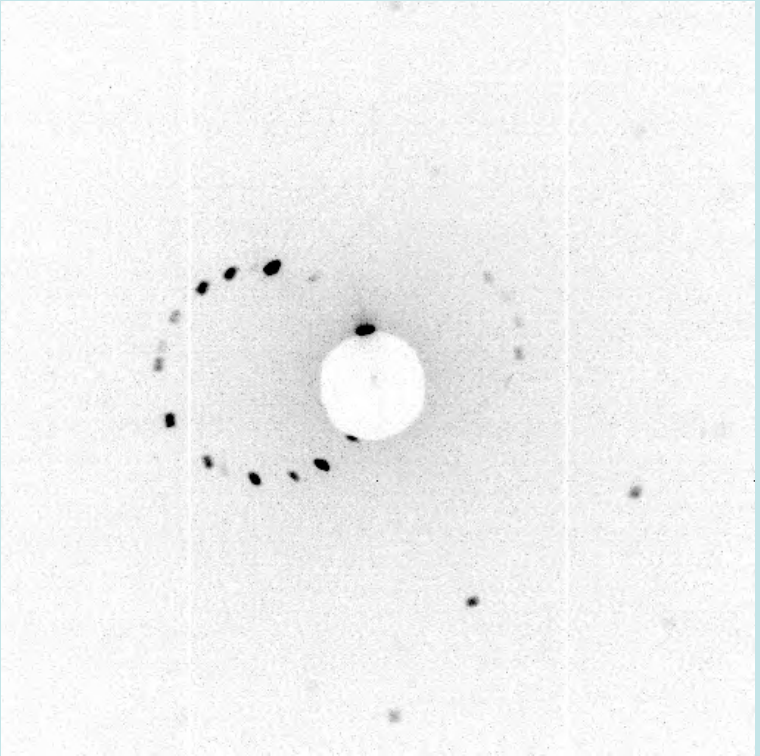
SUMMARY

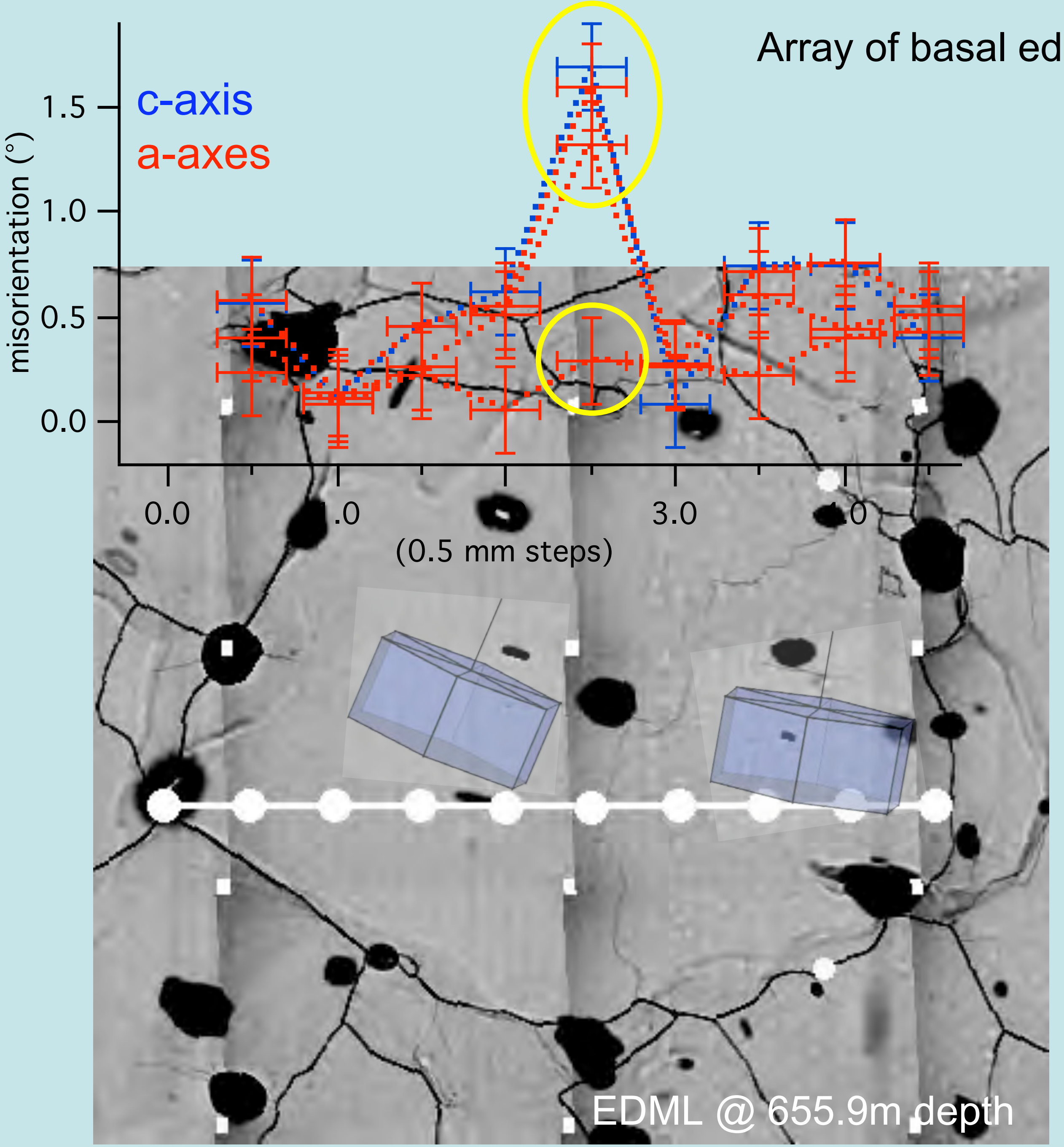
X-ray Laue diffraction

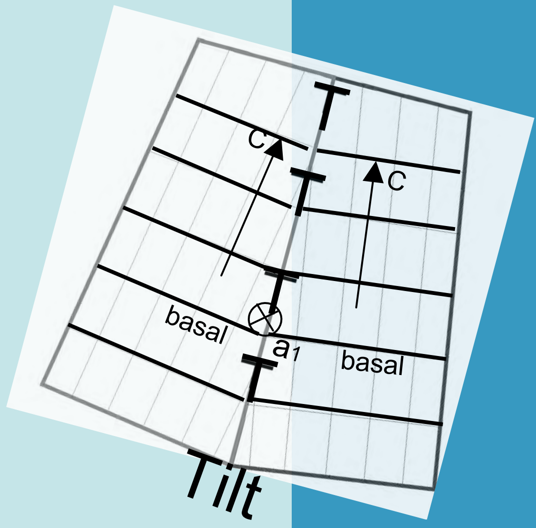
picture:
Miyamoto et al. 2005

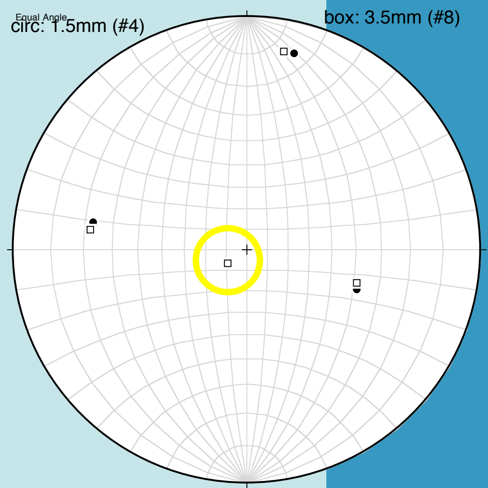




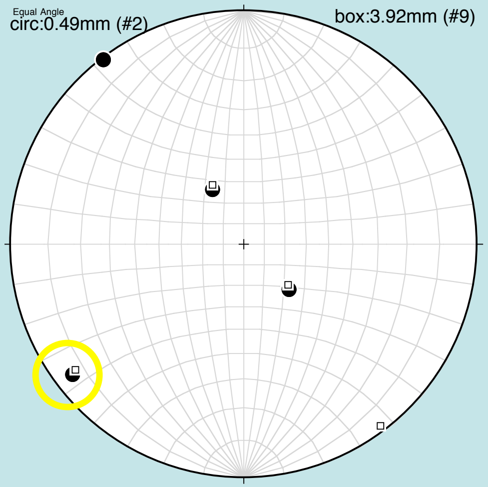
Array of basal edge dislocations

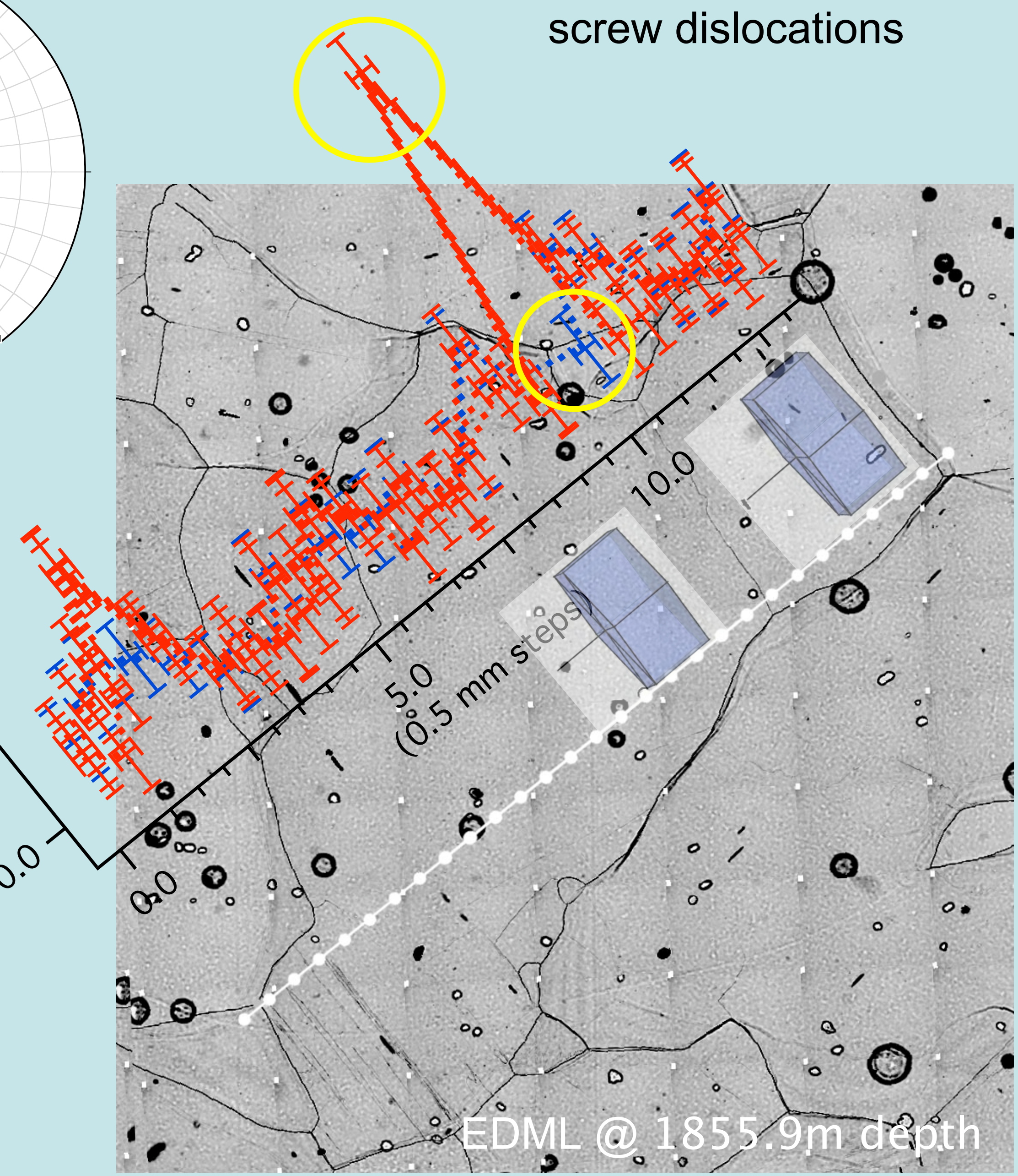


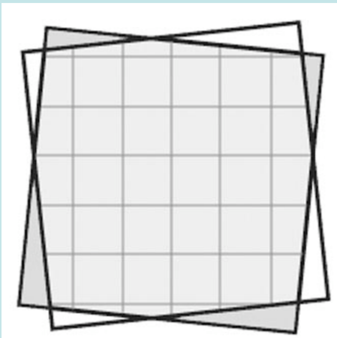




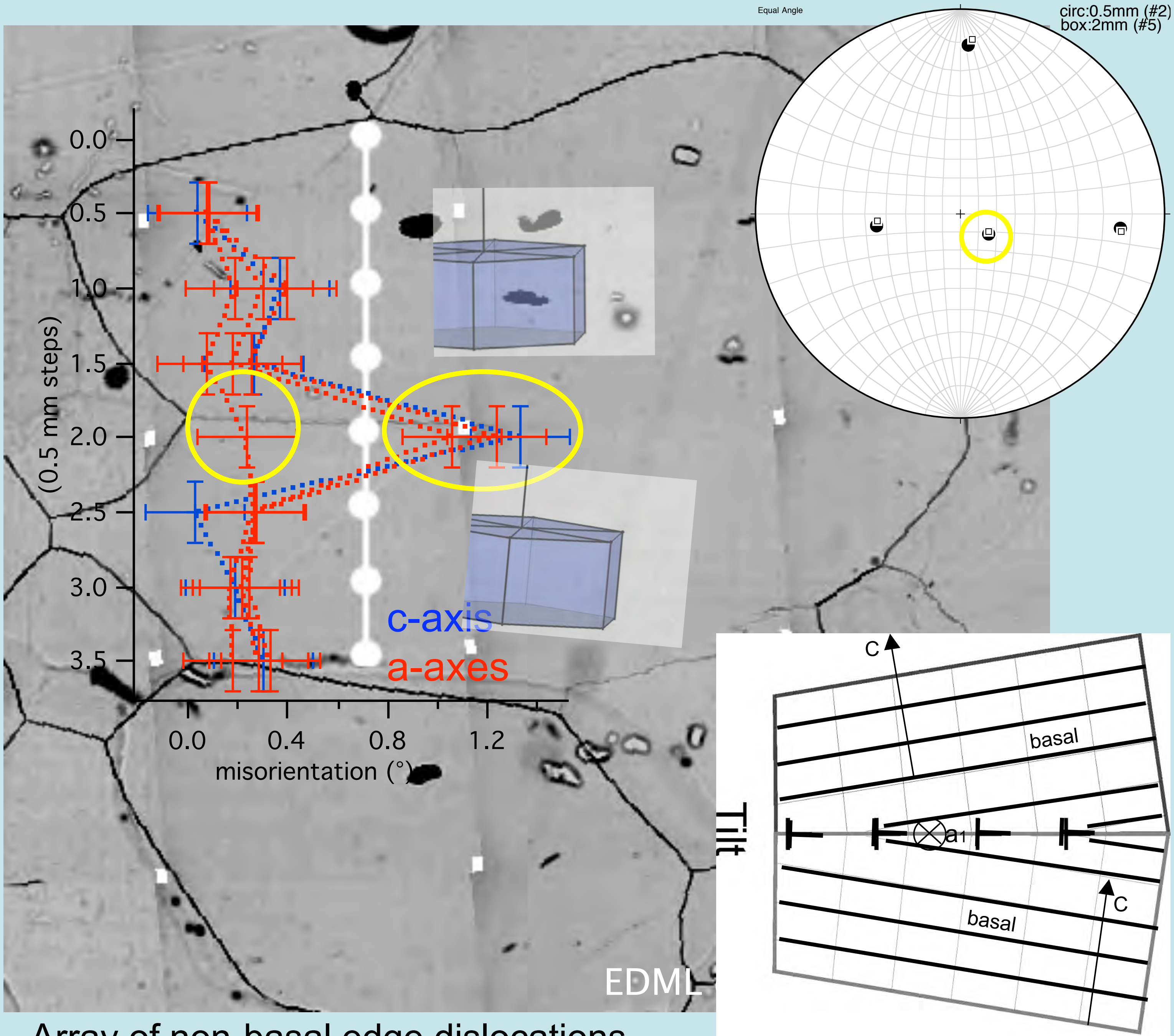
Array of basal screw dislocations







Twist



Array of non-basal edge dislocations

SAMPLES

•EDML

•Creep tests

µS-MAPPING

•GB morphology

•sGB

•Interaction of GB and sGB

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X-ray LAUE

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SUMMARY

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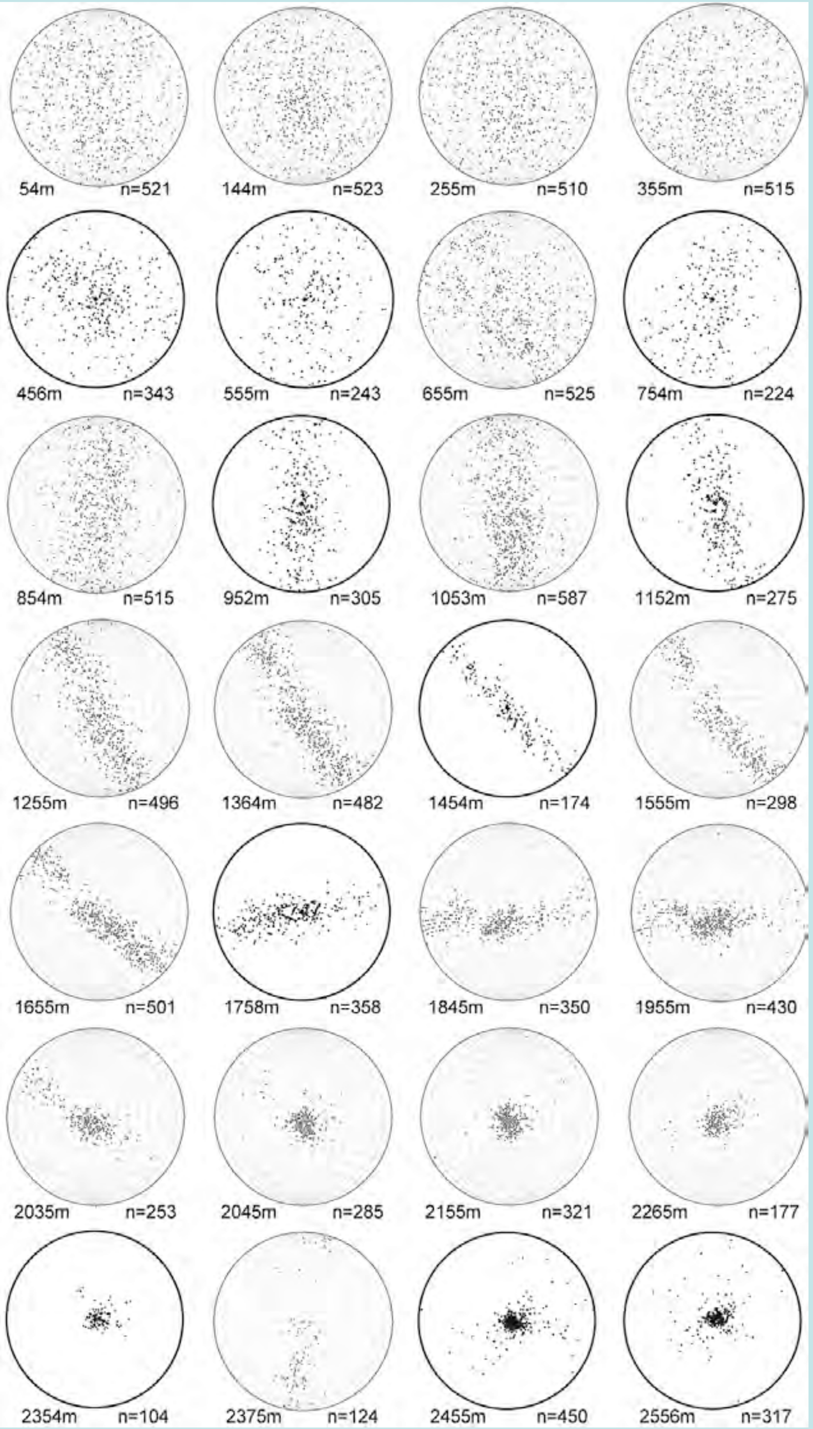
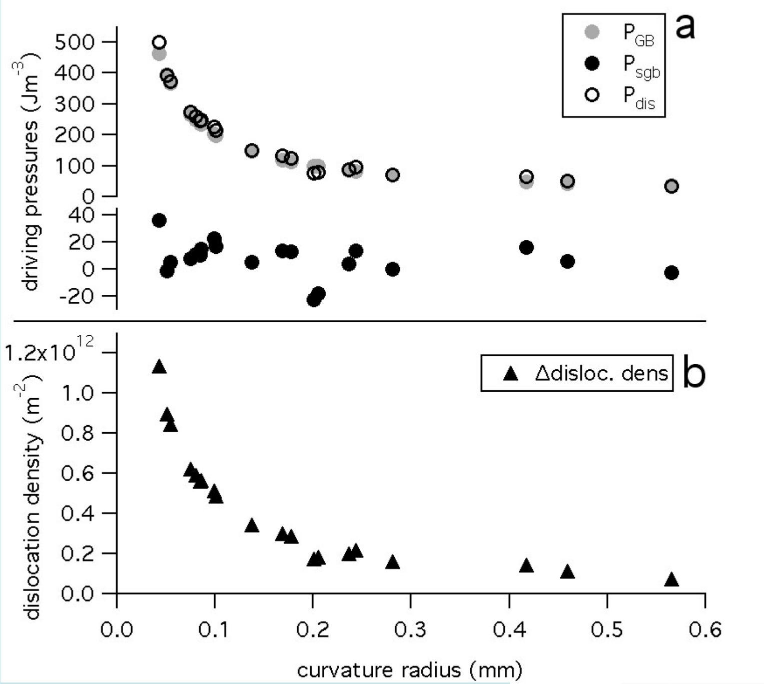
- Subgrain boundary types promise dislocation type classification.
- Moderate values of µstructure parameters (sGB-densities and grain-boundary irregularities) in ice sheets compared to creep tests show that dislocation density decreasing processes (recovery and dynamic recrystallization) play a very important role under low stress conditions.
- How can µstructure parameters with depth in EDML be invariant if the recrystallization regimes should be changing?

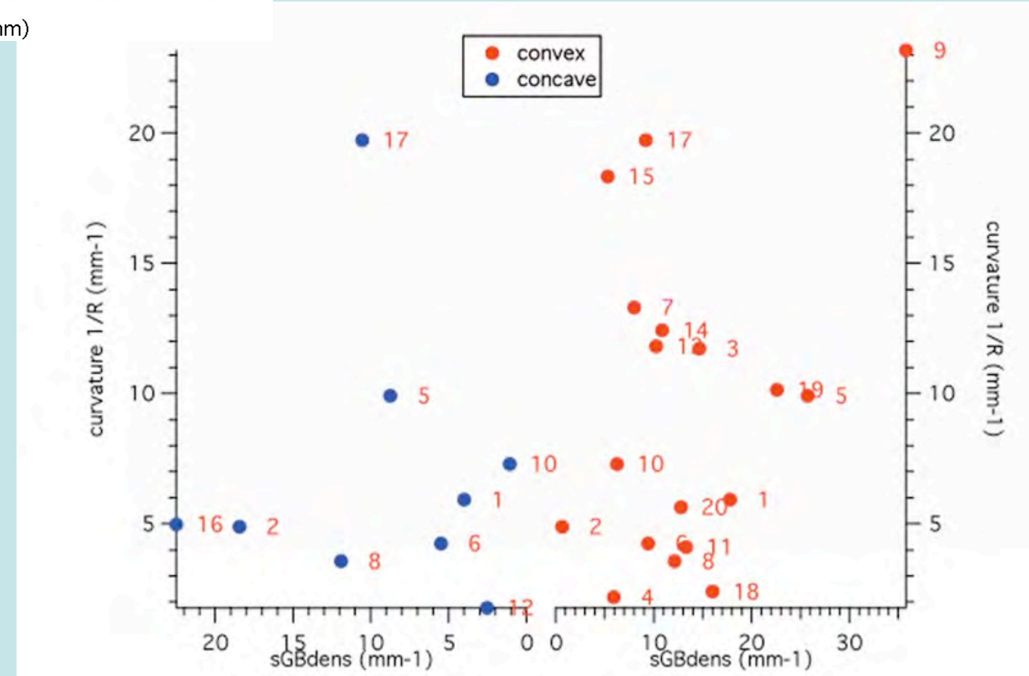

Thank you.

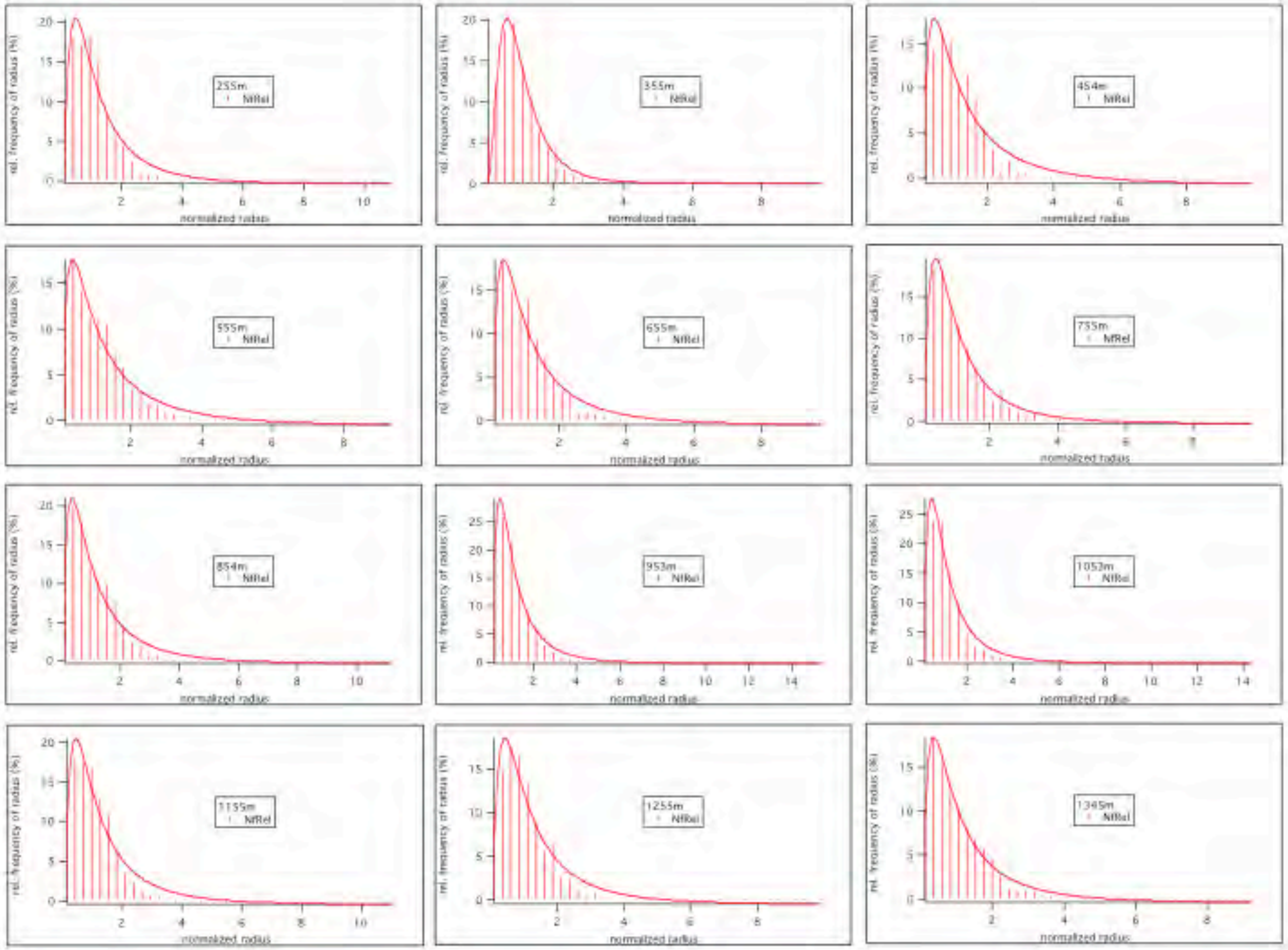

54m n=521
144m n=523
255m n=510
355m n=515
456m n=343
555m n=243
655m n=525
754m n=224
854m n=515
952m n=305
1053m n=587
1152m n=275
1255m n=496
1364m n=482
1454m n=174
1555m n=298
1655m n=501
1758m n=358
1845m n=350
1955m n=430
2035m n=253
2045m n=285
2155m n=321
2265m n=177
2354m n=104
2375m n=124
2455m n=450
2556m n=317

ure

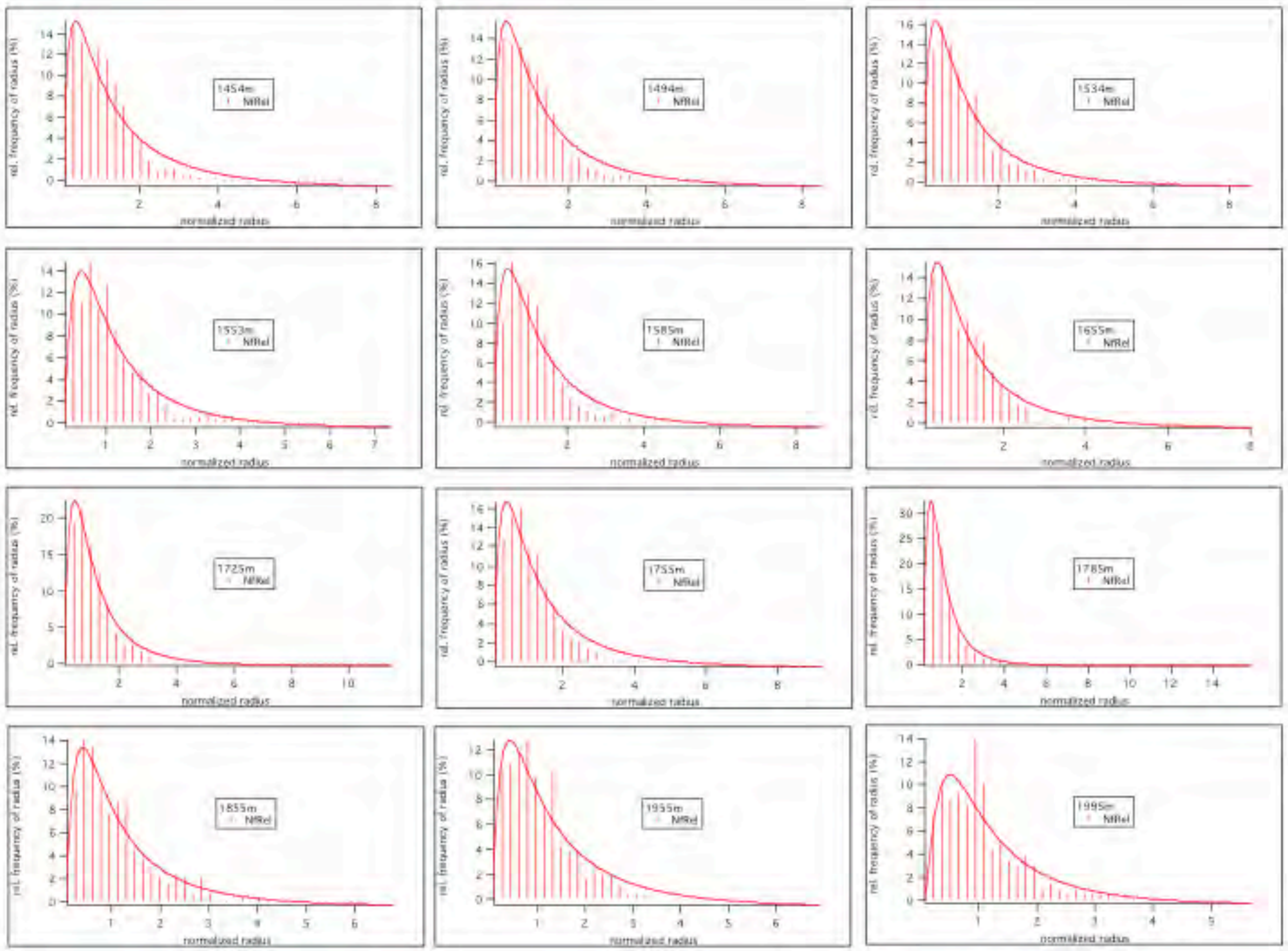


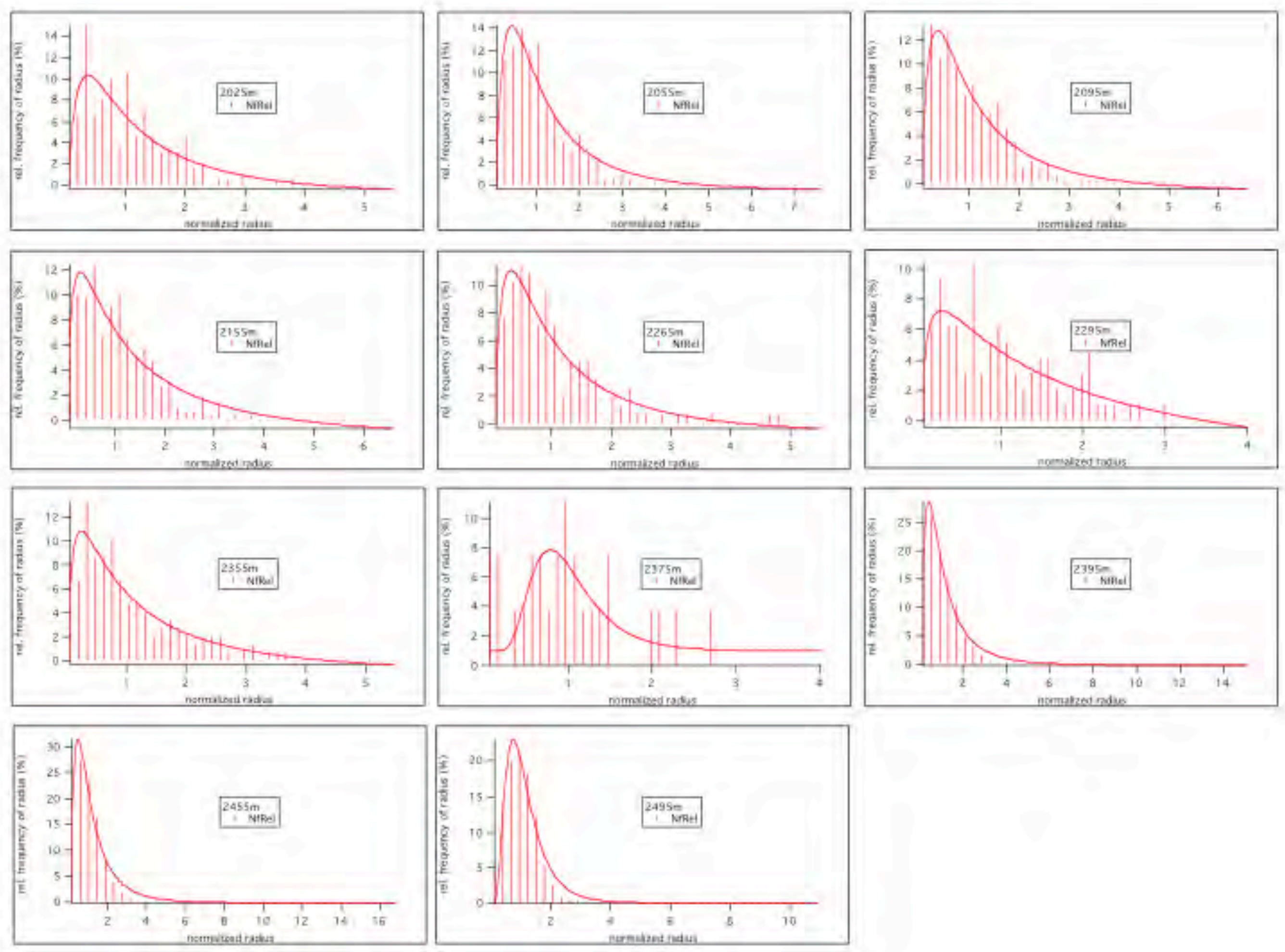
creep test @ T=-4.8°C,
σ=0.52MPa, ε=8.6%

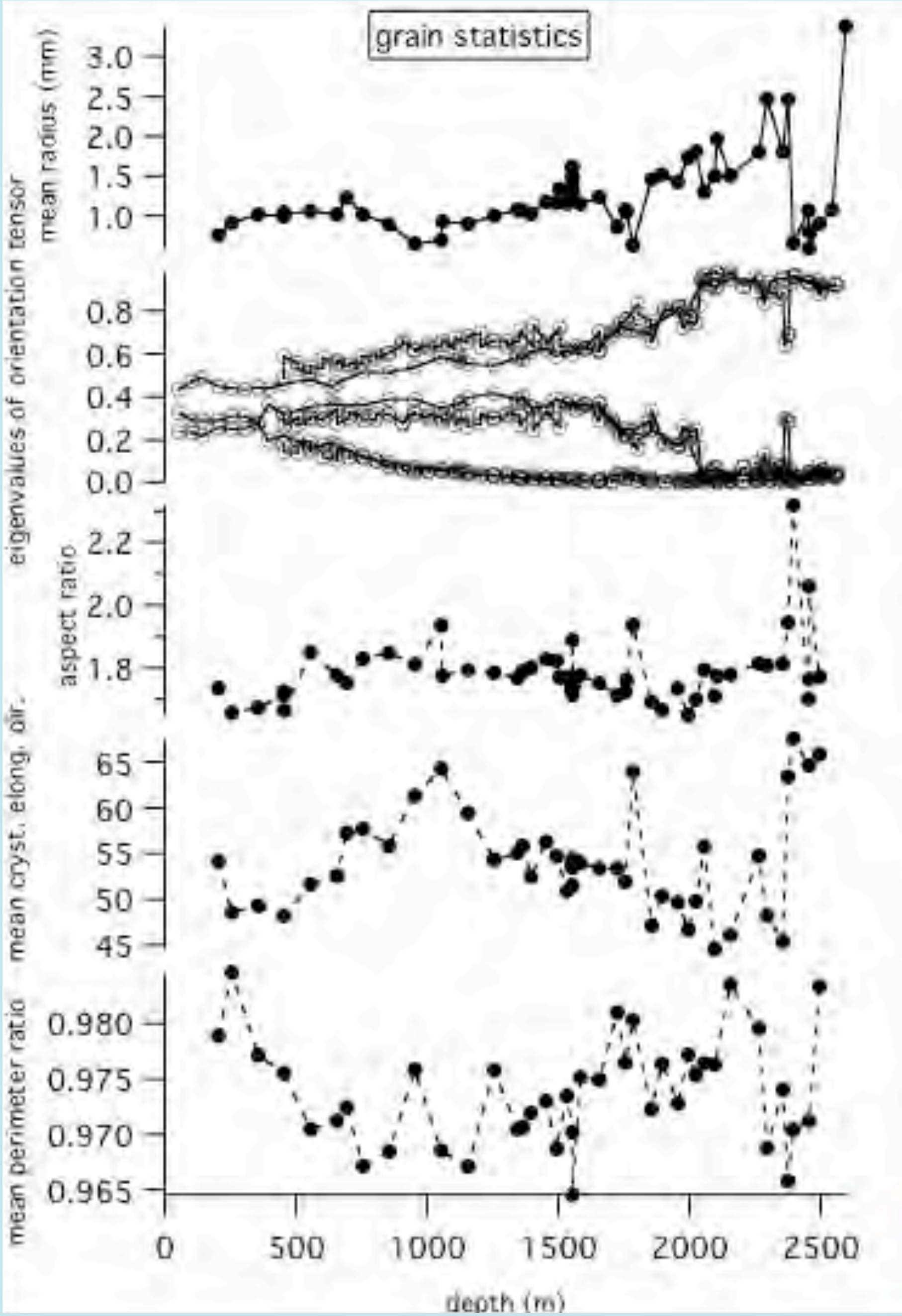




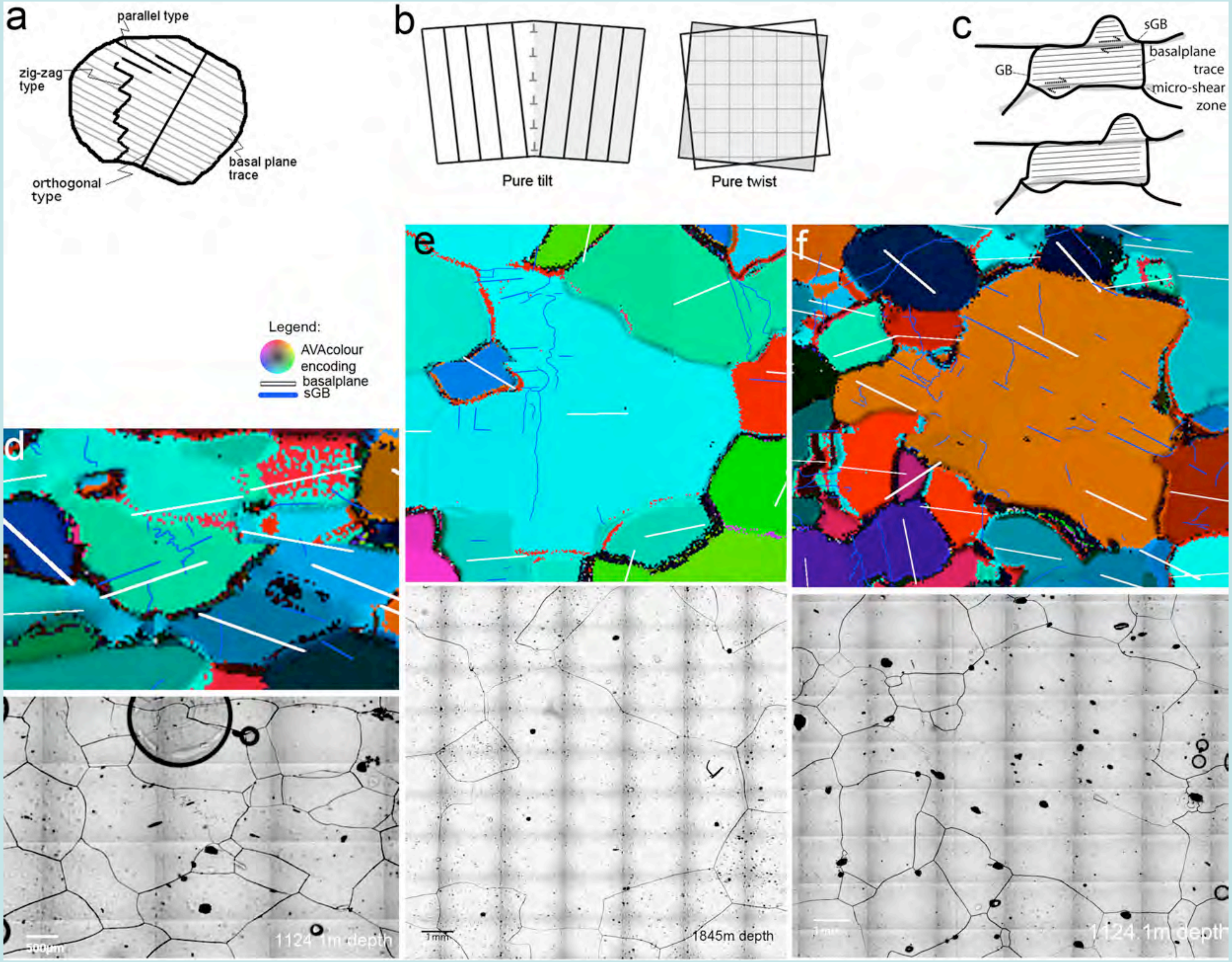
255m
355m
454m
555m
655m
755m
854m
953m
1053m
1155m
1255m
1345m
NfRel
rel. frequency of radius (%)
normalized radius

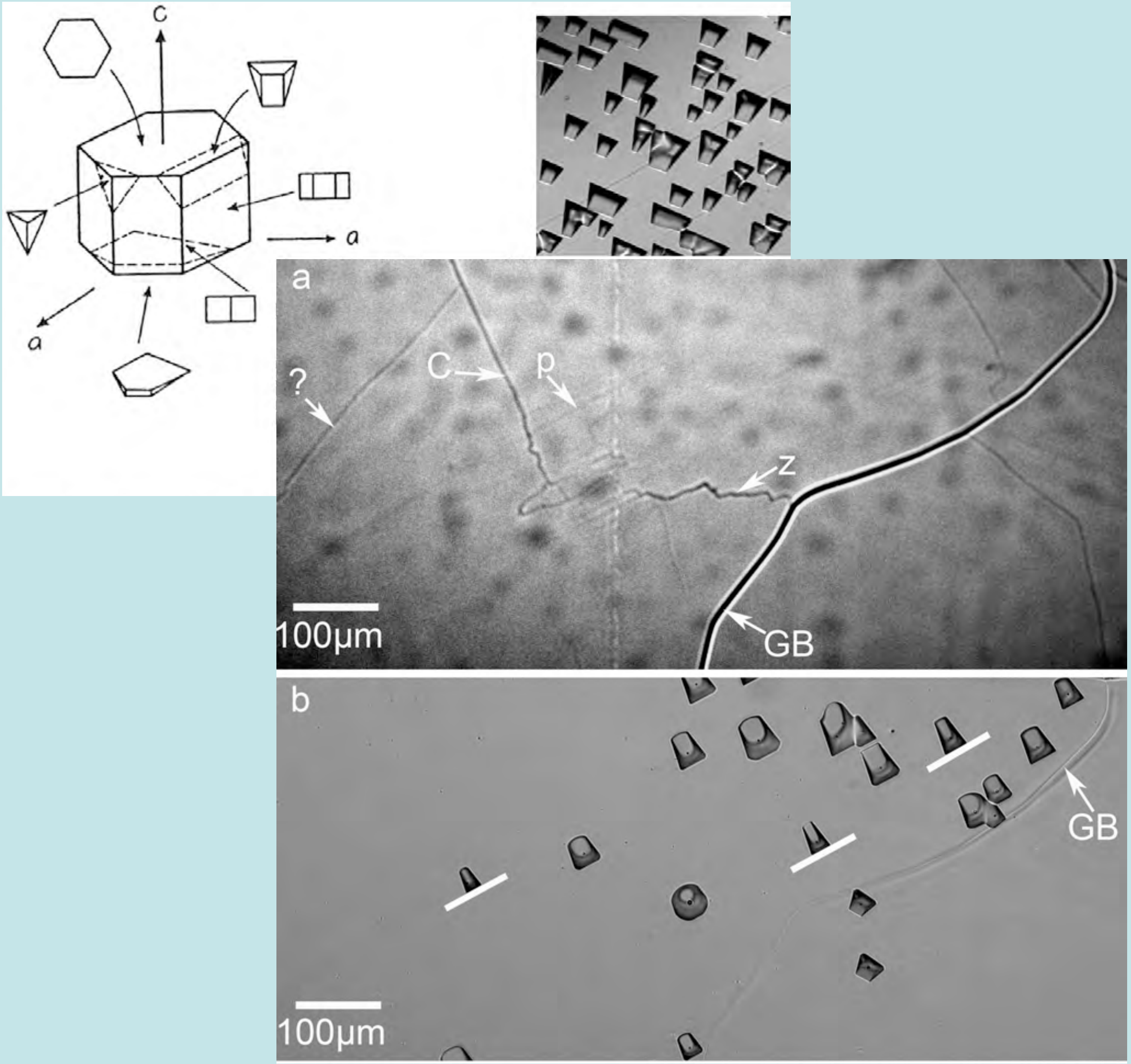

1454m
1494m
1534m
1553m
1585m
1655m
1725m
1755m
1785m
1855m
1955m
1995m
NfRel
normalized radius
rel. frequency of radius (%)


2025m
NfRel
2055m
NfRel
2095m
NfRel
2155m
NfRel
2265m
NfRel
2295m
NfRel
2355m
NfRel
2375m
NfRel
2395m
NfRel
2455m
NfRel
2495m
NfRel
rel. frequency of radius (%)
normalized radius



grain statistics
mean radius (mm)
3.0
2.5
2.0
1.5
1.0
eigenvalues of orientation tensor
0.8
0.6
0.4
0.2
0.0
aspect ratio
2.2
2.0
1.8
mean cryst. elong. dir.
65
60
55
50
45
mean perimeter ratio
0.980
0.975
0.970
0.965
0
500
1000
1500
2000
2500
depth (m)


a
parallel type
zig-zag type
orthogonal type
basal plane trace
b
Pure tilt
Pure twist
c
sGB
basalplane trace
GB
micro-shear zone
Legend:
AVAcolour encoding
basalplane
sGB
d
e
f
500µm
1124.1m depth
1mm
1845m depth
1mm
1124.1m depth


c
a
a
a
?
C
p
z
100µm
GB
b
GB
100µm

Overview

- Samples
  - EDML
  - Creep tests
- µSM-method
  - Grain-boundary morphology
    - Perimeter ratio statistics
  - sGB
    - sGB-density statistics
  - Interaction of GB and SGB
  - sGB-types
- X-ray Laue method
  - sGB-types