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Physical properties of the NEGIS ice core – The upper 1700m in EGRIP

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Universiteit Utrecht
bc3 BASQUE CENTRE FOR CLIMATE CHANGE Klima Aldaketa Ikergai
Sustainability, that's it!
SOKENDAI
ikerbasque Basque Foundation for Science
NiPR National Institute of Polar Research
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EBERHARD KARLS UNIVERSITÄT TÜBINGEN
国立大学法人 長岡技術科学大学 Nagaoka University of Technology
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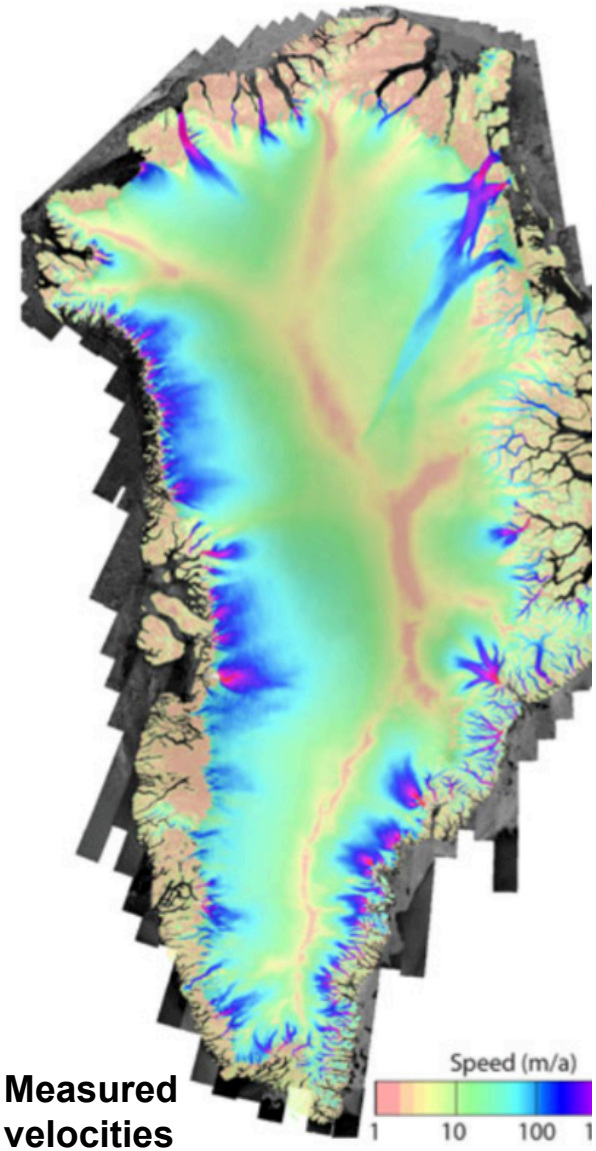
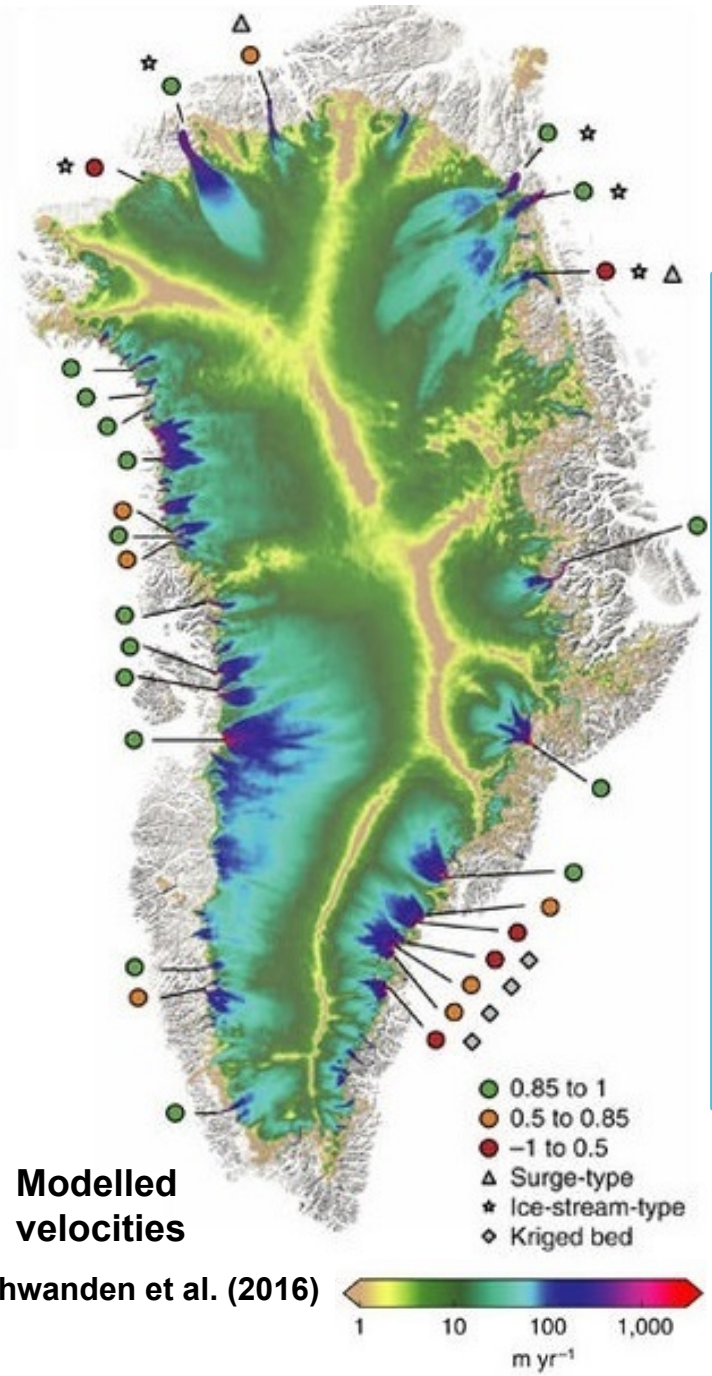


Measured velocities

Joughin et al. (2017)



Modelled velocities

Aschwanden et al. (2016)

IPCC 5 (2013)

- Models are still not able to predict **solid ice discharge** and **ice sheet contribution** well enough
- Significant uncertainties remain regarding the magnitude and rate of ice stream contribution towards sea-level rise
  ➔ **ice streams**

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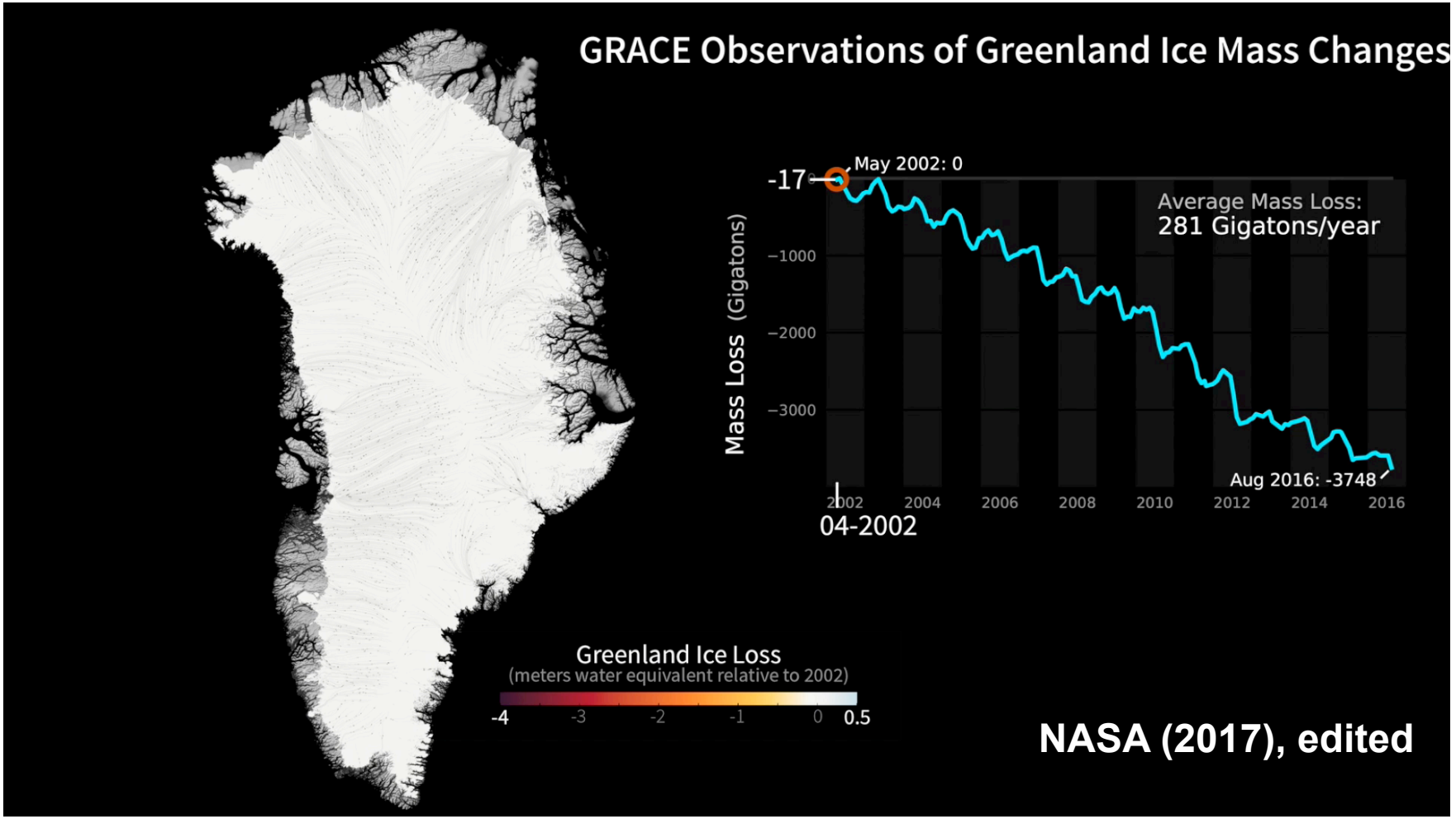
Motivation

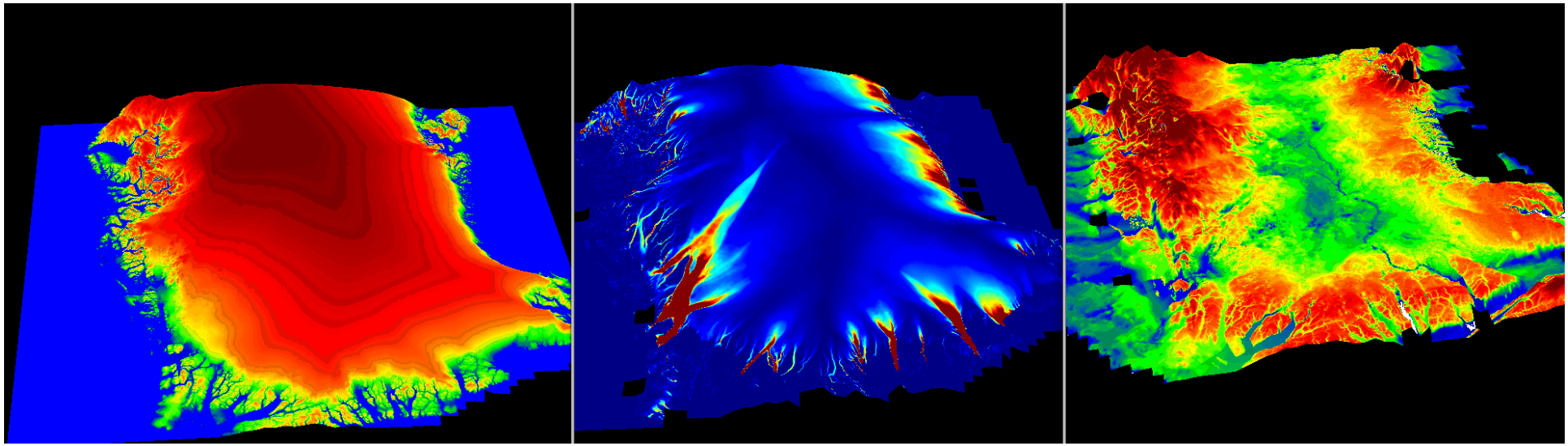

GRACE Observations of Greenland Ice Mass Changes
May 2002: 0
-17
Average Mass Loss:
281 Gigatons/year
Mass Loss (Gigatons)
−1000
−2000
−3000
Aug 2016: -3748
2002
2004
2006
2008
2010
2012
2014
2016
04-2002
Greenland Ice Loss
(meters water equivalent relative to 2002)
-4
-3
-2
-1
0
0.5
NASA (2017), edited

Motivation

- Negative mass balance contributes to sea level rise → **Melting at top and base**
- Ice streams account for 50% of mass loss in Greenland → **Discharge of solid ice**

  ➔ need for better understanding of rheology of ice

- Analysis of microstructures and physical properties of fast flowing ice at *Northeast Greenland Ice Stream* (NEGIS)



Ice surface elevation | Ice surface velocities | Bedrock elevation

< 10m/a (“sheetish”)

> 50m/a (“streamish”)

Bamber et al. (2013,) Joughin et al. (2016), Illustration: D. Jansen (AWI)

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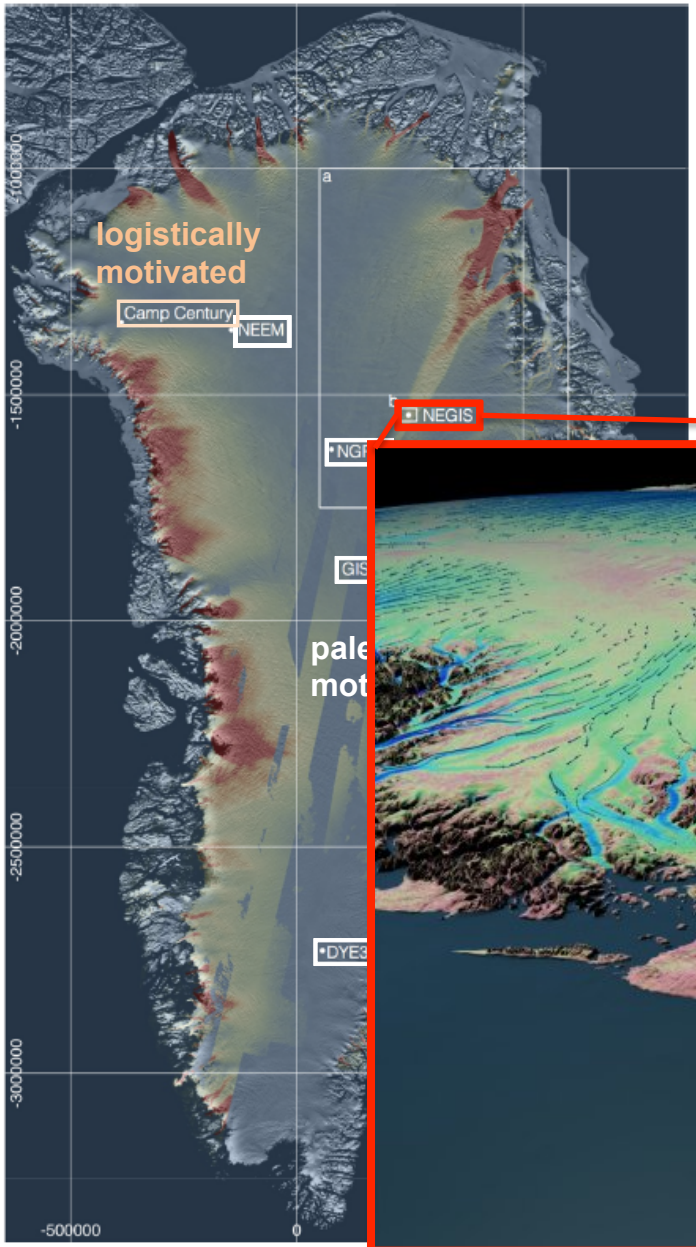
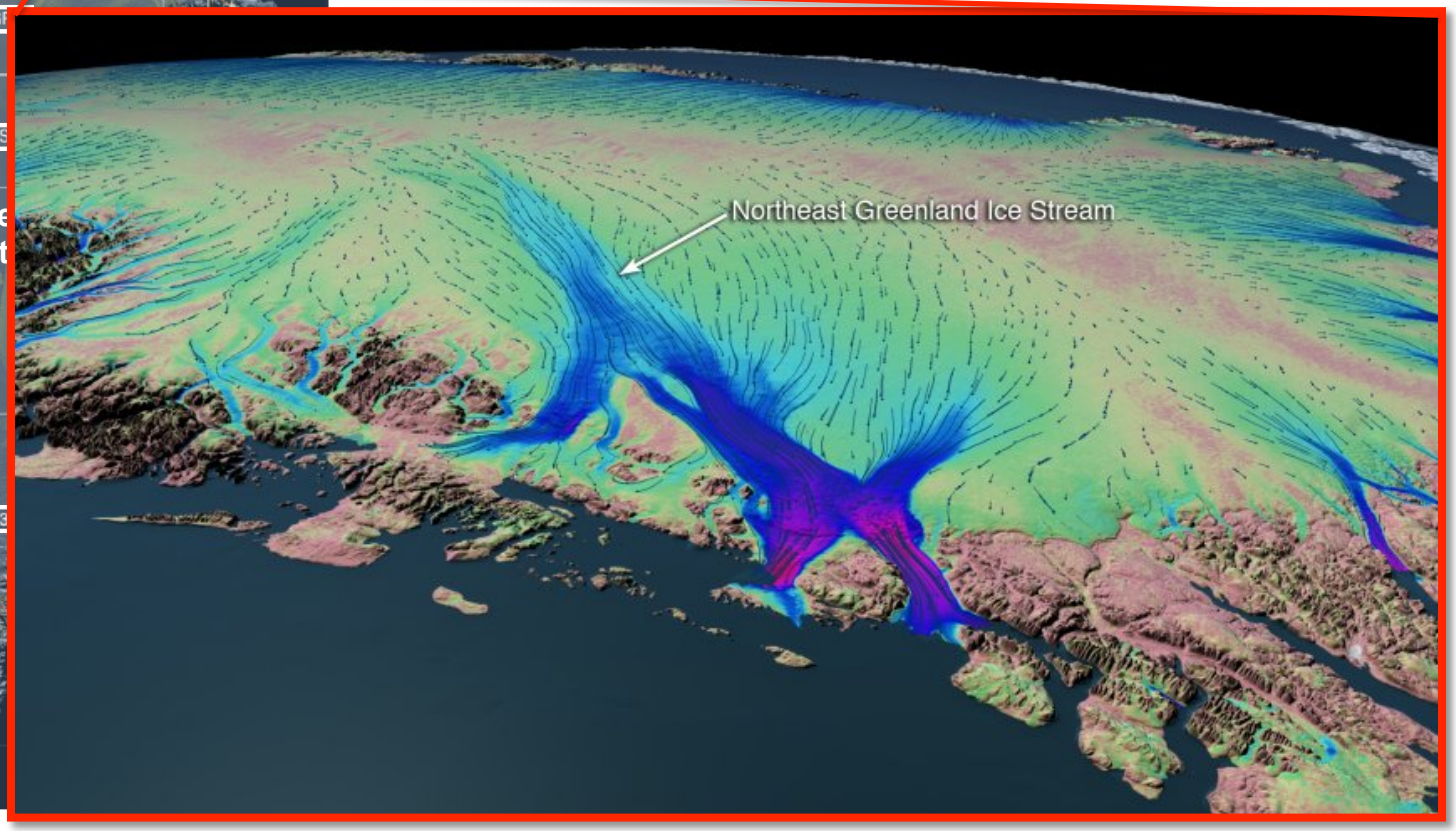


Vallelonga et al. (2014), edited

EastGRIP

First physically-motivated ice core → new insights into:

- Deformation mechanisms
- Size and shape of grains
- Subgrain structures
- C-axis orientation
- Inclusions/ impurities
- Large scale structures and folding



NASA (2016)

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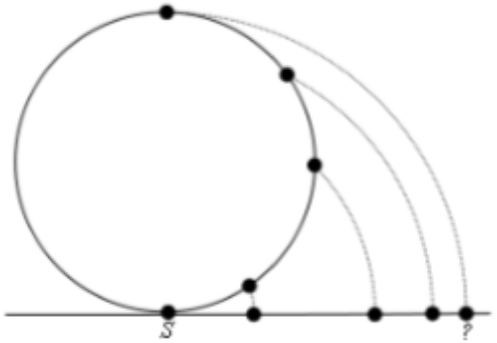
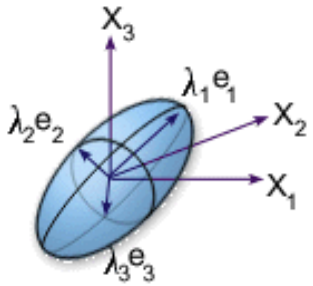
Motivation

- Different planes in crystal ➔ easiest deformation along *basal* plane (perpendicular to *c-axis*)
- *Schmidt diagrams* project c-axes 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

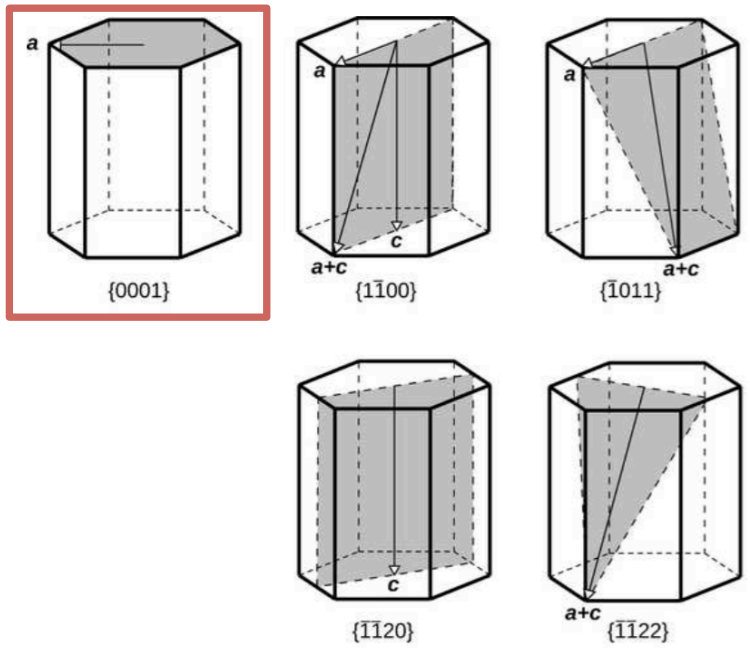


Eichler (2013)



Moldflow Insight (2017)

eigenvalues	inertia shape	distribution
$\lambda_1 = \lambda_2 = \lambda_3 = 1/3$	sphere	uniform distribution
$\lambda_1 = \lambda_2 < \lambda_3$	prolate ellipsoid	unimodal cluster
$\lambda_1 < \lambda_2 = \lambda_3$	oblate ellipsoid	girdle fabric



Basal Prismatic Pyramidal

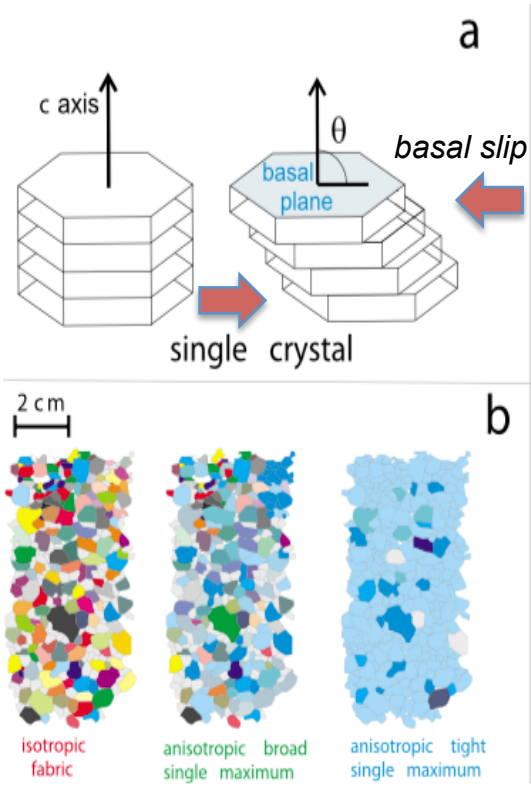
Faria et al. (2013)

Motivation

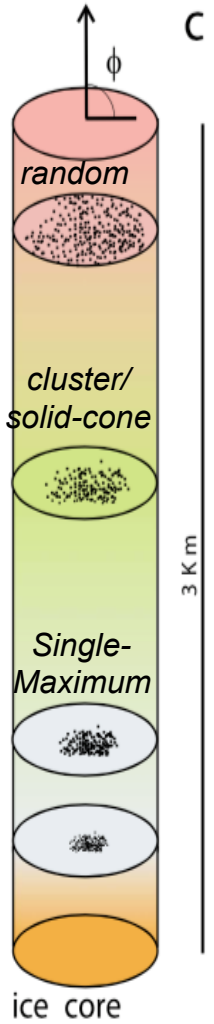
- Deformation of crystals ➔ ice sheets flow and deform ➔ flow behaviour depends on *crystal preferred orientation* (CPO), *mode* and *direction* of deformation

- Evolution of fabric depends mainly on dominant strain conditions ➔ c-axis distribution rotates towards compression axes

„[...] a depth-varying fabric implies corresponding depth-varying rheological behavior. Determining this depth-varying rheological structure is critical for modeling flow near ice divides and interpreting ice core records (Gusmeroli et al., 2012).



Gusmeroli et al. (2012), edited



Work in the “lab”

- International project in NE-Greenland, aiming to retrieve an ice core from *NEGIS*
- Worldwide cooperation in the field and during the following analyses, managed by Centre for Ice and Climate (Denmark)
- Major partners: Germany, Japan, Norway, US, France

Greenland.net (30.11.2017)

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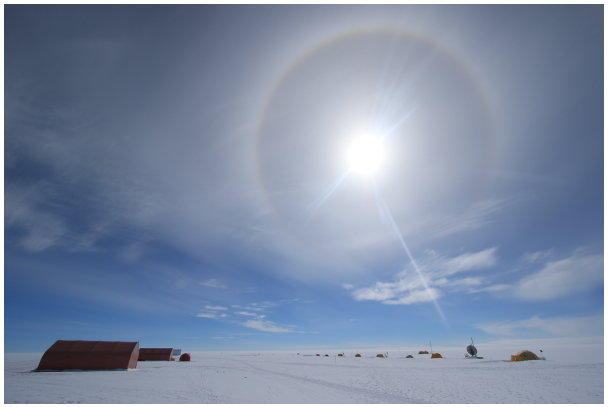
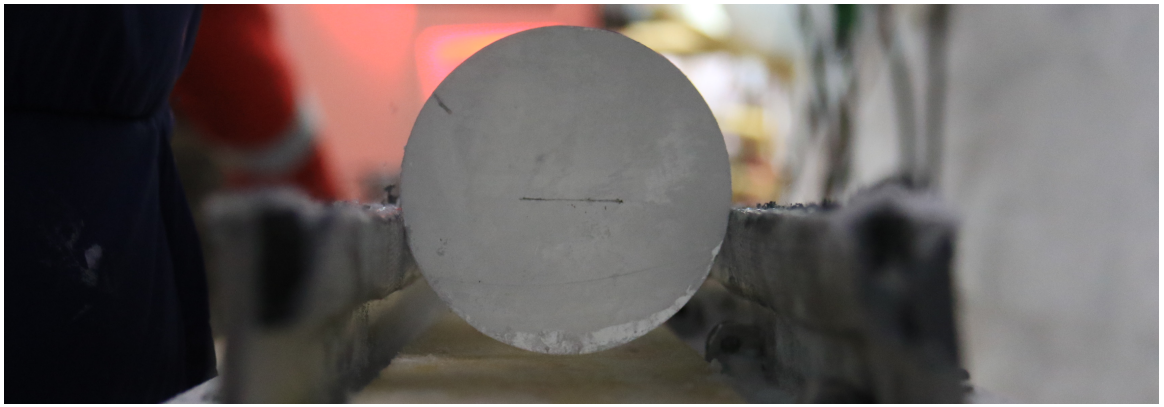
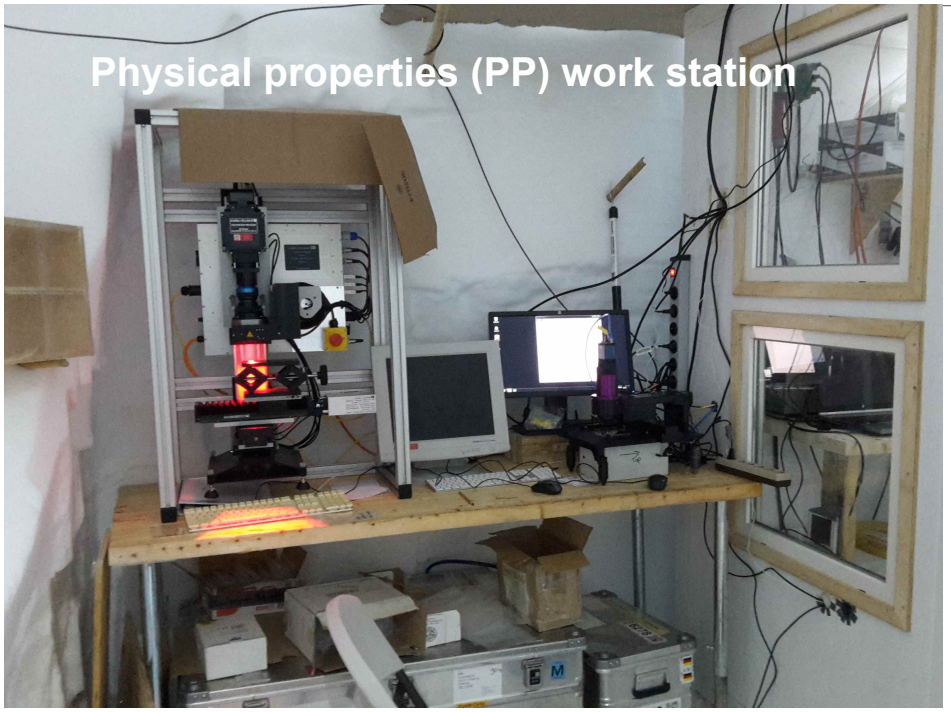
Work in the “lab”

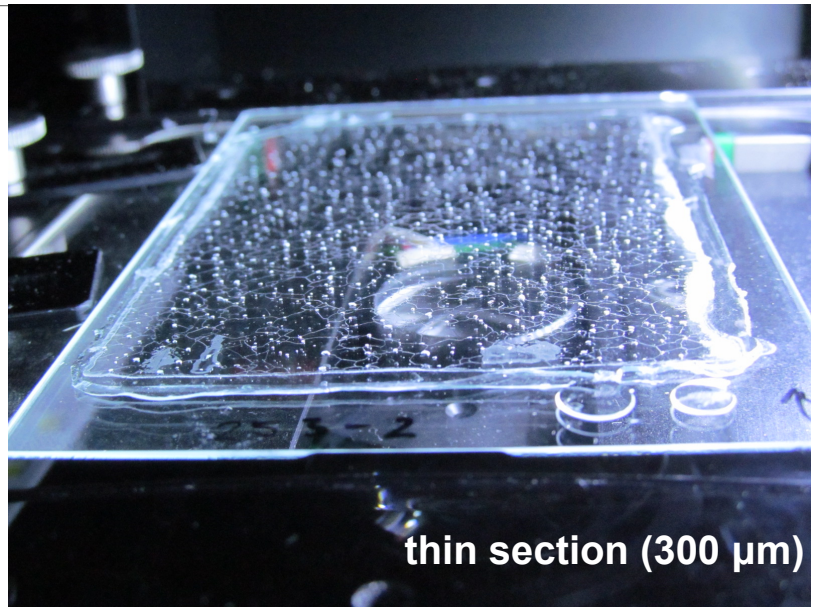
- Camp consists of airstrip, science trenches, accomodations and workshops
  ➔ logistical hub for other projects
- Ice thickness of about 2550m and rather undisturbed layers
- Surface velocity of ~65 m/yr ➔ EastGRIP camp moves 1 diameter/day

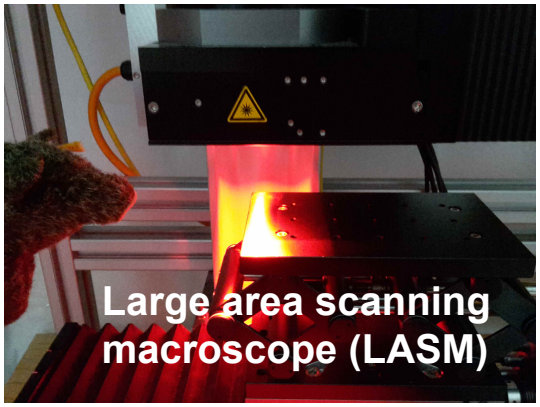


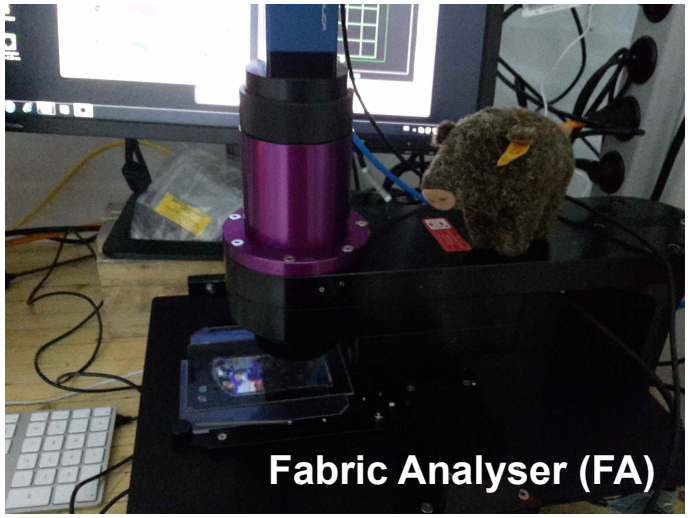


Work in the “lab”









Photos by J. Kerch and D. Jansen (AWI)

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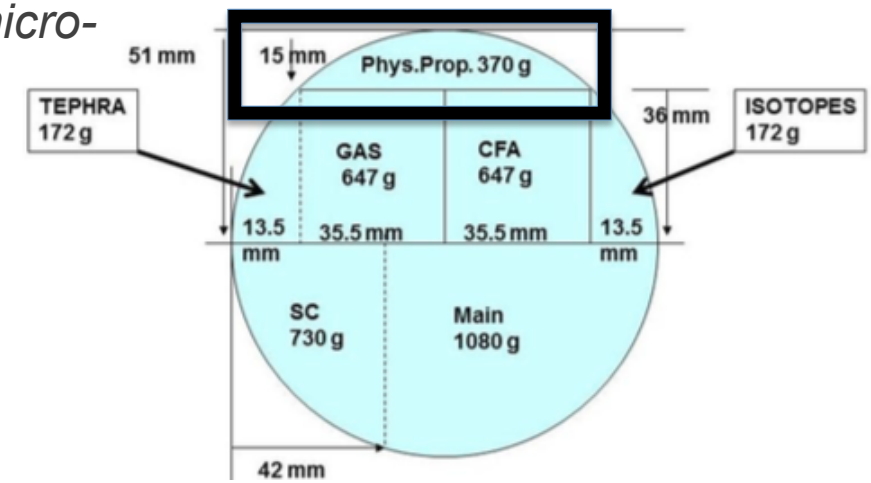
Work in the “lab”

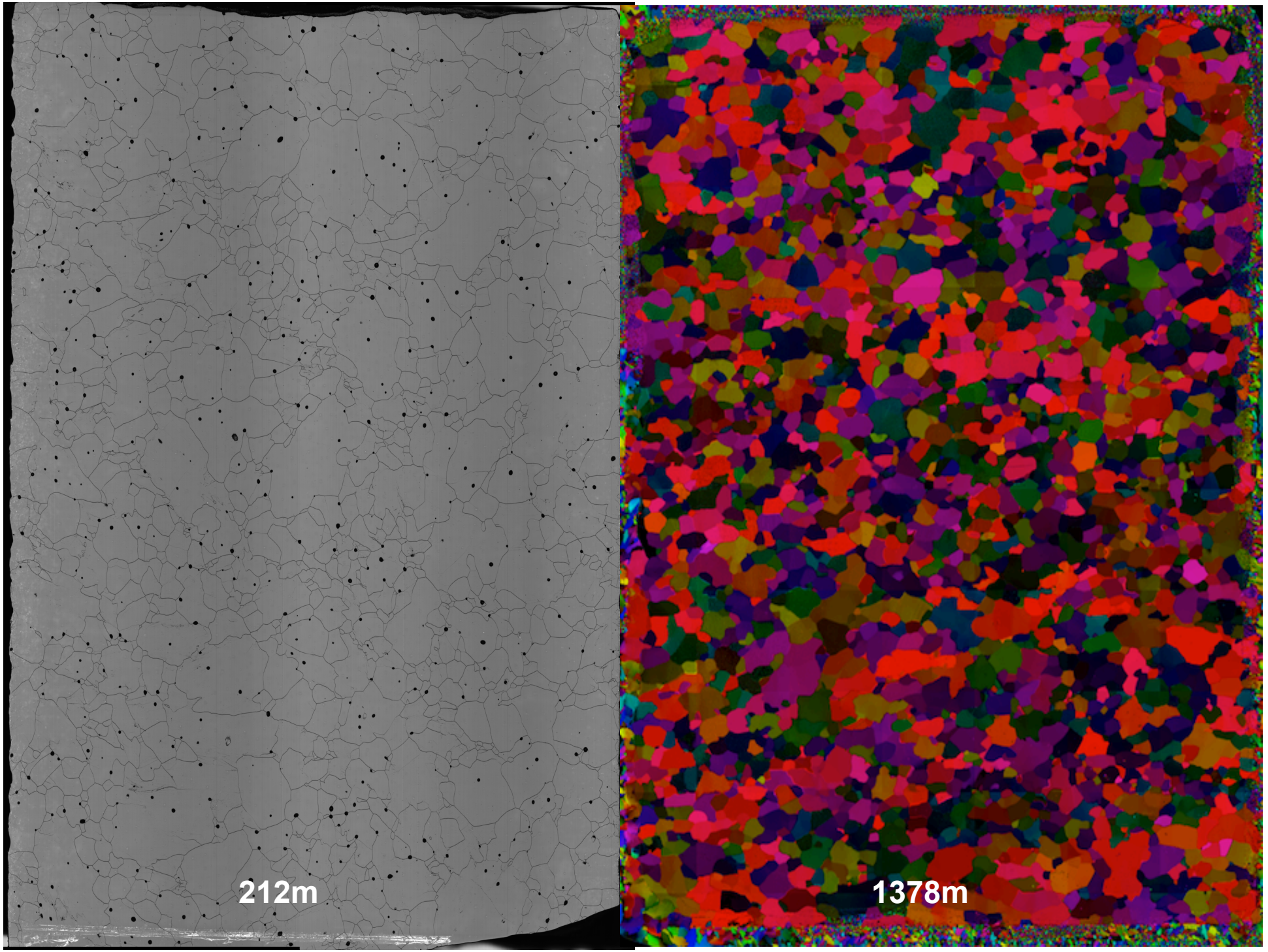
- Combined analysis of crystal fabric and microstructure maps by making and examining thin sections (~every 10-30m of depth)

- **Large area scanning macroscope (LASM)**:
  specialized scanner for ice core research ➔ air inclusions, *texture* and *deformation-related features*

- **Fabric Analsyer (FA)**:
  Automated polarized-light microscope
  ➔ *textural parameters (i.e. fabric)* and *micro-structure*

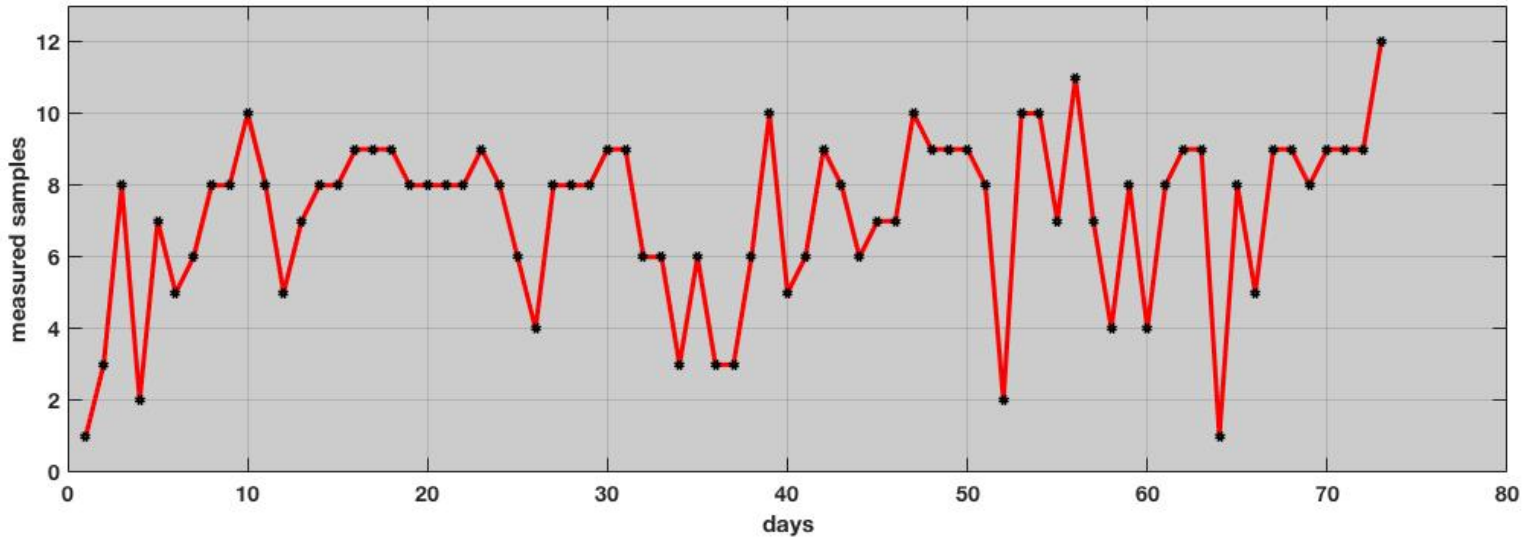


EastGRIP steering committee (2016)


212m
1378m

Fabric overview

- *2017*: **275** samples measured ≈ resolution of one full measurement every **10m** ➔ representative for upper ~250 m + some areas with higher resolution
- *2018*: **522** samples measured ➔ measurements every **10-15m**, including lower brittle zone and **nine volume cuts**
- **Total**: 744 vertical samples
  53 horizontal samples

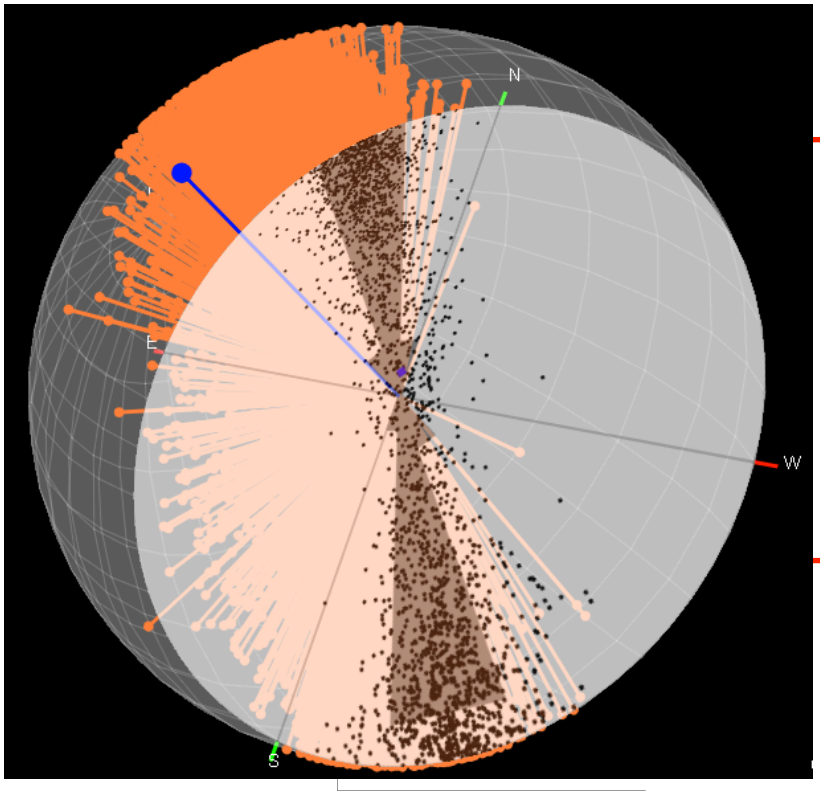


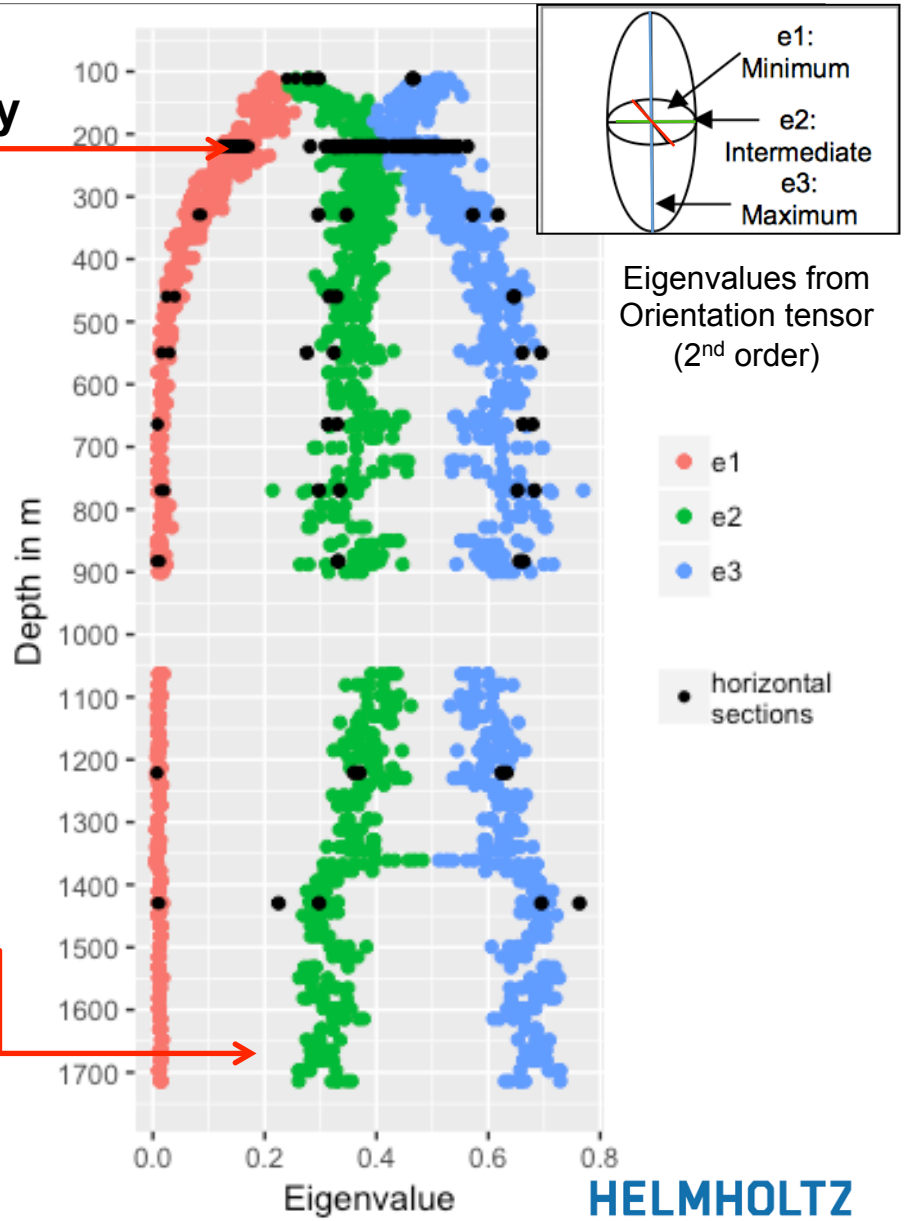
Fabric overview

- **major findings:**

  1) rapid evolution of c-axes anisotropy compared to lower dynamic sites

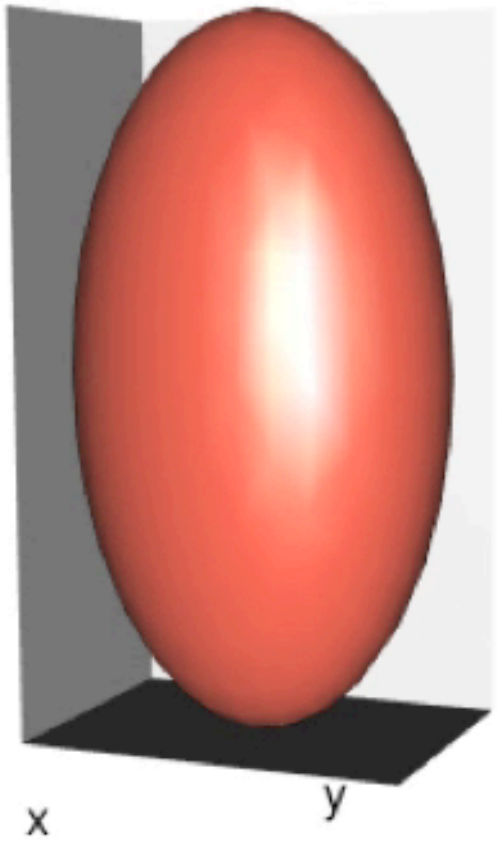
  2) partly novel characteristics in crystal prefered orientation (CPO) patterns

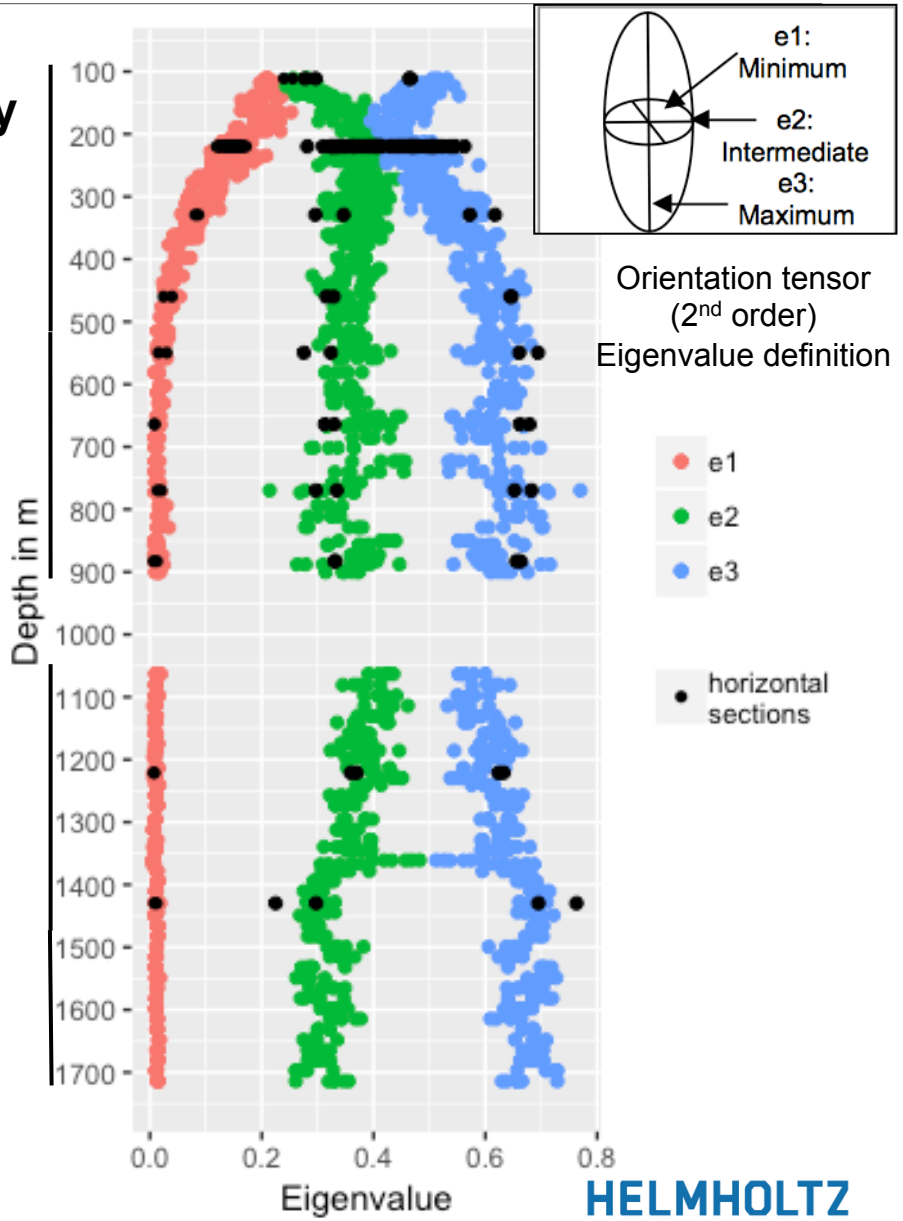




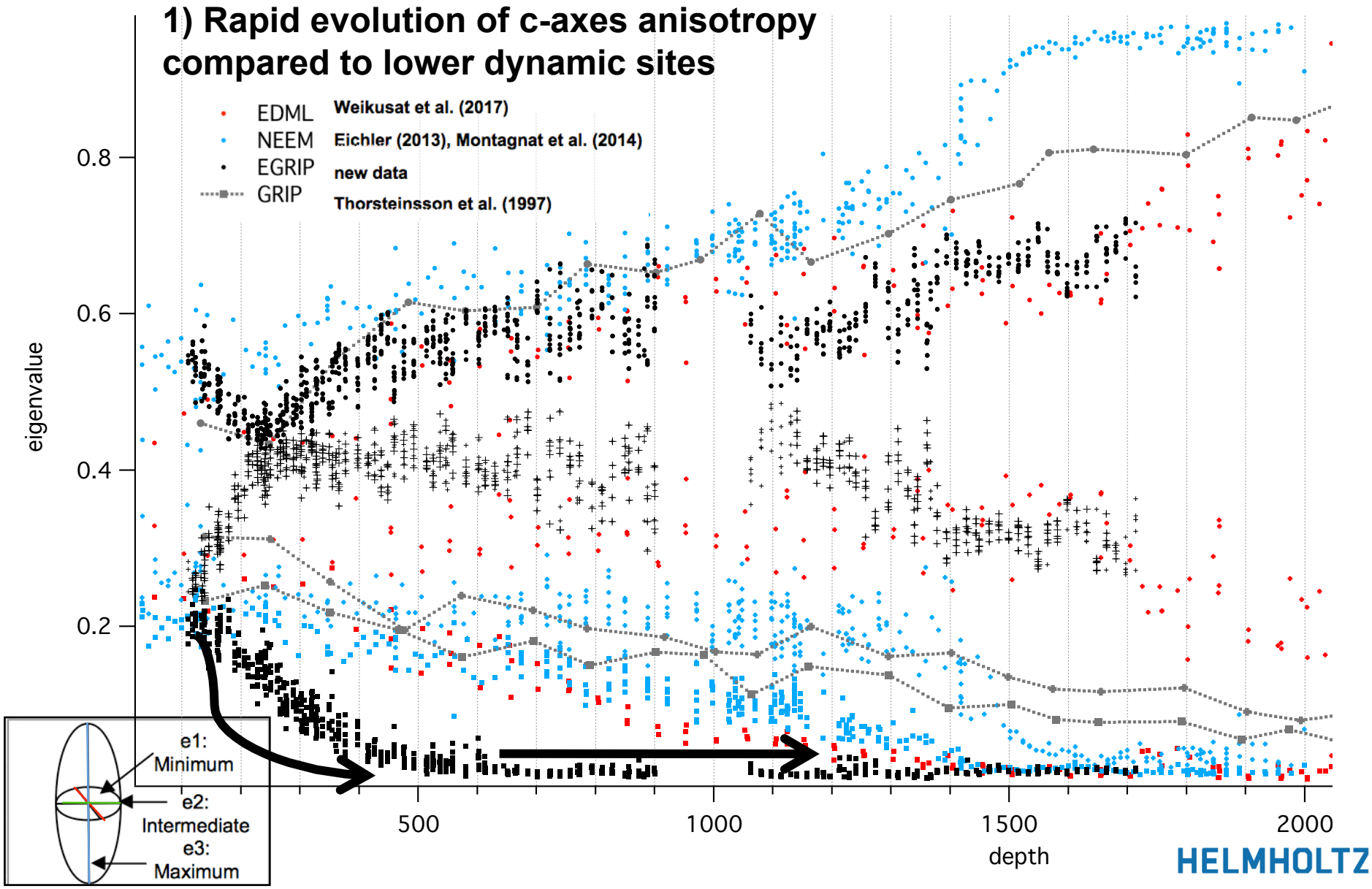
Fabric overview

1) rapid evolution of c-axes anisotropy compared to lower dynamic sites





Fabric overview



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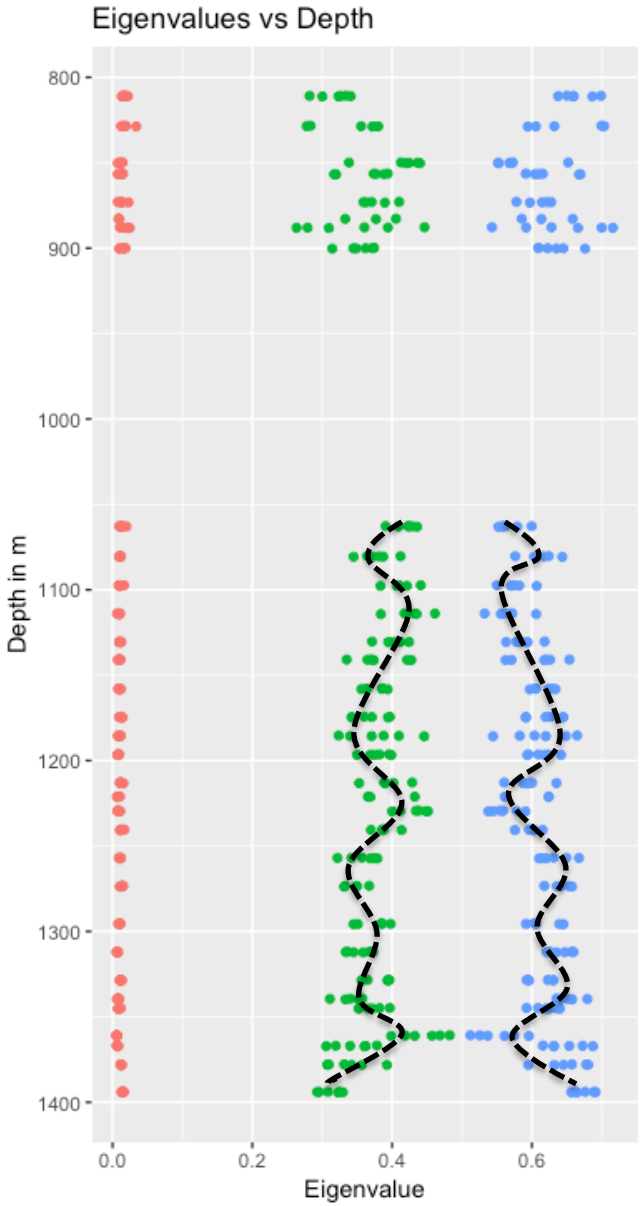
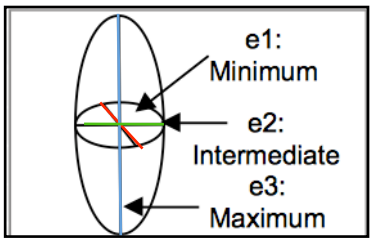
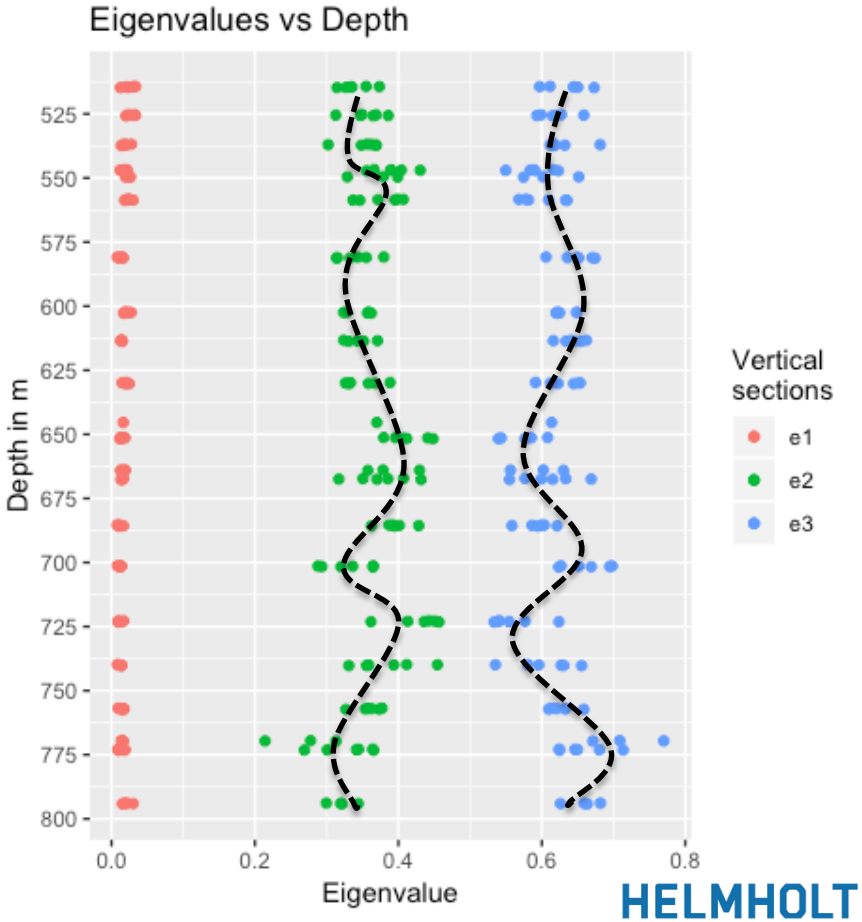
Fabric overview



New characteristic:

Two larger orientation tensor´s eigenvalues fluctuate in 50-150m intervals → „**wavy**“ form





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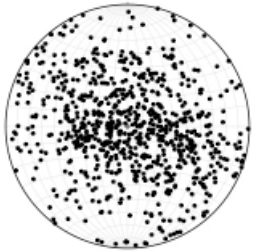
Fabric overview

2) partly novel characteristics in CPO patterns

Common CPO patterns

Broad single maximum



Broad girdle

Fully developed girdle
≈ 1400m at ice divides

Strong girdle

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CPO in detail

2) partly novel characteristics in CPO patterns

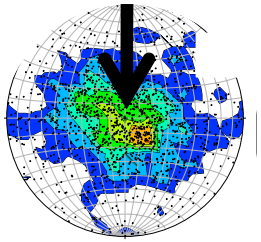
Common CPO patterns

Broad single maximum → **vertical compression** from overlying layers or temperature-gradient **snow metamorphosis**

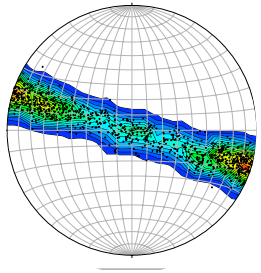
Fully developed girdle → **extension** along flow and ice deforms rather than being translated by *rigid block movement*

Strong girdle

Compression

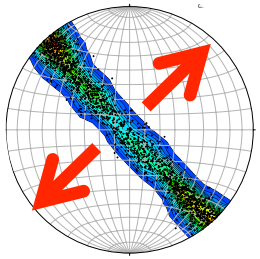


118m

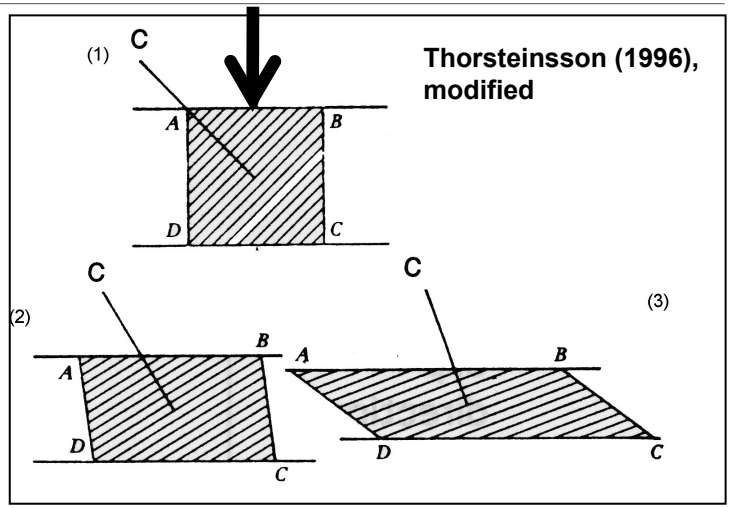


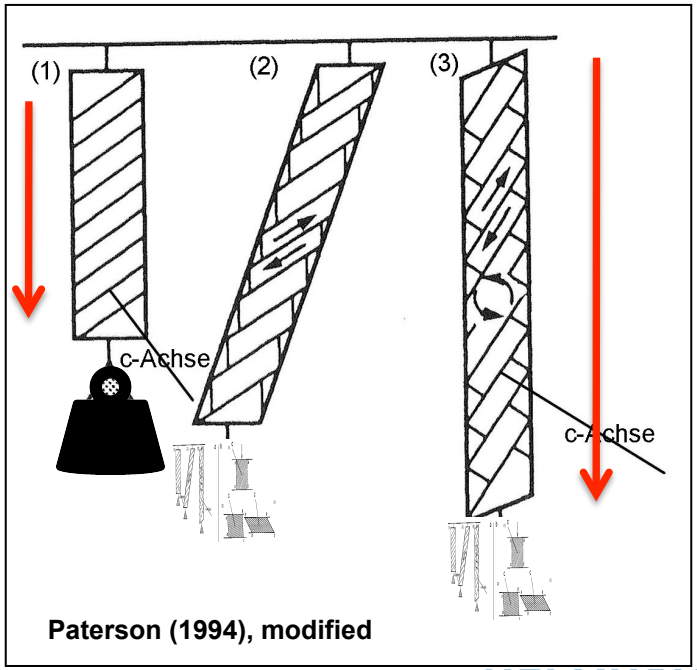
701m

Extension



1367m



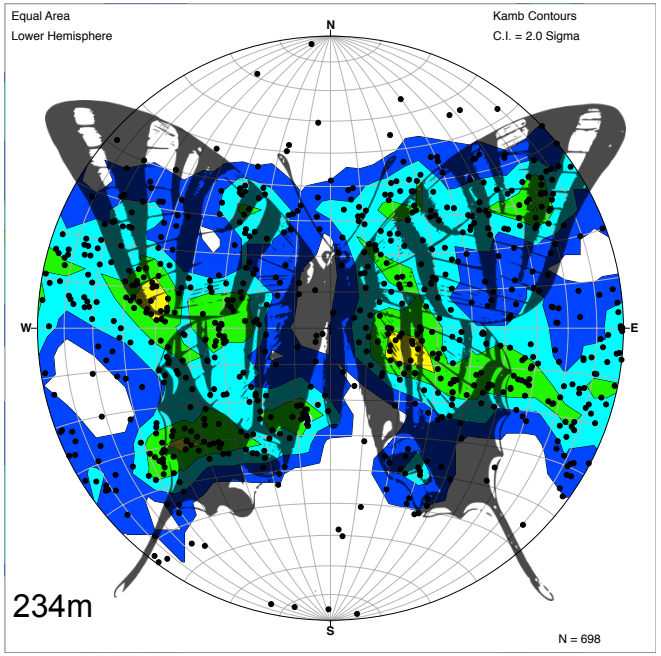


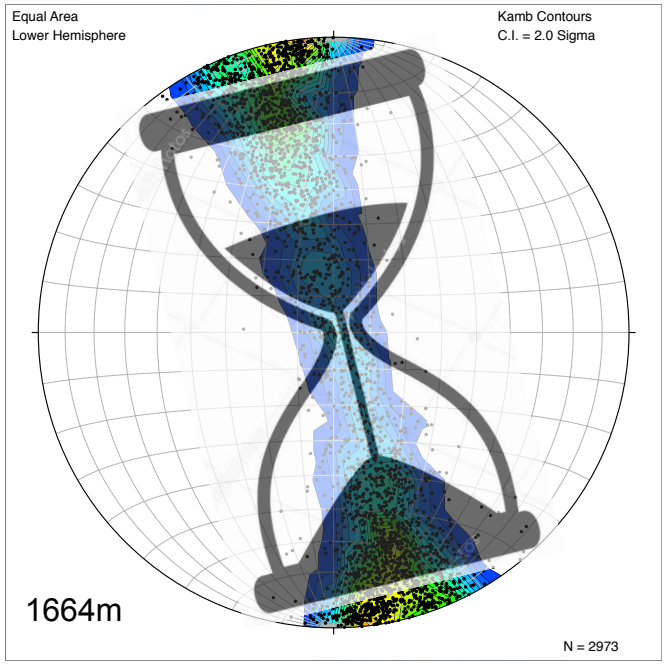
CPO in detail

2) partly novel characteristics in CPO patterns

Novel CPO patterns from EGRIP

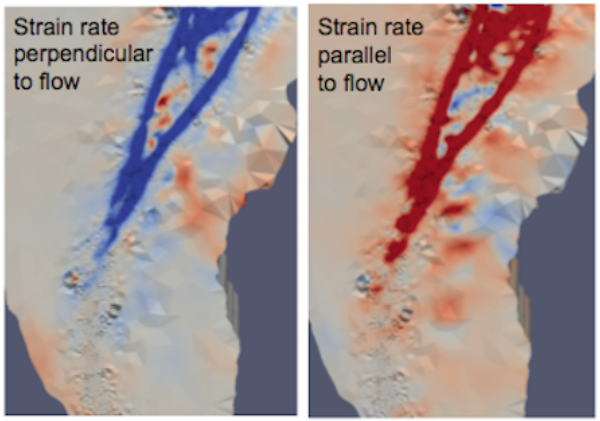
- “**butterfly shaped**” cross girdle
- broad “**hourglass shaped**” girdle





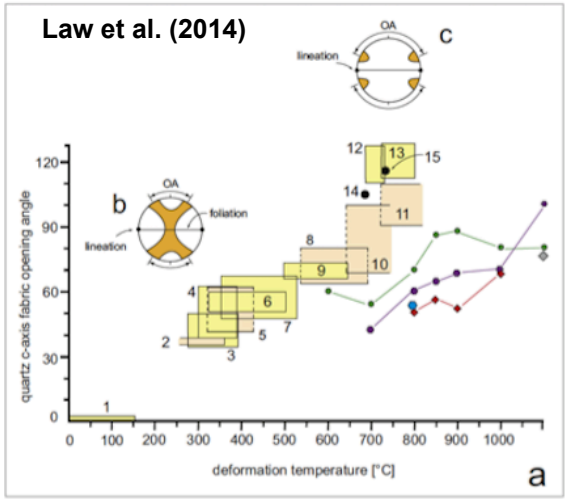
Hypotheses

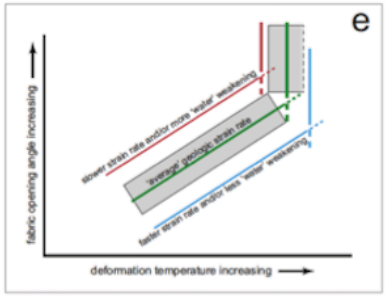
Join me at the following poster session (OMp29) for more information



ISSM : Rückkamp & Humbert, Illustration: Jansen

Law et al. (2014)



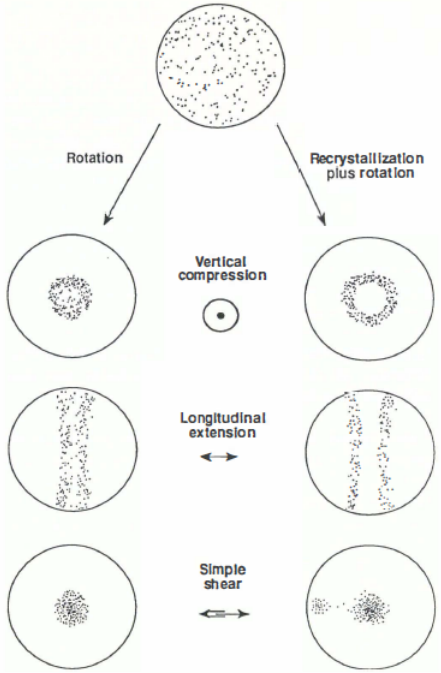


A
Reminiscent features from previous deformation modes ("girdle overlay") e.g. at ice stream margins

B
Thermodynamic activation of multiple dislocation slip systems [2], as known from e.g. quartz [3]

C
Early onset of dynamic migration recrystallisation under horizontal uniaxial extension

Kerch (EGU 2018)



Alley (1992)

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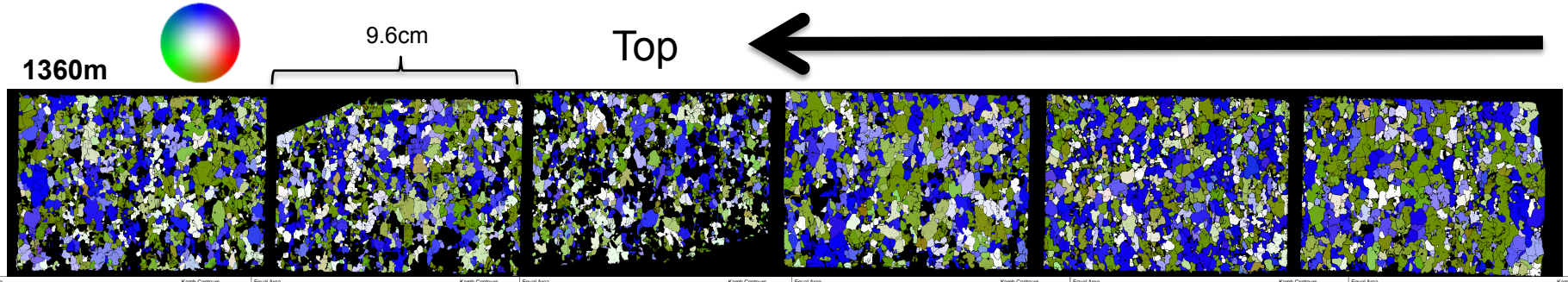
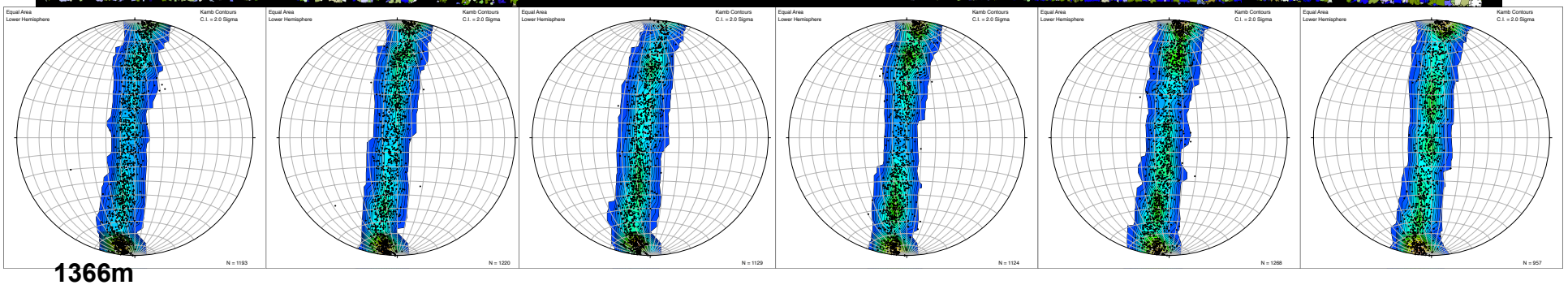
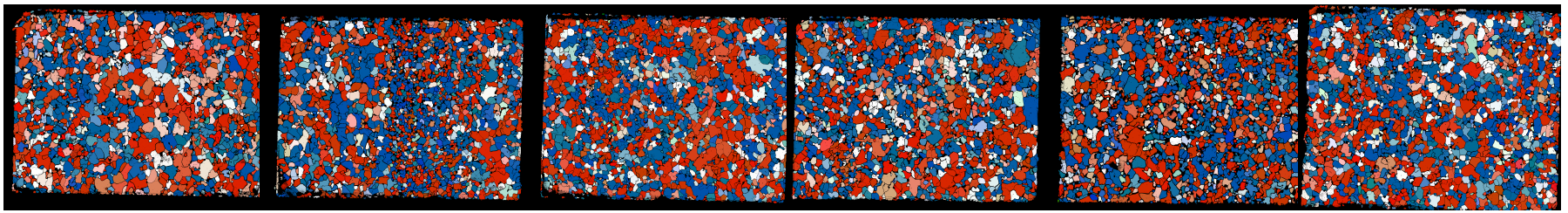
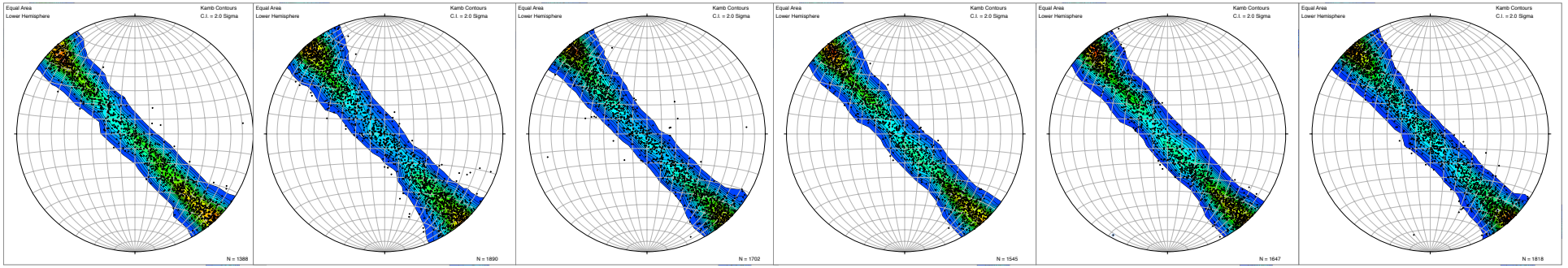
Small-scale changes



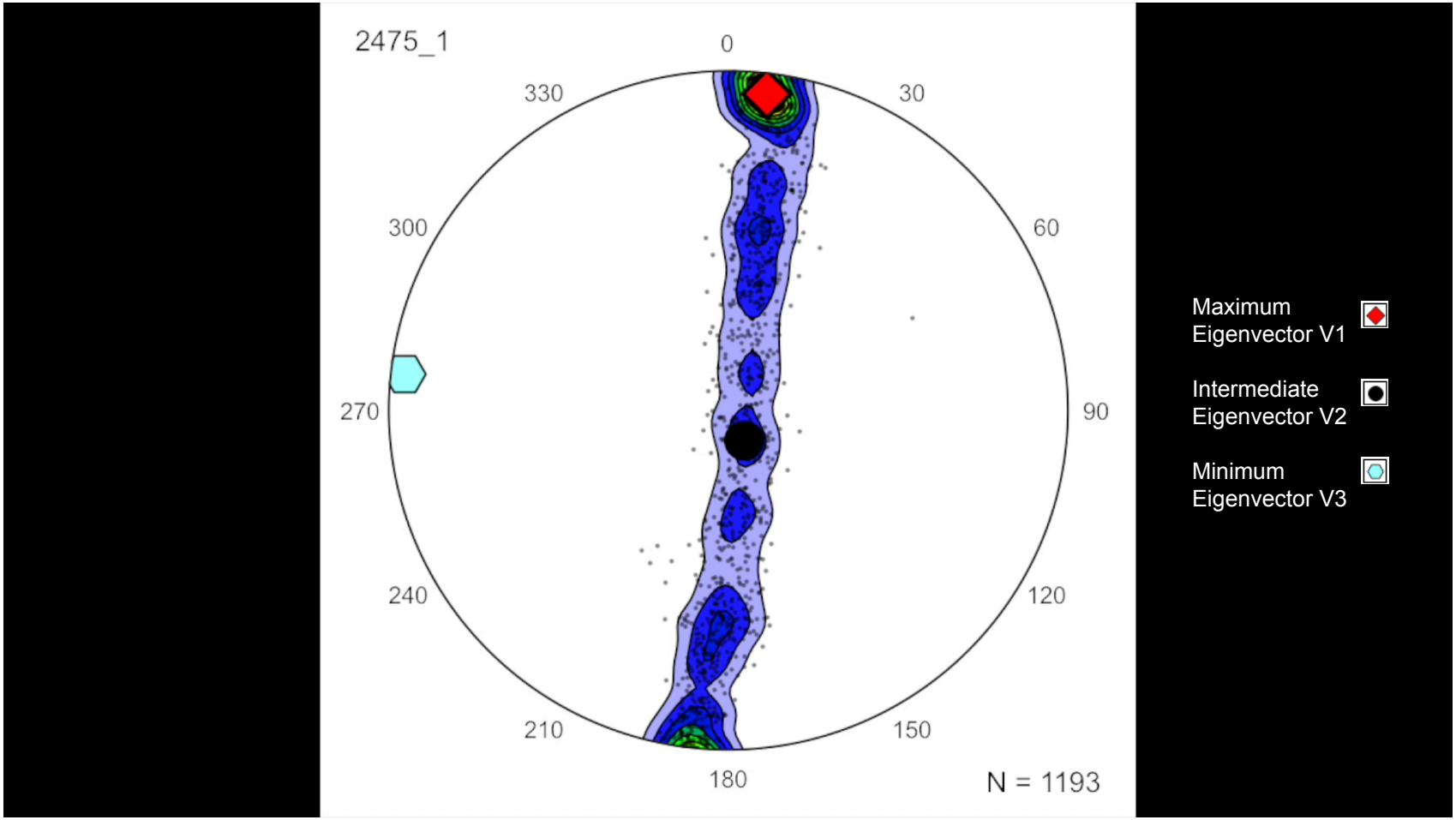






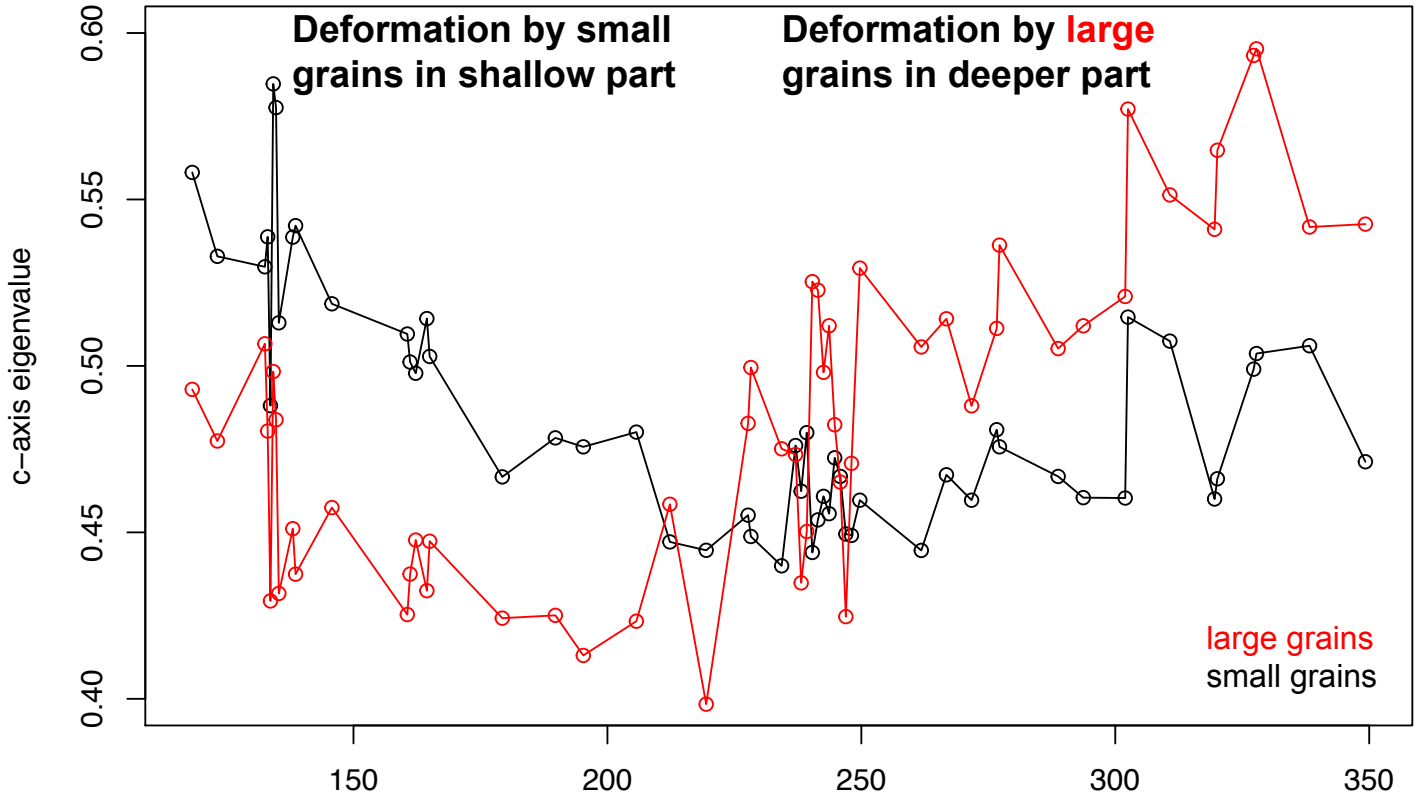
Small-scale changes

Eigenvectors



Evolution of grain properties
Grain size

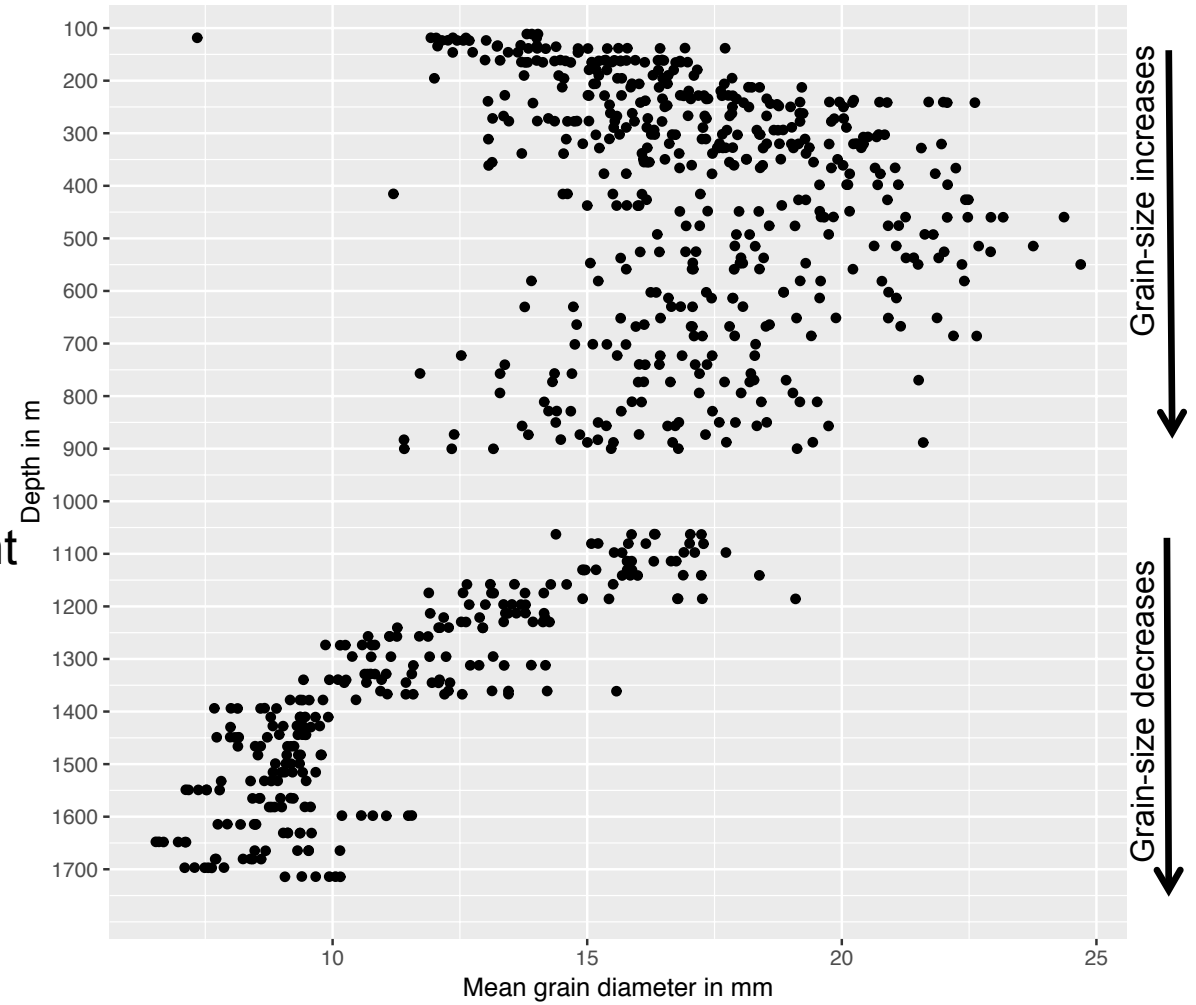
- Evolution of a **grain-size dependent anisotropy** in the first 350m of ice core
- Bulk anisotropy caused by **deformation** and **early recrystallisation (?)**



e3 = measure for **bulk anisotropy strength**

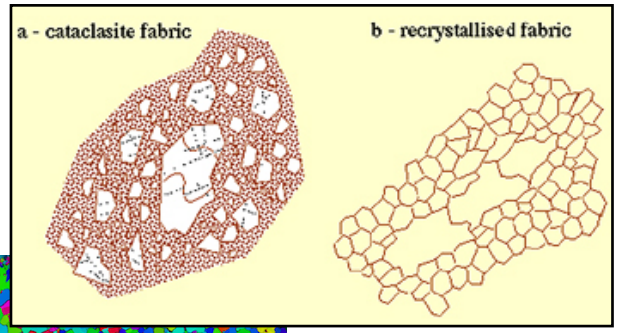
Evolution of grain properties
Grain size

- Mean grain-size (GS) increases until 550m, decreases afterwards
- Constant GS between 1400-1714m
- GS variability extreme between 550–900m
- GS variability smaller in glacial and rather constant between 1400-1714m

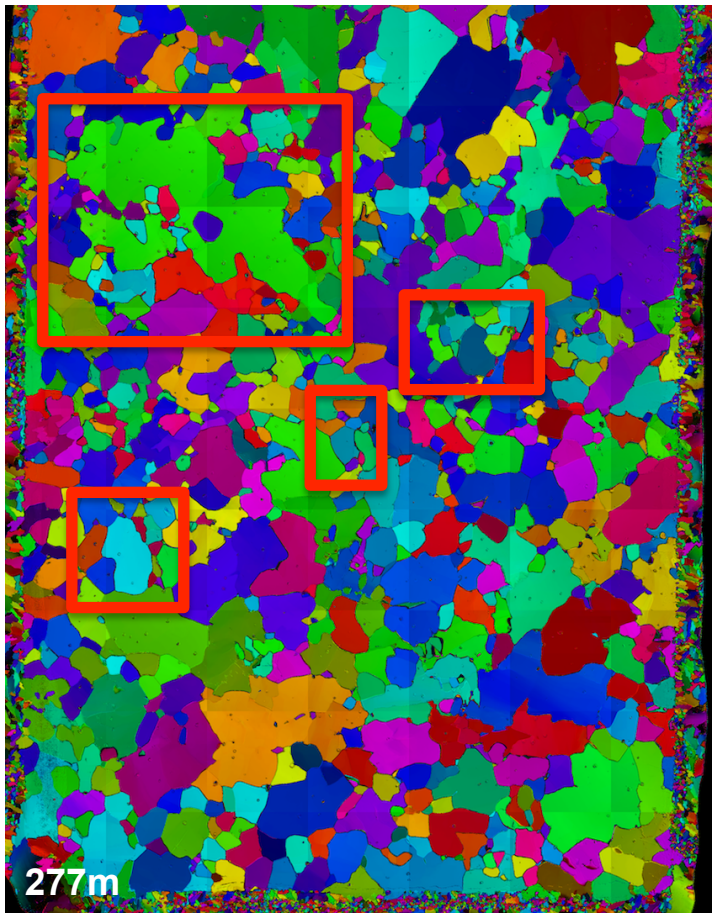


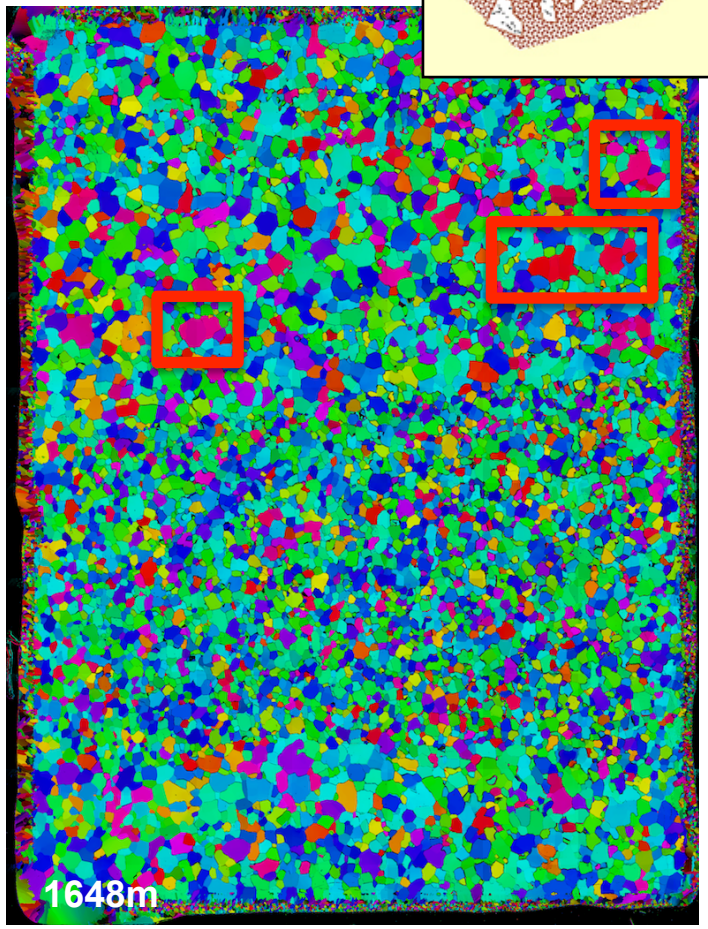
Evolution of grain properties
Grain clustering

• Small grains with similar orientations seem to **cluster** around large grains with different orientation
→ „*core and mantle structure*“



Passchier & Trouw (2005)





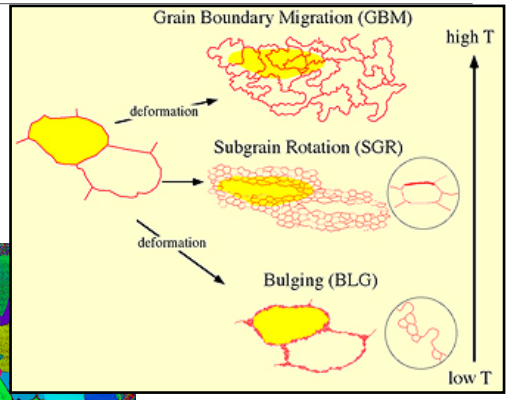
Medium GS

Small GS

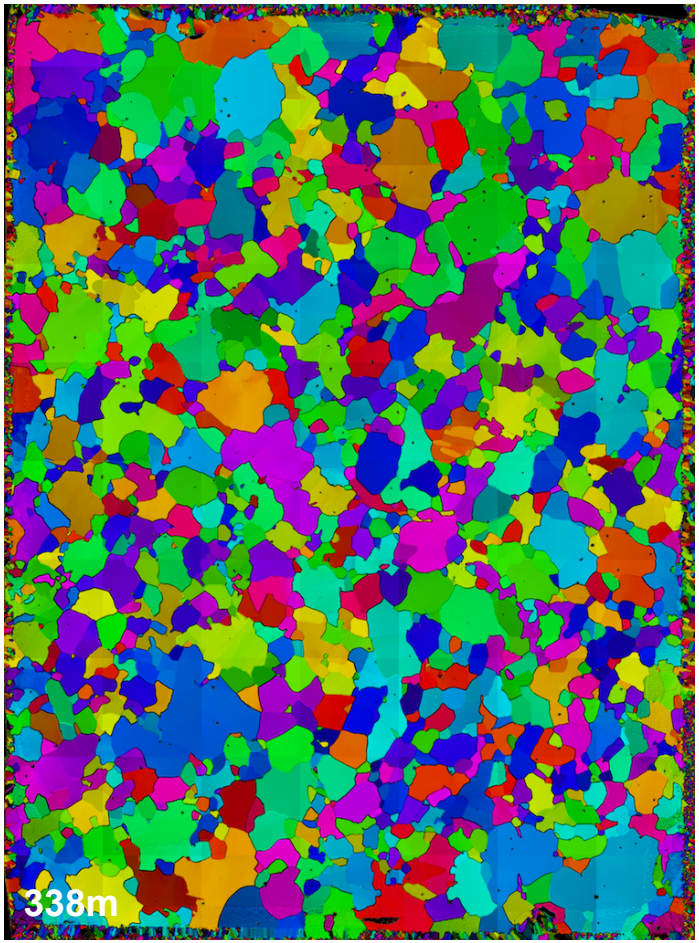
Medium GS

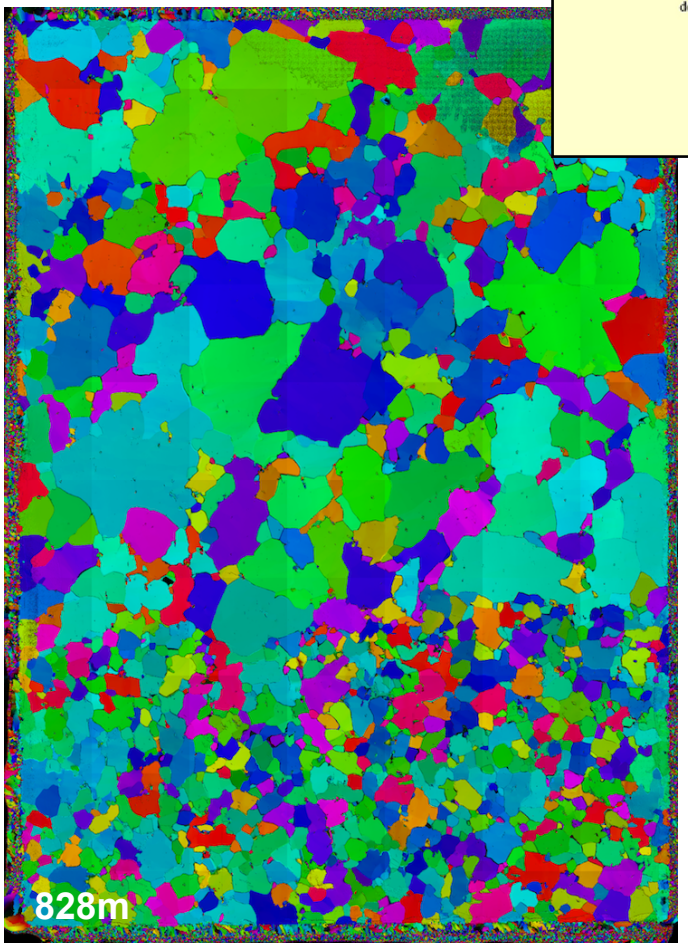
Evolution of grain properties
Grain shape

• Characteristic are also **amoeboid** grain shapes and **sutured** grain boundaries, typical features of grain boundary migration



Passchier & Trouw (2005)





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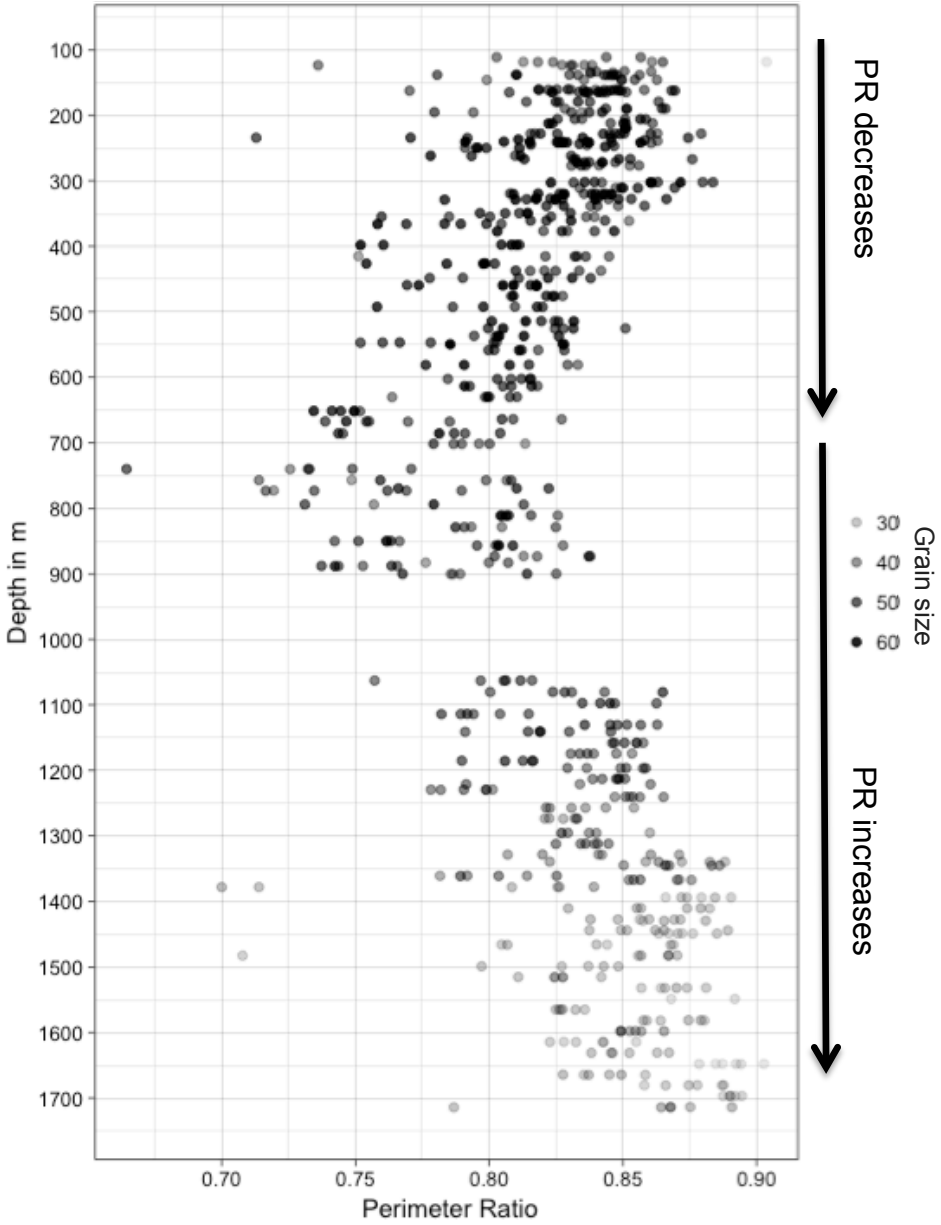
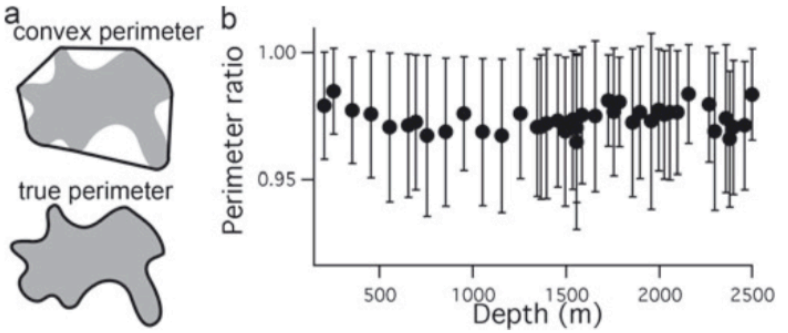
Evolution of grain properties
Grain irregularity



- Larger perimeter ratios (PR) than in EDML core
- PR decreases until 722m, then increases linearly until final depth
- Large, but constant PR variability

EDML

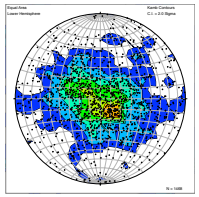


Weikusat et. al (2009)

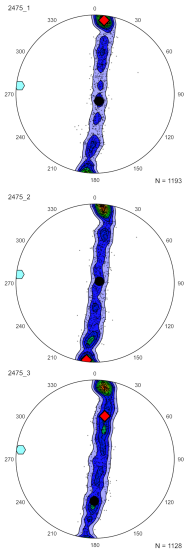
PR = measure for grain **irregularity**

Take home message

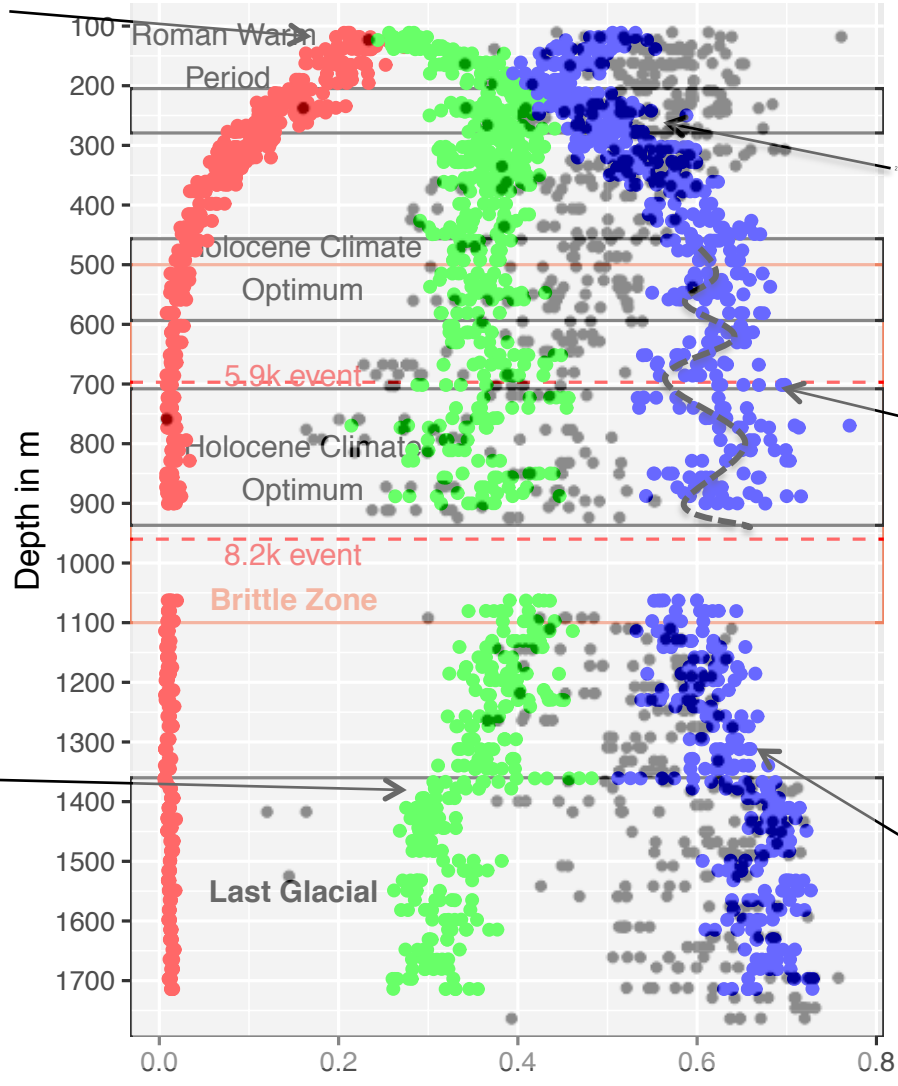
Vertical eigenvector V1 and broad single maximum CPO



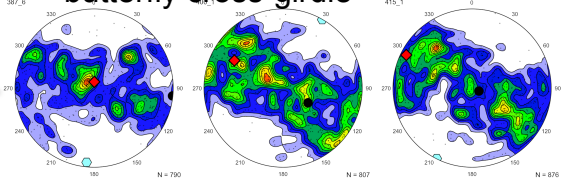
Horizontal girdle CPO and flipping eigenvector



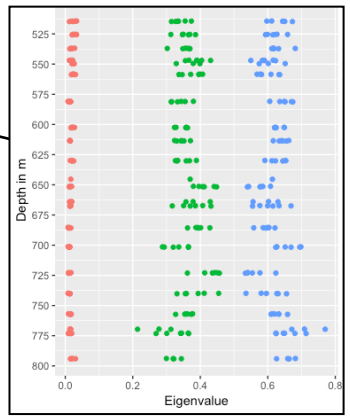
Small perimeter ratio



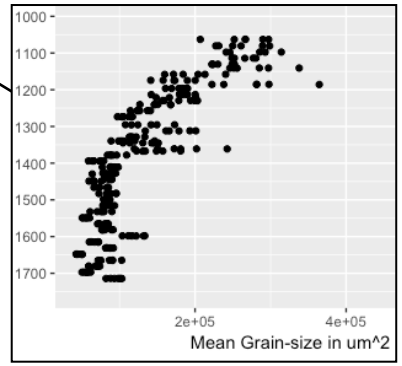
Tipping of eigenvectors, "crossing" of eigenvalues and butterfly cross-girdle



"Wavy" eigenvalue evolution

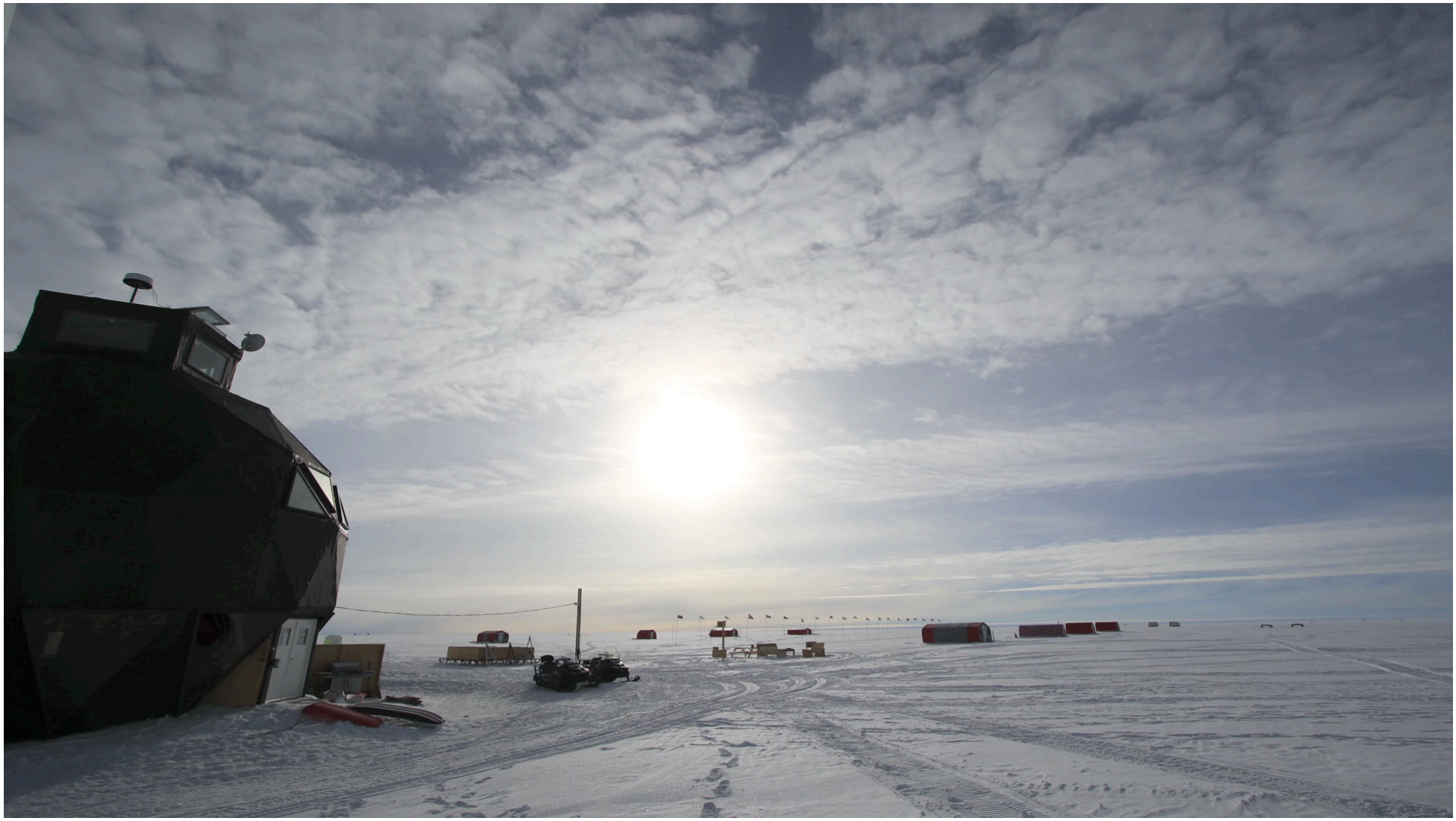


Strong decrease of grain-size



Age model: Sune Rasmussen, Interpolated from 900m on

Take home message



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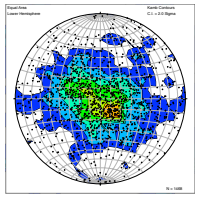
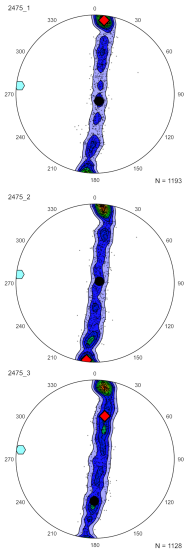
Take home message

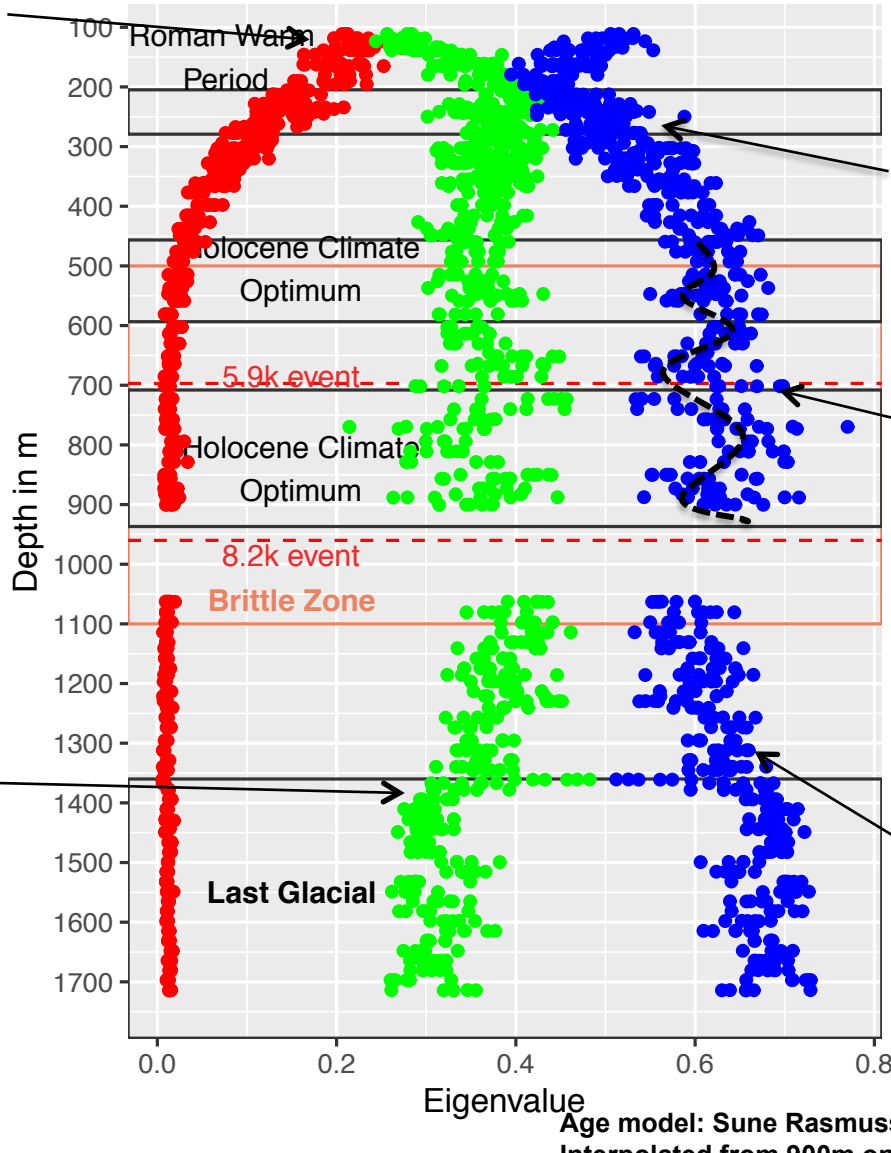
Vertical eigenvector V1 and broad single maximum CPO



Horizontal girdle CPO and flipping eigenvector



Small perimeter ratio



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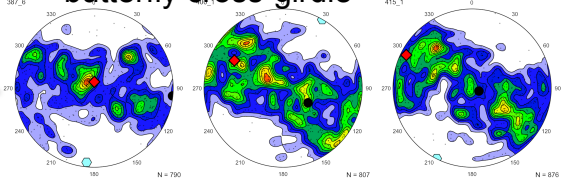
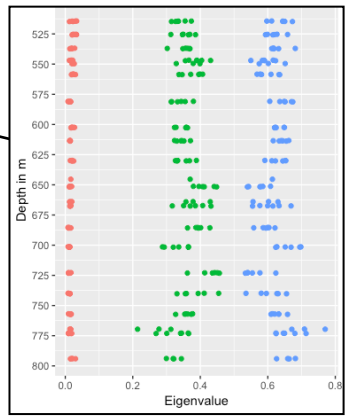


"Wavy" eigenvalue evolution



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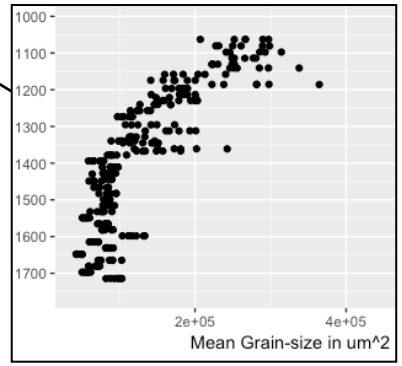

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