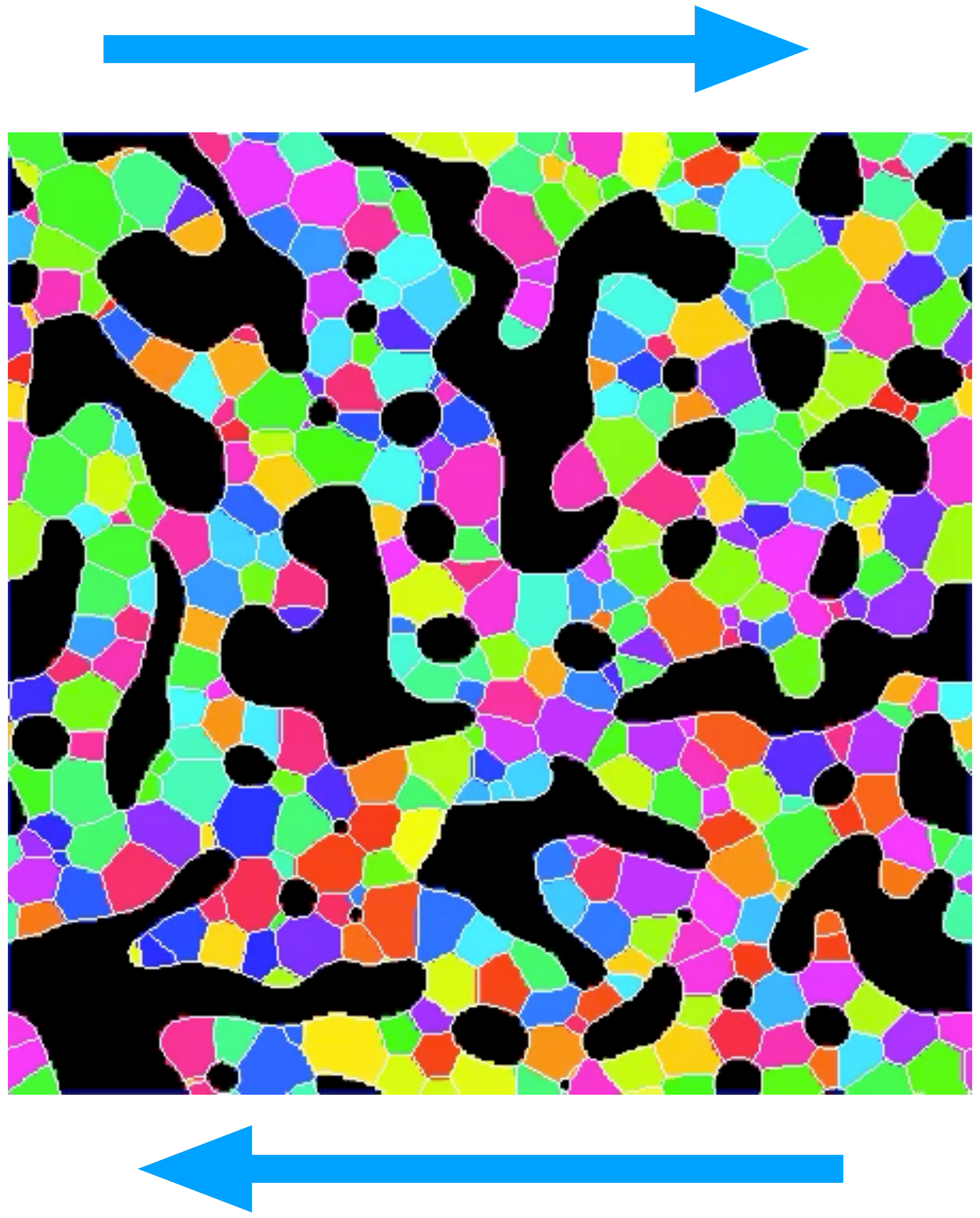
Ilka Weikusat & Nicolas Stoll
Johanna Kerch, Ina Kleitz, Jan Eichler, Wataru Shigeyama, Tomoyuki Homma, Daniela Jansen, Maddalena Bayer-Giraldi, Ernst-Jan Kuiper, Julien Westhoff, Tomotaka Saruya, Sebastian Hellmann, Steven Franke, Pia Götz, Kumiko Goto-Azuma, Nobuhiko Azuma, Sérgio Henrique Faria, Sepp Kipfstuhl, Dorthe Dahl-Jensen

EastGRIP ice down to 2121m - fabric and microstructure

EastGRIP Steering Committee 2019

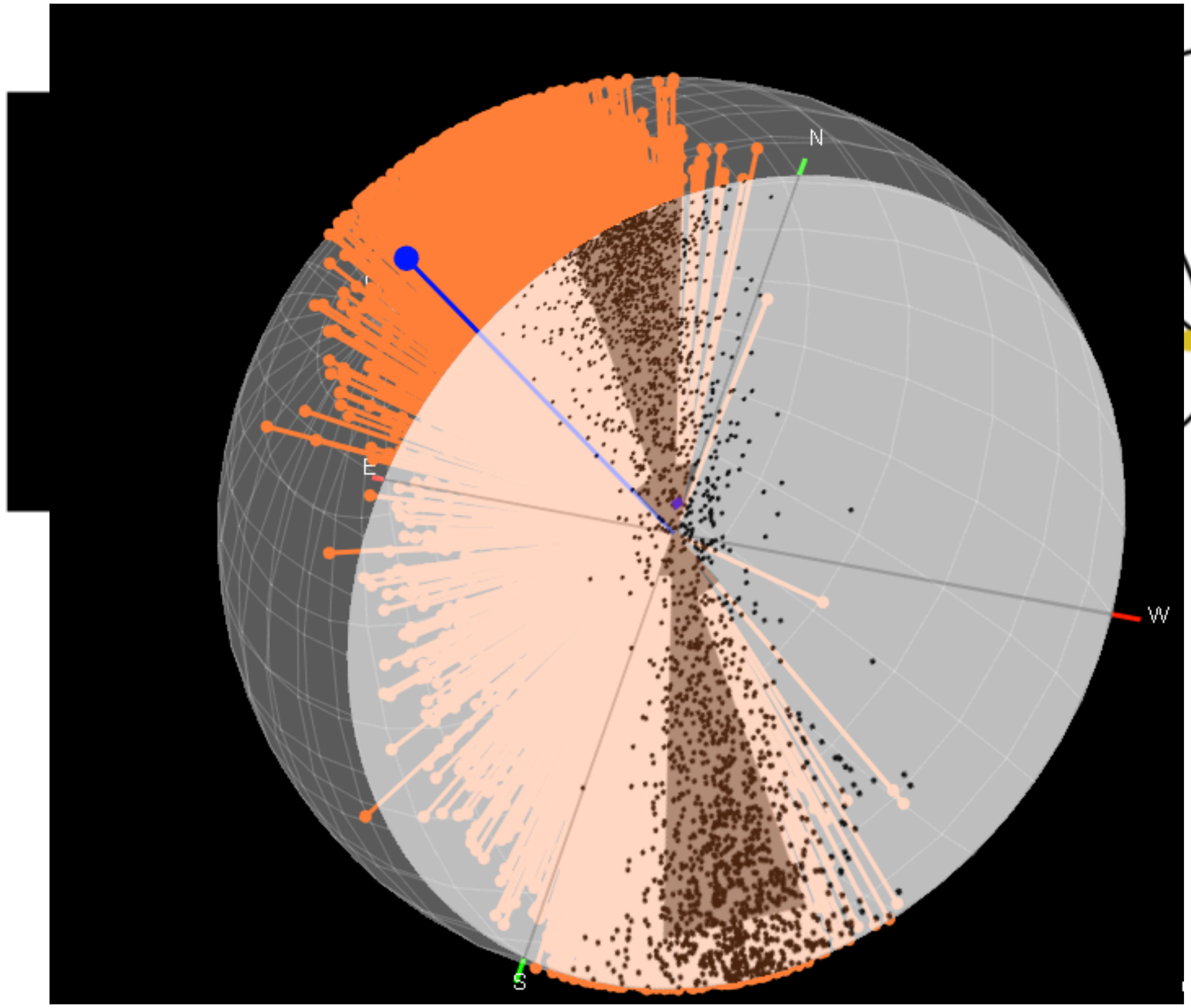
Introduction

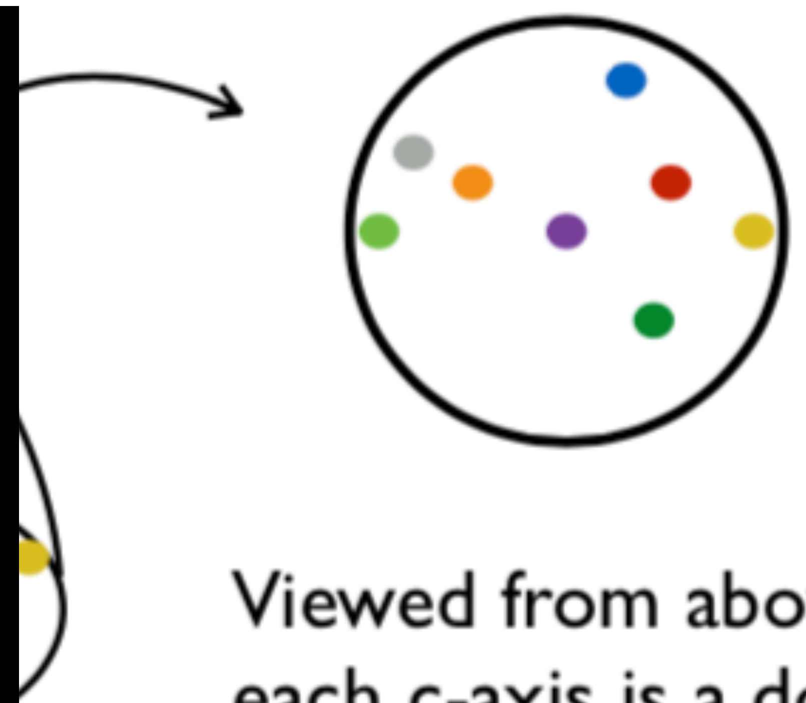


F. Steinbach, Uni Tübingen

Introduction

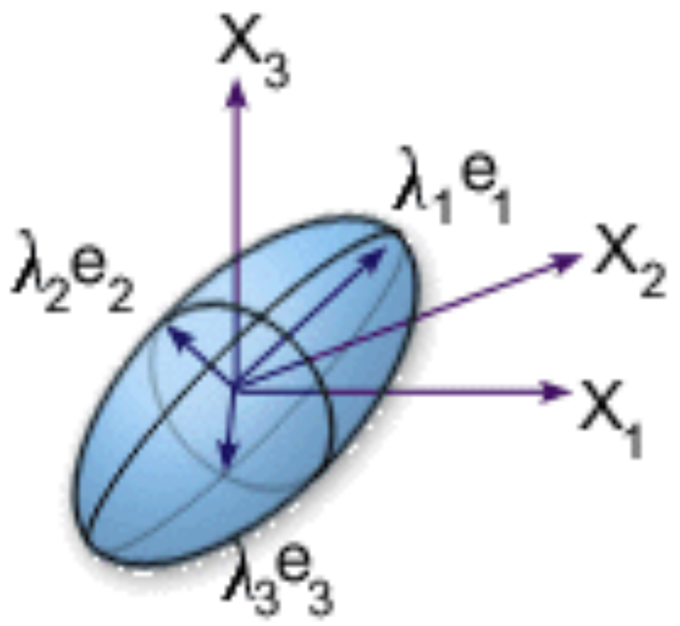
- Different planes in crystal ➔ easiest deformation along *basal* plane (perpendicular to *c-axis*)
- C-axes projected as pole figures, core axis is represented through the centre of the circle
- *Eigenvalues* portray c-axis distribution as the three principal axes of an ellipsoid



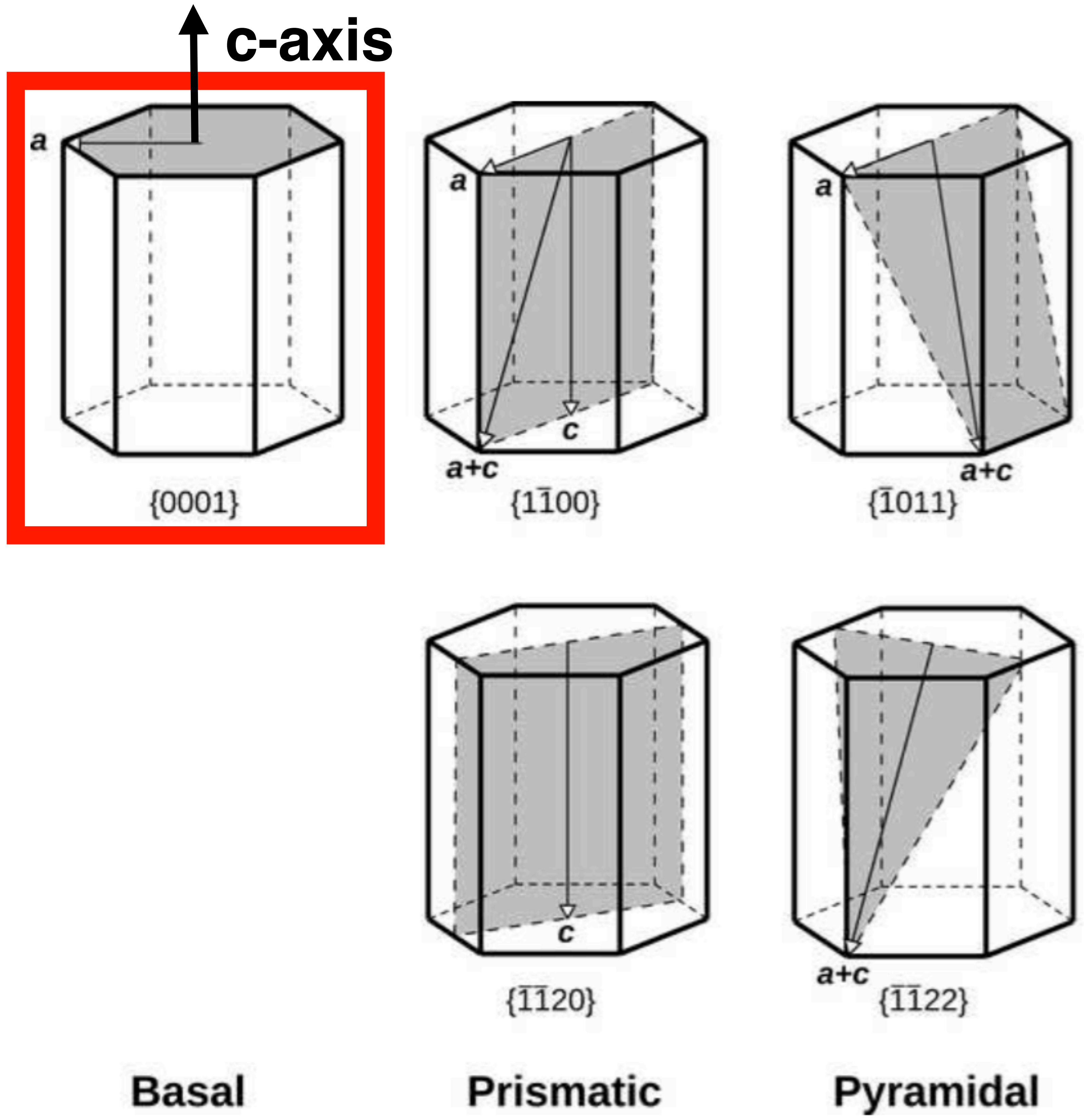


Viewed from above,
each c-axis is a dot

I. Hewitt, course material *Rheology of Ice*

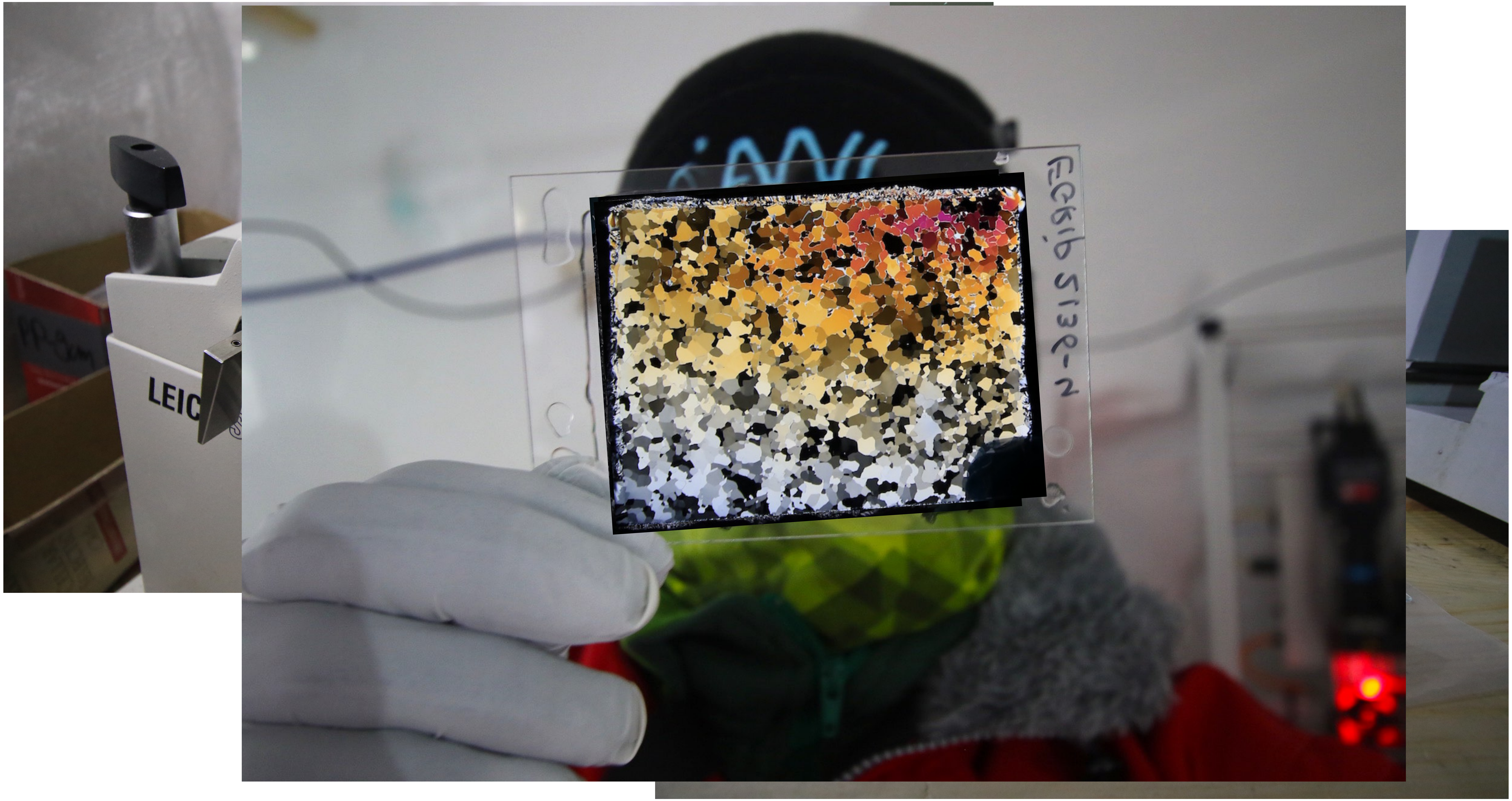


Moldflowinsight.com (2017)

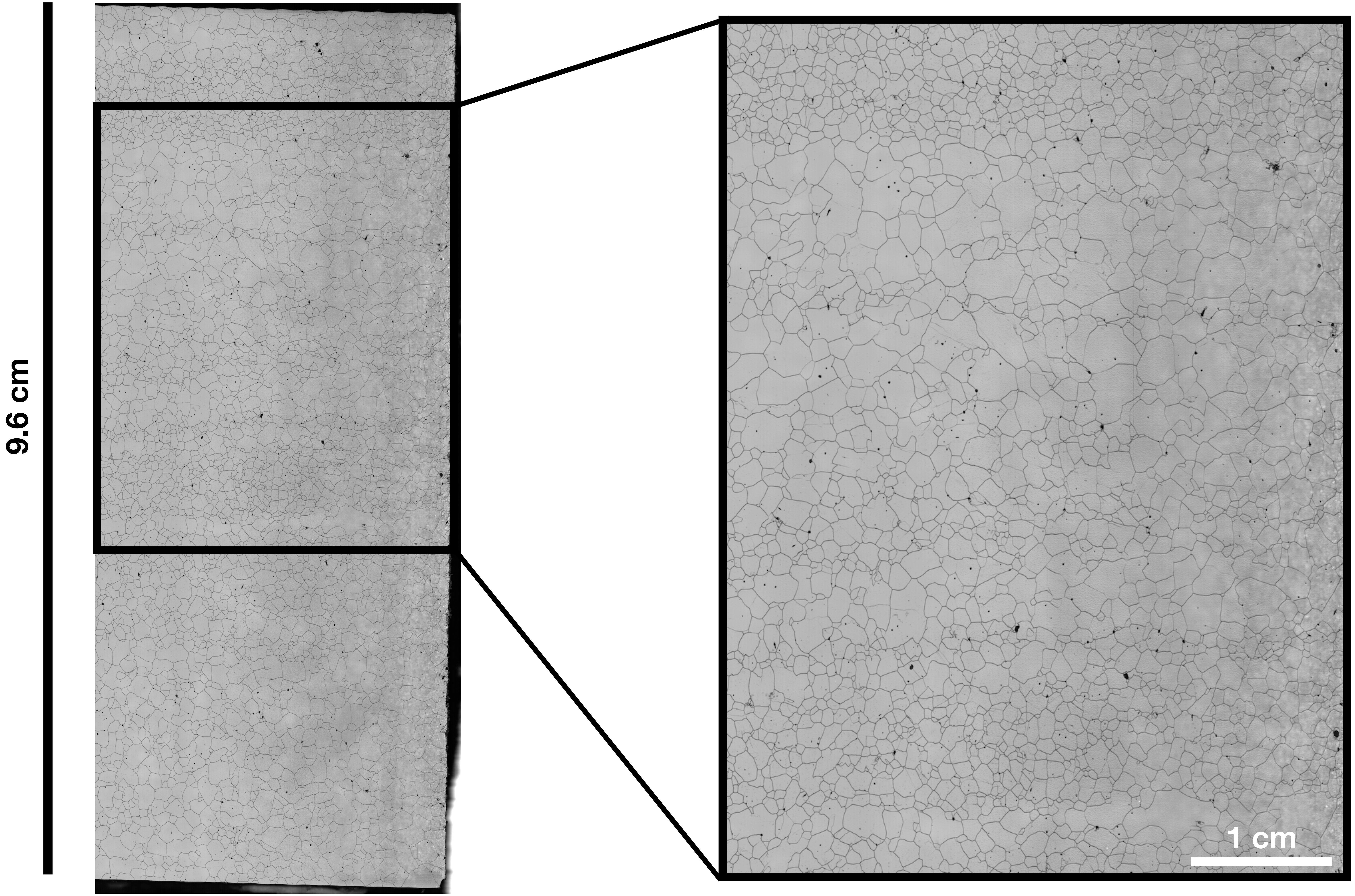


After Hondoh (2000),
displayed by Faria et al. (2014)

Introduction



Introduction

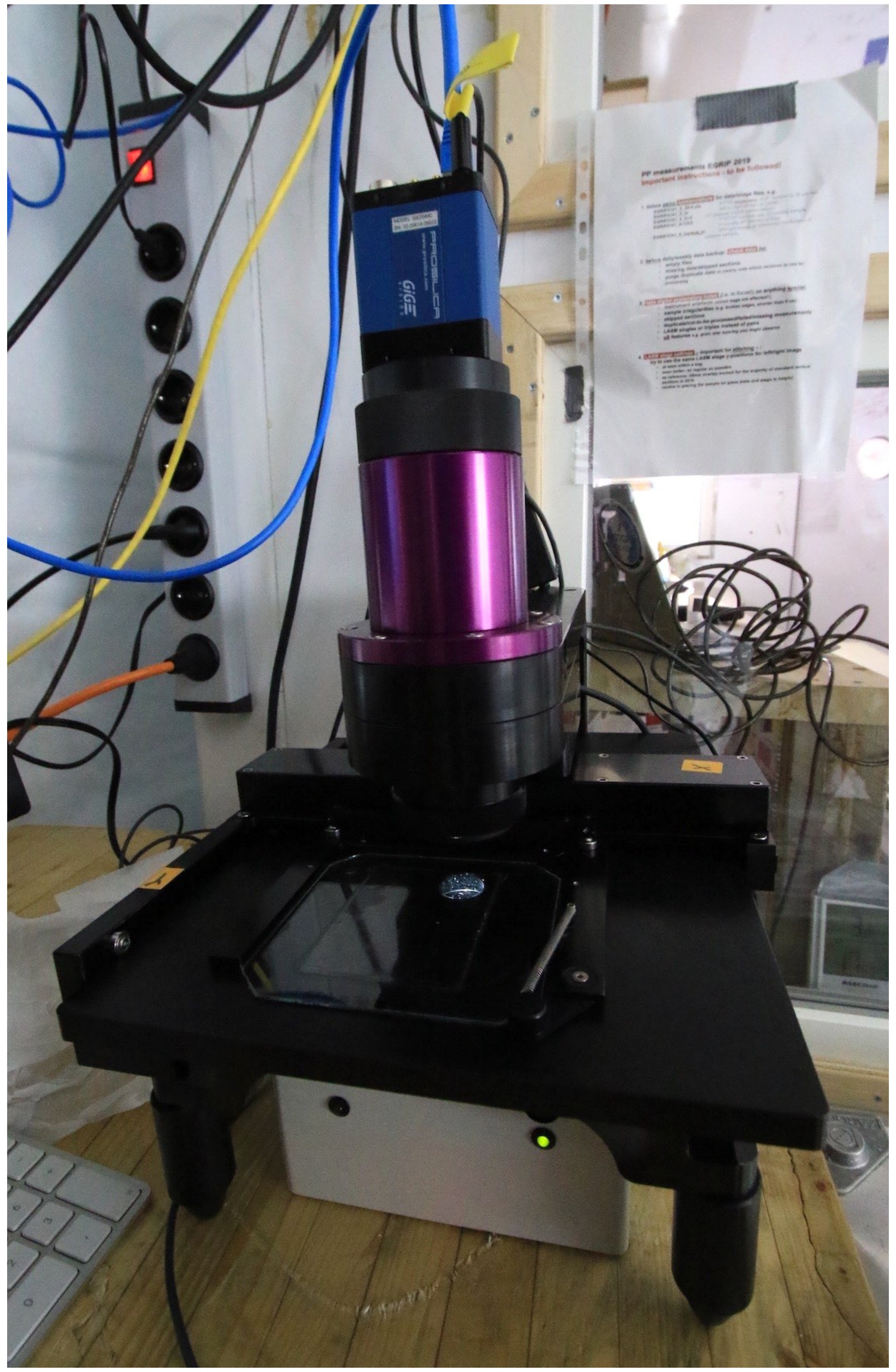


Large Area Scanning Macroscope

Introduction

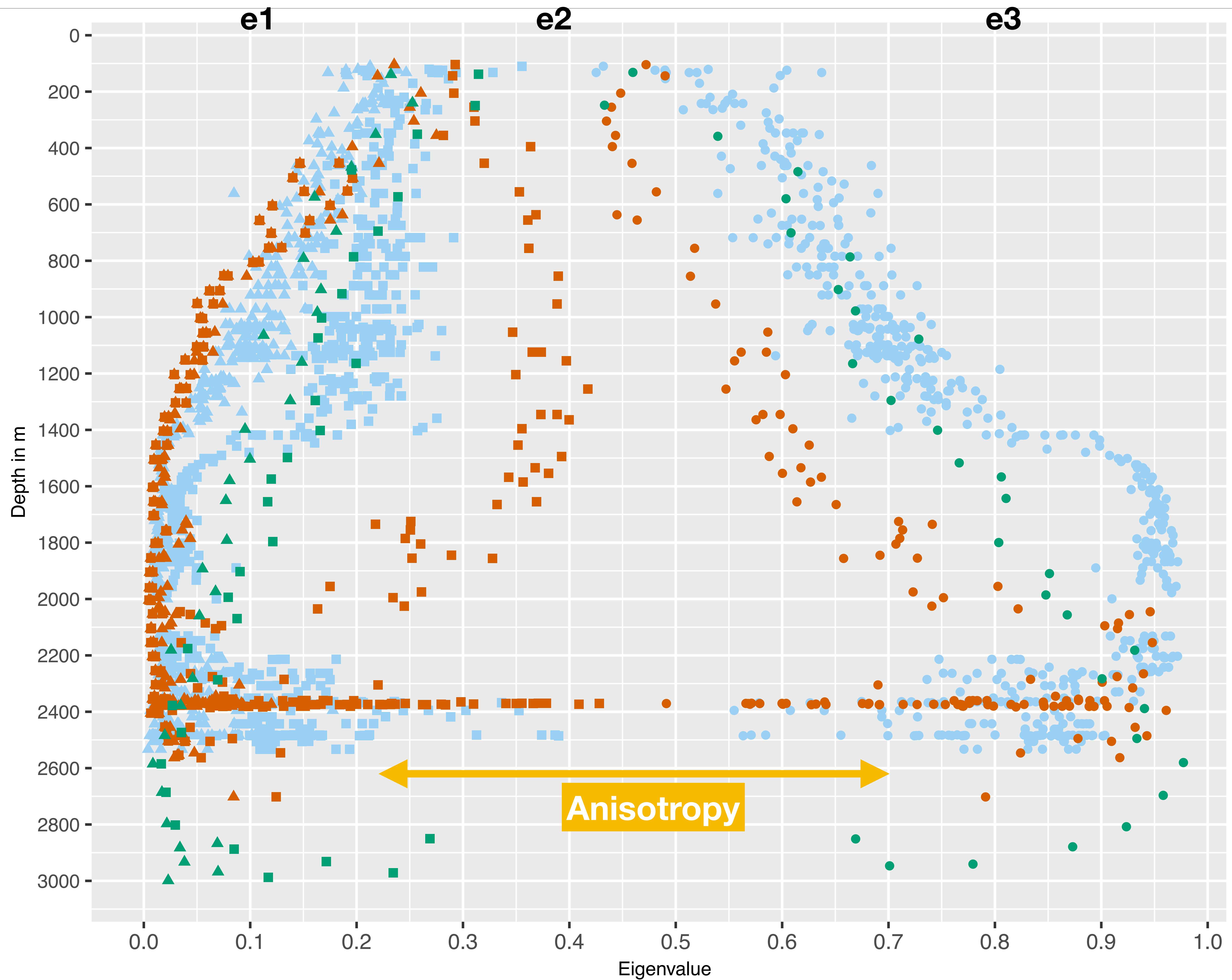
A

Fabric Analyser G50



I. Hewitt, course material *Rheology of Ice*

Eigenvalues



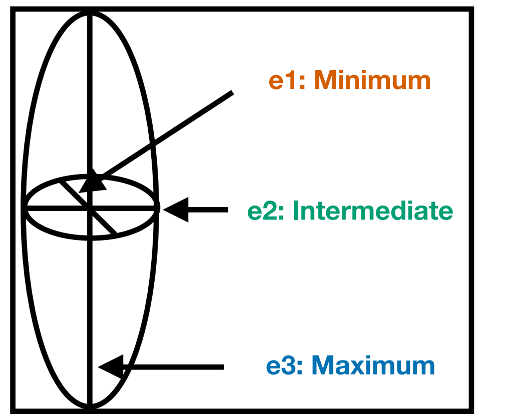
Studies before EGRIP

NEEM (Eichler, 2013, Montagnat, 2014)

GRIP (Thorsteinsson et al., 1997)

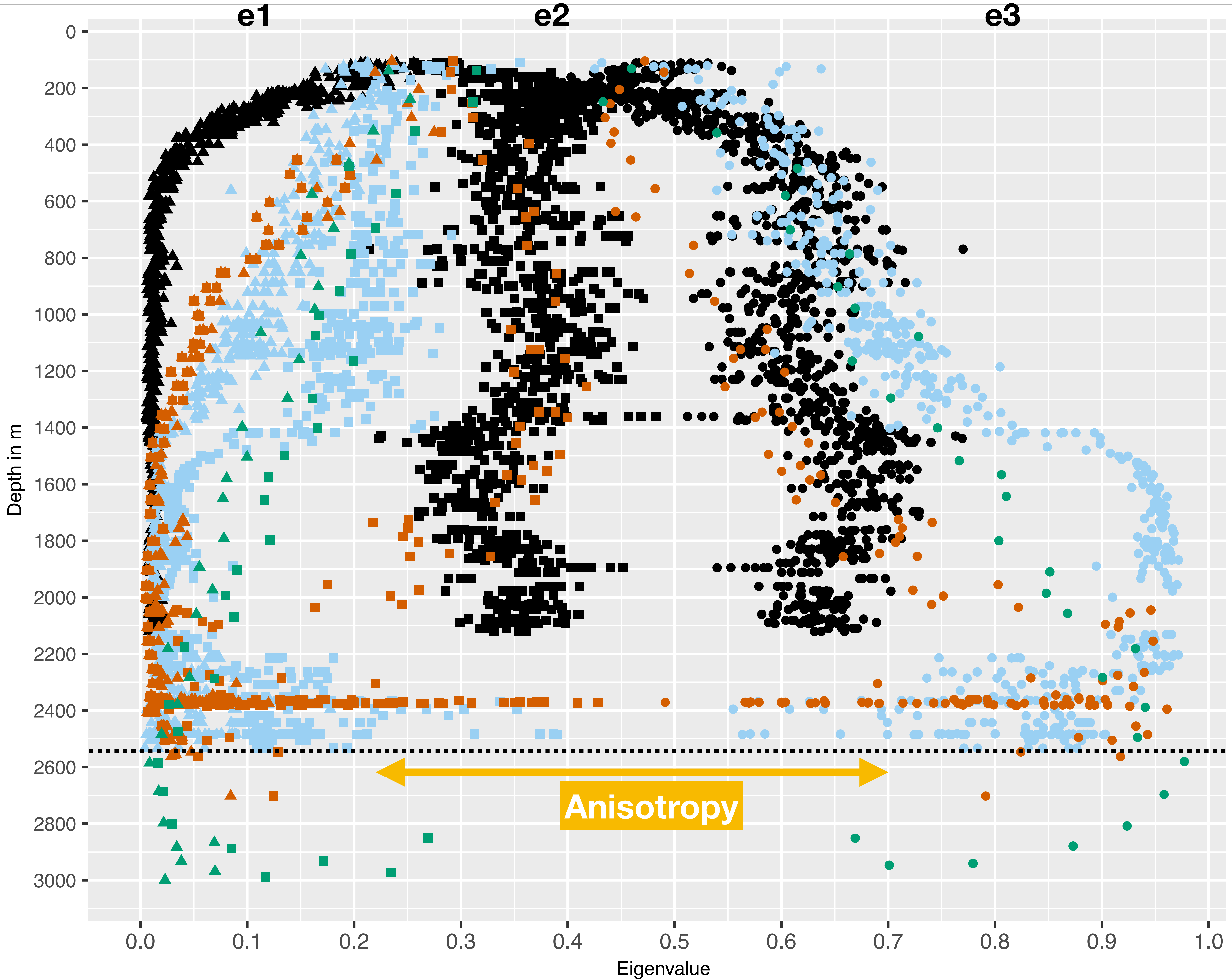
EDML (Weikusat et al., 2017)

strain ellipsoid



HELMHOLTZ

Eigenvalues



3000 m

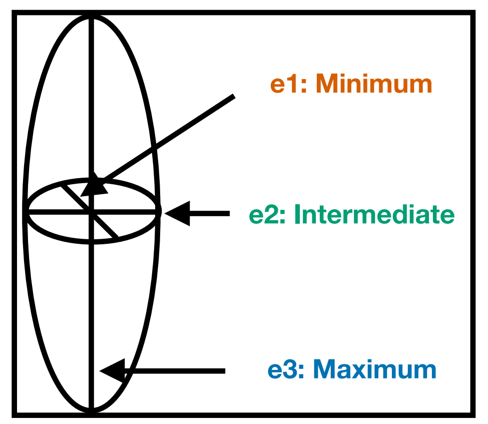
NEEM (Eichler, 2013, Montagnat, 2014)

GRIP (Thorsteinsson et al., 1997)

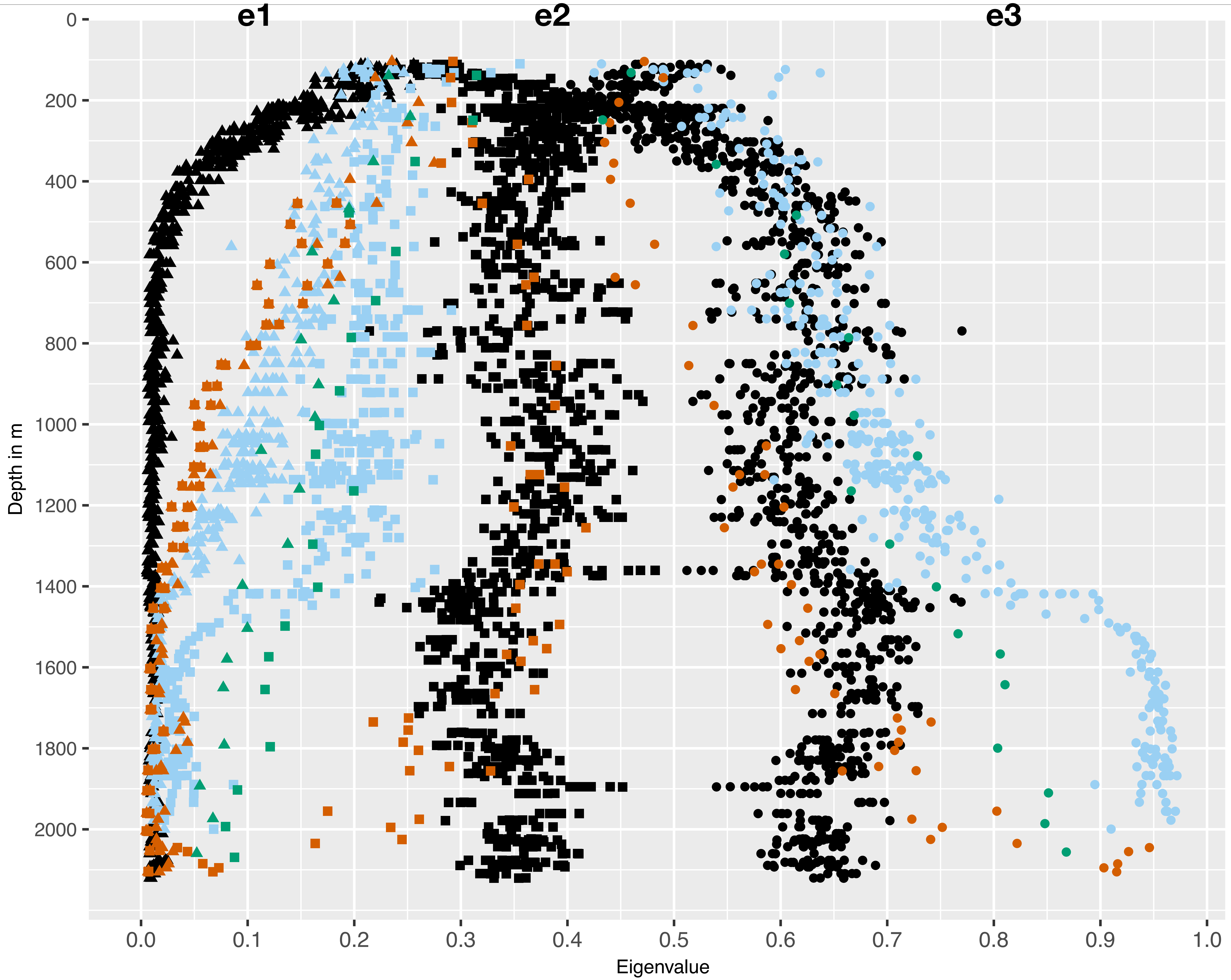
EDML (Weikusat et al., 2017)

EGRIP

strain ellipsoid



Eigenvalues



2121 m

NEEM (Eichler, 2013, Montagnat, 2014)

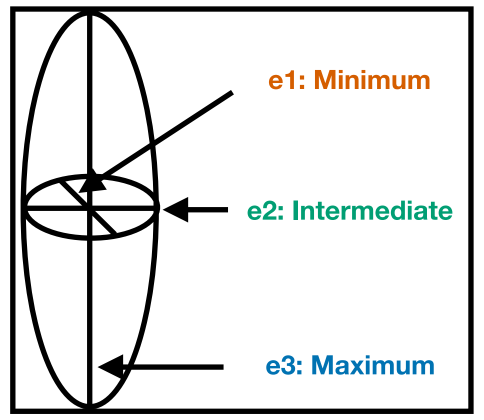
GRIP (Thorsteinsson et al., 1997)

EDML (Weikusat et al., 2017)

EGRIP

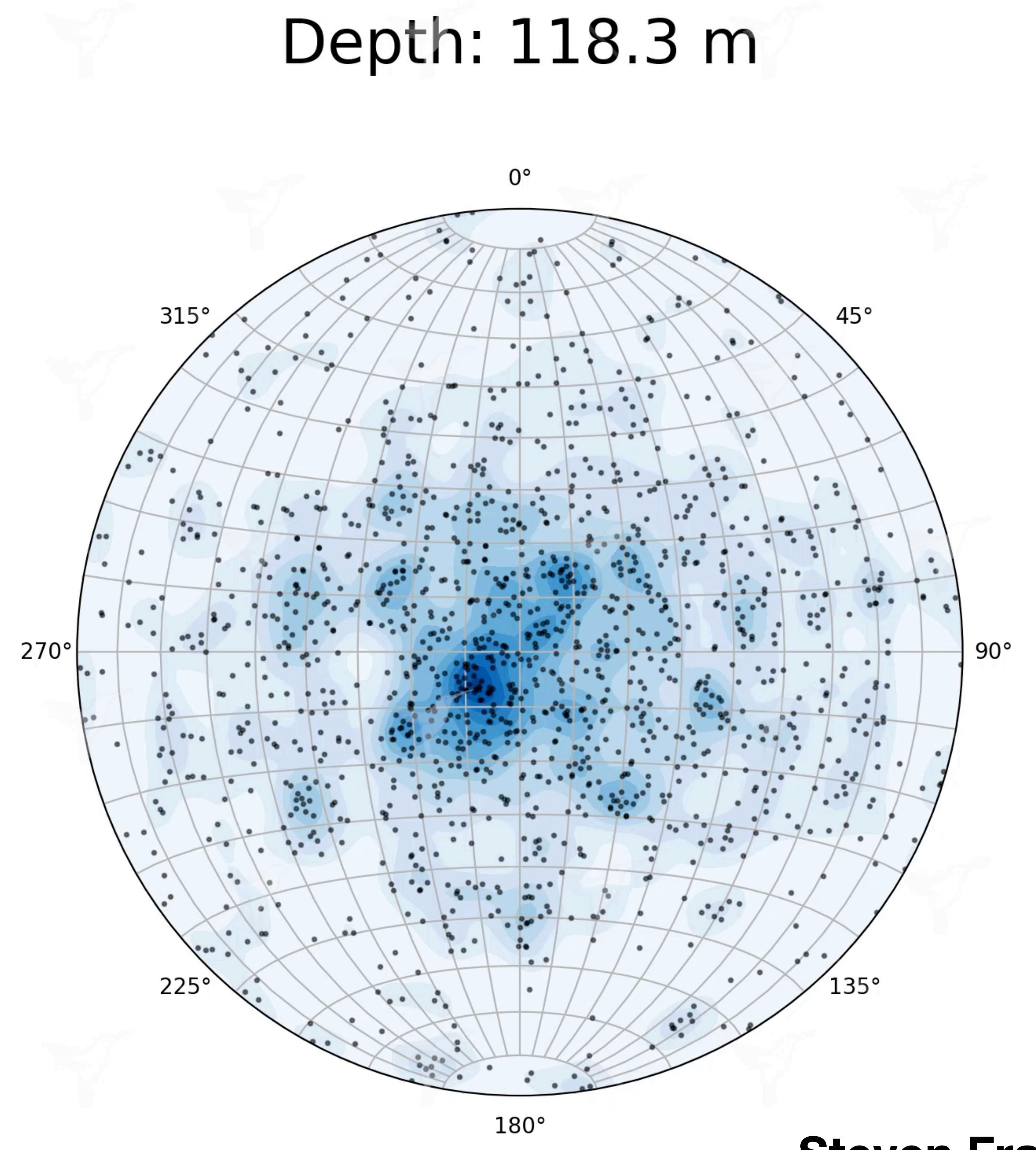
- **High-resolution data (full bag every 5-15m)**
- **15 volume cuts (= 3x vertical + 2x horizontal)**

strain ellipsoid

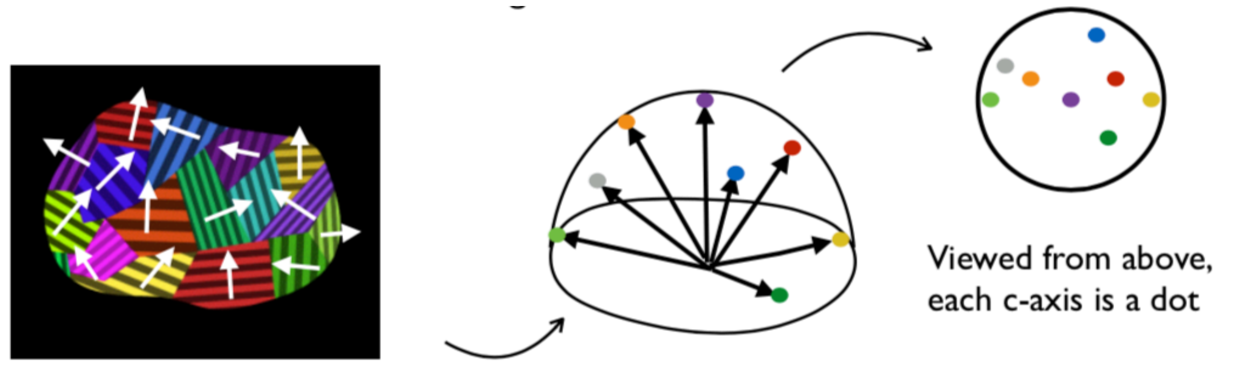


Eigenvalues

EGRIP

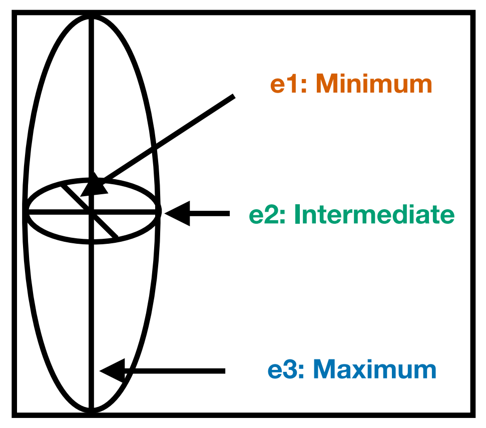


Steven Franke, AWI



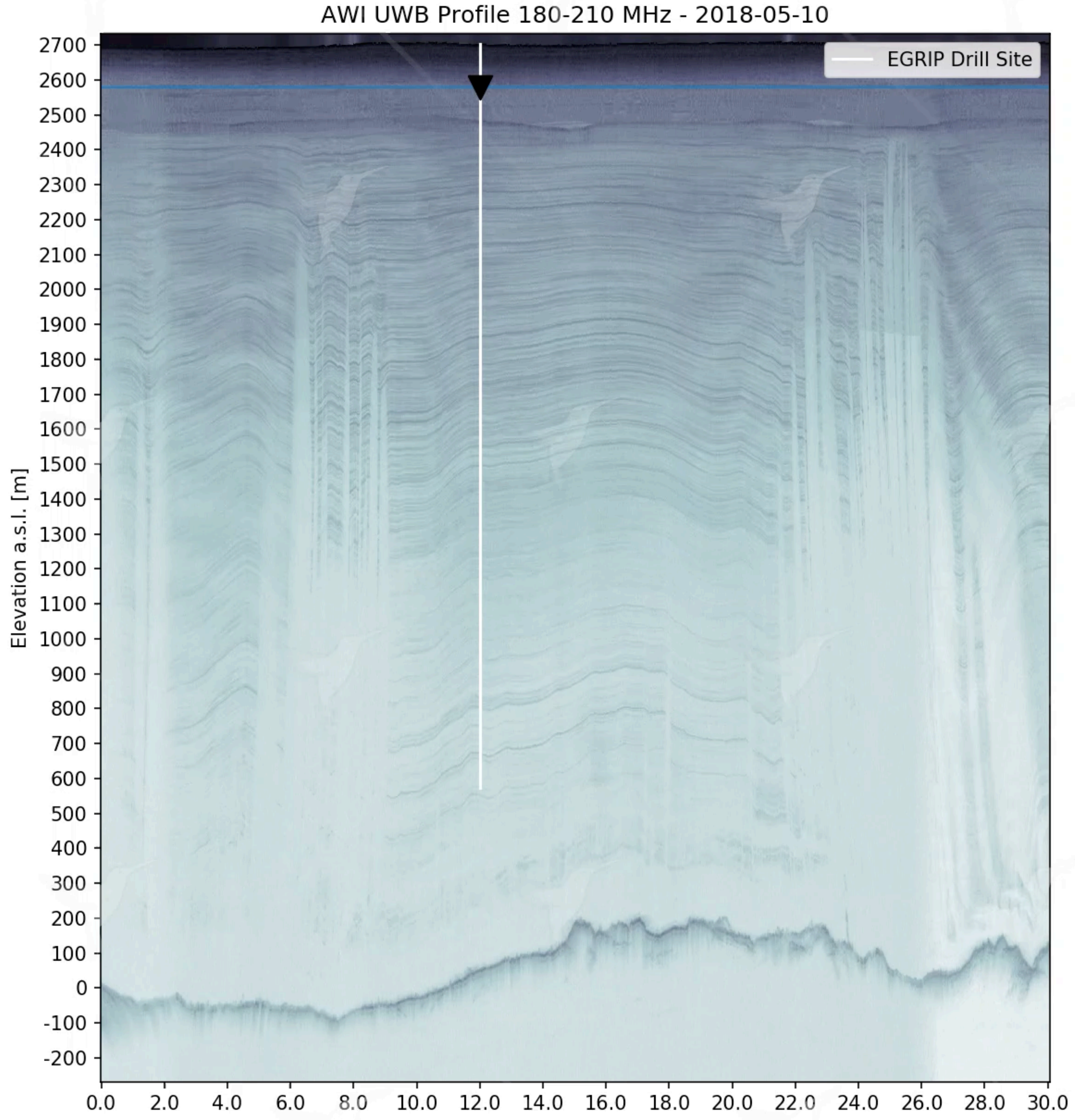
I. Hewitt, course material *Rheology of Ice*

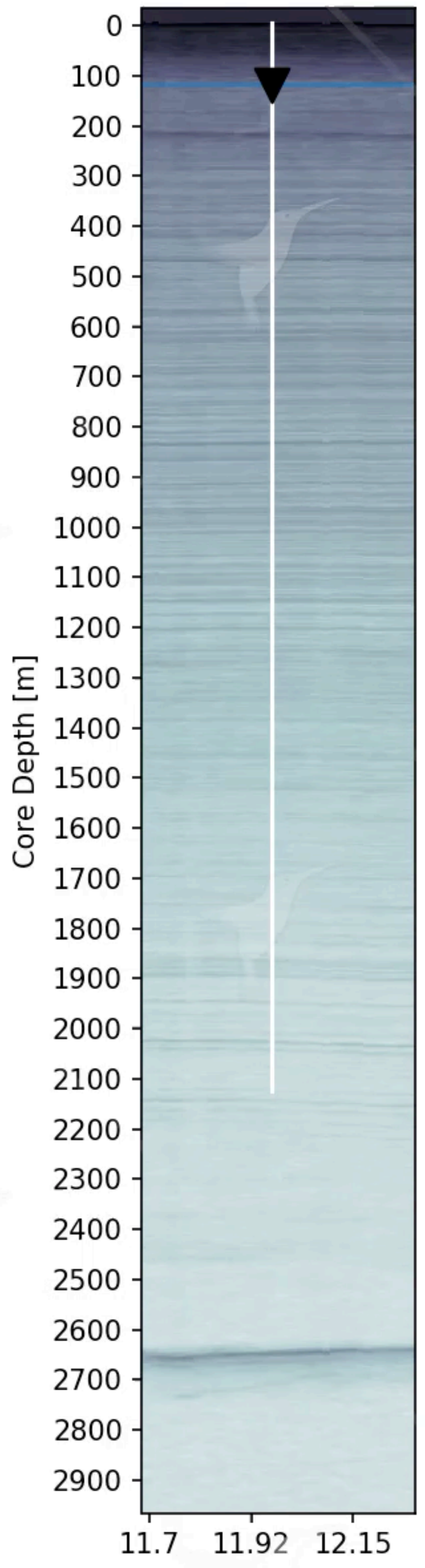
strain ellipsoid

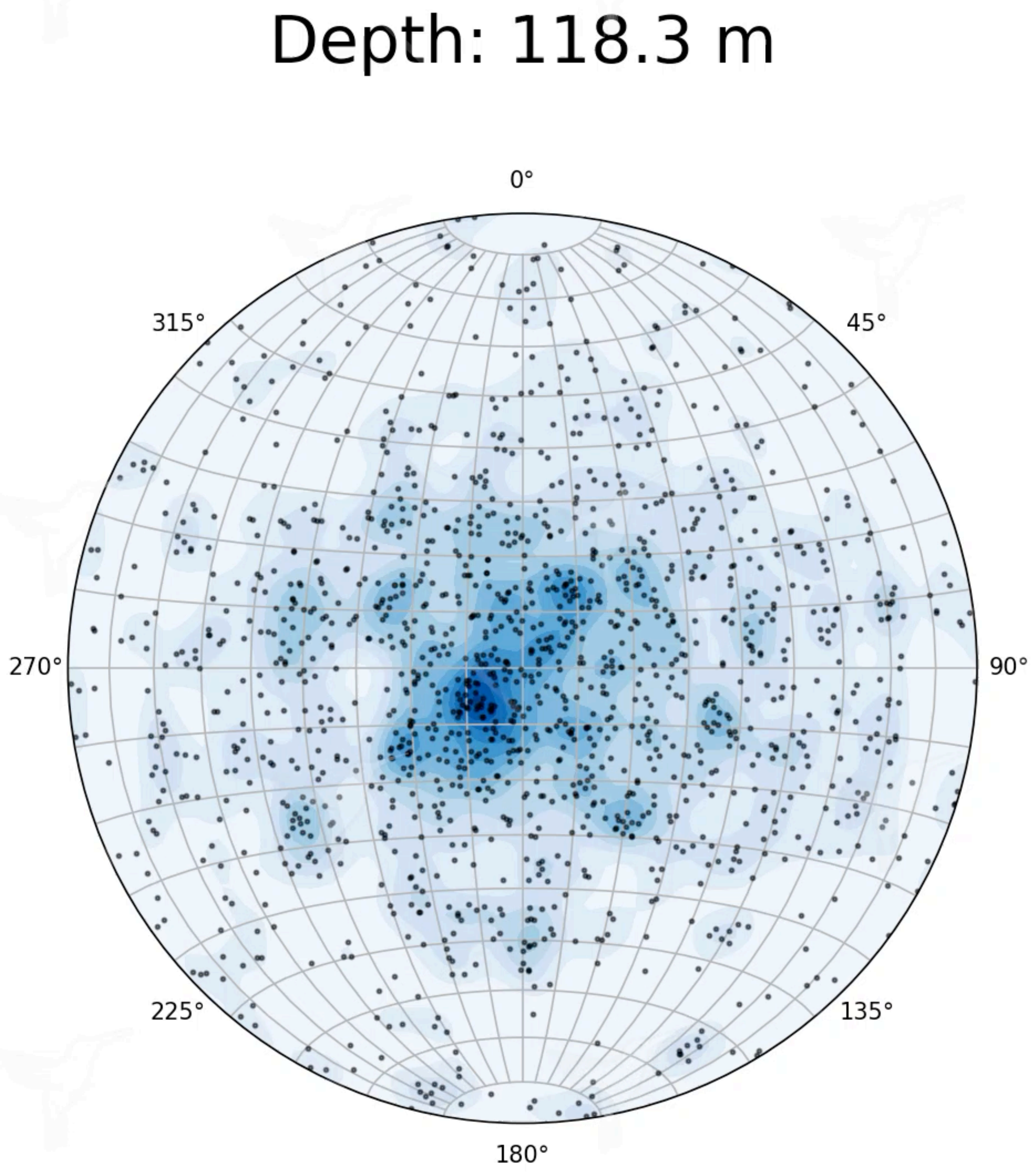


Crystal preferred orientations

Combine different scales

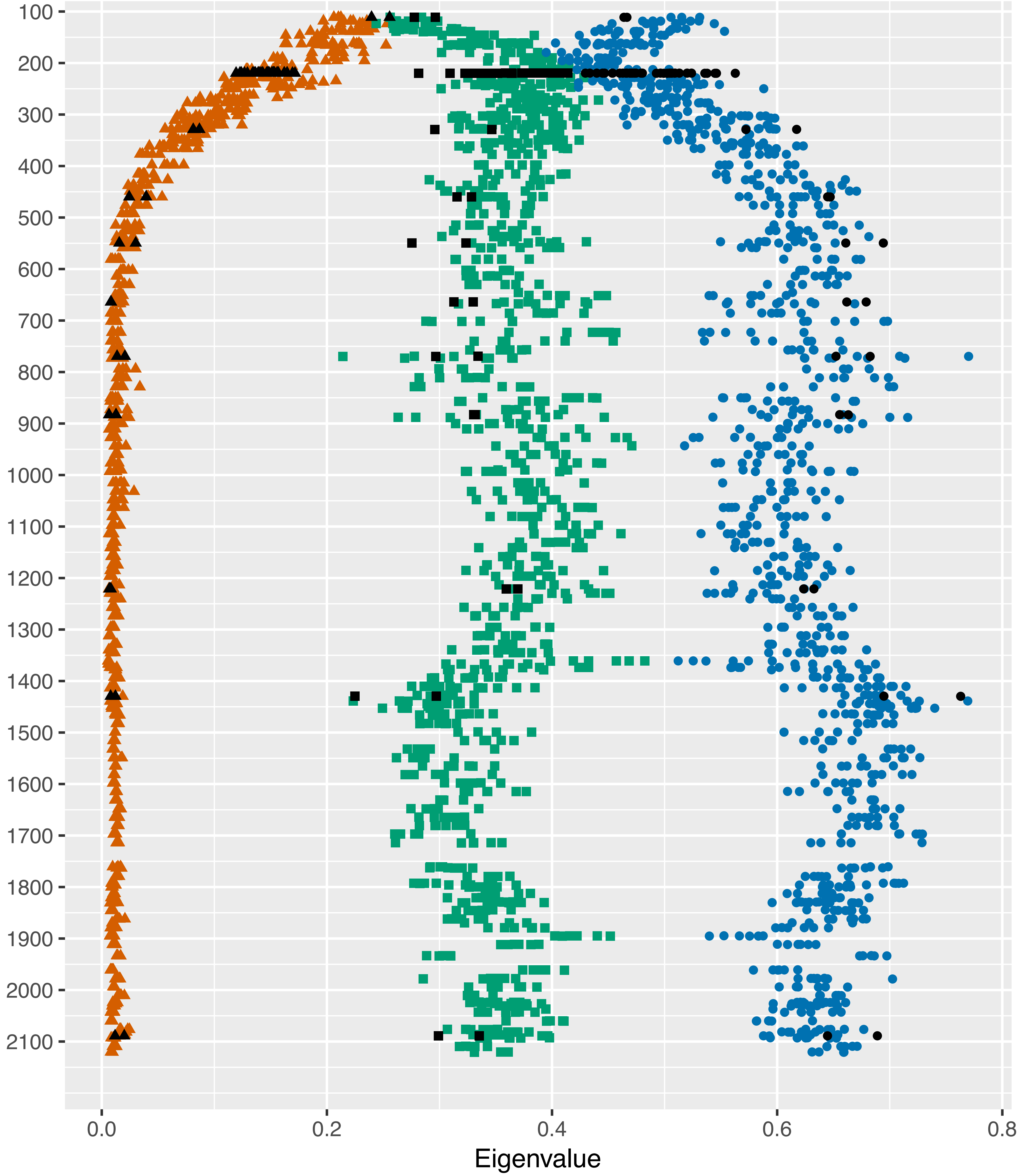


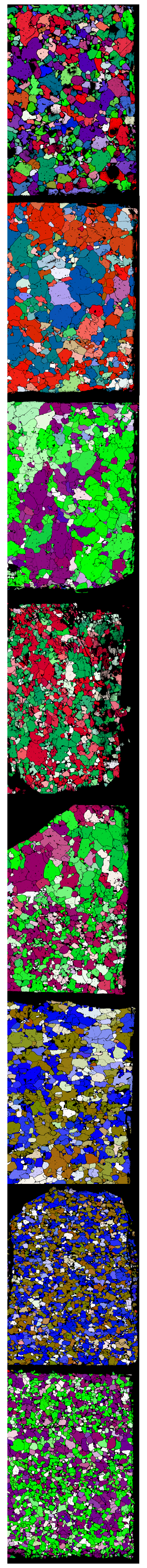


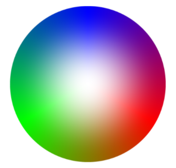


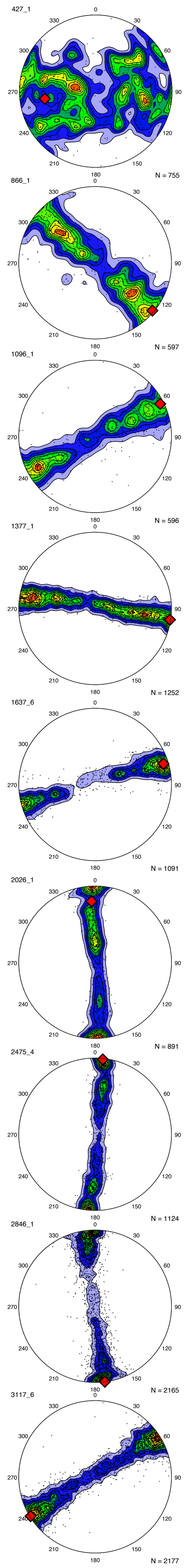
Steven Franke, AWI

Crystal preferred orientations









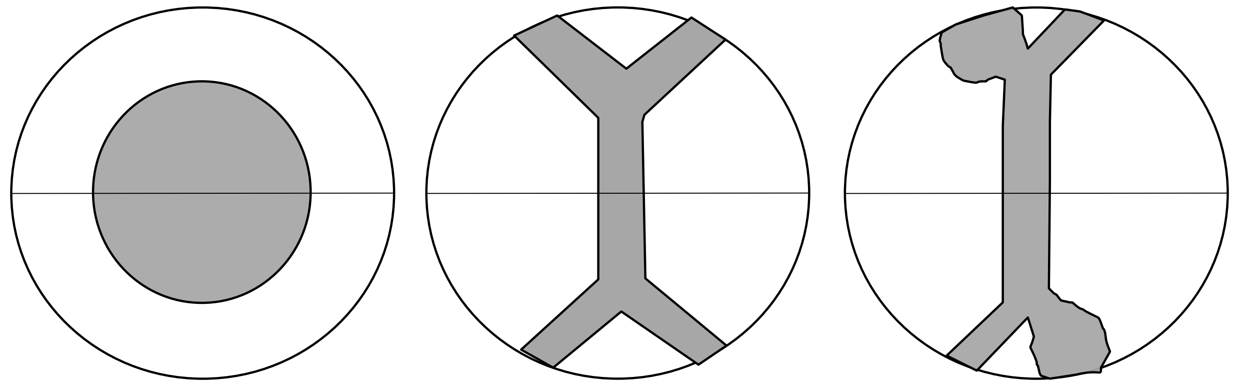
Broad single Maximum

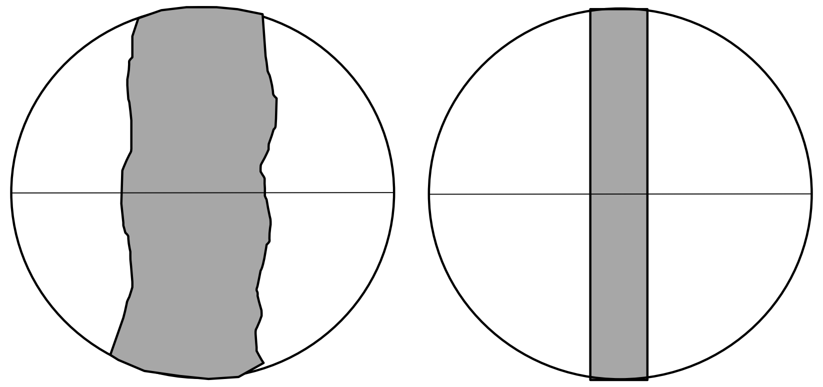
Crossed Girdle

Developed Girdle

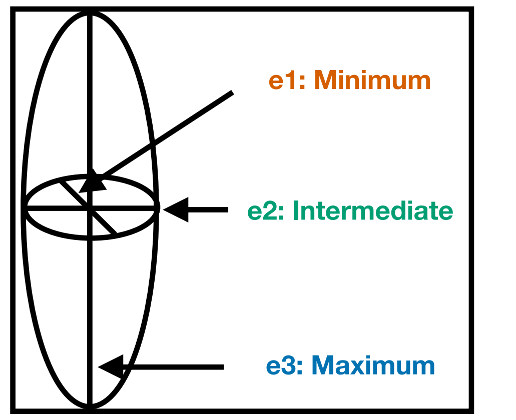
Strong Girdle

Strong Girdle with horizontal maxima

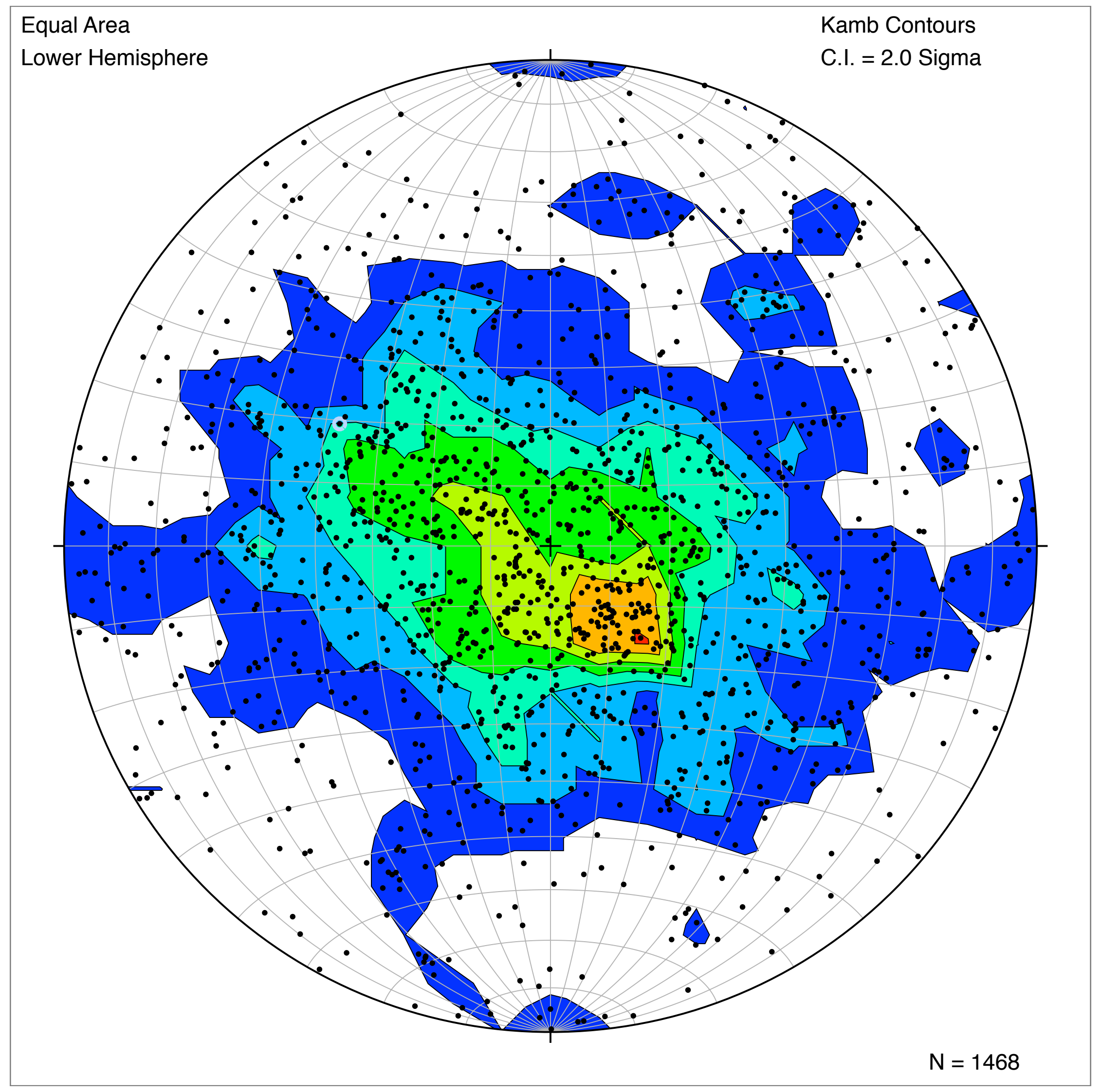


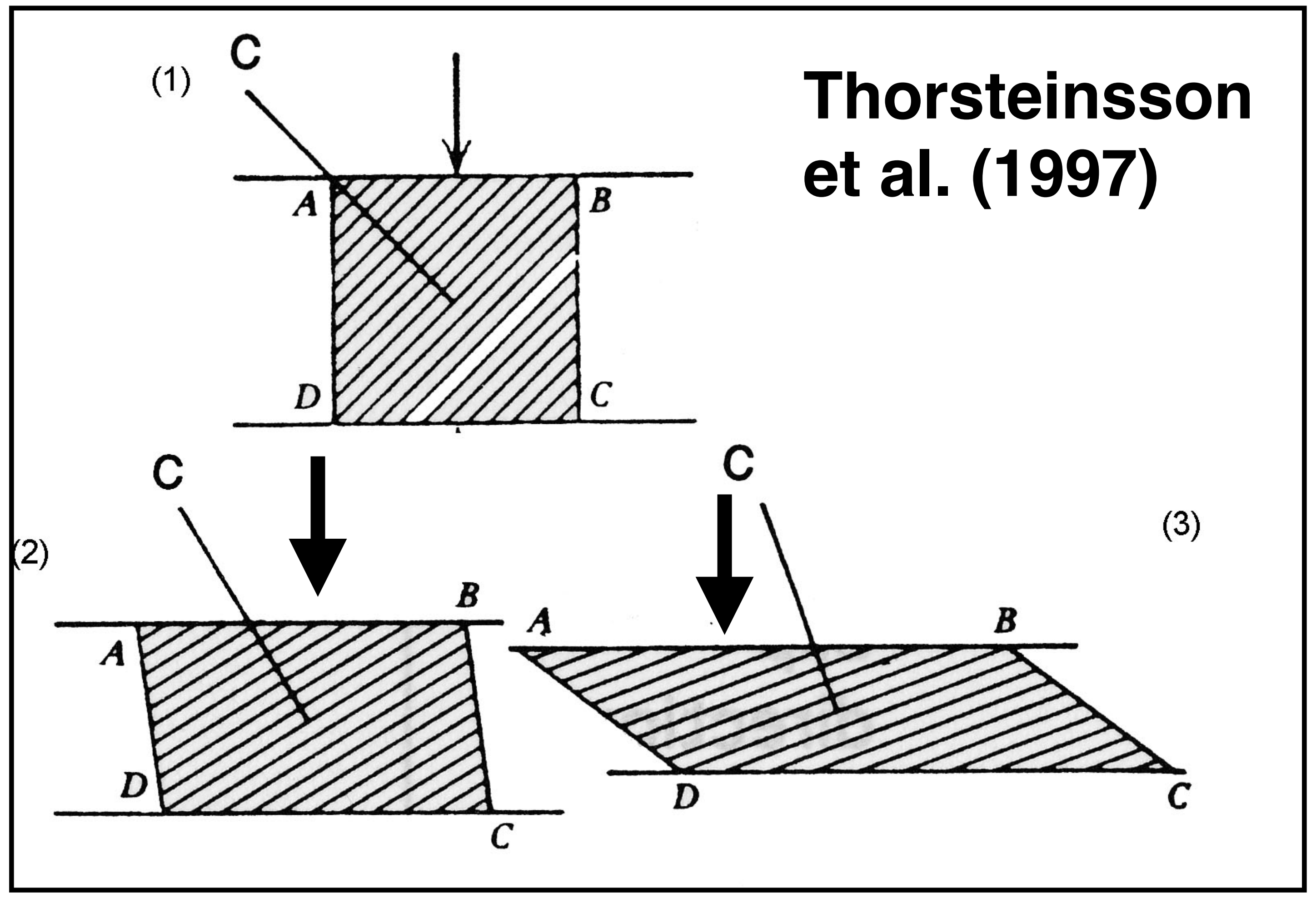


strain ellipsoid



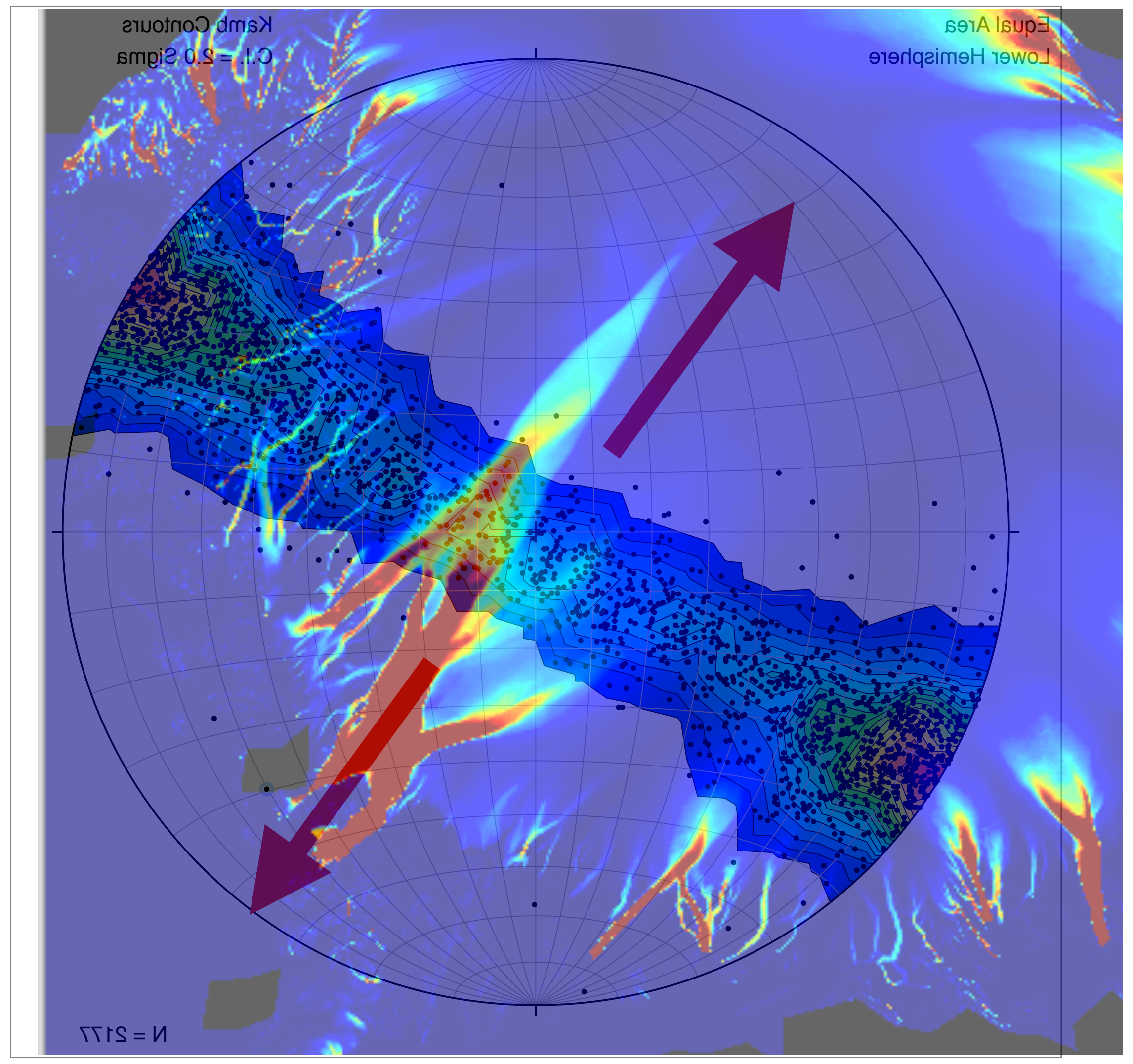
Crystal preferred orientations





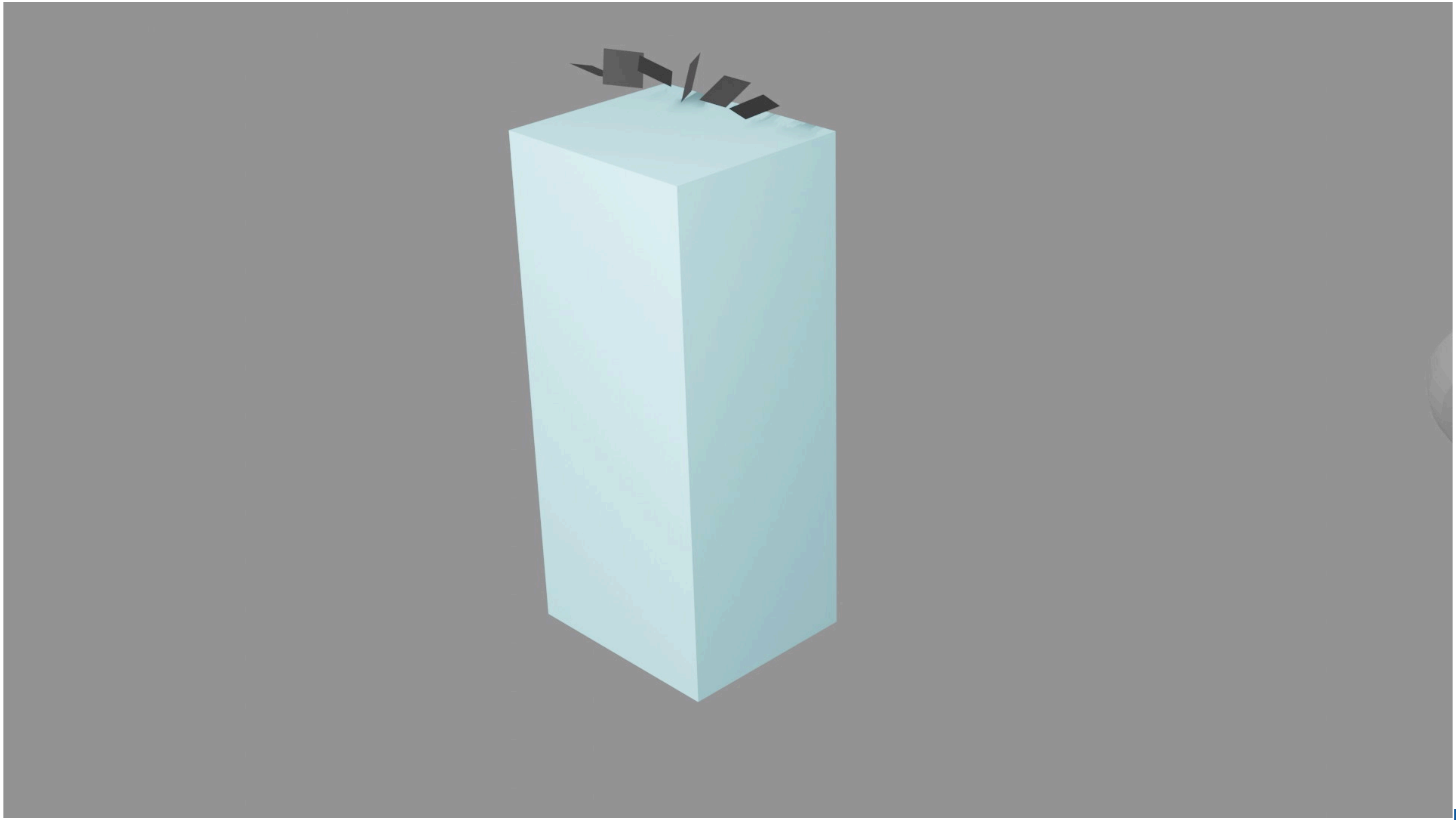
Thorsteinsson et al. (1997)

Broad Single Maximum ->
Vertical Compression from above



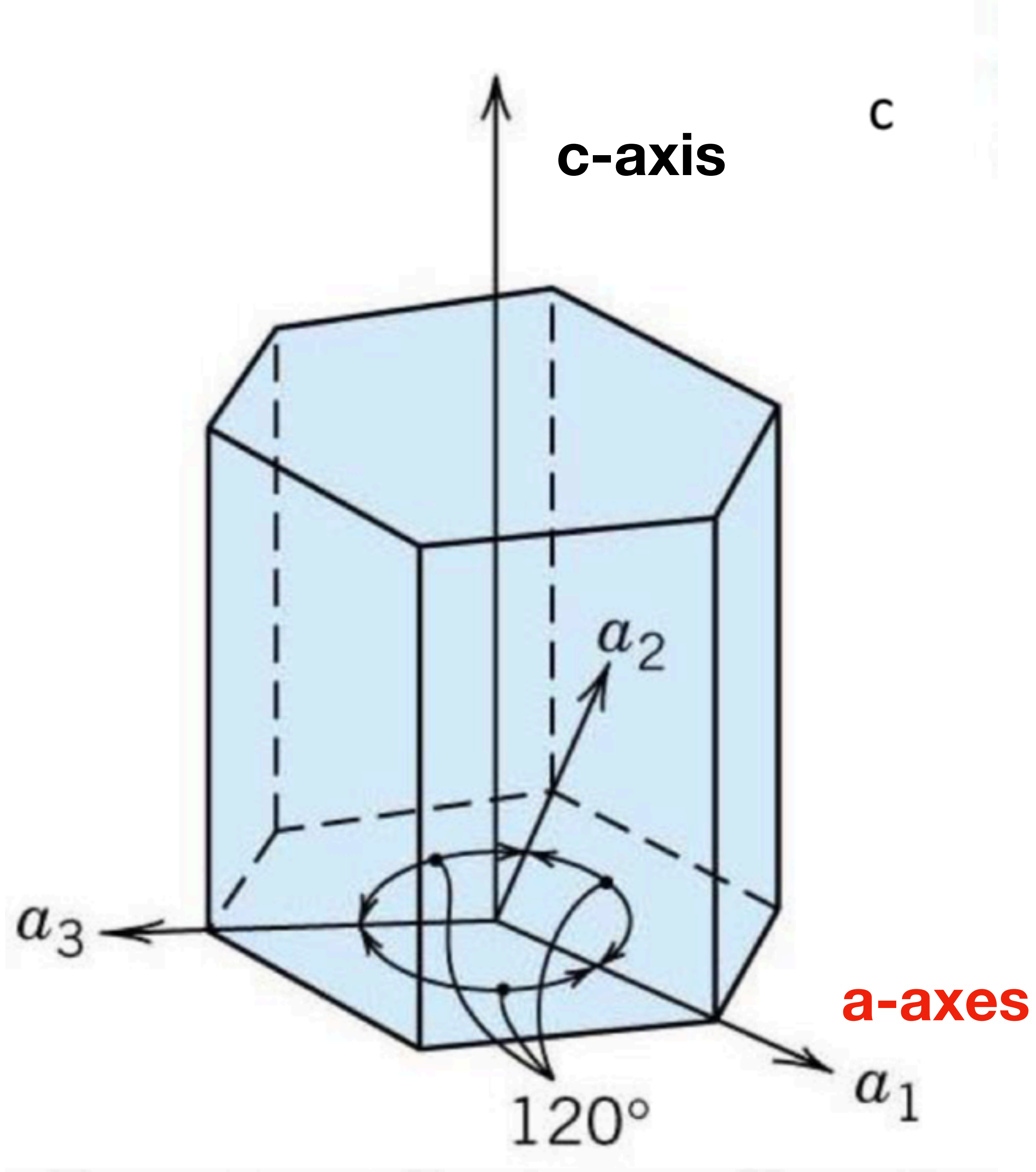
Girdle ->
Extensional deformation

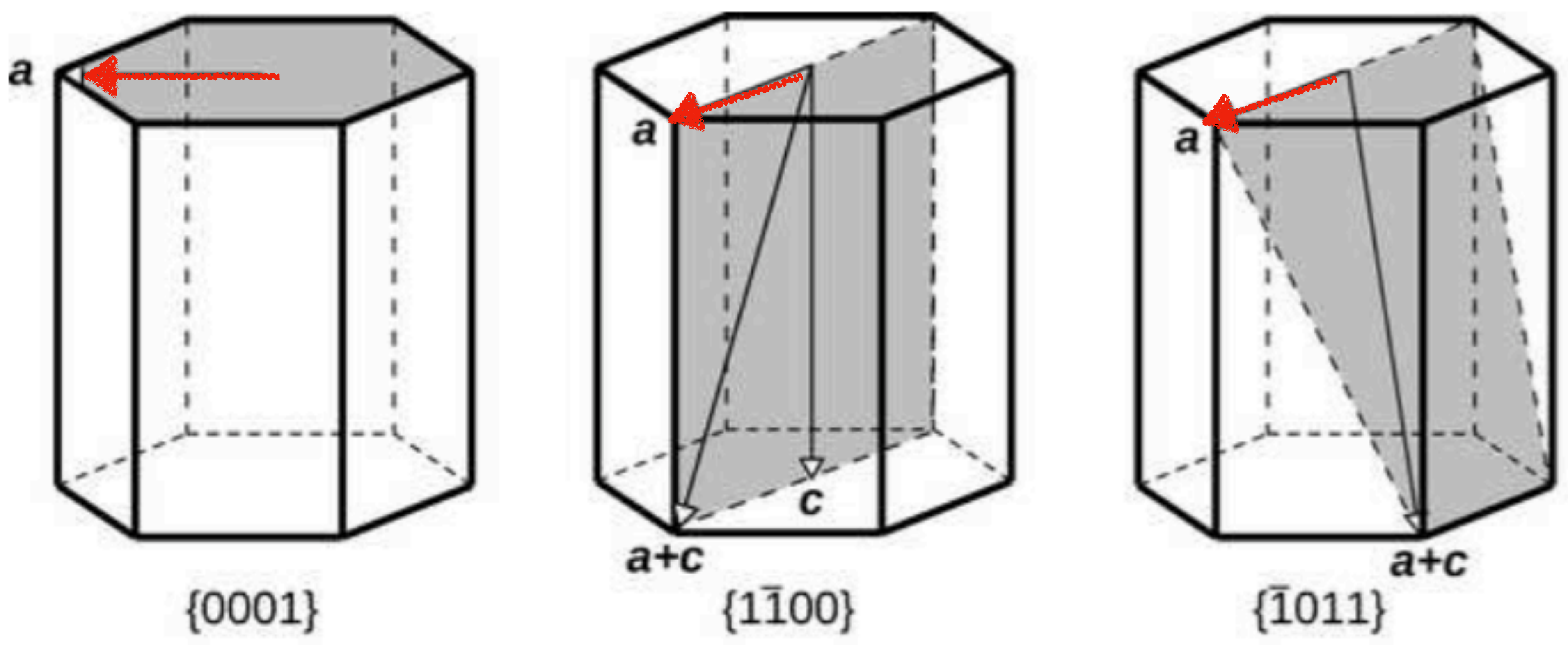
Crystal preferred orientations



Crystal preferred orientations

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





After Hondoh (2000), displayed by Faria et al. (2014)

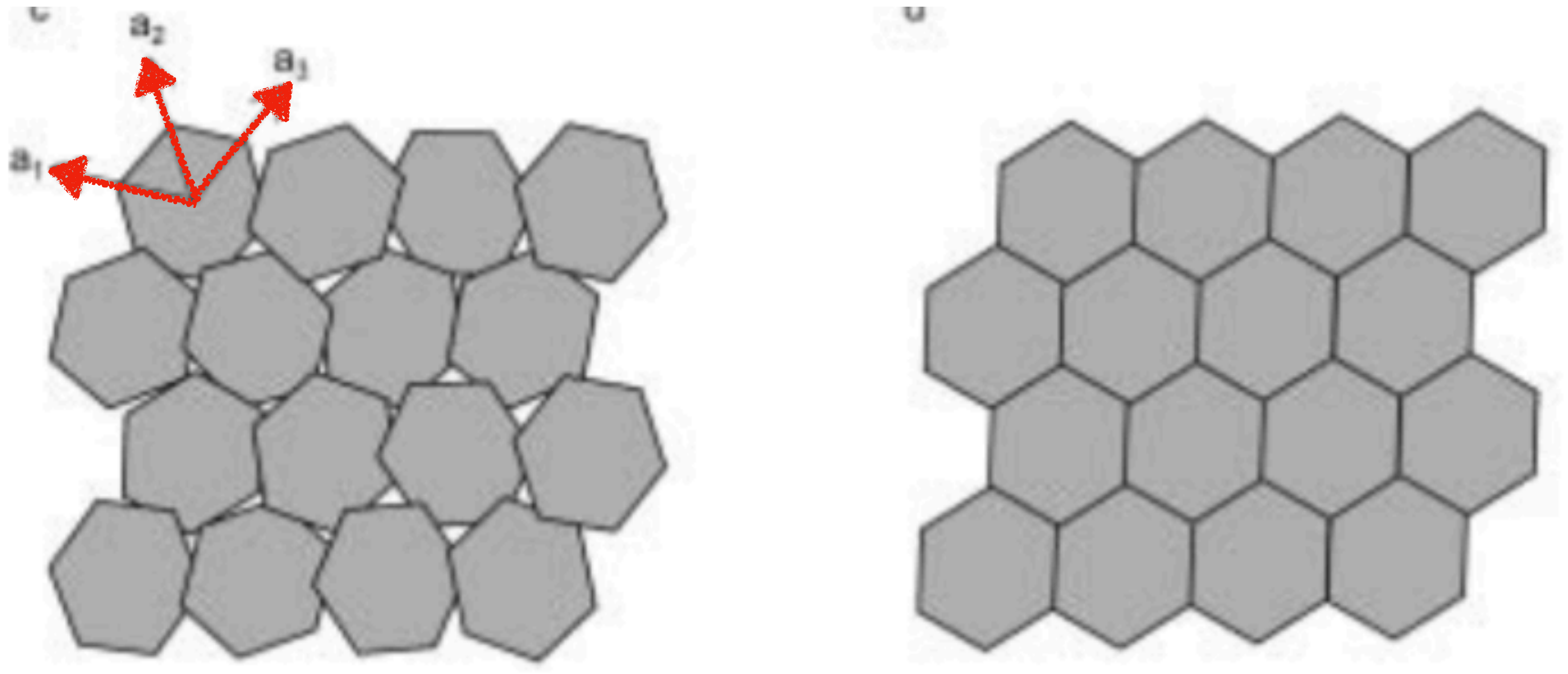


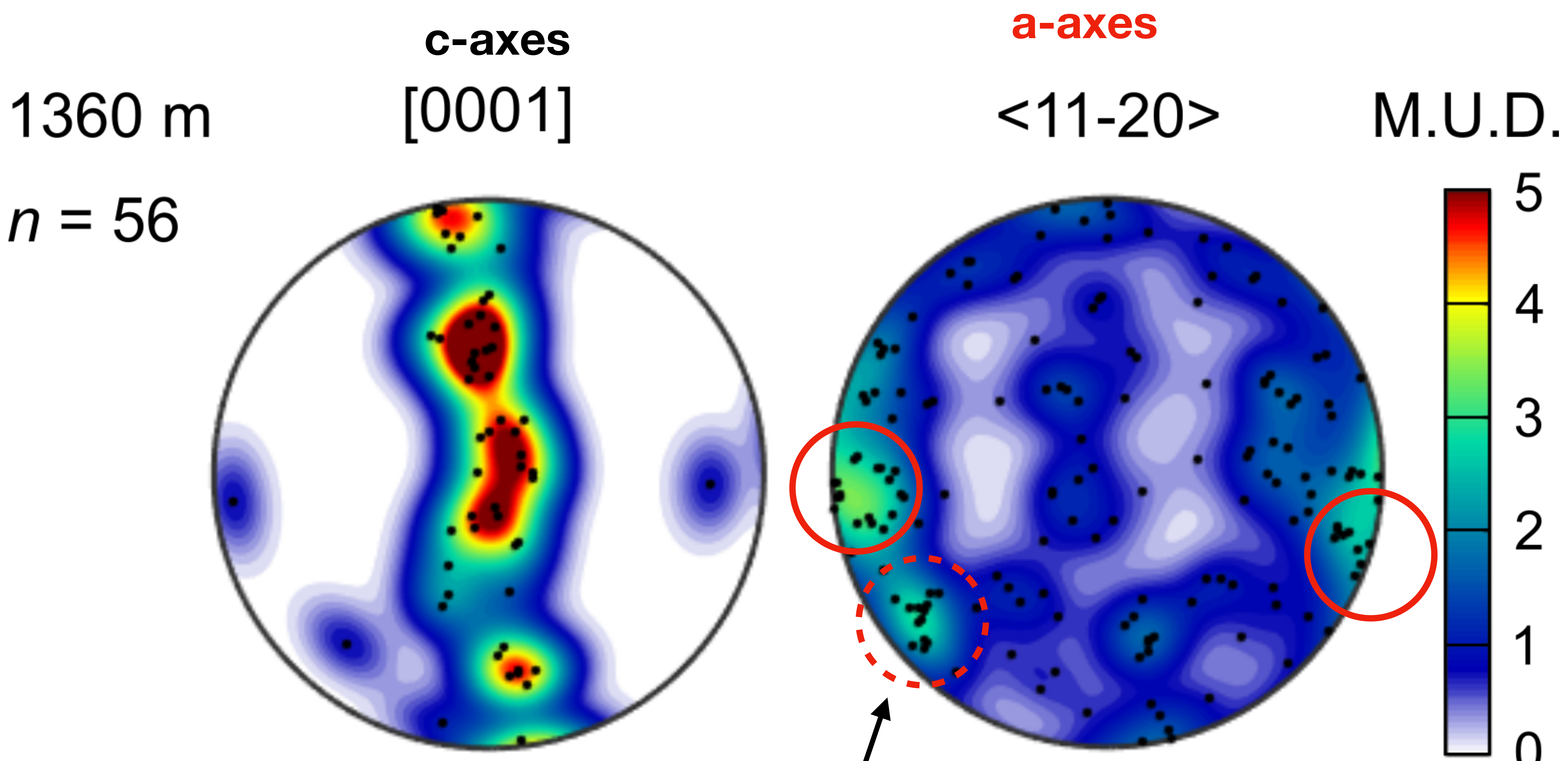
Fig. 6. Explanation of distribution of *a* axes. (a) The *c*-axis orientation distribution which is generated artificially. (b) Random distribution of azimuth of *a* axes. (c) Schematic illustration of random orientation of *a* axes. (d) Schematic illustration shows *a* axes are aligned.

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**

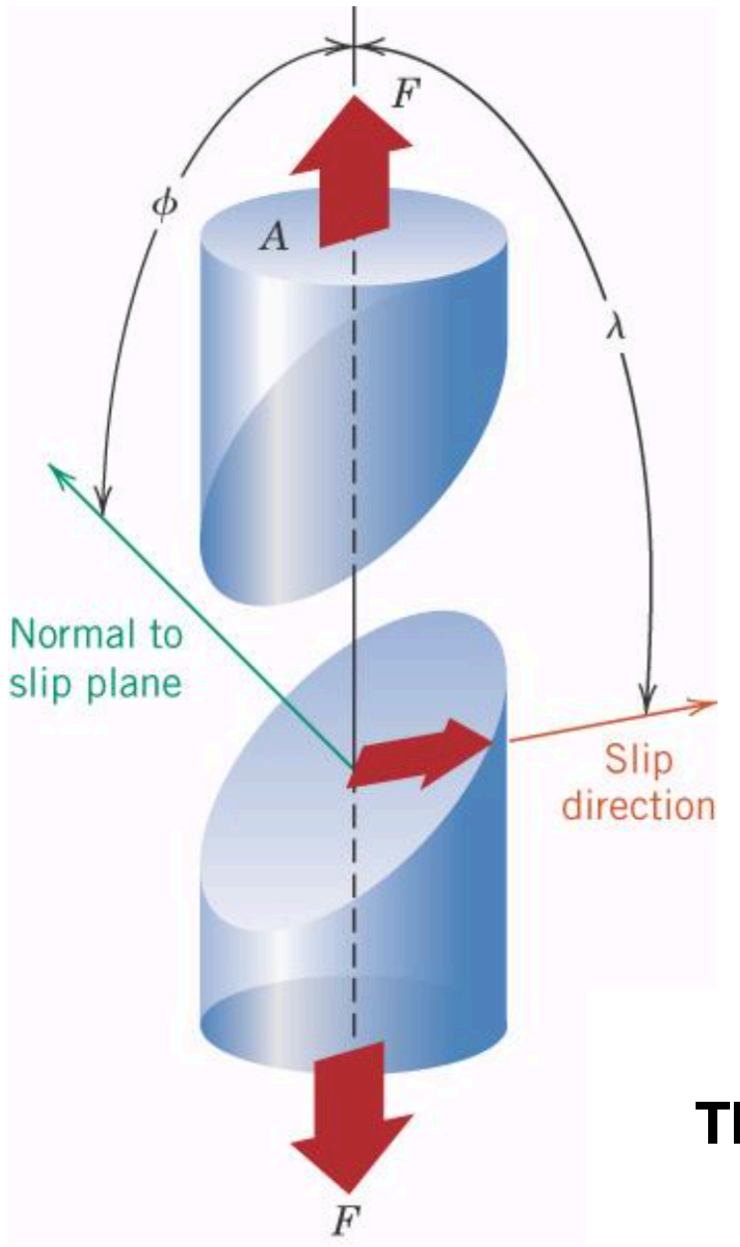


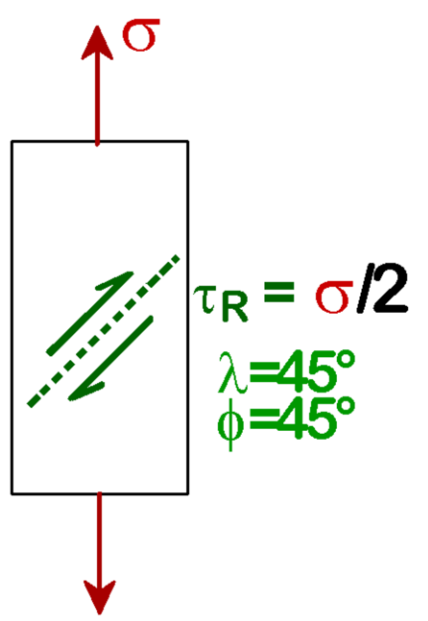
flow direction

M. Drury and D. Wallis, Utrecht University

recrystallized grains (?) -> larger resolved shear stress

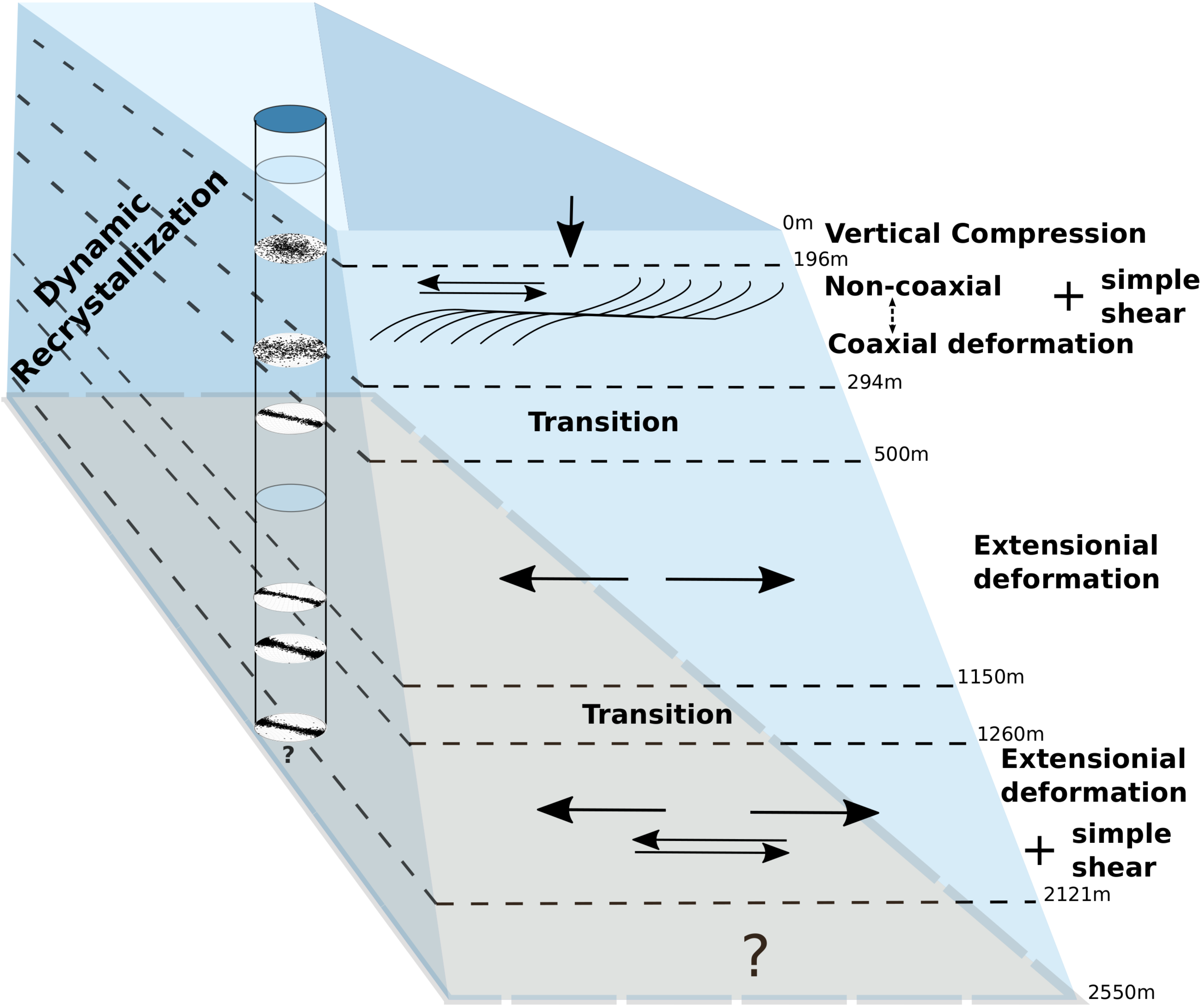
Resolved Shear Stress





The Arc, 2019

Deformation modes



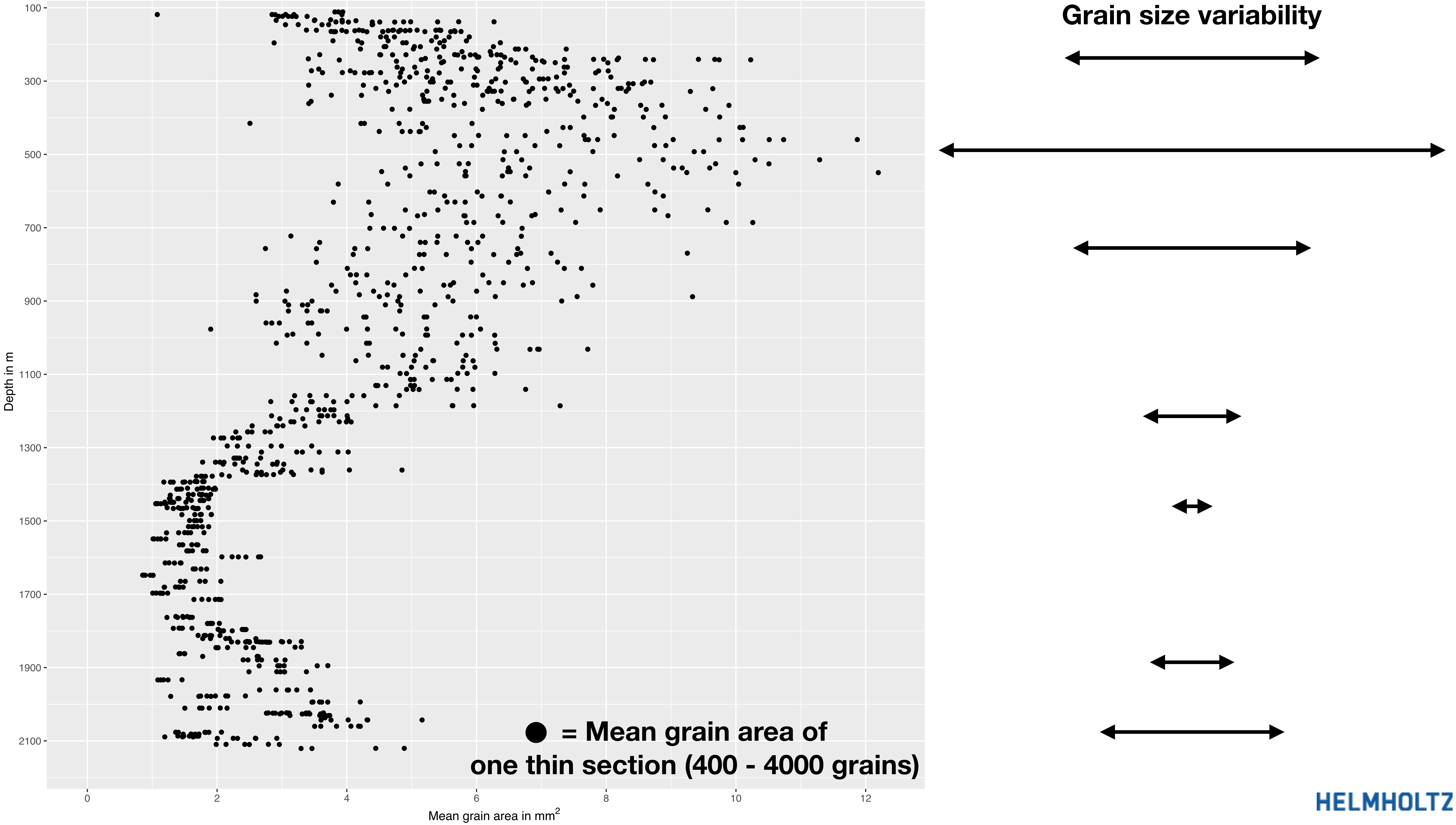
Grain size

Increase

Decrease

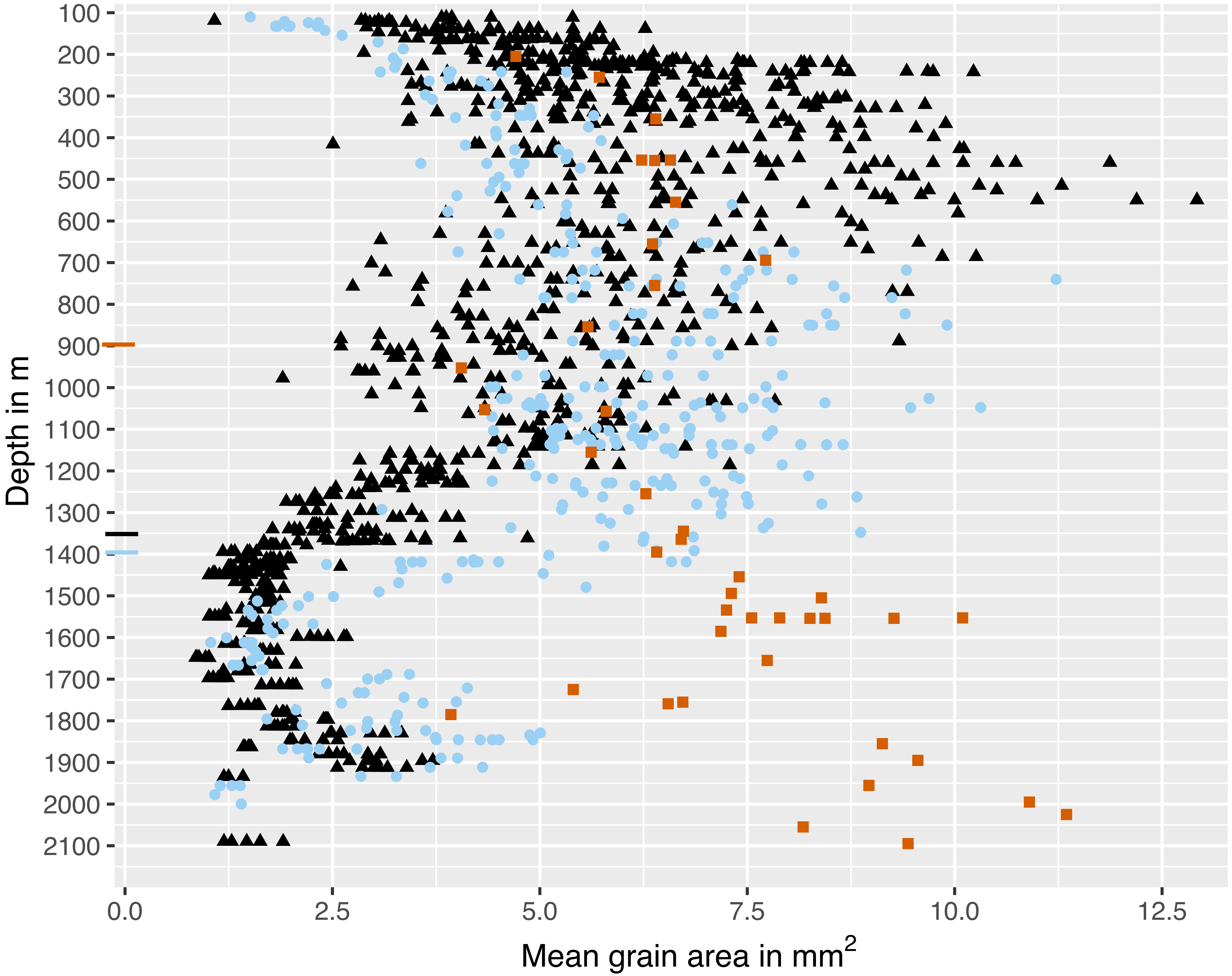
Constant

Increase



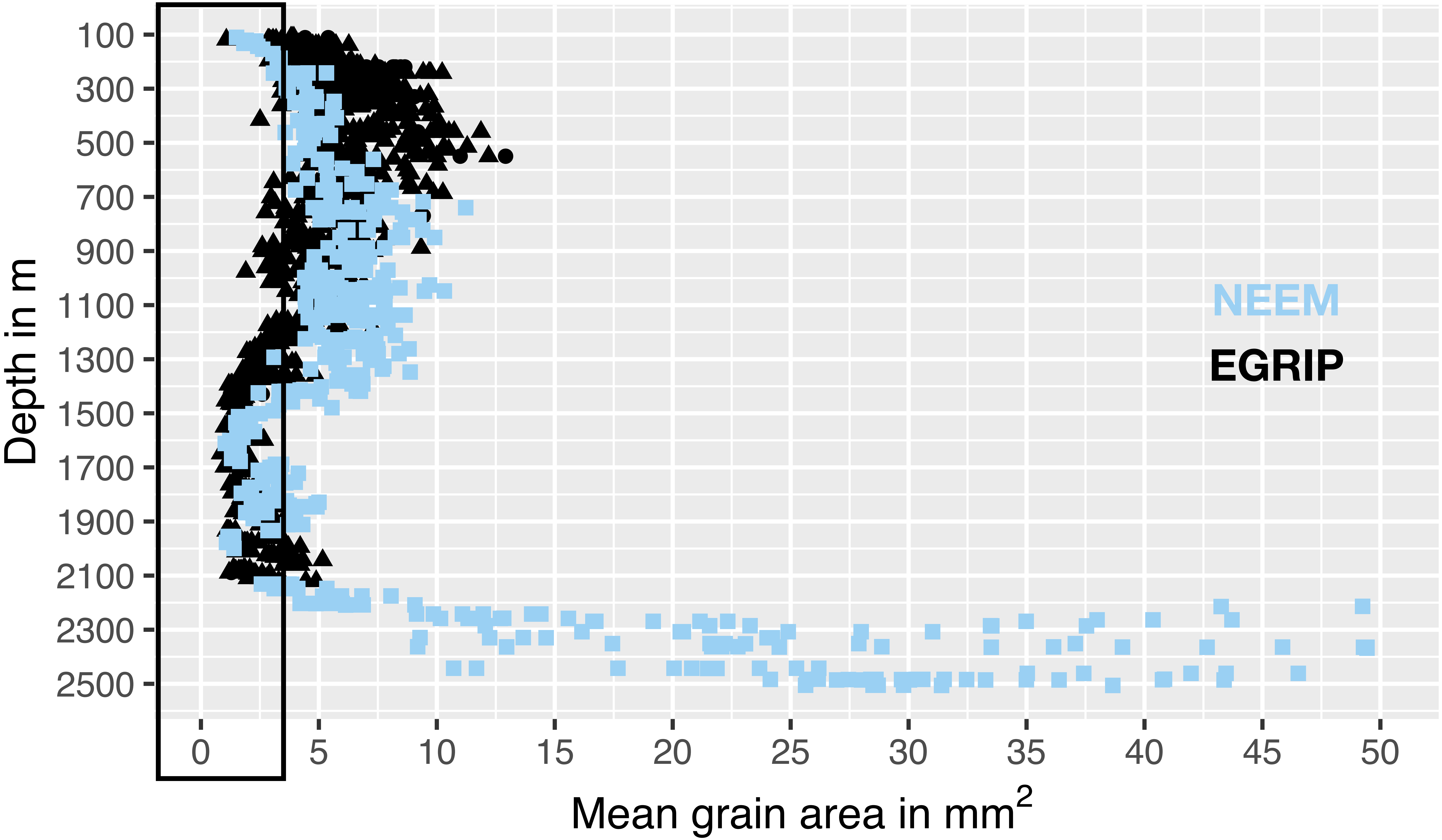
Grain size

End of last Glacial



NEEM
EDML
EGRIP

Grain size


Depth in m
100
300
500
700
900
1100
1300
1500
1700
1900
2100
2300
2500
0
5
10
15
20
25
30
35
40
45
50
Mean grain area in mm²
NEEM
EGRIP

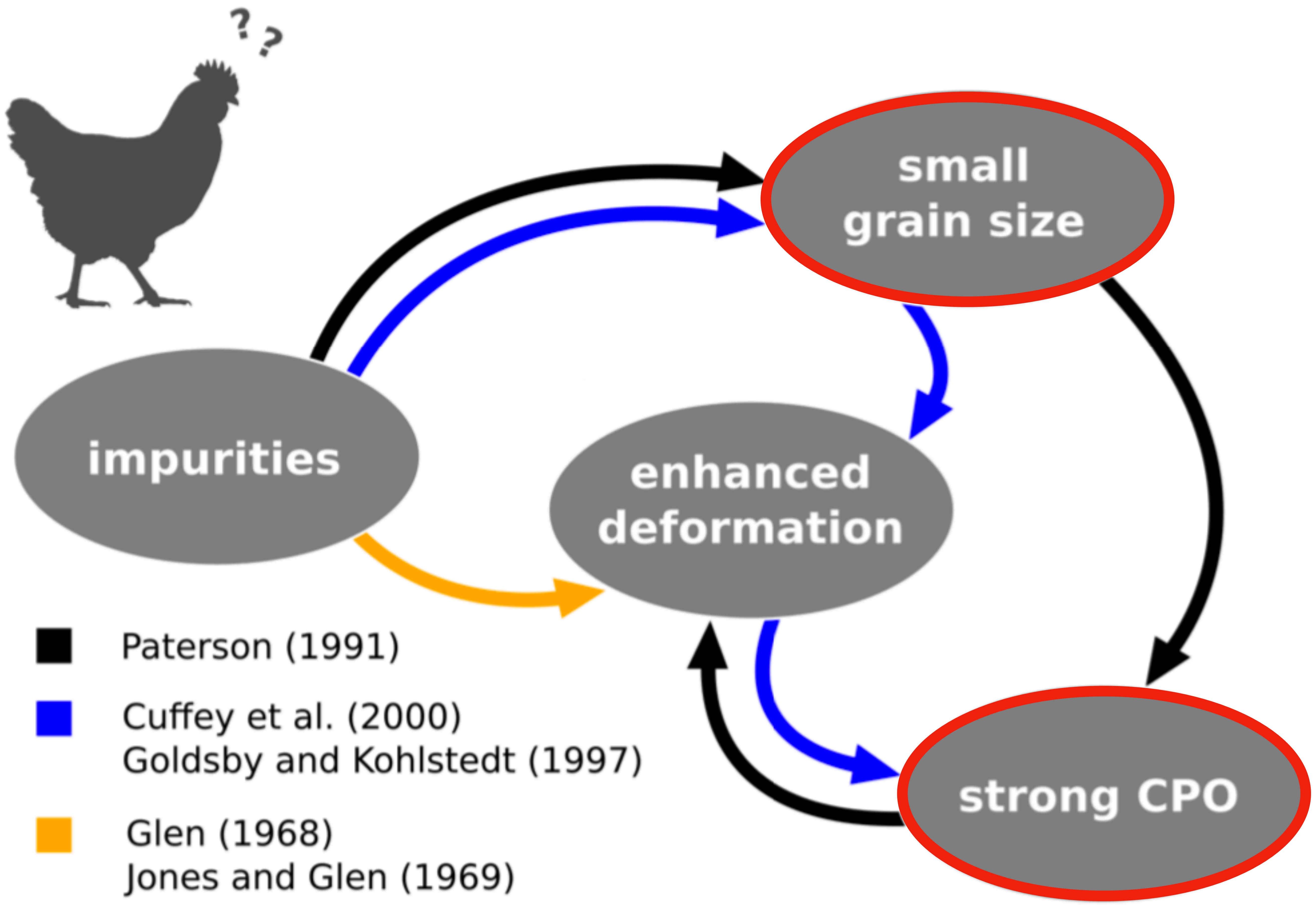
Grain size & crystal orientations

HELMHOLTZ

Outlook - Micro-Cryo-Raman Spectroscopy

- **Impurities influence physical properties of ice matrix**

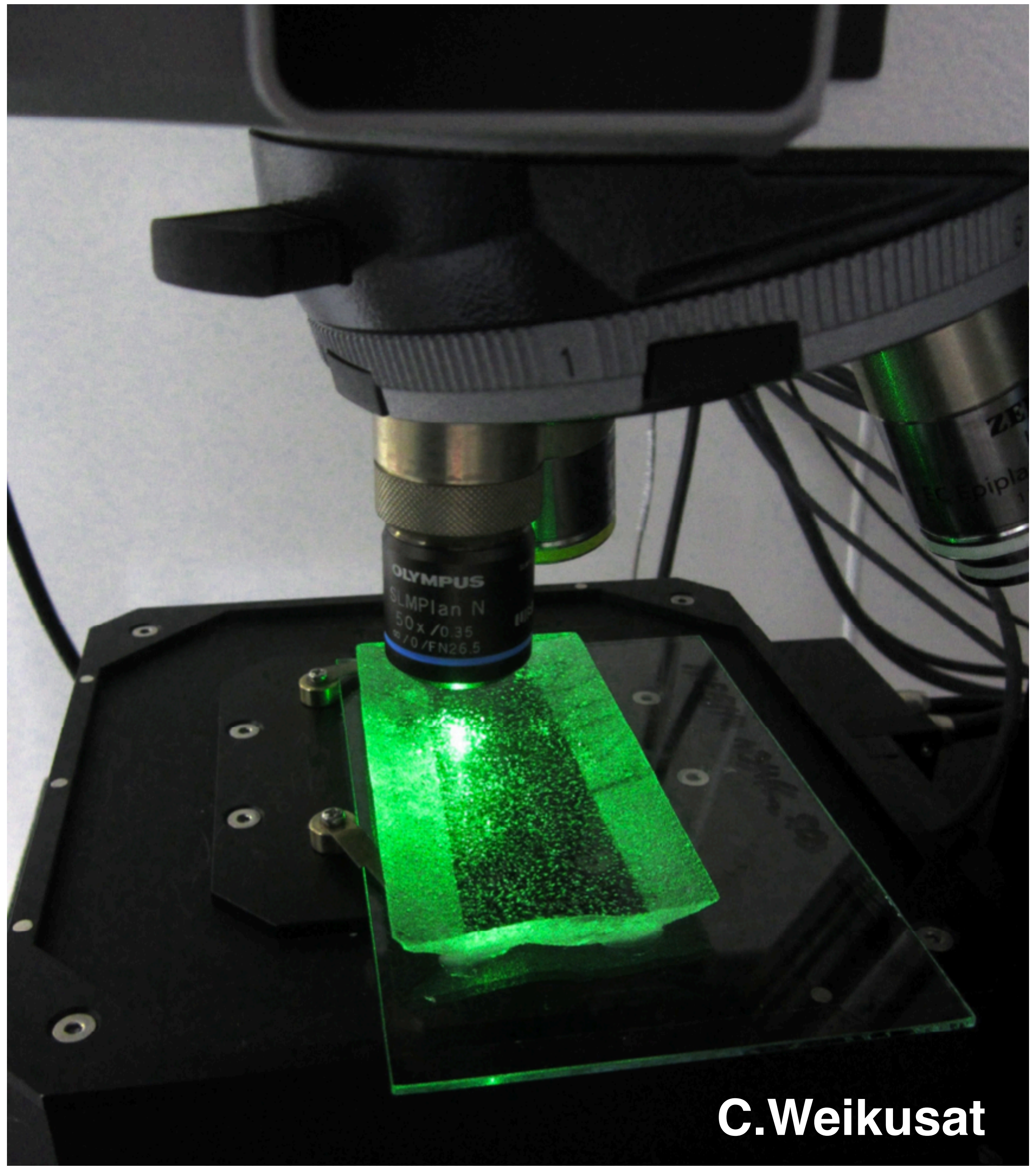
  -> lack of data regarding in-situ spatial distribution and incorporation of impurities

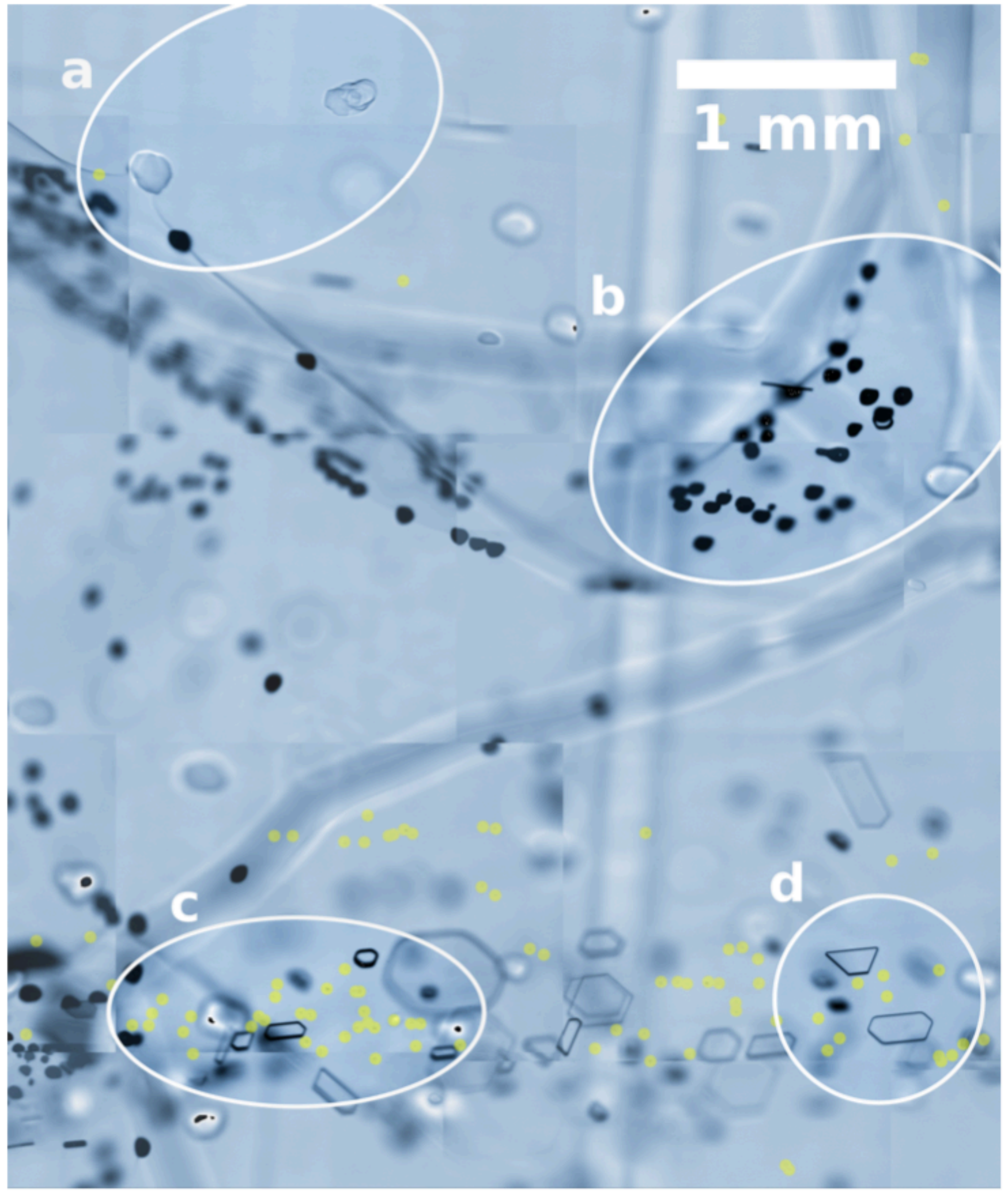


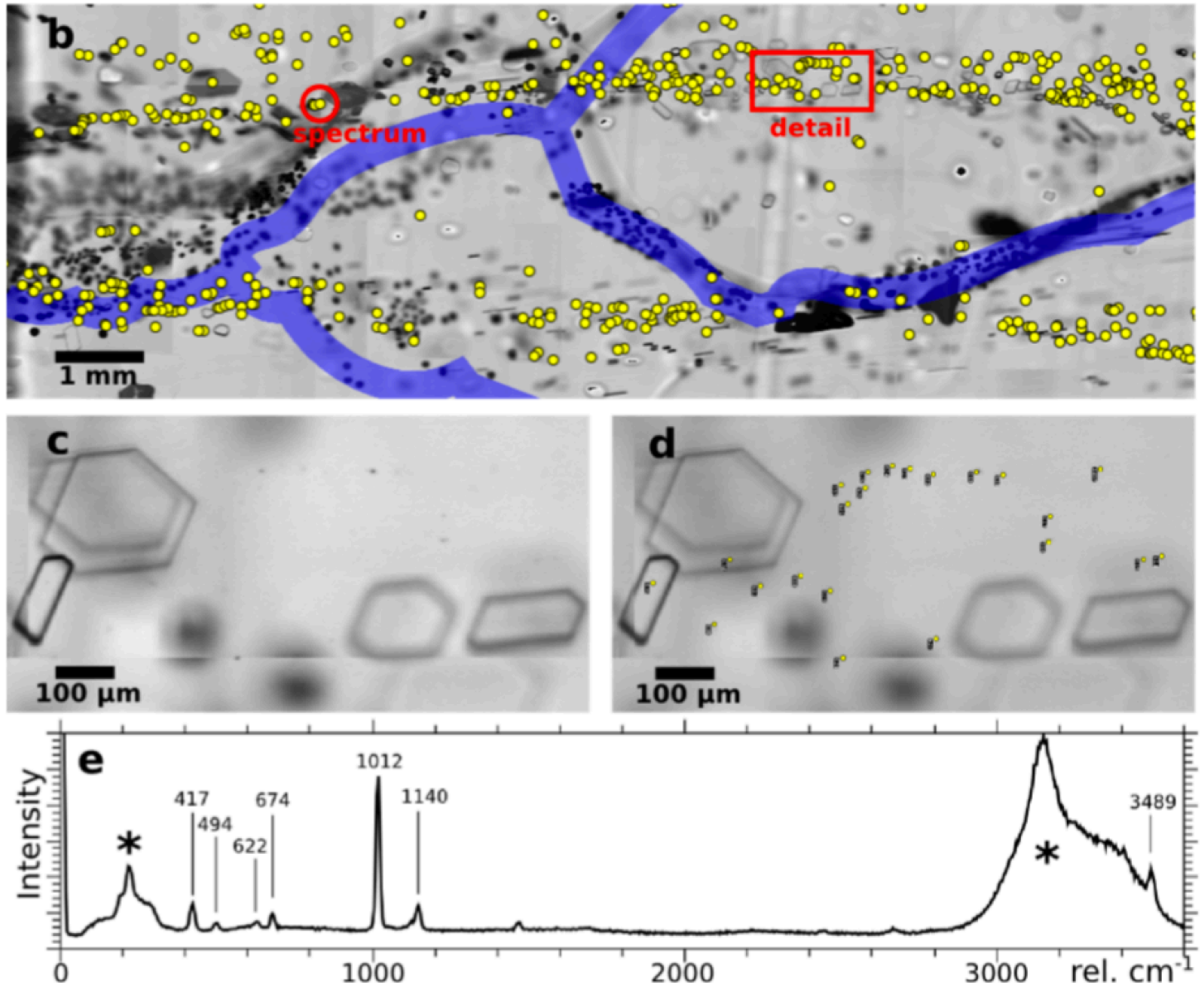
Eichler (2019)

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**







Eichler (2019)

Outlook - Micro-Cryo-Raman Spectroscopy

EGRIP bag 995 (546.7-547.25m)

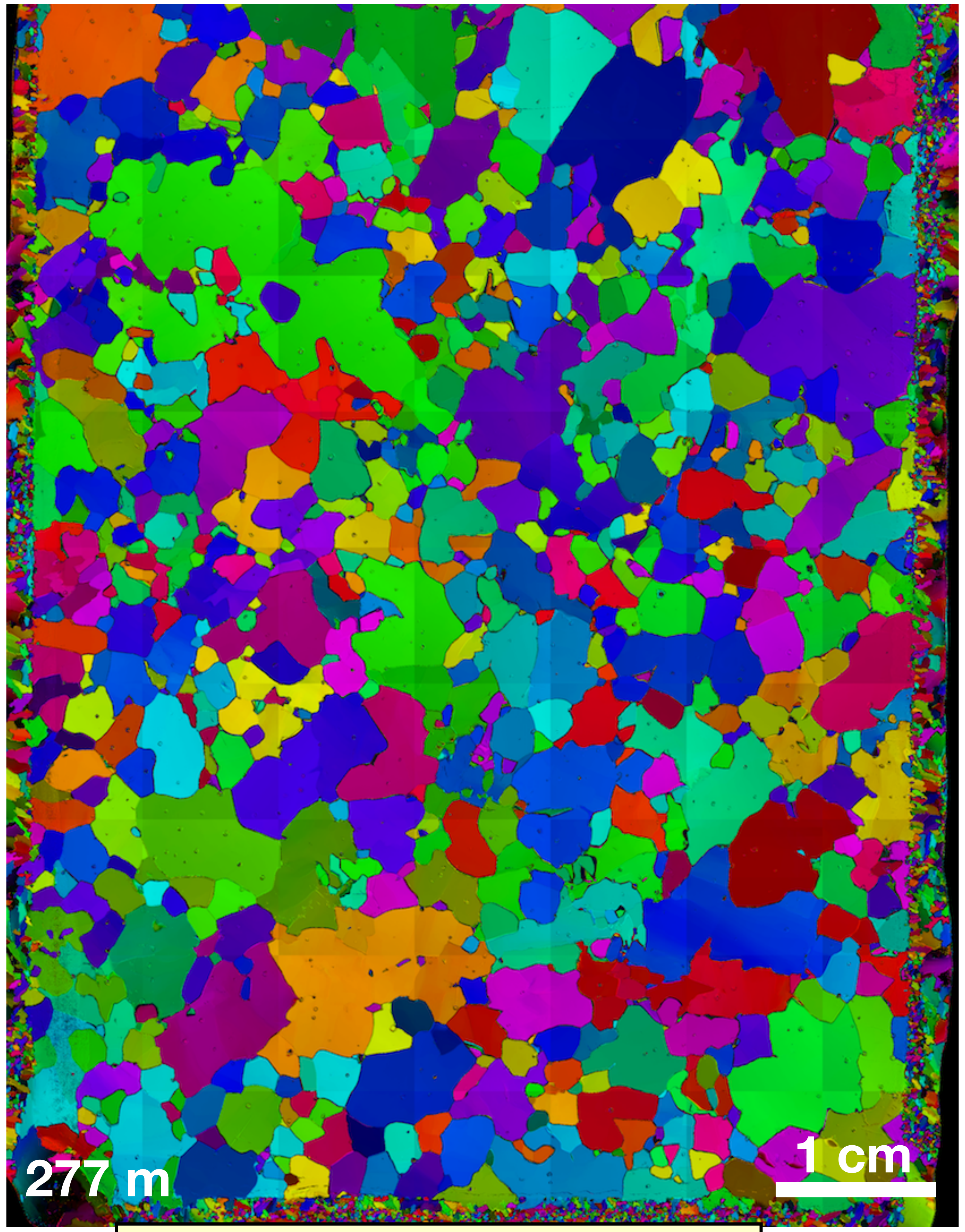
Visual Stratigraphy by J. Westhoff, CIC

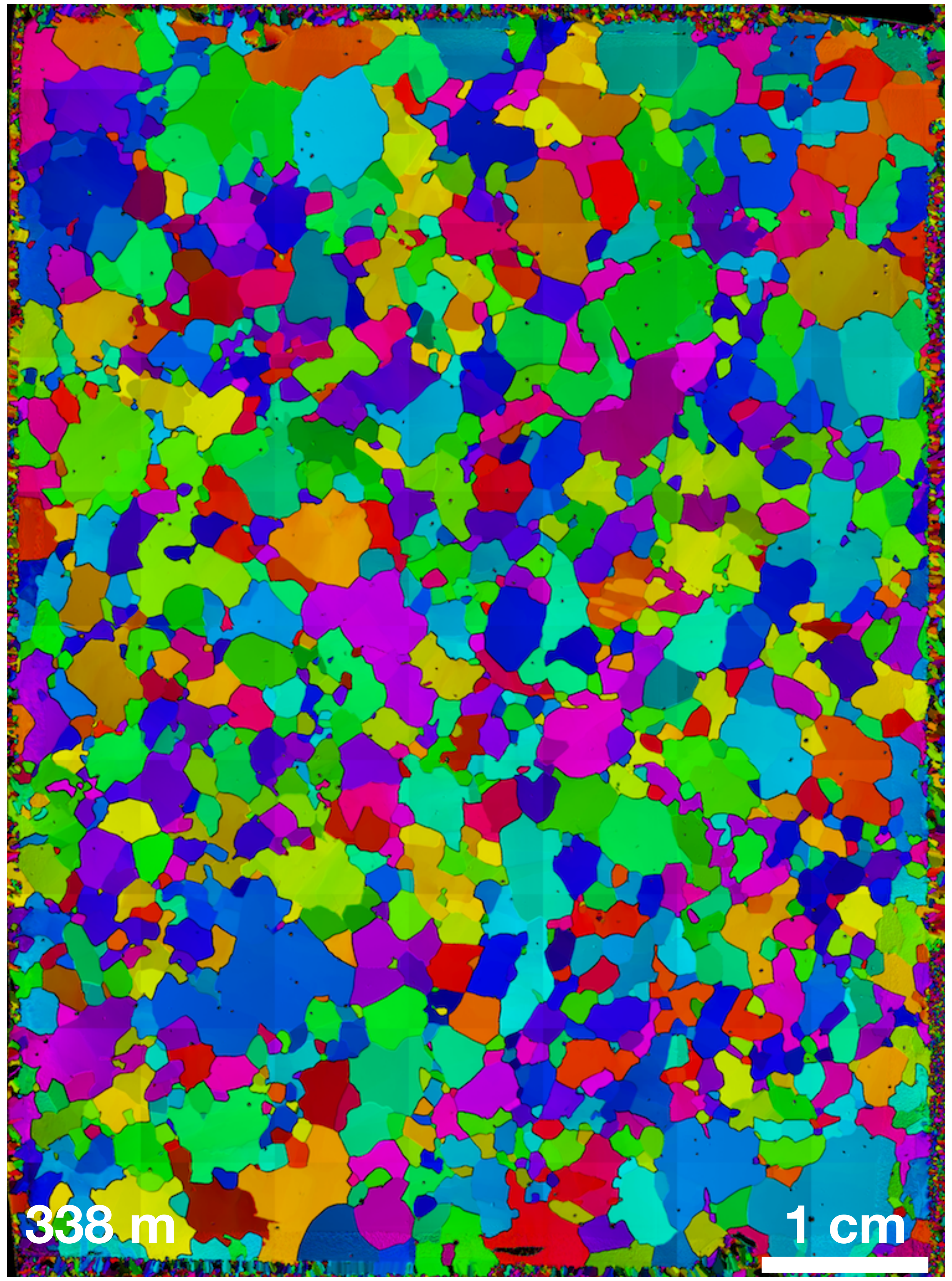
CFA/ICP-MS data by T. Erhardt & C. Jensen, Uni Bern

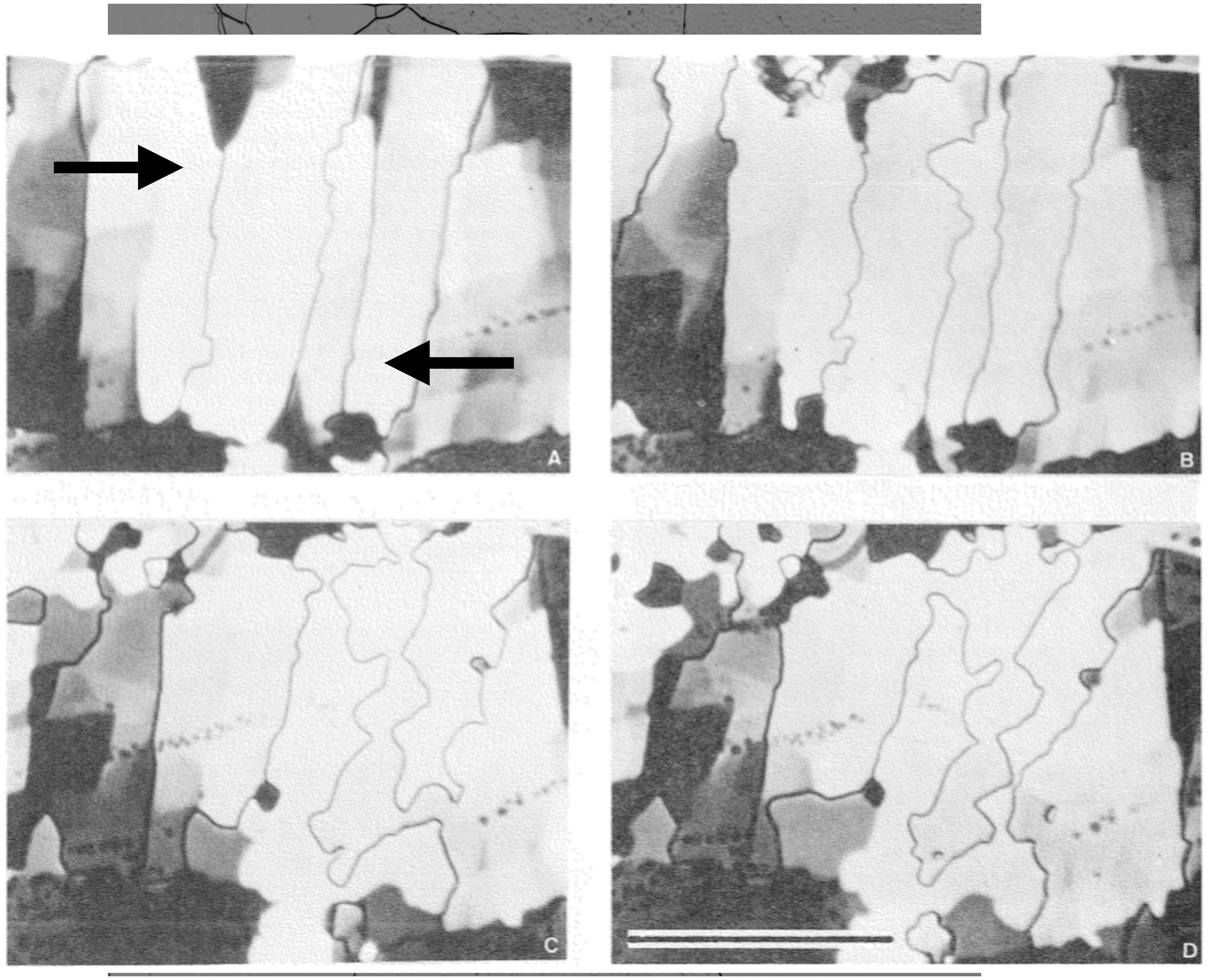

Thanks to everyone involved!
Questions?

Dynamic Recrystallisation

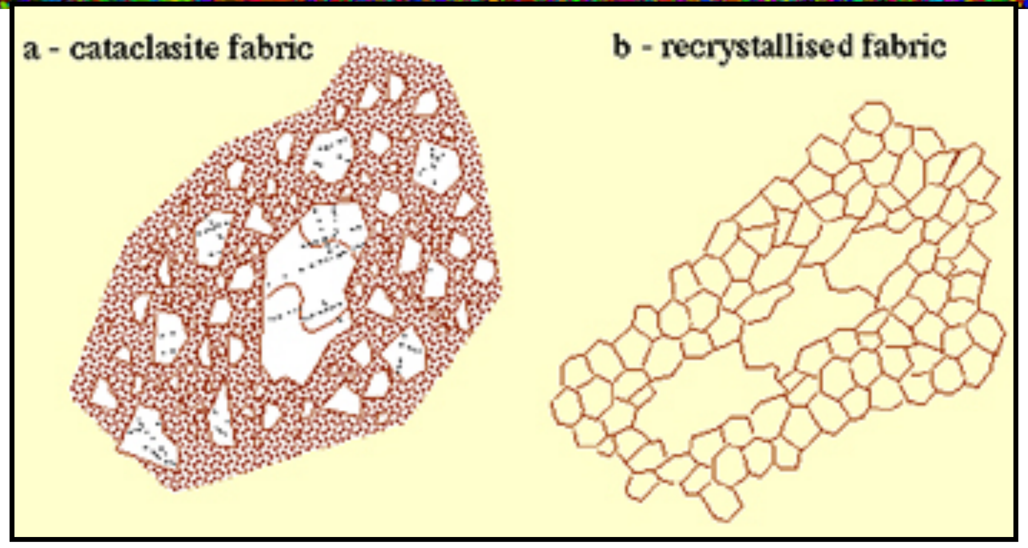
Dynamic Recrystallisation

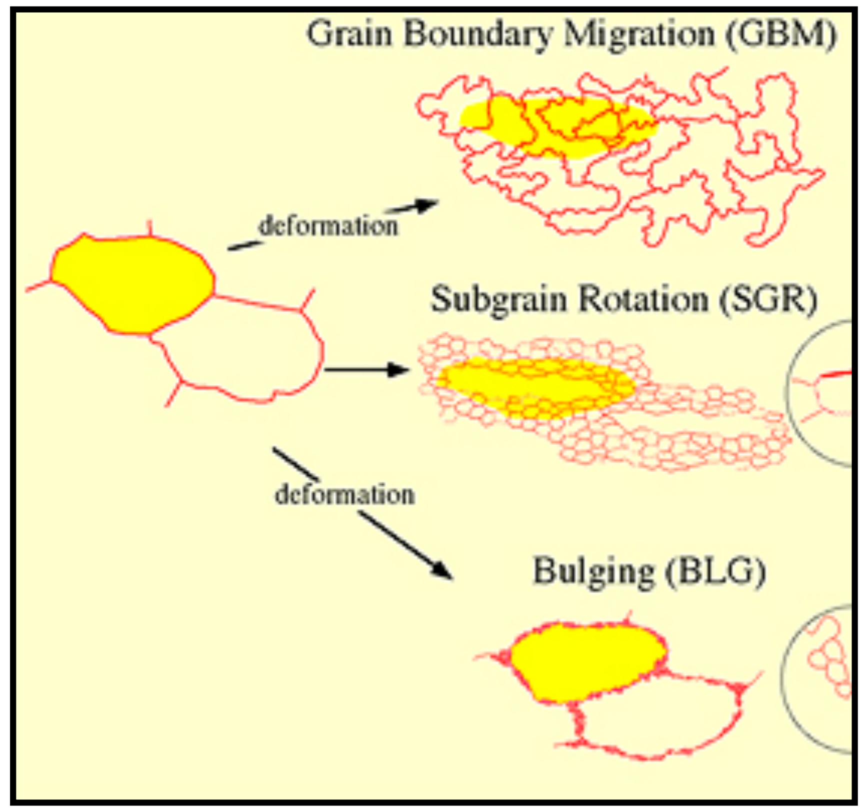






Urai et al. (1986)





Passchier & Trouw (2005)

Dynamic Recrystallisation

Grain size & crystal orientations

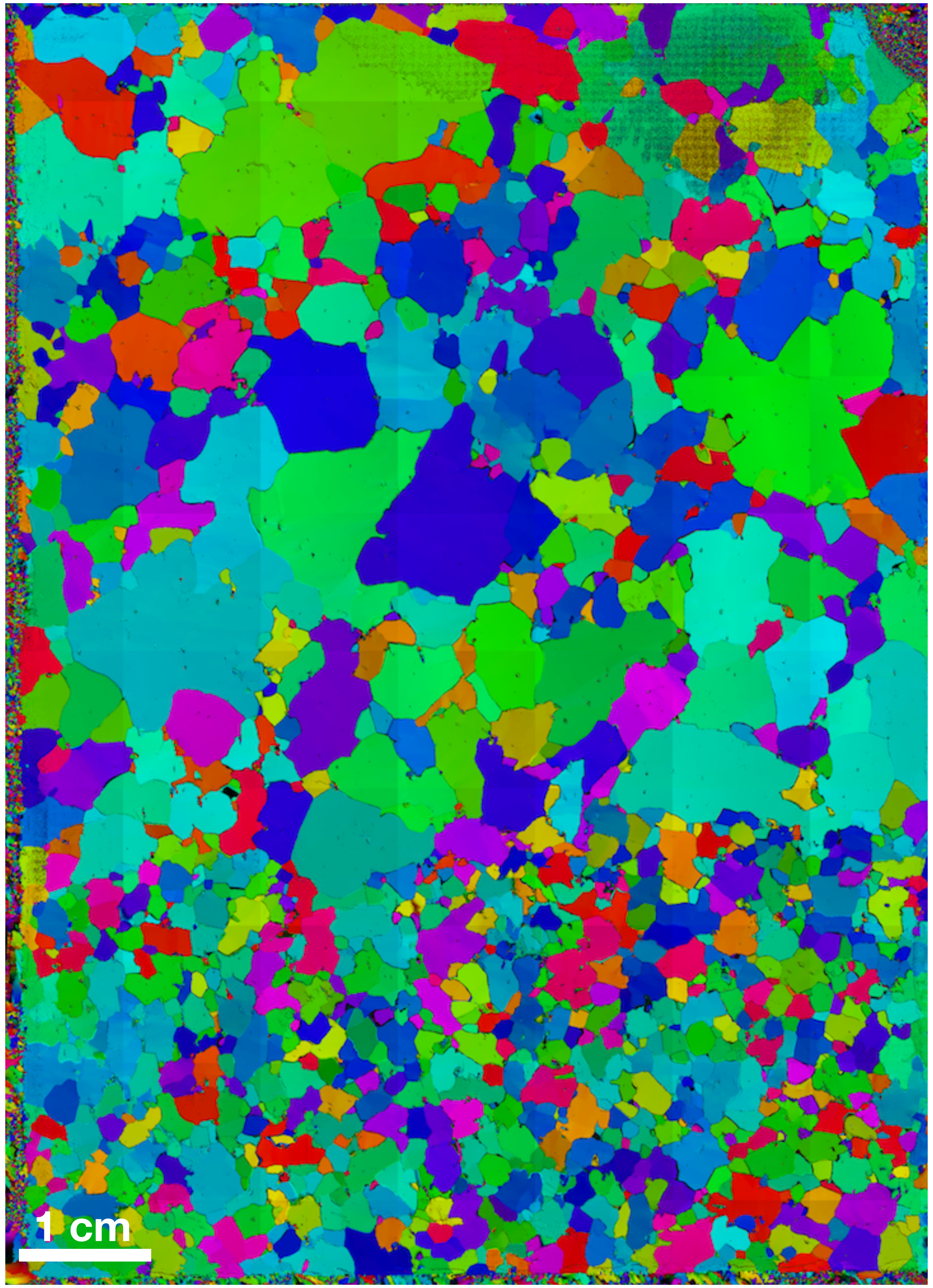
bag 1346
739.78-740.3m

Visual Stratigraphy by J. Westhoff, CIC

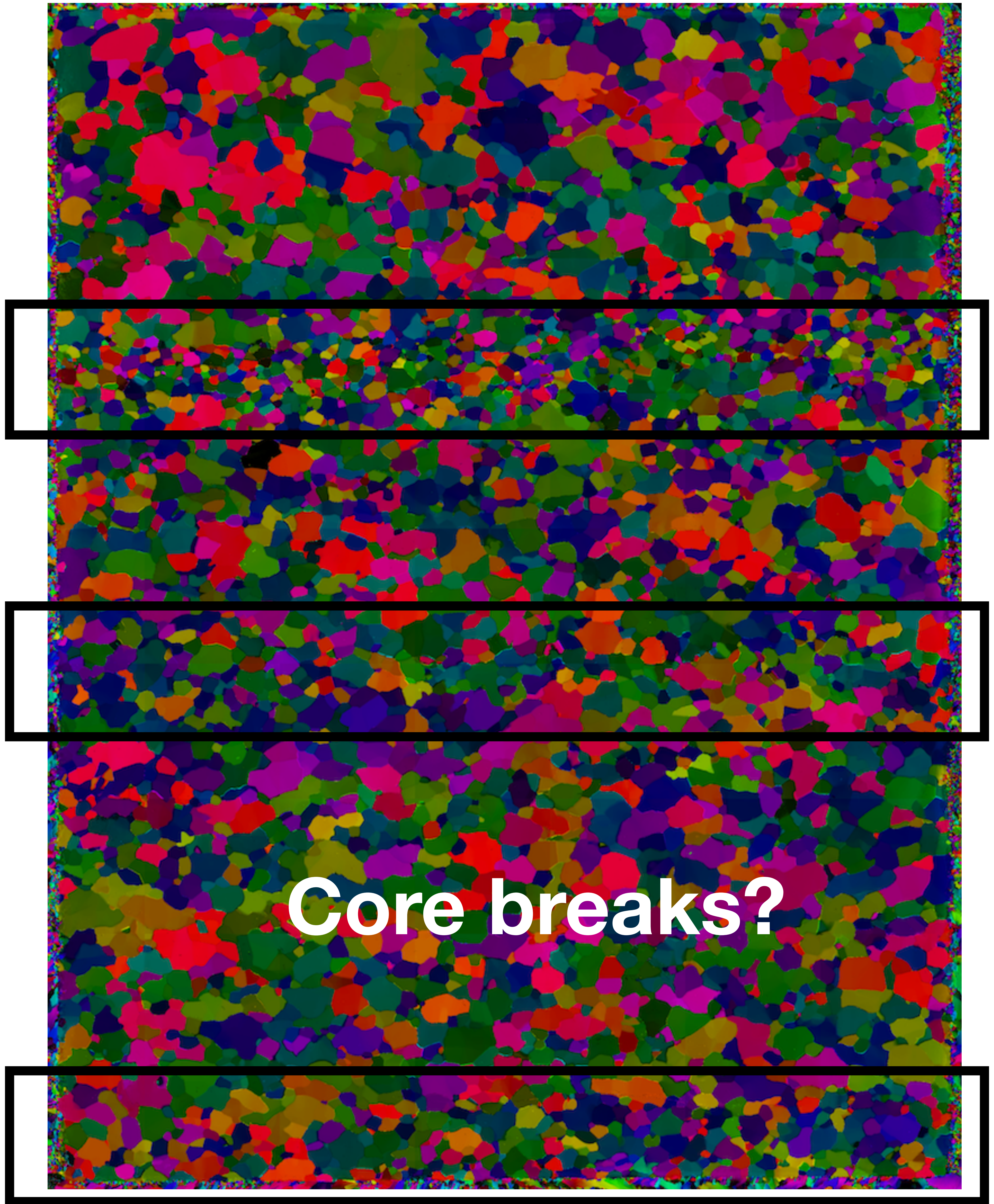
CFA/ICP-MS data by T. Erhardt & C. Jensen, Uni Bern

Grain size

828 m

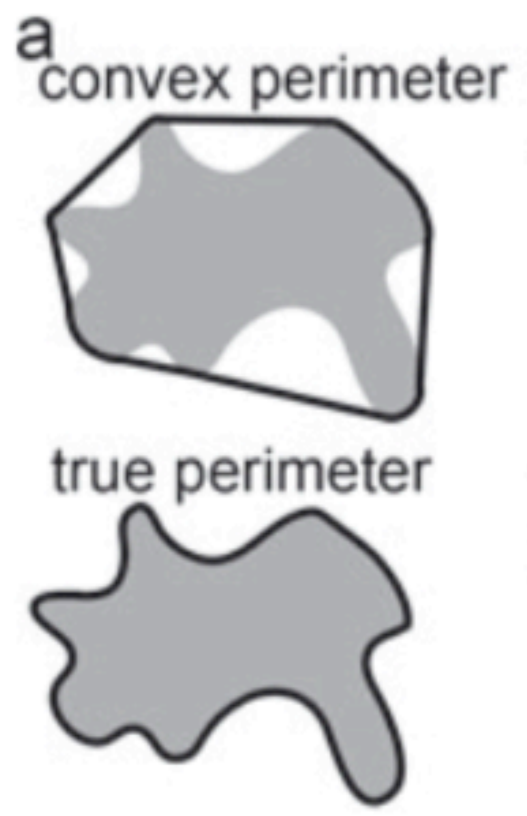


1444 m



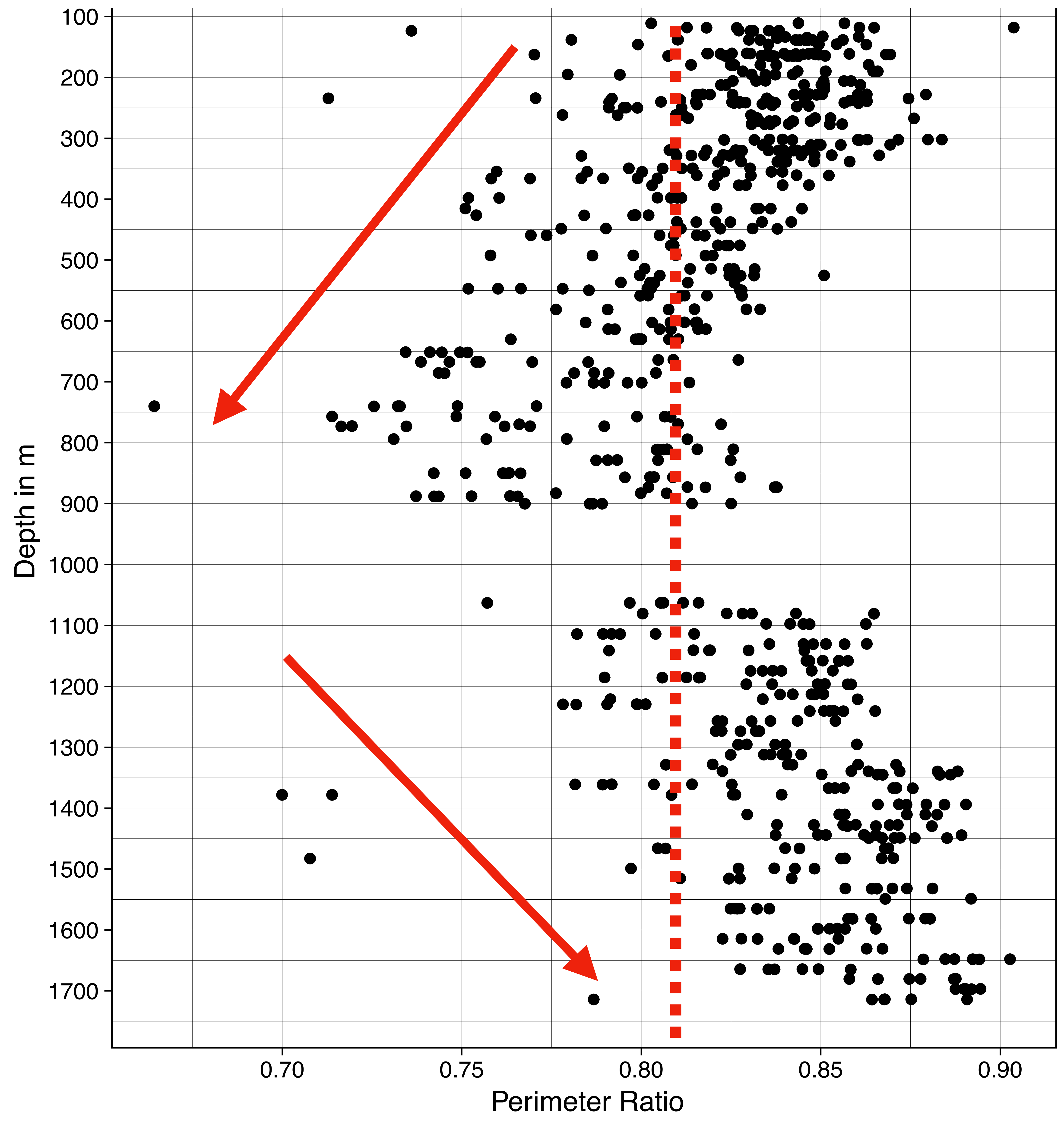
Perimeter Ratio

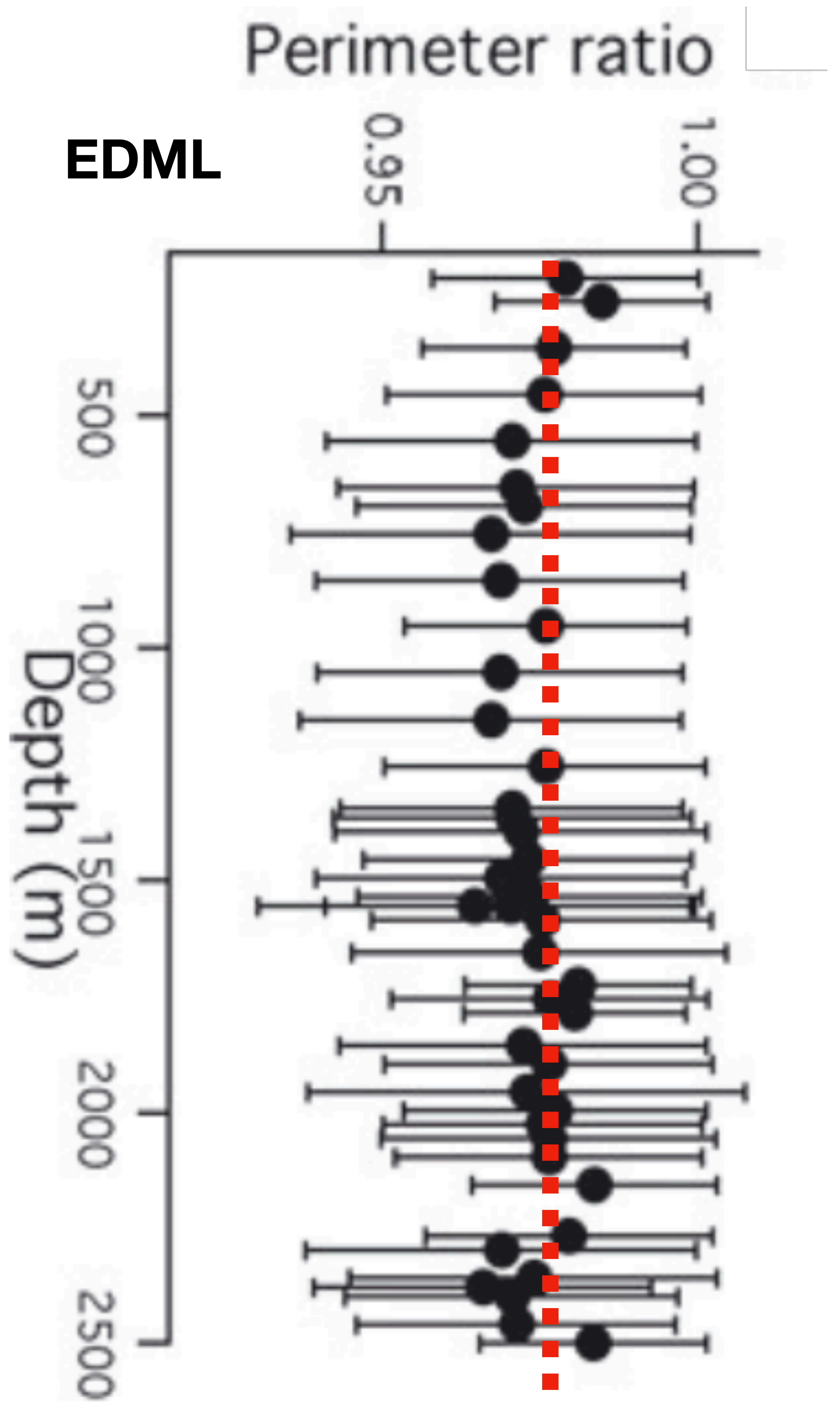
Perimeter ratio = measure for grain **irregularity**



Weikusat et al. (2009)

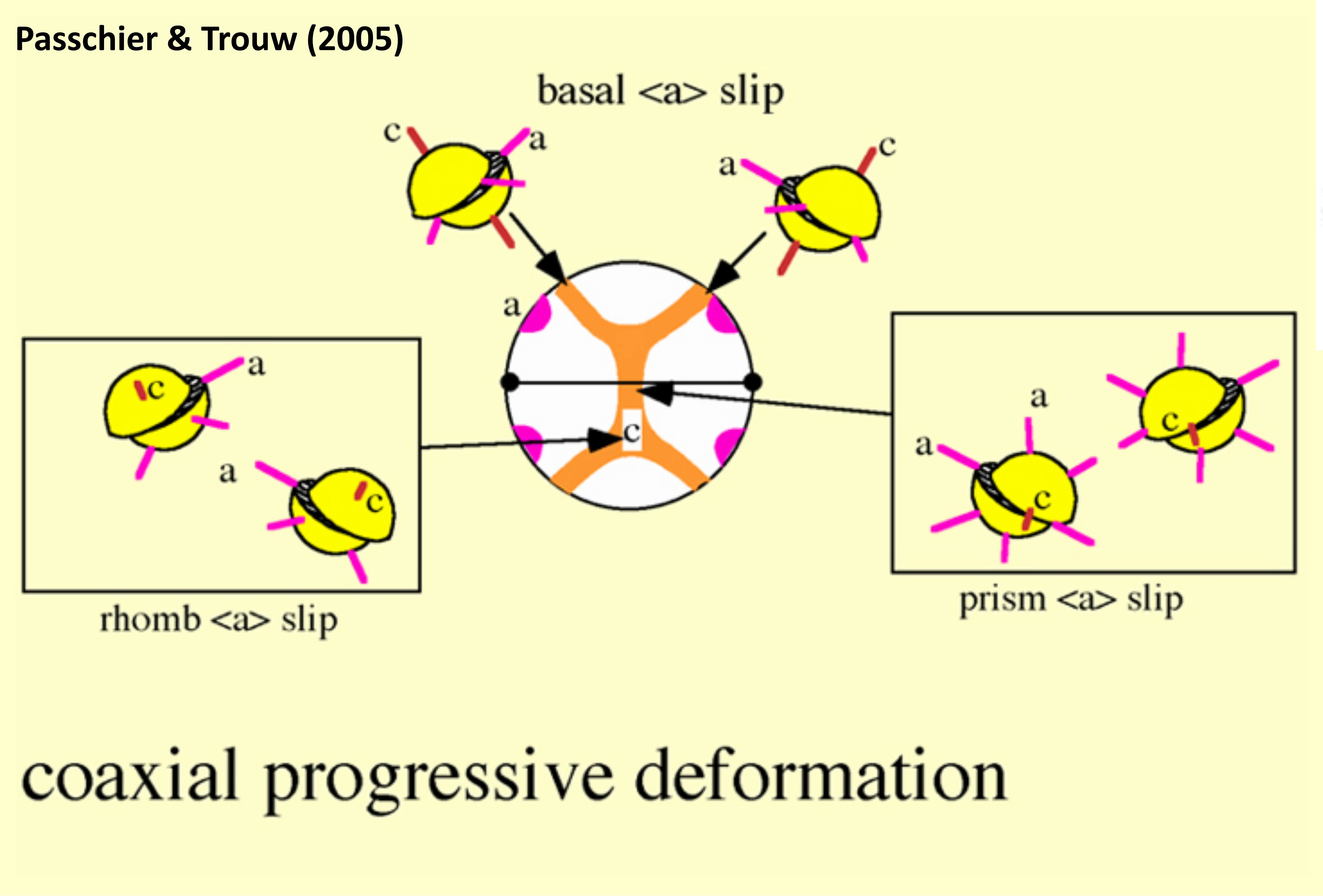
Further down to 2121 m?



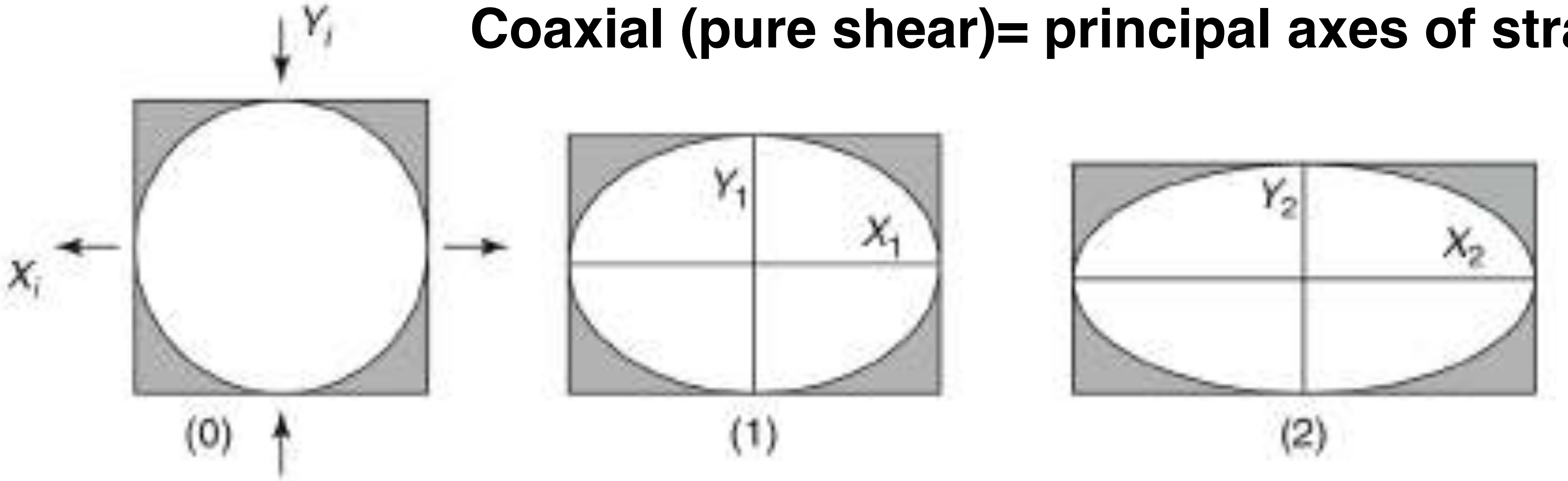


Weikusat et al. (2009)

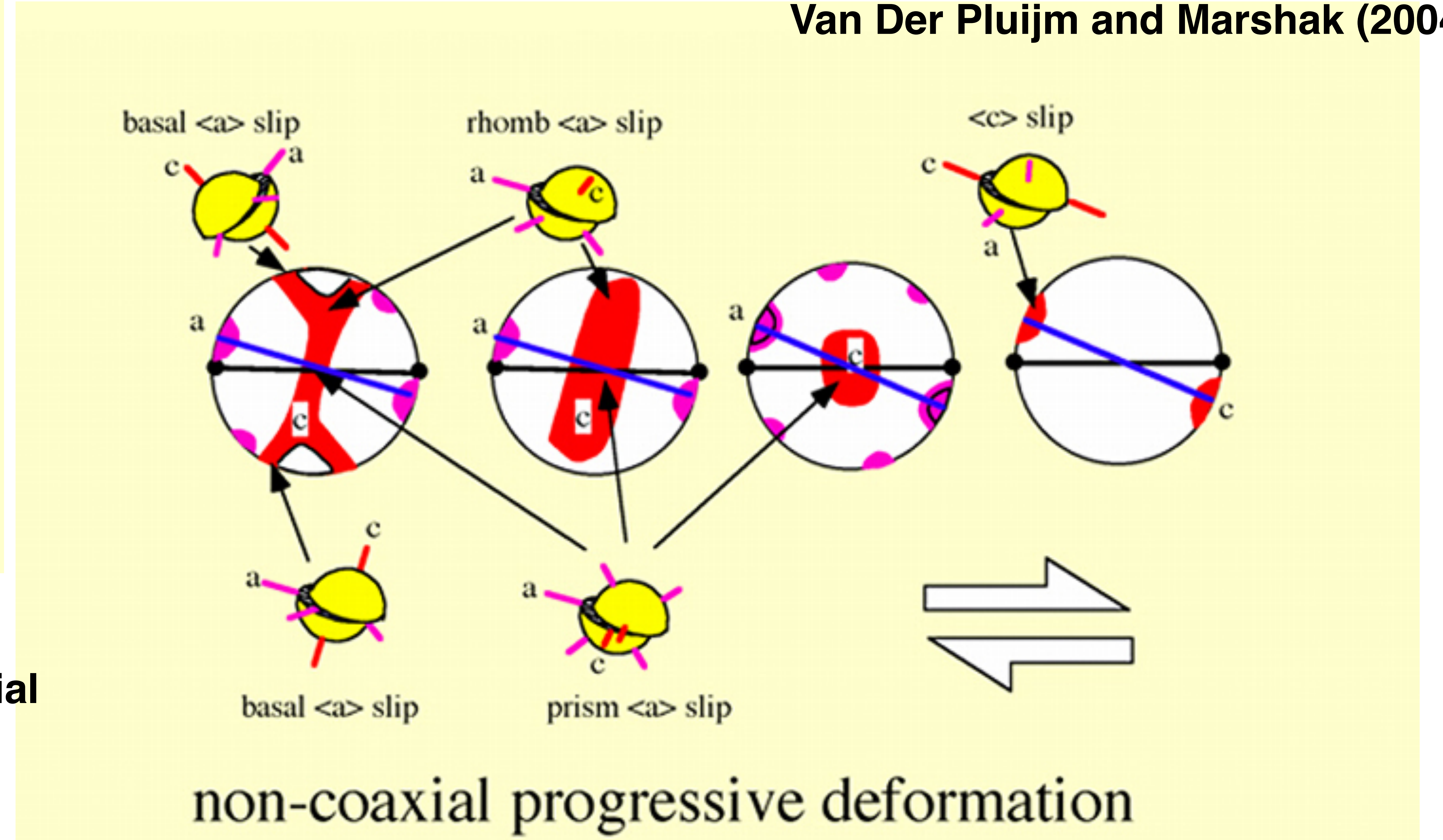
Deformation modes



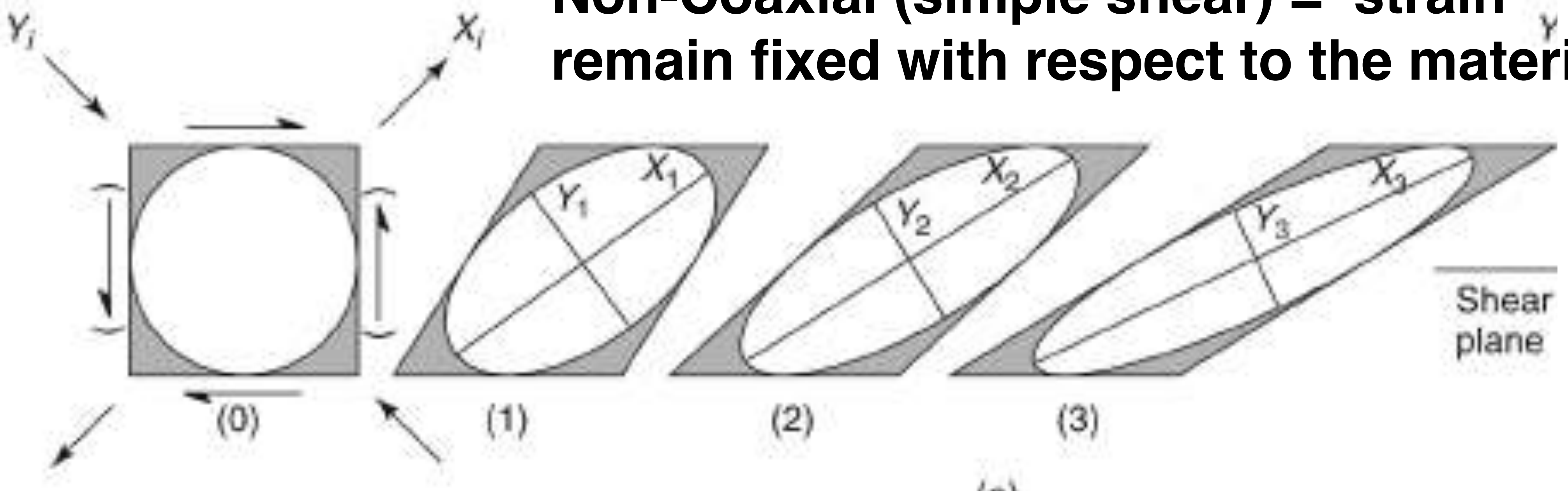
Coaxial (pure shear)= principal axes of strain rotate



Van Der Pluijm and Marshak (2004)



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



different slip-systems influence different parts of the crossed girdle

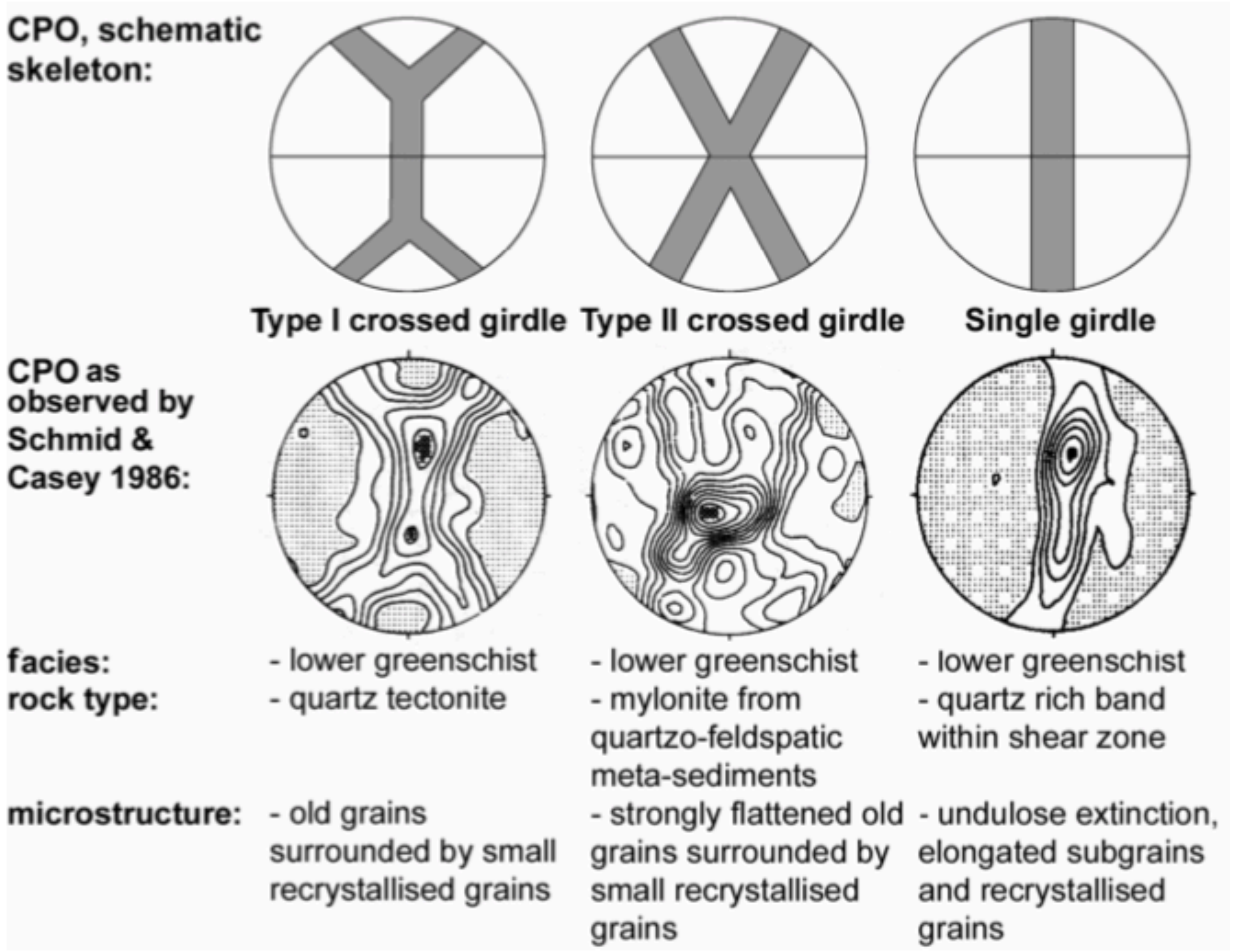
->EBSD?

HELMHOLTZ

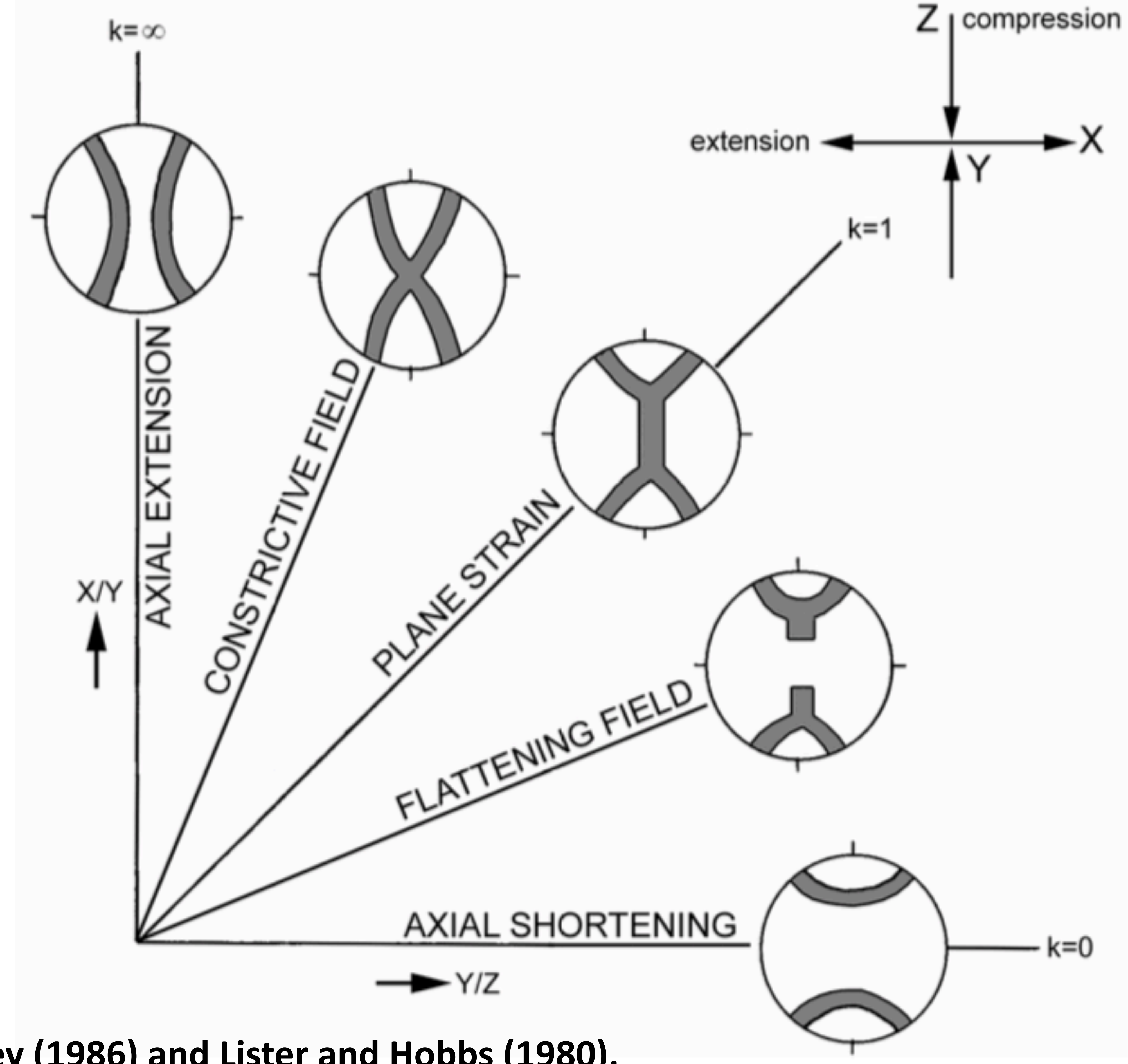
Crystal preferred orientations

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)



Schmid and Casey (1986)



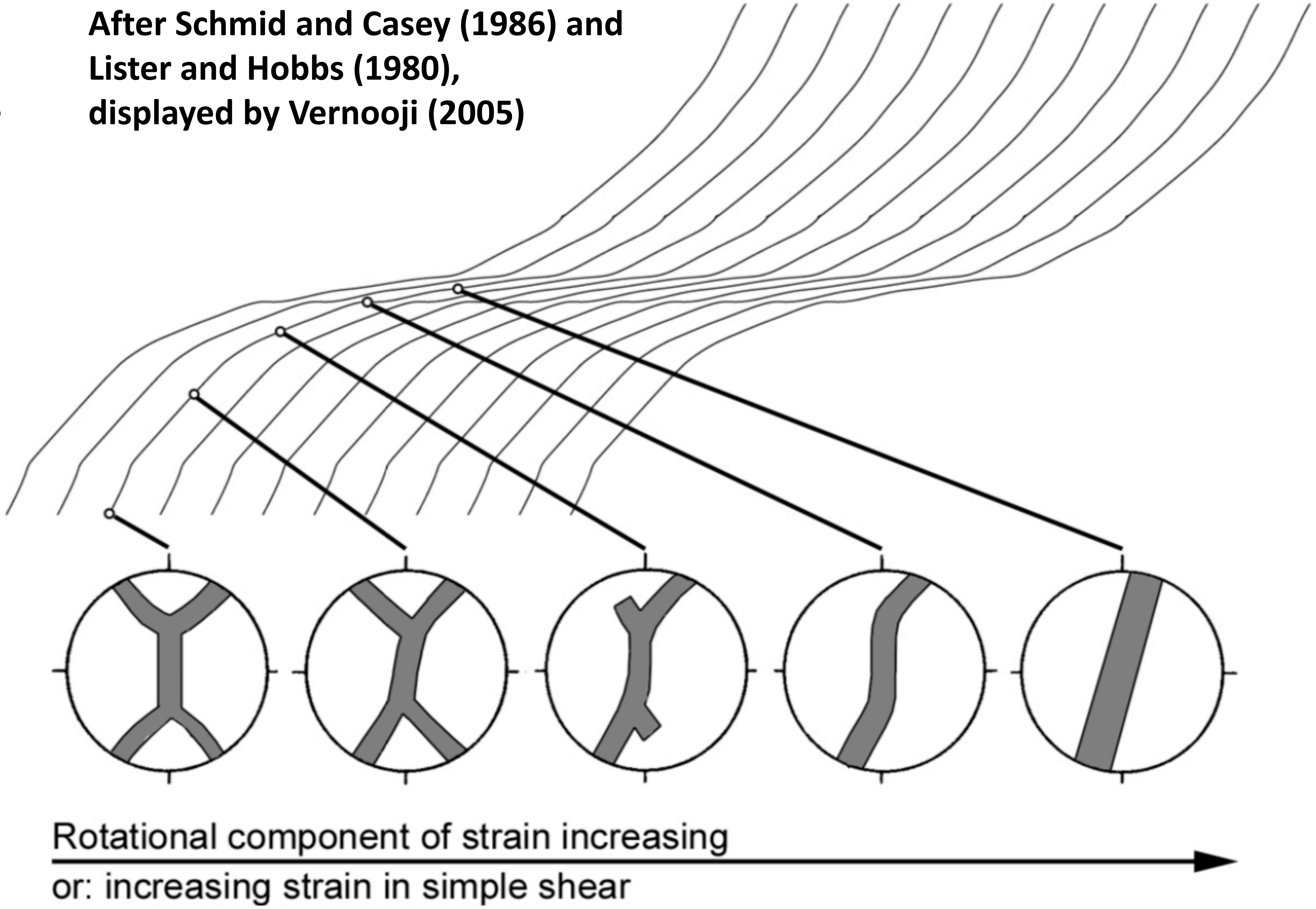
After Schmid and Casey (1986) and Lister and Hobbs (1980), displayed by Vernooji (2005)

Deformation modes

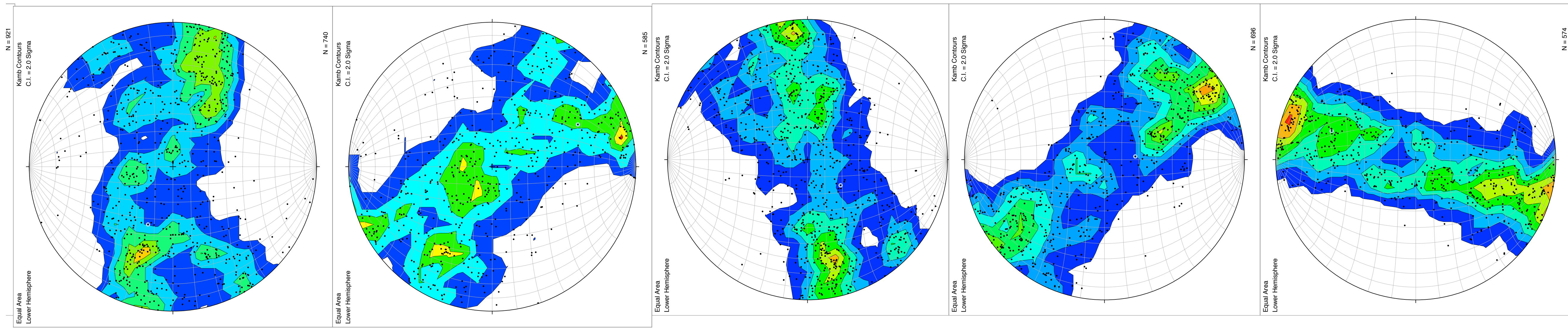
- in many naturally deformed rocks, a spatial *transition* of symmetrical crossed girdles to asymmetrical single girdles occurs
- related to an increasingly *non-coaxial* strain path

- 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)

After Schmid and Casey (1986) and Lister and Hobbs (1980), displayed by Vernooji (2005)



EGRIP



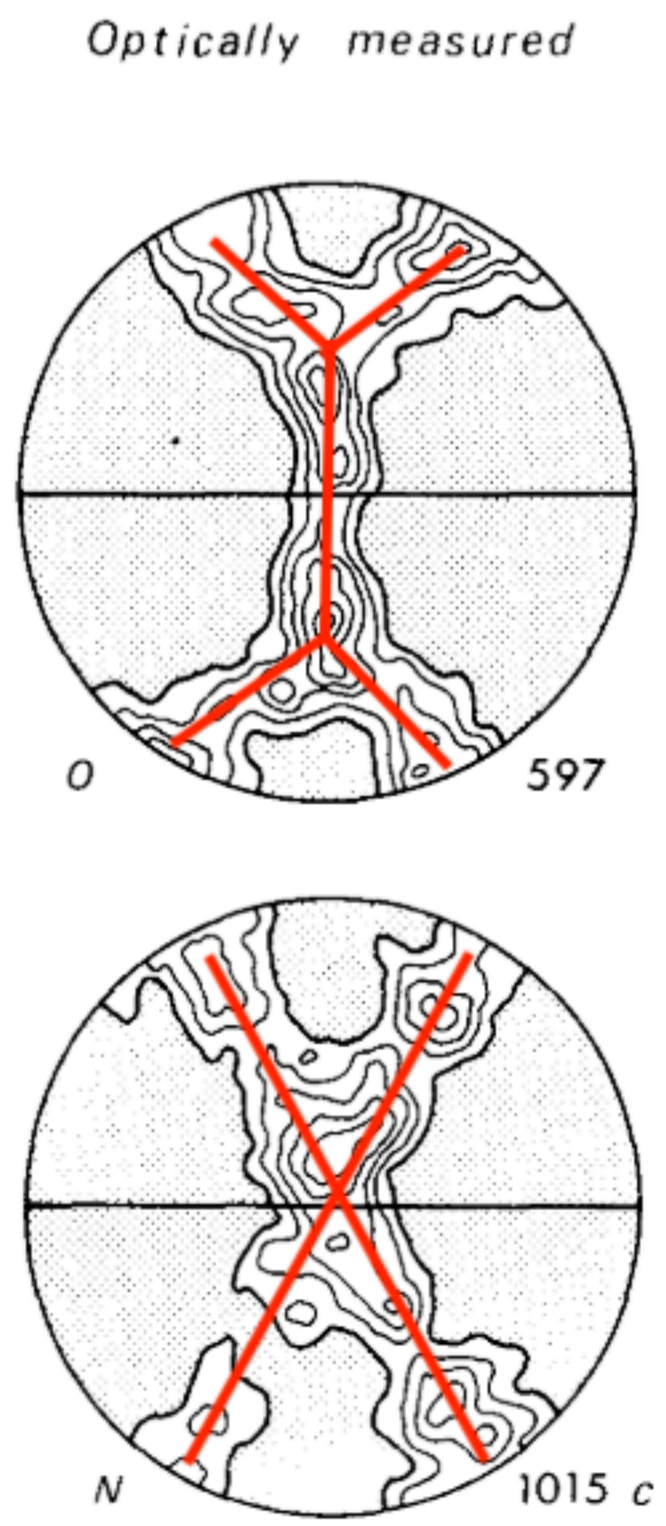
234 m 241 m 289 m 328 m 398 m

Crystal preferred orientations

Crossed girdle in quartz

Type I

Type II



Law et al. (1986), modified