Small-scale disturbances in the stratigraphy of the NEEM ice core: observations and numerical simulations

D. Jansen1, M.-G. Llorens1,1, J. Westhoff2, F. Steinbach2,3, S. Kipfstuhl1, P.D. Bons2, A. Griera3, and I. Weikusat1,1

[1] Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
[2] Department of Geosciences, Eberhard Karls University Tübingen, Tübingen, Germany
[3] Departament de Geologia, Universitat Autònoma de Barcelona, Cerdanyola del Vallès, Spain

NEEM ice core

• „North Greenland Eemian Ice Drilling”
• 2008–2010
• Position: 77.45°N, 51.07°W
• Mean annual temperature -29°C
• Accumulation rate 0.22 m/a
• Core until bedrock, 2540 m

Observations: Methods

Line scan stratigraphy:
- Dark field method, light is scattered at dust particles, bubbles.
- Transparent ice appears black in the record.
- Continuous except for brittle zone

Problem: Disturbances and folding only visible when the impurity content is high (cloudy bands)

Measuring c-axes orientation:
- Polarized light microscopy on thin sections
- Not continuous, but for NEEM measured for entire core segments in selected depth

Svensson et al., 2005
G60 Fabric Analyser, photo by Anneke Tammen

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Observations: LineScan

1761 m

1 cm

1 cm

1.10 m
Observations: LineScan

Observations: Fabric

Observations: Fabrics

• Striking of the bands is consistent throughout core sections (0.55 cm)
• Tilted layers indicate folding on a larger scale
• c-axes tilt with the layers
FFT code (Lebensohn 2001, Lebensohn et al., 2008), purely viscoplastic dislocation glide

Modelling: Elle FFT

Simulation Setup
- resolution of 256x256 Fourier points (unodes)
- Each unode represents a small area or crystallite with a certain lattice orientation and dislocation density
- Wrapping boundaries
- Initial misorientation between grains <5º from vertical, randomly distributed
- 10 steps of dynamic recrystallization (GBM and recovery) per deformation (FFT) step (γ=0.04)

\[ \gamma = 0.2 \]

c-axes orientation

Modelling: Elle FFT

\[ \gamma = 0.4 \]

c-axes orientation

Modelling: Elle FFT

\[ \gamma = 0.6 \]

c-axes orientation
Modelling: Elle FFT

\[ \beta = 0.8 \]

\[ \beta = 1 \]

\[ \beta = 1.2 \]

\[ \beta = 1.4 \]
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Modelling: Elle FFT

\[ \gamma = 1.6 \]

\[ \gamma = 1.8 \]

\[ \gamma = 2 \]

\[ \gamma = 2.2 \]
Modelling: Elle FFT

$\gamma = 2.4$

$\gamma = 2.6$

$\gamma = 2.8$

$\gamma = 3$
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Microstructure evolution model reproduces the development of the "tilted lattice" bands
The bands form in different generations which interfere with each other
If bands are eroded the disturbance is still visible in the passive marker

Modelling: Elle FFT

Kink- or chevron folds

Localization of strain

Strain rate is highest at the margins of the bands where bending stresses are high
This is most prominent for younger bands with steep inclination
The localization intensifies with ongoing deformation

Summary

Small scale folding in NEEM sets in at about 1500m, buckle folding unlikely
Folding causes layer thickening and doubling, disturbances on the decimeter scale, maybe larger
Microstructural modelling indicates that folding is initiated by "tilted lattice bands", process similar to chevron folding
Strong anisotropy is required (single maximum)
Initial disturbance in the c-axes distribution is needed to seed the folds

Published in:
The Cryosphere, 10, 359-370, 2016
www.the-cryosphere.net/10/359/2016
doi:10.5194/tc-10-359-2016