EastGRIP ice down to 2121m - fabric and microstructure
Introduction

F. Steinbach, Uni Tübingen
Different planes in crystal ➔ easiest deformation along *basal* plane (perpendicular to *c-axis*).
- C-axes projected as pole figures, core axis is represented through the centre of the circle.
- *Eigenvalues* portray *c-axis* distribution as the three principal axes of an ellipsoid.

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Viewed from above, each *c-axis* is a dot.

I. Hewitt, course material *Rheology of Ice*.
Introduction
Introduction

Large Area Scanning Macroscope

- Grain shape & shape-preferred orientations
- Grain boundaries & Sub-grain boundaries
- Grain-size
- Number of grains
- …
Introduction

A

Fabric Analyser G50

I. Hewitt, course material Rheology of Ice
Studies before EGRIP

NEEM (Eichler, 2013, Montagnat, 2014)
GRIP (Thorsteinsson et al., 1997)
EDML (Weikusat et al., 2017)

Eigenvalues

Depth in m

Anisotropy
Eigenvalues

Depth in m

NEEM (Eichler, 2013, Montagnat, 2014)
GRIP (Thorsteinsson et al., 1997)
EDML (Weikusat et al., 2017)
EGRIP

Anisotropy
Eigenvalues

Depth in m

Eigenvalues

EGRIP  NEEM (Eichler, 2013, Montagnat, 2014)
GRIP (Thorsteinsson et al., 1997)
EDML (Weikusat et al., 2017)

• High-resolution data (full bag every 5-15m)
• 15 volume cuts (= 3x vertical + 2x horizontal)
Eigenvalues

EGRIP

Depth: 118.3 m

Steven Franke, AWI

I. Hewitt, course material Rheology of Ice
Crystal preferred orientations

Combine different scales

Depth: 118.3 m
Crystal preferred orientations

- Broad single Maximum
- Crossed Girdle
- Developed Girdle
- Strong Girdle
- Strong Girdle with horizontal maxima

Depth in m: 0.0 0.2 0.4 0.6 0.8
Eigenvalue: e1: Minimum e2: Intermediate e3: Maximum

- Broad single maximum
- Type I crossed girdle symmetric
- Type I crossed girdle asymmetric
- Developed girdle
- Strong girdle

strain ellipsoid
Crystal preferred orientations

Broad Single Maximum ->
Vertical Compression from above

Girdle ->
Extensional deformation

Thorsteinsson et al. (1997)
Crystal preferred orientations
Crystal preferred orientations

Electron backscatter diffraction (EBSD) -> information about \(a\)-axes

Fig. 6. Explanation of distribution of \(a\) axes. (a) The \(c\)-axis orientation distribution which is generated artificially. (b) Random distribution of azimuth of \(a\) axes. (c) Schematic illustration of random orientation of \(a\) axes. (d) Schematic illustration shows \(a\) axes are aligned.

Miyamoto et al. (2005)
Crystal preferred orientations

Preliminary a-axes data for EGRIP at 1360 m:

- Uniaxial extension and dominant basal slip
- Hard orientation of slip-plane -> harder to deform

$1360 \text{ m}$
$n = 56$

M. Drury and D. Wallis, Utrecht University

Recrystallized grains (?) -> larger resolved shear stress

M. Drury and D. Wallis, Utrecht University

The Arc, 2019
Deformation modes

- Vertical Compression
- Non-coaxial Coaxial deformation
- Extensional deformation
- Simple shear

Dimensions:
- 0m to 196m
- 294m
- 500m
- 1150m
- 1260m
- 2121m
- 2550m
Grain size variability

- Increase
- Decrease
- Constant
- Increase

\[ \text{Grain size} = \text{Mean grain area of one thin section (400 - 4000 grains)} \]
Grain size

End of last Glacial

NEEM
EDML
EGRIP
Grain size

Mean grain area in mm²

Depth in m

NEEM
EGRIP
Grain size & crystal orientations

2010 m

1 cm
Outlook - Micro-Cryo-Raman Spectroscopy

- Impurities influence physical properties of ice matrix
  
  -> lack of data regarding in-situ spatial distribution and incorporation of impurities

- Paterson (1991)
- Cuffey et al. (2000)
- Goldsby and Kohlstedt (1997)
- Glen (1968)
- Jones and Glen (1969)

Eichler (2019)
Outlook - Micro-Cryo-Raman Spectroscopy

- Micro-cryo-Raman spectroscopy on EastGRIP ice core + data about microstructure
- aim: to identify location, phase and composition of small inclusions
Outlook - Micro-Cryo-Raman Spectroscopy

EGRIP bag 995 (546.7-547.25m)

Visual Stratigraphy by J. Westhoff, CIC

CFA/ICP-MS data by T. Erhardt & C. Jensen, Uni Bern
Thanks to everyone involved!
Questions?
Dynamic Recrystallisation
Dynamic Recrystallisation

Passchier & Trouw (2005)

Urai et al. (1986)
Grain size & crystal orientations

1614 m
Grain size

828 m

1444 m

Core breaks?
Perimeter Ratio

Perimeter ratio = measure for grain irregularity

Further down to 2121 m?

Weikusat et al. (2009)
Deformation modes

Coaxial (pure shear) = principal axes of strain rotate

Non-Coaxial (simple shear) = strain remain fixed with respect to the material

Passchier & Trouw (2005)

Coaxial progressive deformation

Van Der Pluijm and Marshak (2004)

different slip-systems influence different parts of the crossed girdle

EBSD?
Crystal preferred orientations

Coaxialy deformed quartz:
- CPOs predicted by a theoretical model for dislocation glide -> based on the Taylor-Bishop-Hill analysis (Lister et al. 1978, Lister and Hobbs 1980)
- These theoretical CPOs are supported by both experimental studies (Tullis et al. 1973, Tullis 1977) and analysis of naturally deformed quartzites (Price 1985, Schmid and Casey 1986)

Deformation modes

- in many naturally deformed rocks, a spatial transition of symmetrical crossed girdles to asymmetrical single girdles occurs
- related to an increasingly non-coaxial strain path
- this transition marks the bulk finite strain at which grains in unfavourable orientations for continued intracrystalline slip are 1) partially substituted through grain boundary migration of more favourably oriented grains and
2) partially reoriented by selective recrystallisation (Schmid and Casey, 1986)

Crystal preferred orientations

Crossed girdle in quartz

*Optically measured*

Type I

Type II

Law et al. (1986), modified