Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research, Bremerhaven, Germany
Interdisciplinary Center for Scientific Computing (IWR), University of Heidelberg, Germany

DFG-SCHWERPUNKTPROGRAMM 1158
ANTARKTIS FORSCHUNG
mit vergleichenden Untersuchungen in arktischen Eisgebieten

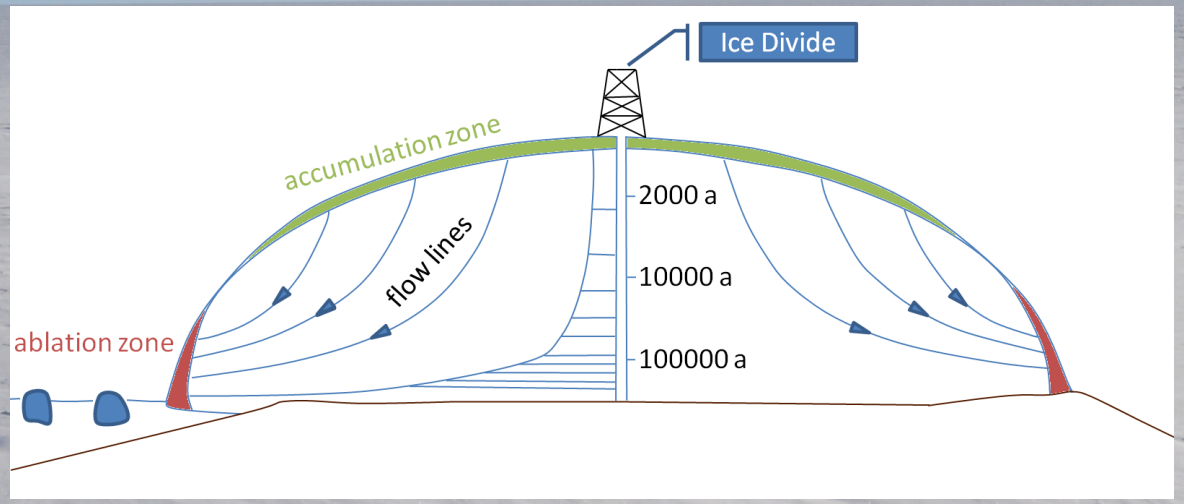
Automated microstructure characterization along deep ice cores using sublimation etching

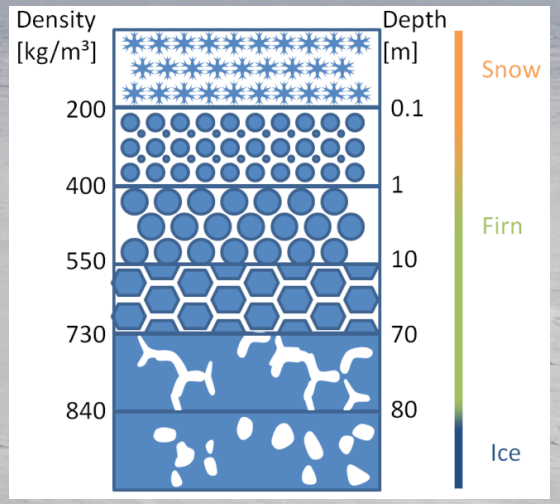
Tobias Binder, Ilka Weikusat, Johannes Freitag, Christoph S. Garbe, Dietmar Wagenbach, Sepp Kipfstuhl

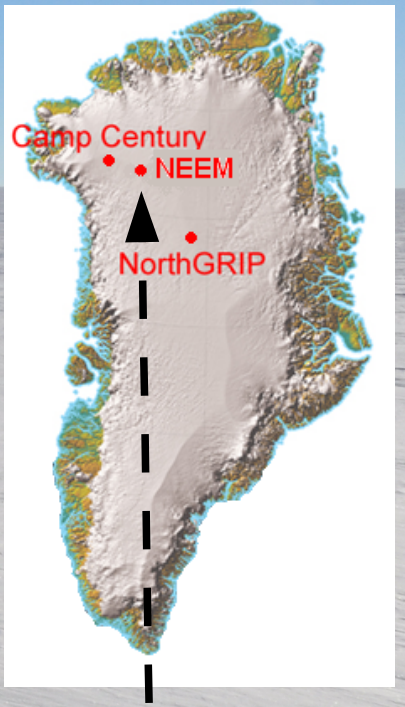
5th International Conference on Recrystallization & Grain Growth

Sydney, 06/05/2013

Ice sheets



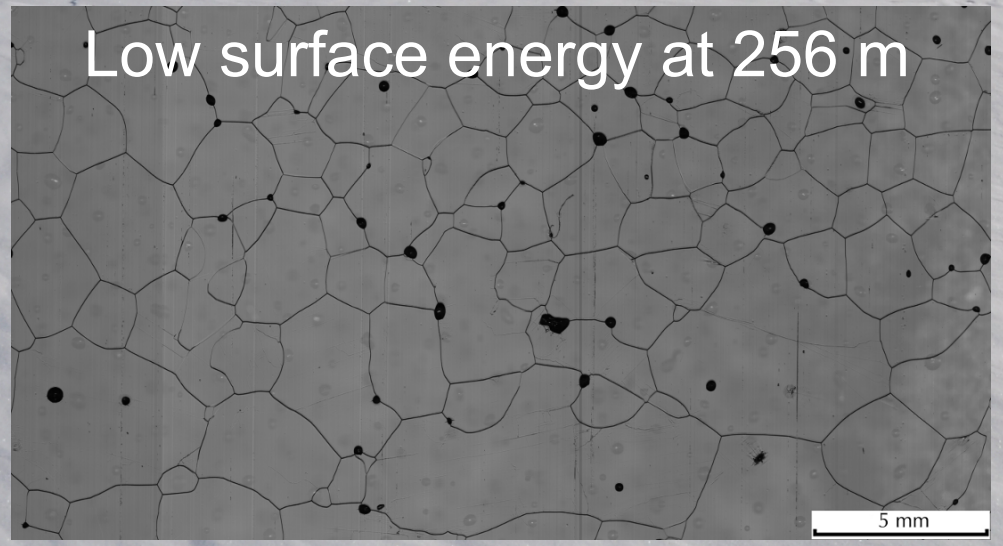


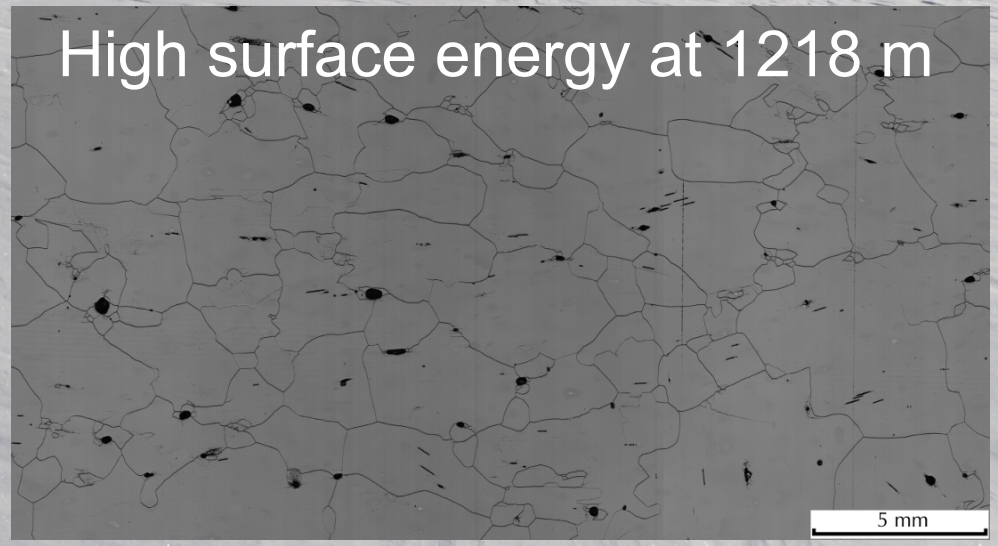


- Unique densification/deformation experiment
- Important climate archive
- Deep ice cores drilled in Greenland and Antarctica (cold, dry)
- Homologous temperature > 0.8

Ice microstructure in ice sheets

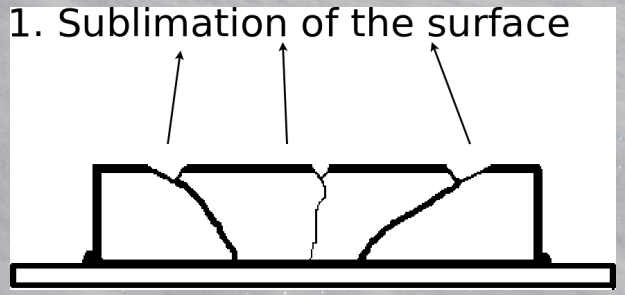
- In nature: hexagonal structure (Ih)
- Optical anisotropy → Polarisation microscopy
- Mechanical anisotropy (2 slip systems) → High local stresses
- Changing combination of ReX processes with depth, on which scale?

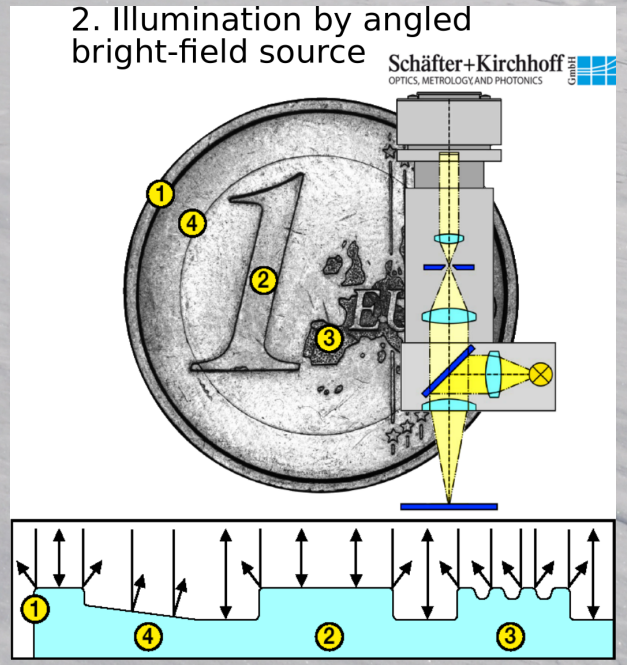


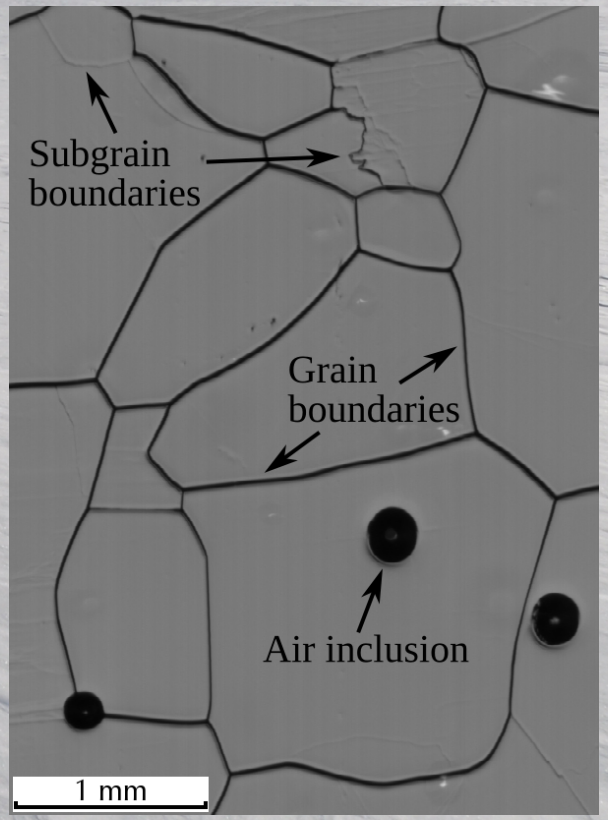


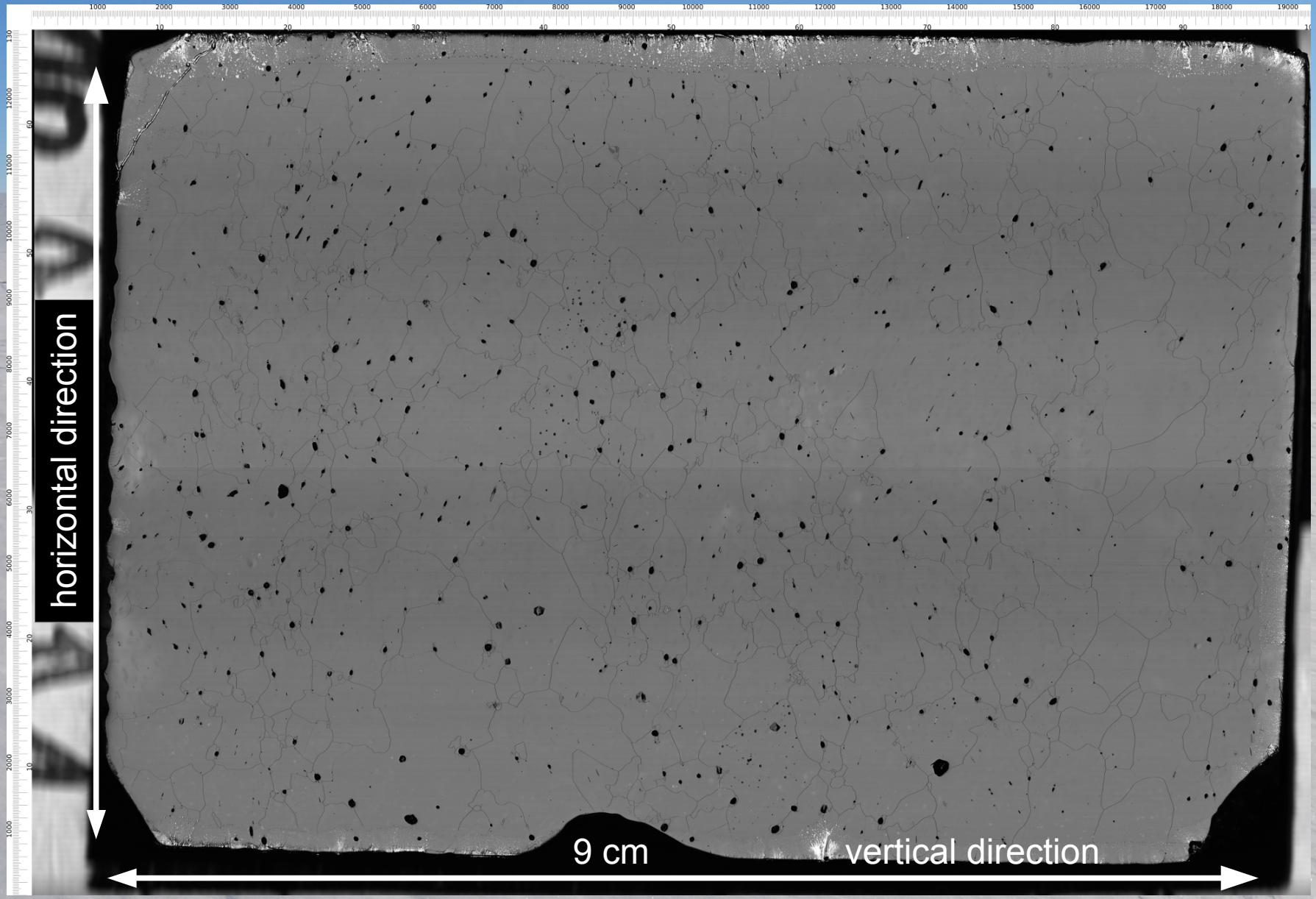
Sublimation groove images

- SEM, EBSD are too slow for quasi-continuous analysis
- Preparation of thin sections for polarization microscopy even time-consuming
- Reflection microscopy of **sublimation grooves** by “Large Area Scanning (**LASM**)









Images

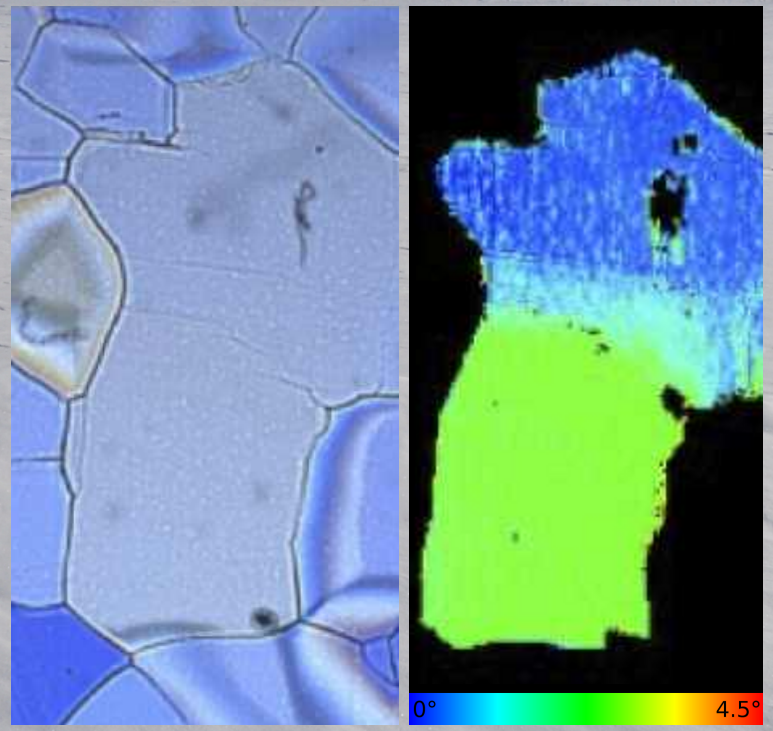
Six consecutive 6 cm x 9 cm sections

Steps of 20 m

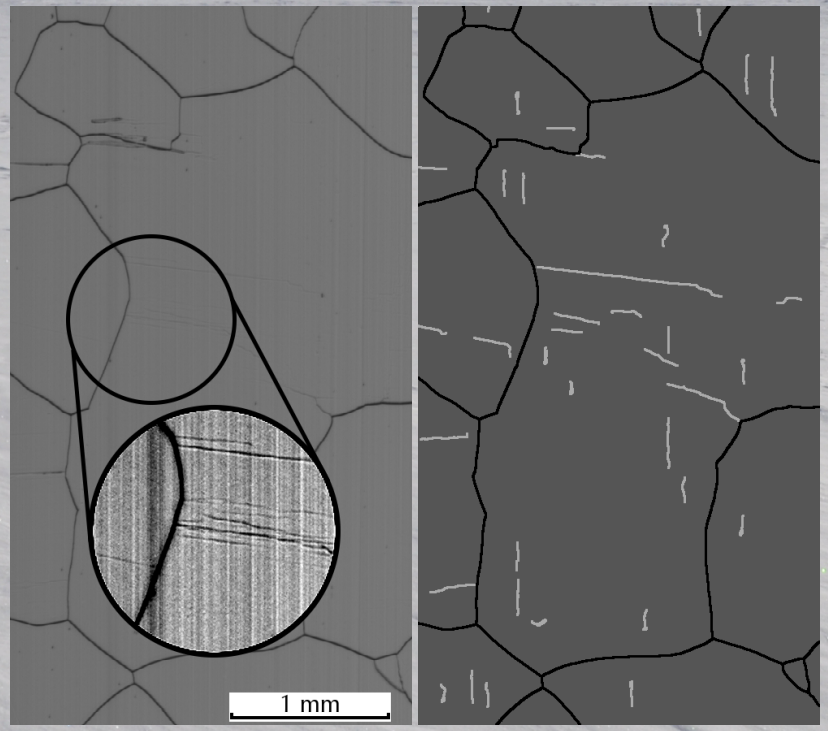
Total:
800 images

10-15 µm wide grain boundaries

Low-angle lattice distortions



Fabric Analyer (FA)

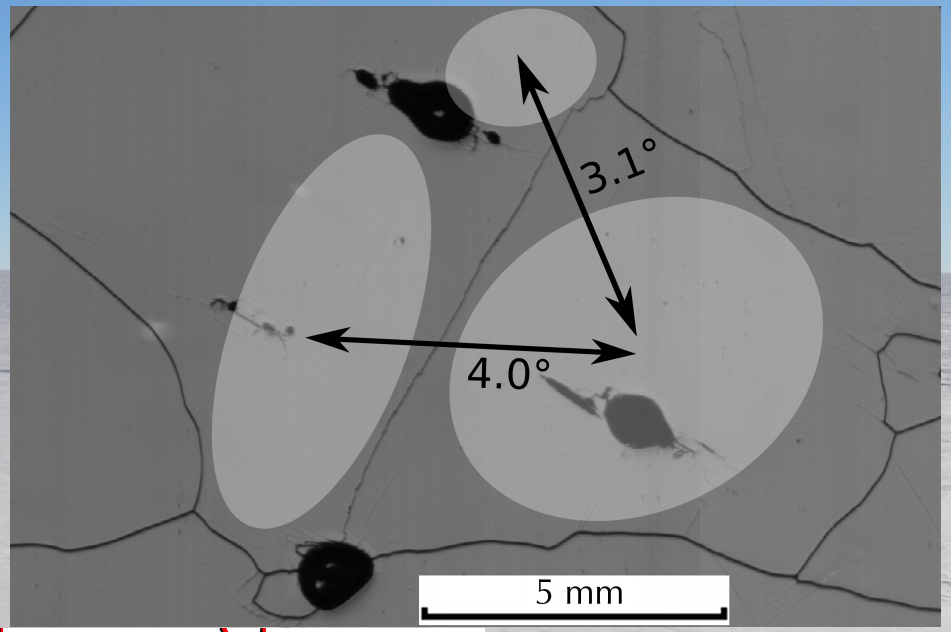


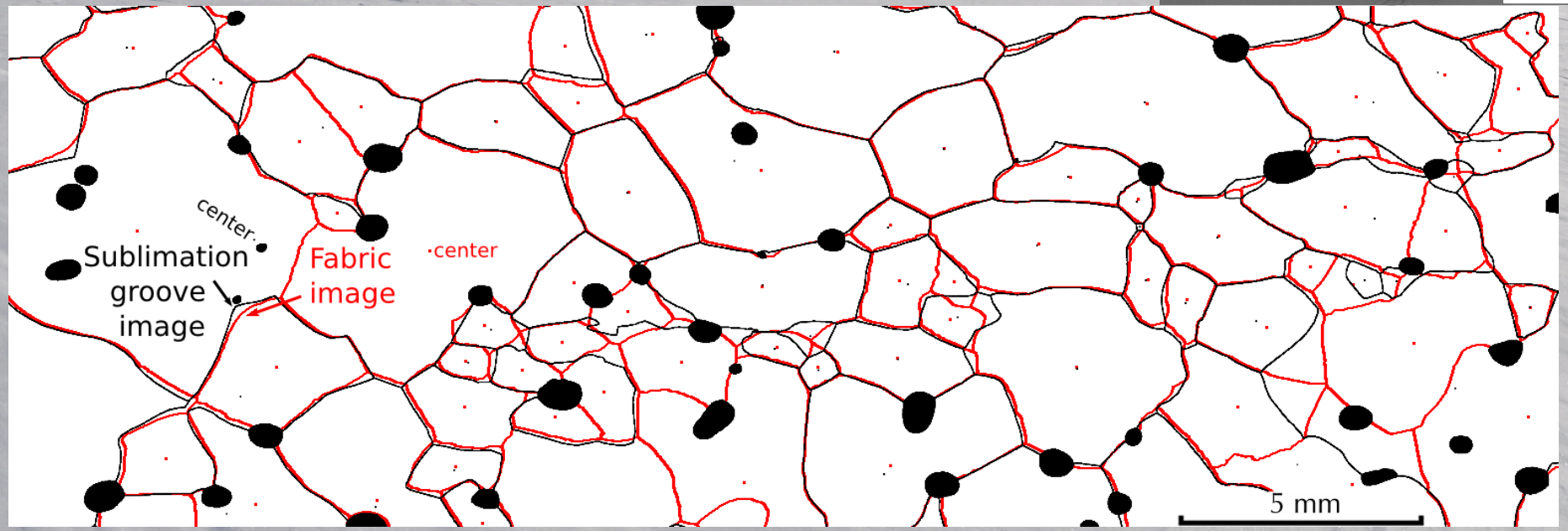
LASM

- Subgrains in ice: regions with misorientation smaller 5°
- In LASM: high sensitivity, automatic extrac-tion of GBs/sGBs

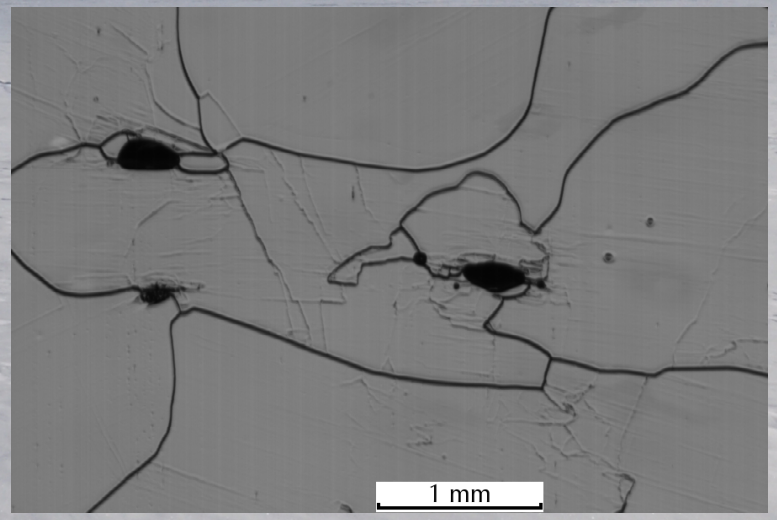
Matching FA/LASM

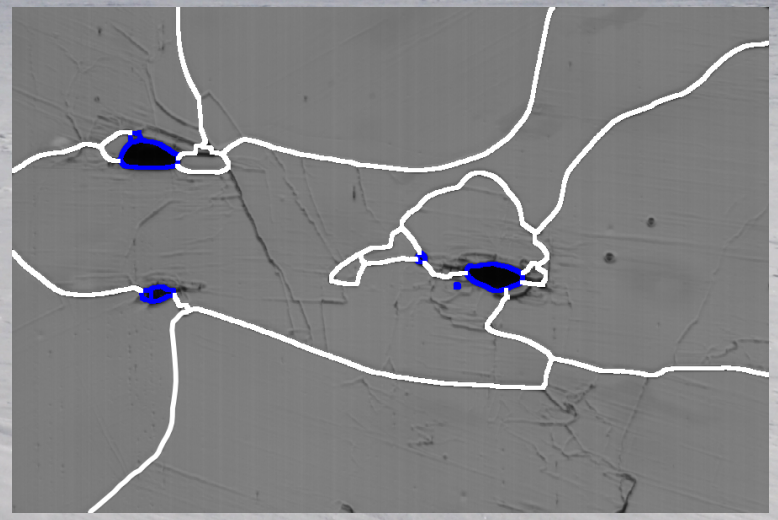
- Combination of both imaging techniques yields additional information.

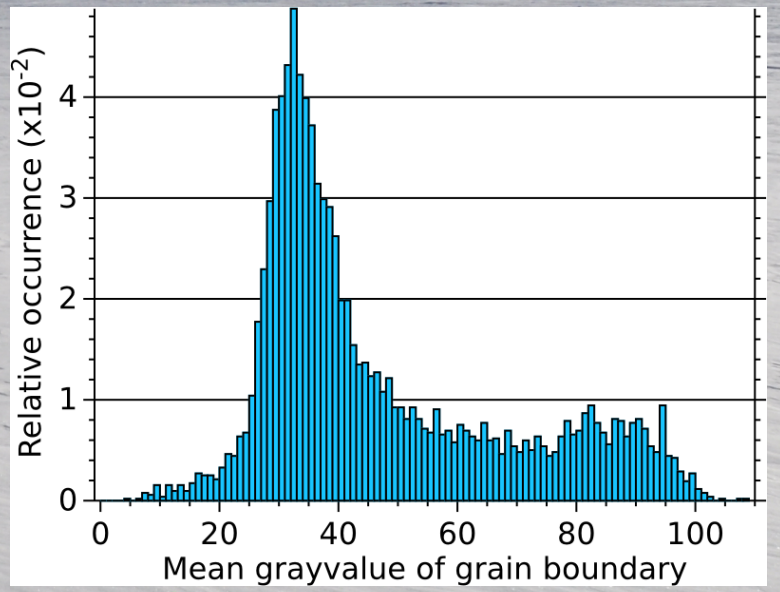




Characteristics of LASM images

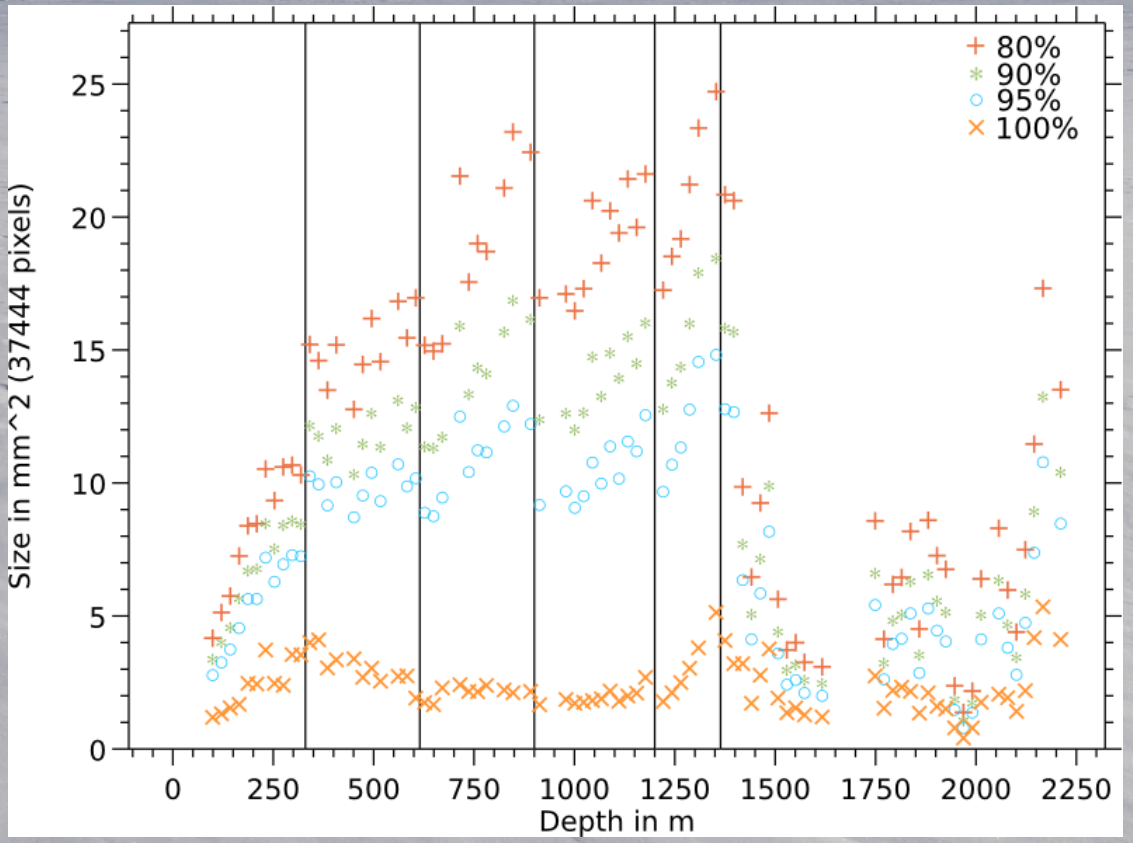






- Smaller grains extracted
- High-angle boundaries appear darker than low-angle boundaries

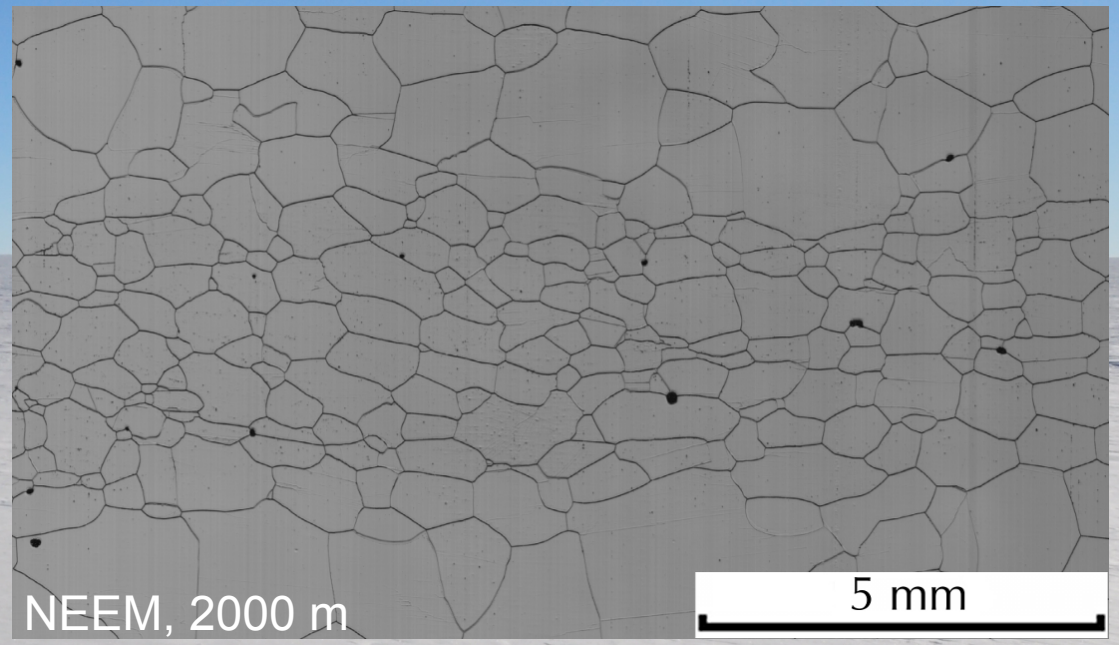
Parameterization, e.g. mean grain size

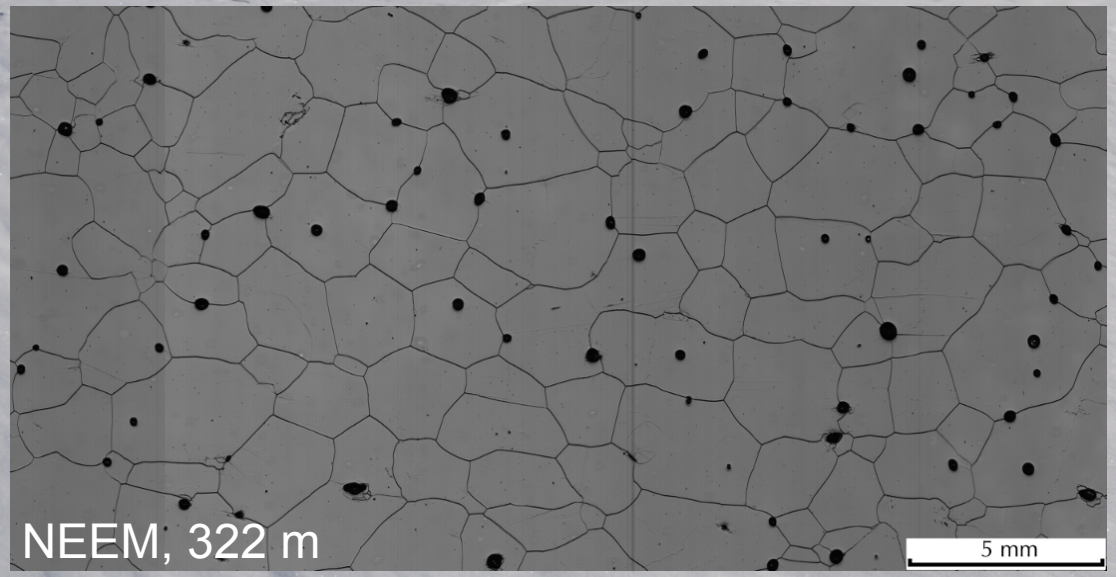


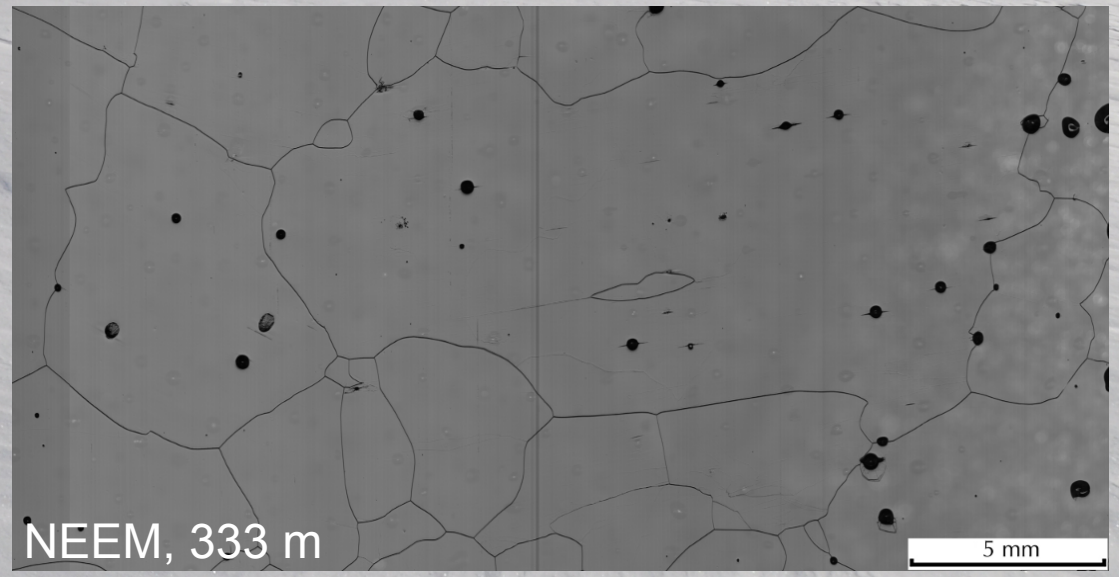
- Diverse parameterization of grains and grain boundaries
- Up to now: No standard parameterization for texture established in glaciology (different image types)
- Problem with mean grain size: How many small grains are considered?
- Where does grain growth stop?
- Climate transitions

Variability in grain size

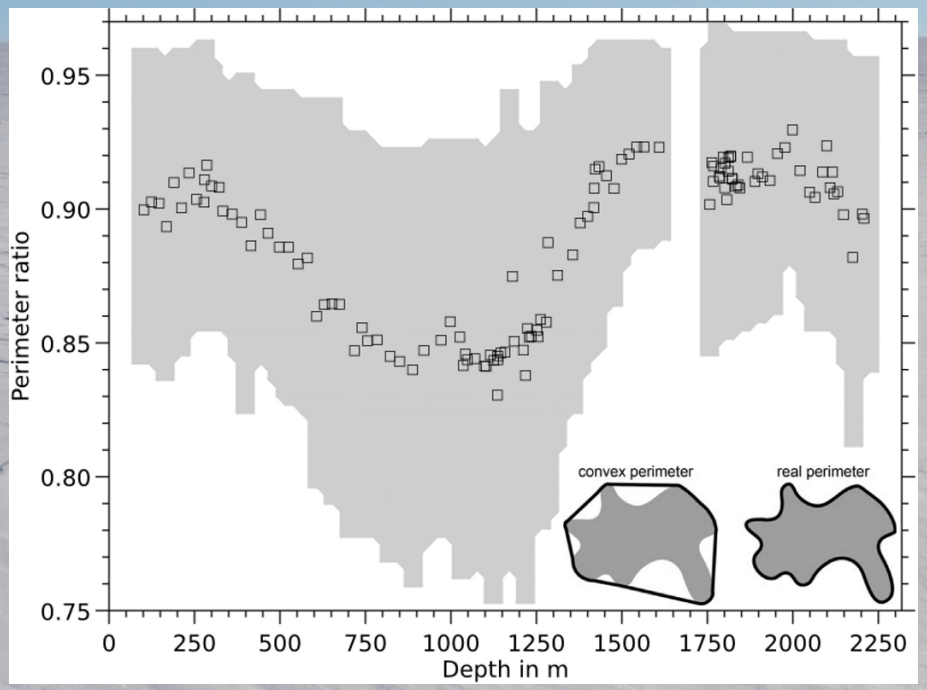
- On mm scale (“cloudy bands“)
- *On cm scale (within a section)*
- On m scale (not observed before)
- *On km scale (through ice sheet)*

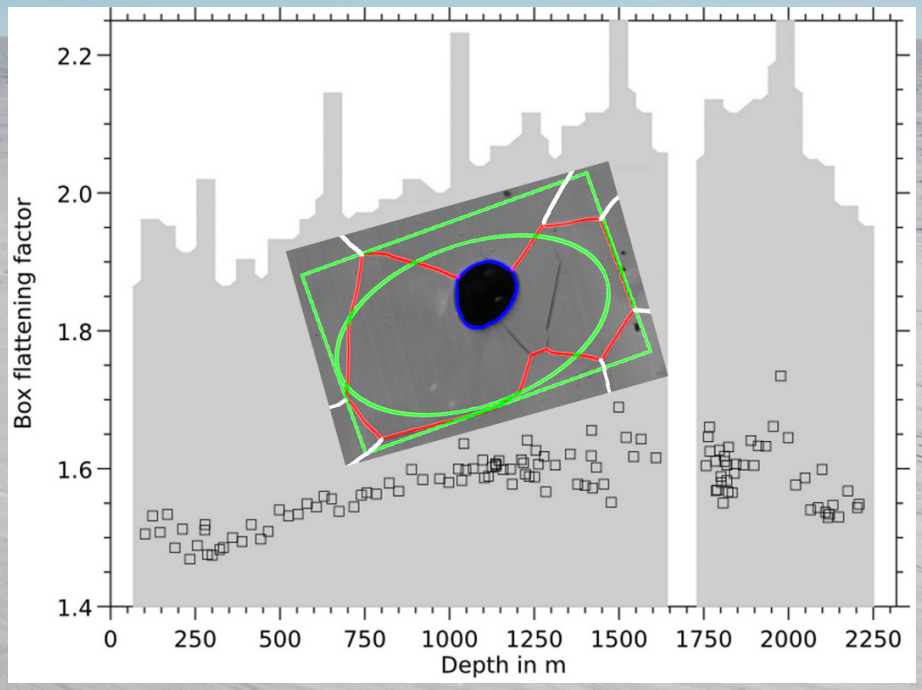






Grain shape

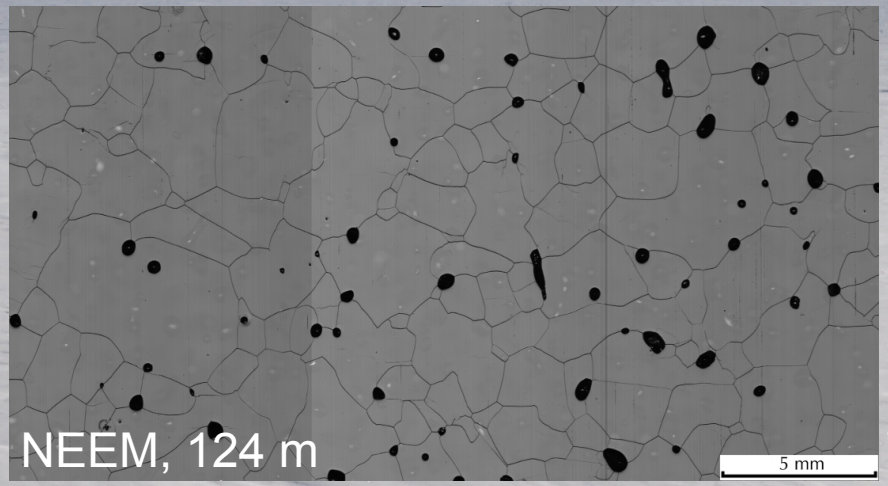


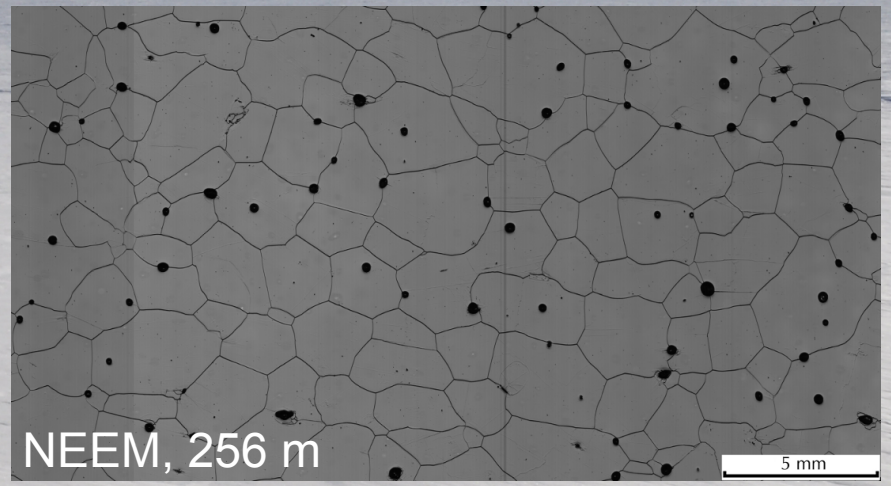


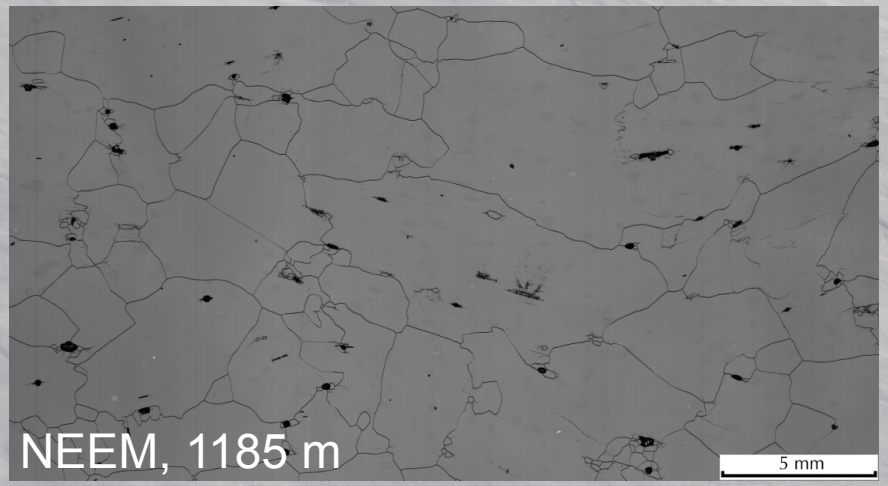
- Strong influence of high-pressurized air bubbles on grain shape
- Increasing flattening
- Reduction in strain energy between 100 m and 250 m?

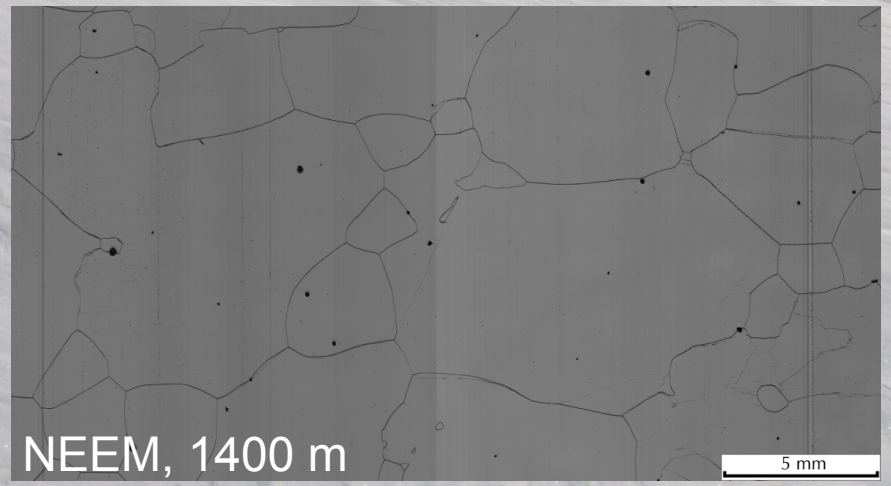
Reduction in surface energy

- Just below firn-ice transition (pore close-off)
- During air bubble – clathrate hydrate transition





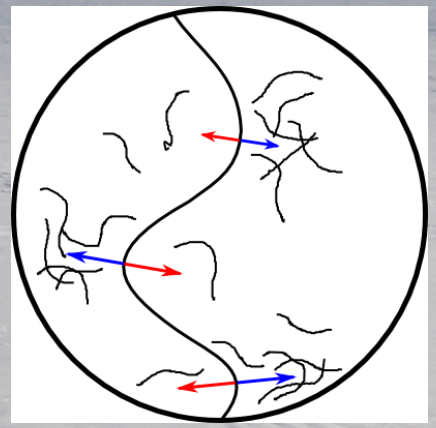


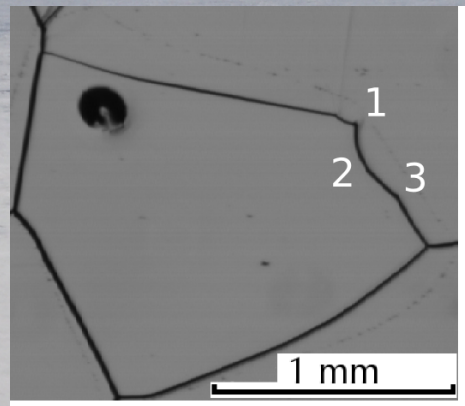


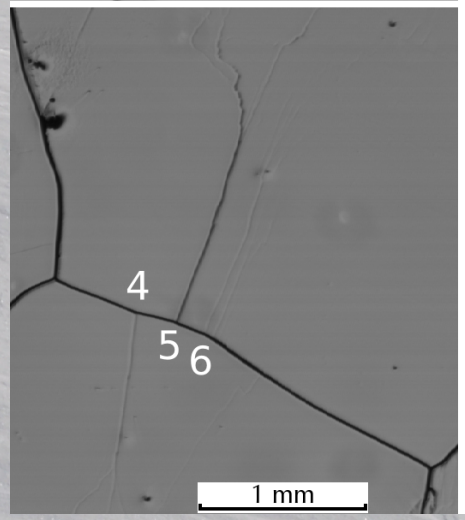
Driving forces on grain boundaries

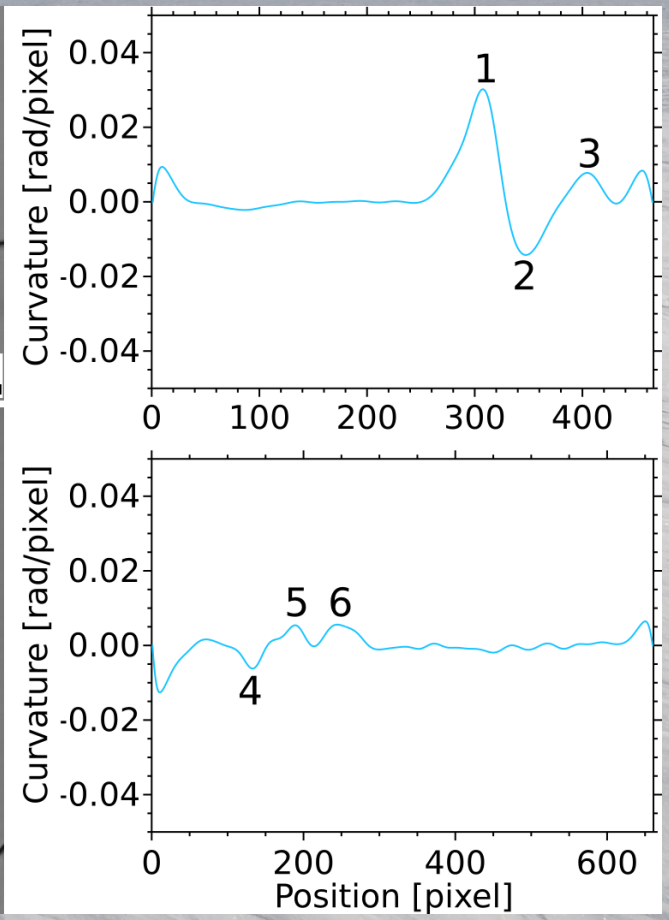
- Equilibrium assumed
- Highly curved grain boundaries are generated by: migration recrystallization or sub-GB pinning

→ Integrated curvature is lower estimate for dislocation density









- Quasi-continous microstructure analysis along deep ice core has become possible using sublimation groove images
- Automatic extraction of the grain boundary network
- Variability of grain size and grain shape found on different scales
- Comparison between different definitions of lower cut-off in grain size

Further information

- S. Kipfstuhl, I. Hamann, A. Lambrecht, J. Freitag, S.H. Faria, D. Grigoriev, N. Azuma
  Microstructure mapping: a new method for imaging deformation-induced microstructural features of ice on grain scale, **2006**,
  Journal of Glaciology 178: 398-406
- T. Binder, C.S. Garbe, D. Wagenbach, J. Freitag, S. Kipfstuhl
  Extraction and parameterization of grain boundary networks in glacier ice, using a dedicated method of automatic image analysis, **2013**,
  Journal of Microscopy 250 (2): 130-141
- Visit **ice-image.org** to download software

Thanks for your attention!