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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Microstructure Mapping

Detour:

μS-Mapping validation
Detour:

µS-Mapping validation

Microstructure Mapping

EDML ice core @ 2095.1 m

air hydrate

grain boundary

subgrain boundary

slipband

500 µm

EDML ice core @ 2095.1 m
X-ray Laue diffraction

picture: Miyamoto et al. 2005

Detour: µS-Mapping validation
EDML ice core @ 2366.8m depth
Hamann and others: Deformation-related microstructures in polar and artificial ice
EDML ice core @ 2575.8m depth

mismatch orientation (°)

(0.5 mm steps)

c-axis

EDML ice core @ 2575.8m depth
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 (°)

(mm)
EDML ice core @ 1555.8m depth

Equal Angle
circ:1.5mm (A4)

(c-axis)

(a-axes)

misorientation (°)

(mm)

EDML ice core @ 1555.8m depth

(c-axis)

(a-axes)

misorientation (°)

(mm)
Hamann and others: Deformation-related microstructures in polar and artificial ice.
Hamann and others: Deformation-related microstructures in polar and artificial ice
• Measured samples: 15
• Measured grains: 83
• Measured sGB: 235

• Shallow sublimation groove (“sGB”)
misorientation frequencies (rough figures!!)

<table>
<thead>
<tr>
<th></th>
<th>c-axes</th>
<th>a-axes (max. mis.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.5°</td>
<td>40%</td>
<td>34%</td>
</tr>
<tr>
<td>0.5-1°</td>
<td>28%</td>
<td>32%</td>
</tr>
<tr>
<td>1-2°</td>
<td>17%</td>
<td>22%</td>
</tr>
<tr>
<td>2-3°</td>
<td>8%</td>
<td>6%</td>
</tr>
<tr>
<td>3-4°</td>
<td>5%</td>
<td>4%</td>
</tr>
<tr>
<td>4-5°</td>
<td>1%</td>
<td>1%</td>
</tr>
</tbody>
</table>
EPICA Dronning Maud Land drilling location

SAMPLES
• EDML
• Creep tests

μS-MAPPING
• GB morphology
• sGB
• Interaction of GB and sGB
• sGB-types

X-ray LAUE
• sGB-types

SUMMARY
Deformation Experiments

- SAMPLES
  - EDML
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- \(\mu\)S-MAPPING
  - GB morphology
  - sGB
  - Interaction of GB and sGB
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creep test @ T=-4.5°C, \( \sigma = 0.35 \text{MPa} \), \( \varepsilon = 2.8\% \)
Grain-boundary morphology

initial sample

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

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

Initial sample
Annealing @ $T=-4.9^\circ$C, time=3d
Creep test @ $\sigma=0.52$MPa, $\varepsilon=3.6\%$

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X-ray LAUE
- sGB-types
Grain-boundary morphology

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SUMMARY

![Graph showing creep experiment data](image1)

![Diagram showing convex perimeter and real perimeter](image2)
Grain-boundary morphology

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SUMMARY
Subgrain-boundary

creep test @ T=-4.8°C, σ=0.35MPa, ε=1.2%

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SUMMARY
Subgrain-boundary density

creep experiment data

sGB density (mm⁻¹)

strain (%)
Subgrain-boundary density

creep experiment data

EDML ice core data

sGB density (mm\(^{-1}\))

strain (%)

depth (m)

SUMMARY
Interaction of grain boundary and subgrain boundaries

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SUMMARY

- Interaction of grain boundary and subgrain boundaries

EDML images and graphs showing the interaction of GB and sGB at different depths and the distribution of sGB-types.

Graphs illustrating the percentage of more sGB on convex and concave sides for different depths.

n = number of counted curved grain boundaries
s = number of grains involved in statistics

Images and graphs depicting the morphology and density of GB and sGB at various depths.
Interaction of grain boundary and subgrain boundaries

- Creep test @ T=-4.2°C, $\sigma=0.35$MPa, $\varepsilon=5.5%$
- Creep test @ T=-4.8°C, $\sigma=0.52$MPa, $\varepsilon=8.6%$

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SUMMARY
Interaction of grain boundary and subgrain boundaries

creep test @ T=-4.8°C, $\sigma=0.52\text{MPa}$, $\varepsilon=8.6\%$

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Hamann and others: Deformation-related microstructures in polar and artificial ice
Subgrain-boundary types

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

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Hamann and others: Deformation-related microstructures in polar and artificial ice
Subgrain-boundary types

creep test @ T=-23°C, σ=0.35MPa, ε=1.4%

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SUMMARY

ESF-Workshop April 10th 2008
Hamann and others: Deformation-related microstructures in polar and artificial ice
Subgrain-boundary types

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X-ray Laue diffraction

picture: Miyamoto et al. 2005

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SUMMARY
EDML @ 655.9m depth

Array of basal edge dislocations

Basal tilt boundary

EDML @ 655.9m depth

Basal edge dislocations

Tilt

Basal

Basal

0.0 1.0 2.0 3.0 (0.5 mm steps)

misorientation (°)

1.5 1.0 0.5 0.0 0.0 0.5 1.0 1.5

c-axis

a-axes

Box: 3.5 mm (#8)

Circ: 1.5 mm (#4)

Hamann and others: Deformation-related microstructures in polar and artificial ice
Array of basal screw dislocations

EDML @ 1855.9m depth

TWIST

EDML @ 1855.9m depth

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SUMMARY
Array of non-basal edge dislocations
SUMMARY

• Subgrain boundary types promise dislocation type classification.

• Moderate values of $\mu$structure 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 $\mu$structure parameters with depth in EDML be invariant if the recrystallization regimes should be changing?
Thank you.
creep test @ T=-4.8°C, \(\sigma=0.52\)MPa, \(\varepsilon=8.6\%\)
Hamann and others: Deformation-related microstructures in polar and artificial ice
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