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Recrystallization diagram for polar ice

Deformation of polar ice

The flow or deformation of natural polar ice is mainly the result of dislocation creep, a combination of dislocation glide + climb.

In a polycrystalline material recrystallization is needed to overcome accumulation and entanglement of dislocations (strain hardening). Heterogeneous internal strain energies due to strong plastic anisotropy as well the “hot” temperatures relative to its melting point facilitate dynamic recrystallization in natural ice. Accordingly, it can be observed that grain growth in ice sheets at all depths is mainly driven by dynamic recrystallization.

Here we present a novel dynamic recrystallization diagram, which summarizes the competing recrystallization processes that contribute to the evolution of polar ice microstructure (Faria et al., 2014).

Recrystallization mechanisms

Static: grain boundary area reduction

Normal Grain Growth (NGG)

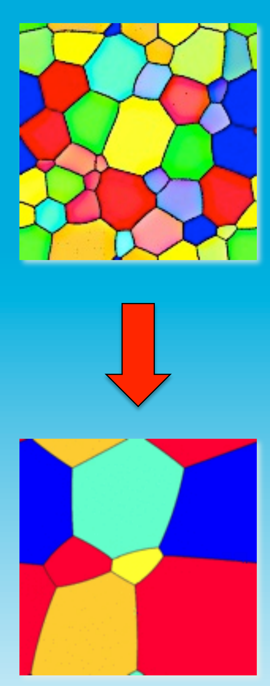
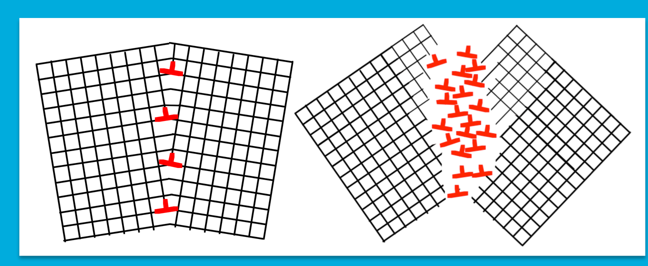


Image: ELLE, courtesy Bons

No strain needed

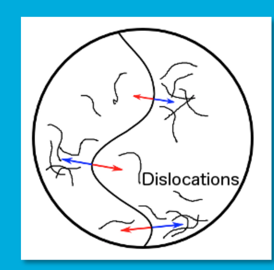
Dynamic: reduction of internal strain energy

Rotation Recrystallization (RRX)

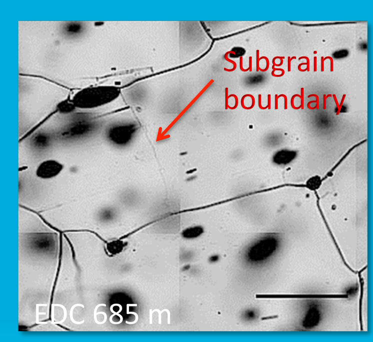


motion of dislocations, **grain size reduction**

Strain induced boundary migration (SIBM)

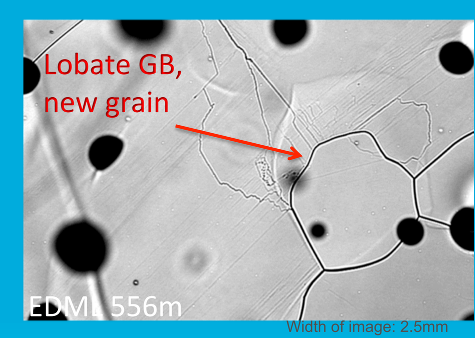


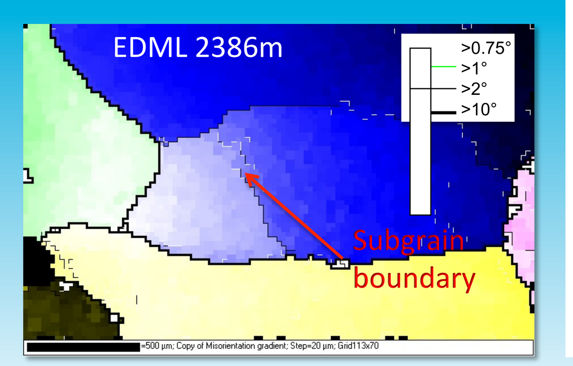
motion of grain boundaries, **grain growth and nucleation**



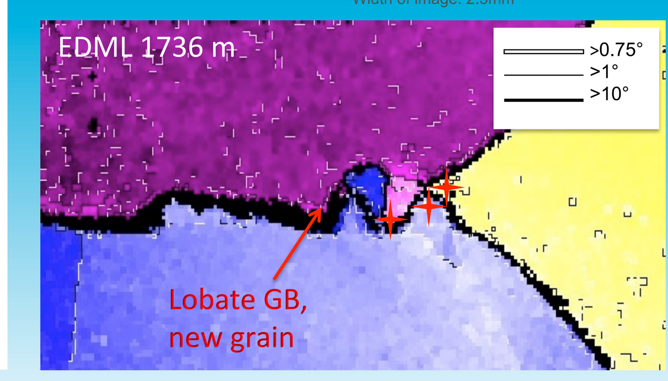
Observational methods

Light microscopy



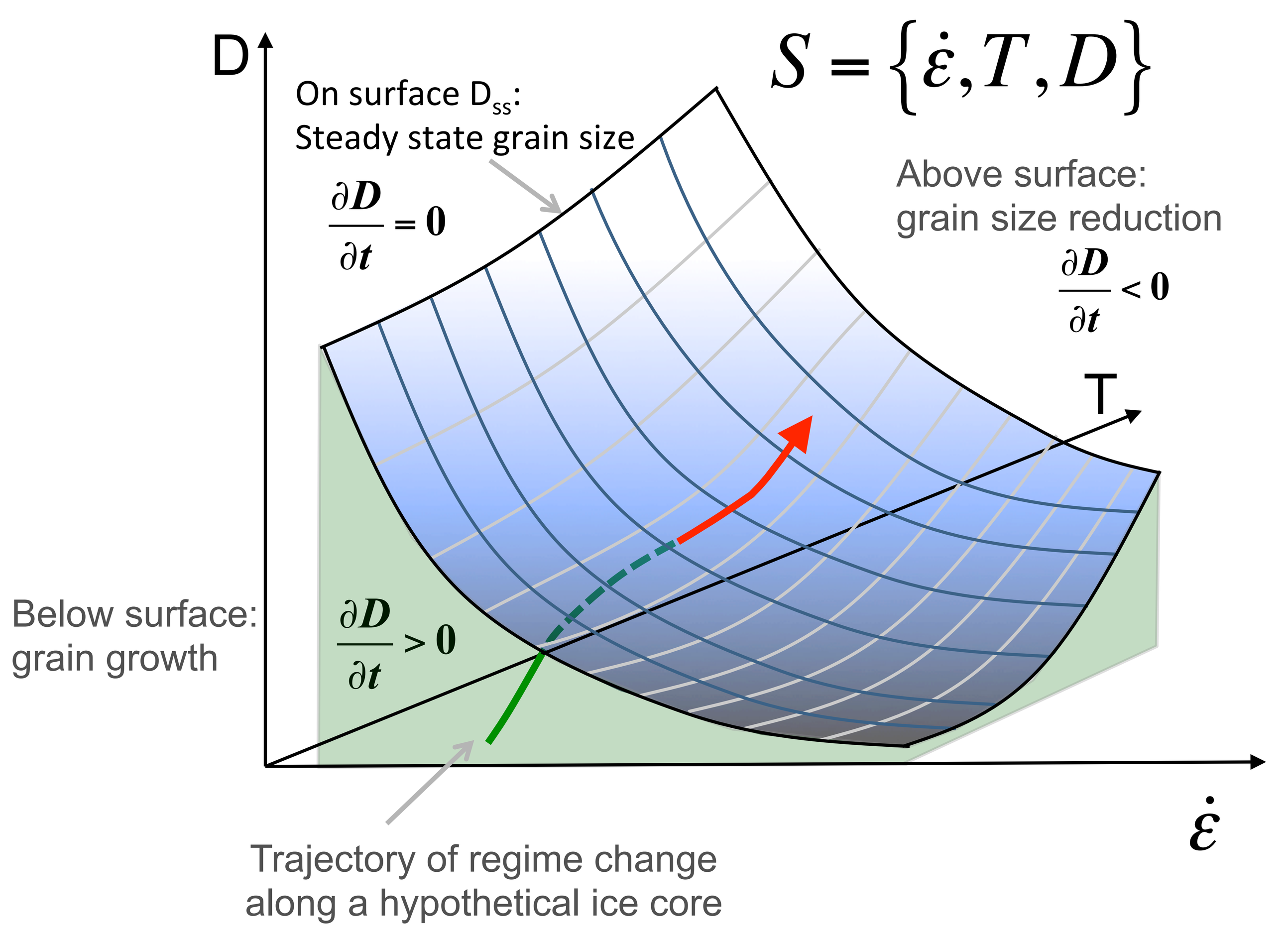


Electron Backscatter diffraction (EBSD)



Present in all depths of ice sheet, even in firn (Kipfstuhl et al., 2009)

New recrystallization diagram



Instead of assigning recrystallization regimes to a certain depth, our aim is to locate them in the three-dimensional state space of strain rate, temperature and mean grain size (D).

The surface D_{ss} describes the steady state grain size as a function of temperature and strain rate.

$D < D_{ss}$: **grain growth** regime, volume **beneath** D_{ss}

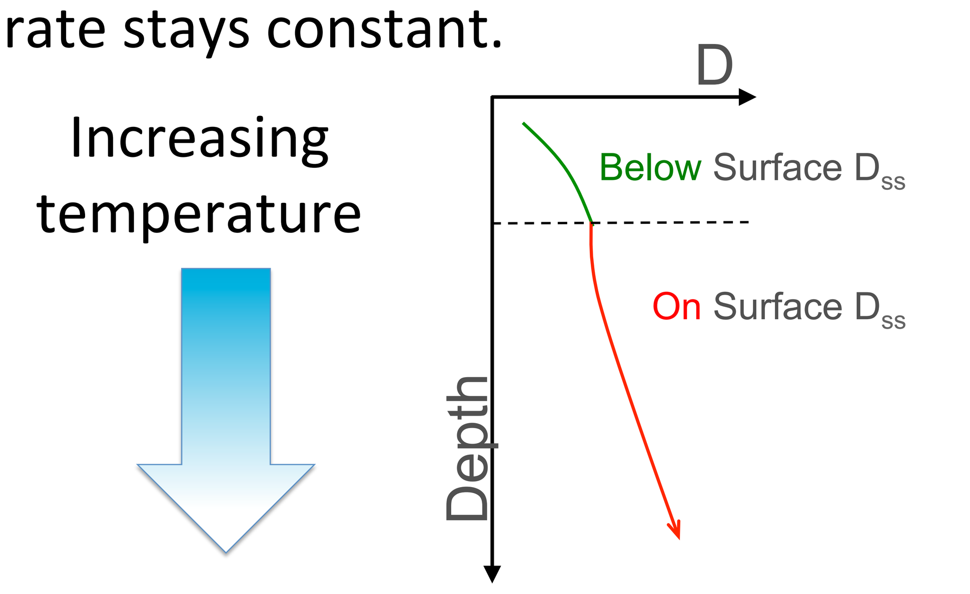
$D > D_{ss}$: **grain reduction** regime, volume **above** D_{ss}

$D = D_{ss}$: steady state

D_{ss} represents an attractor surface in the state space S. An explicit form of D_{ss} as a function of strain rate and temperature can be derived by combining an empirical relation for grain size evolution (Jacka & Li, 1994) and Glen’s flow relation, described in Faria et al. (2014b).

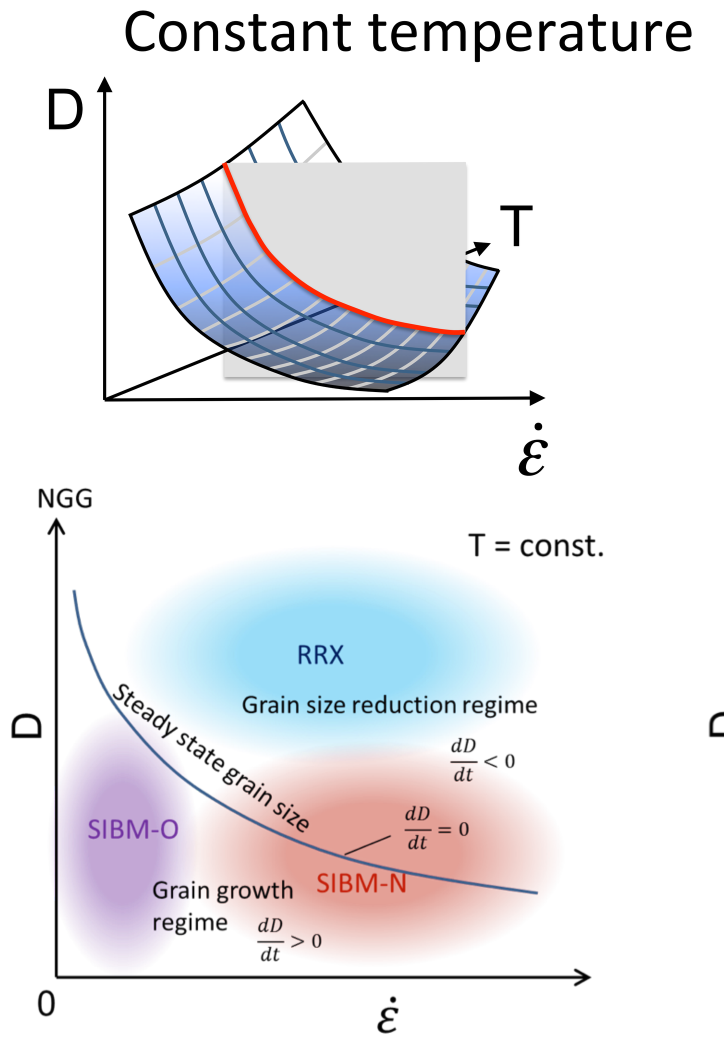
Grain size evolution

Following the path indicated with the green and red arrow in the recrystallization diagram, a grain size evolution can be derived for a volume of ice moving through the state space. Temperature is assumed to be increasing along the path, while the strain rate stays constant.

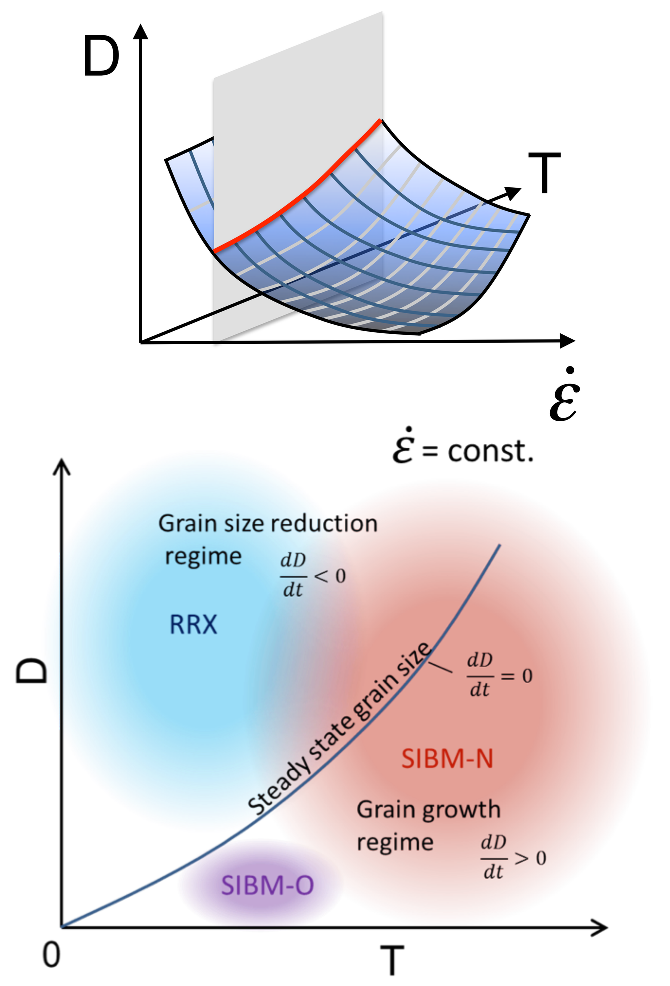


Assuming the ice volume is subducted beneath an ice dome, the vertical axis can be seen as an analogon to depth.

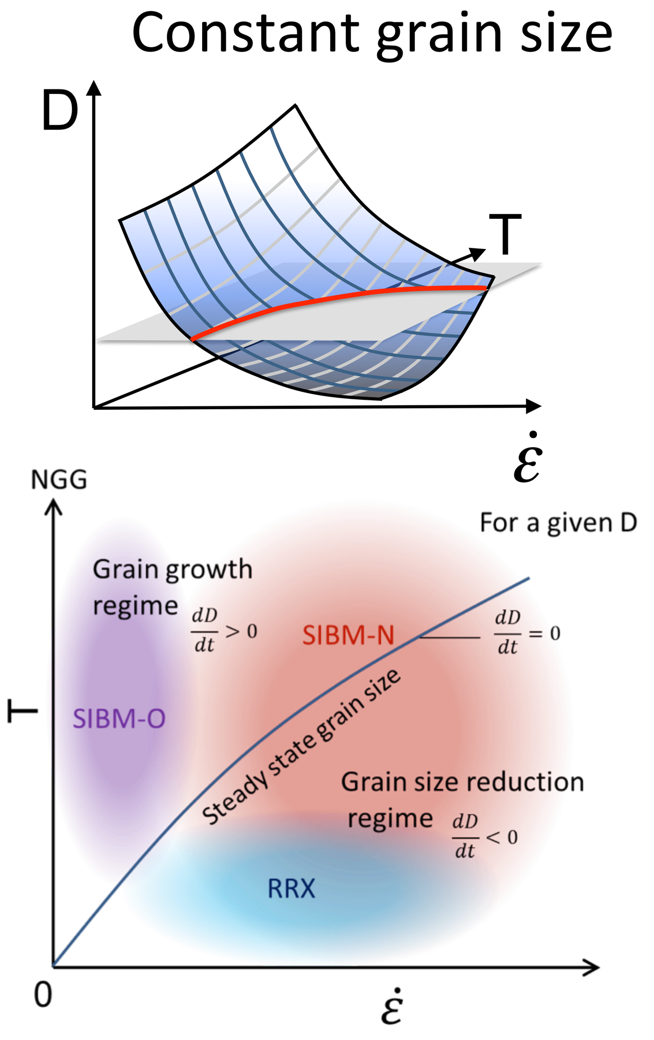
Constant temperature



Constant strain rate



Constant grain size



Dominant recrystallization regimes

- The **NGG** regime is restricted to the plane with zero strain rate in the diagram
- **SIBM-O** (without nucleation) is dominant for low strain rates and lower grain sizes
- **SIBM-N** (with nucleation) is dominant for higher temperatures and higher strain rates
- **RRX** is dominant for larger grain sizes and lower temperatures.

References

Faria, S. H.; Weikusat, I. & Azuma, N. The Microstructure of Polar Ice. Part I(**2014a**): Highlights from ice core research. Journal of Structural Geology, DOI: 10.1016/j.jsg.2013.09.010

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