DFG project BO 1776/12-1

Deformation and recrystallisation at the firn-ice transition - Microstructural simulations -

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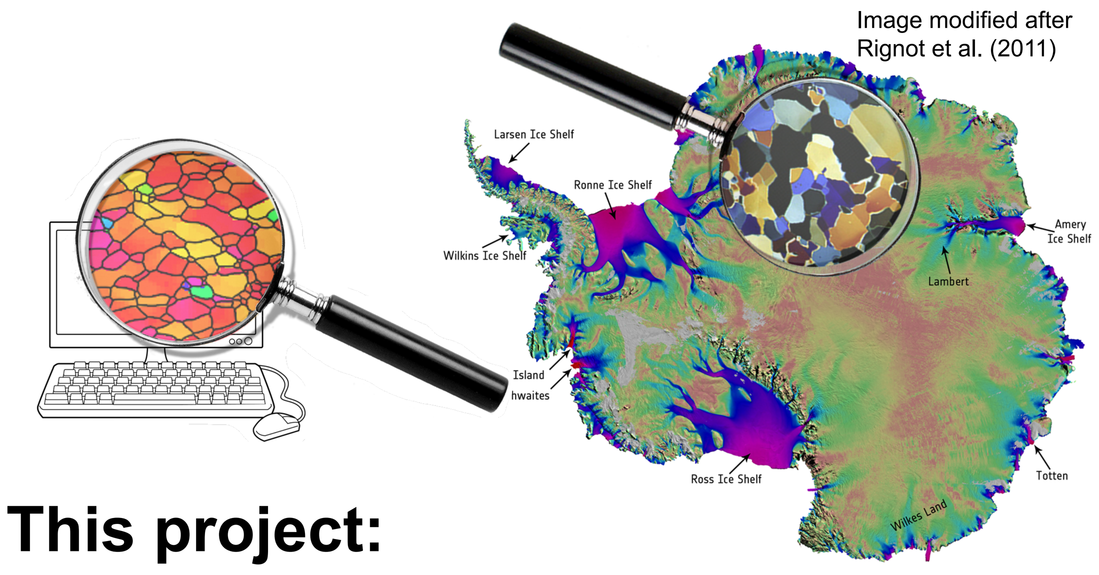
Introduction

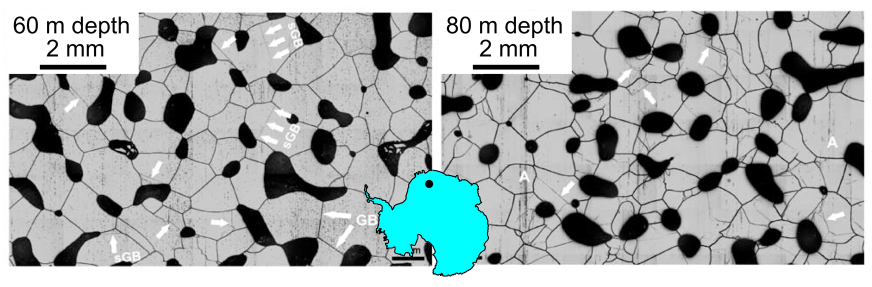
- Necessity to understand the **dynamic processes that control the flow of ice** when investigating the past and future climate
- The mechanical behaviour of ice: Result of **properties of individual ice crystals** and the distribution of **second phases** (e.g. air bubbles)
- At firn-ice transition: **Air bubbles are sealed off** and become a valuable paleo-atmosphere archive
- **Elle / VPFFT** simulations by Llorens et al. (2016) gave insight in deformation and recrystallisation of **pure ice** (free of impurities and bubbles)



This project:

- Updating the numerical approach to **fully incoporate air** as a second phase in simulations
- Systematic simulations to **investigate effects of air bubbles** on deformation and recrystallisation to support microstructural observations:

Firn microstructure images (Kipfstuhl et al, 2009) EDML ice core:



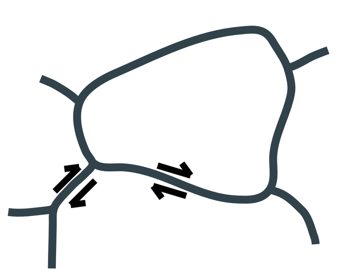
Evidences for static recrystallisation **Evidences for dynamic recrystallisation**

Research conclusions

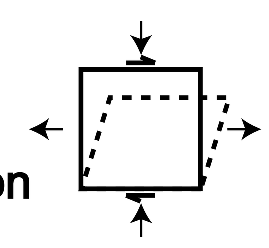
- **Bubbles control strain localisation** and induce more hetereogenuous microstructures in their vicinity
- This localisation leads to a **more localised dynamic recrystallisation** as proposed by Faria et al. (2014) using EDML firn data
- **Dynamic recrystallisation occurs in firn** as observed by Kipfstuhl et al. (2009), it is related to stress bridging and strain localisation between bubbles

Remaining challenges

- Possibility to take into account grain size sensitive processes such as **grain boundary sliding**

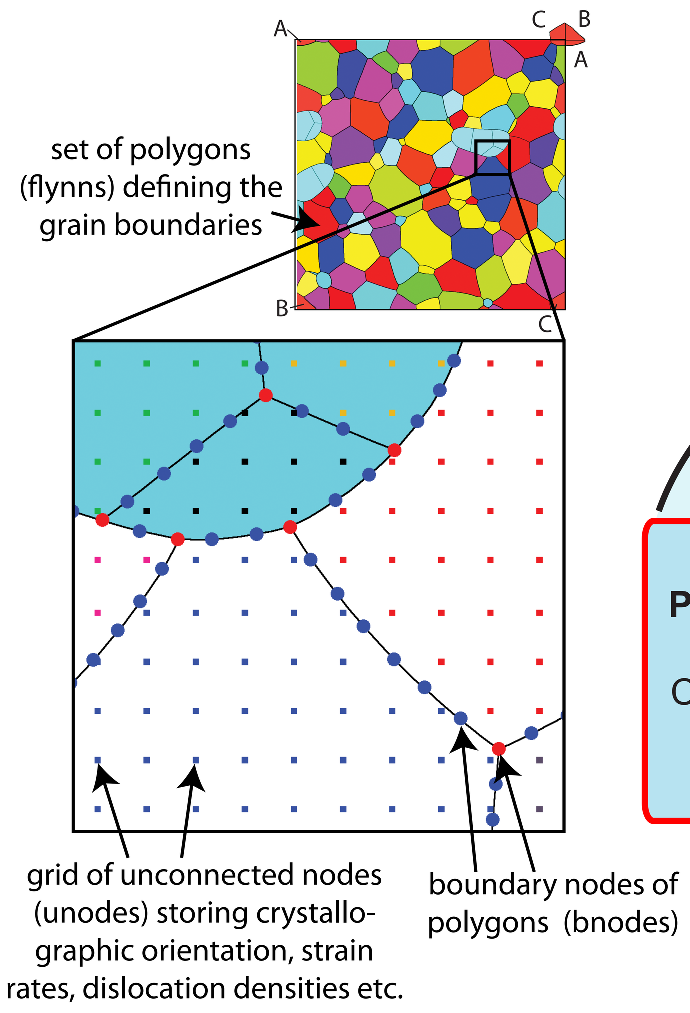


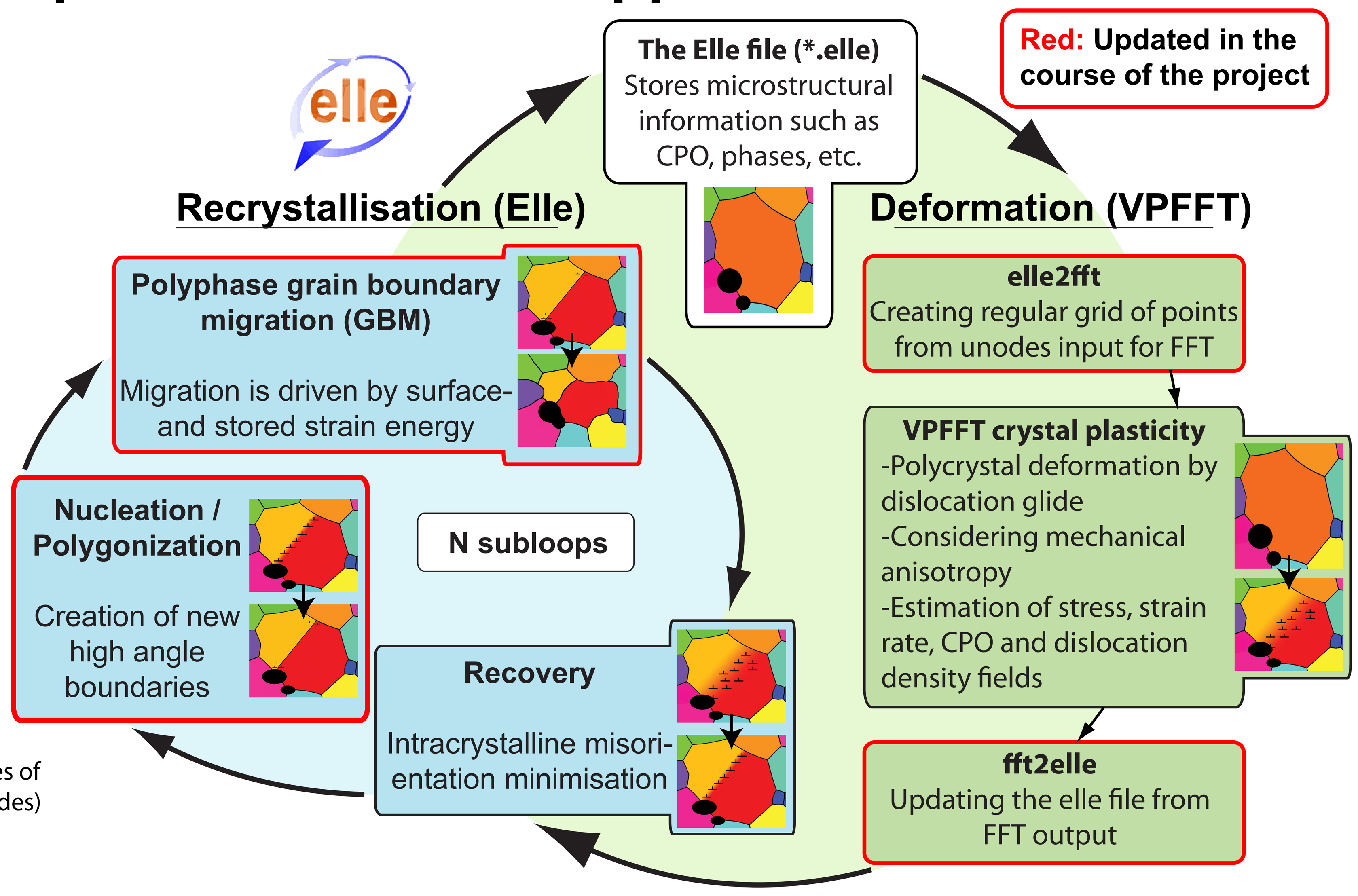
- Update the simulations to be suitable for **general shear deformation**



- Take **impurities** into account and investigate their effect on recrystallisation and deformation

Goals achieved: Updated numerical approach





Microstructure discretization:

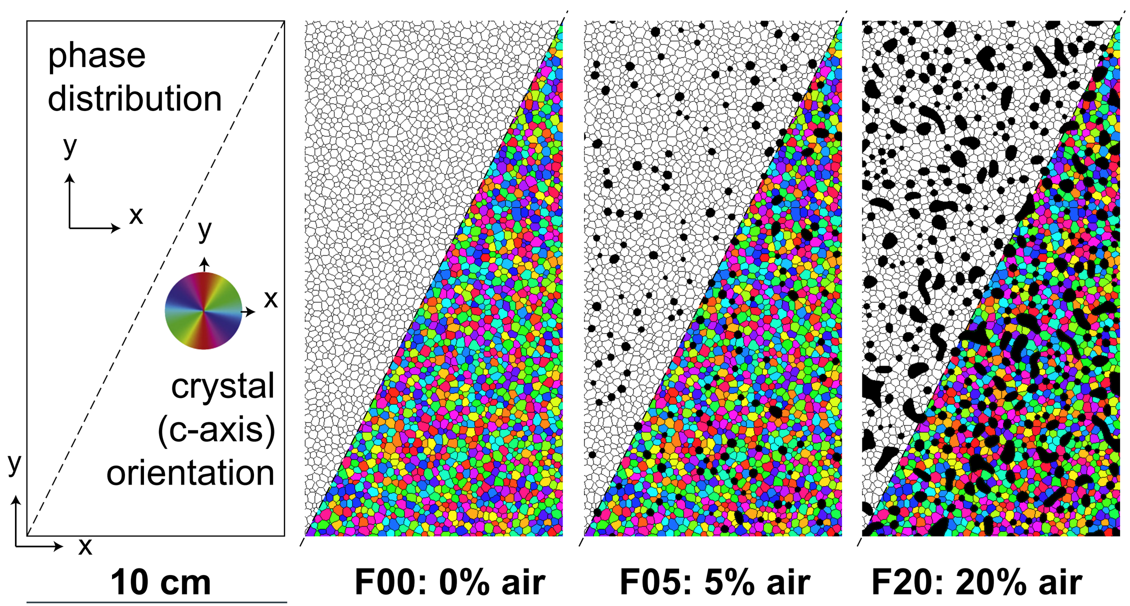
Periodic cell of contiguous polygons overlain by an unconnected regular grid storing intracrystalline properties.

Updated multi-process model with Elle / VPFFT:

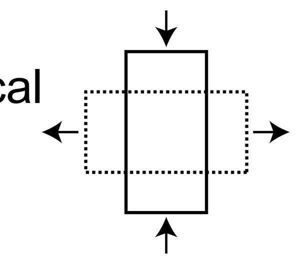
Full-field theory (VPFFT) crystal plasticity code coupled with modelling platform Elle (elle.ws): Successively running different codes in short numerical timesteps effectively enables multi-process modelling of deformation and recrystallisation.

Goals achieved: Systematic simulations

Initial microstructures and setup:



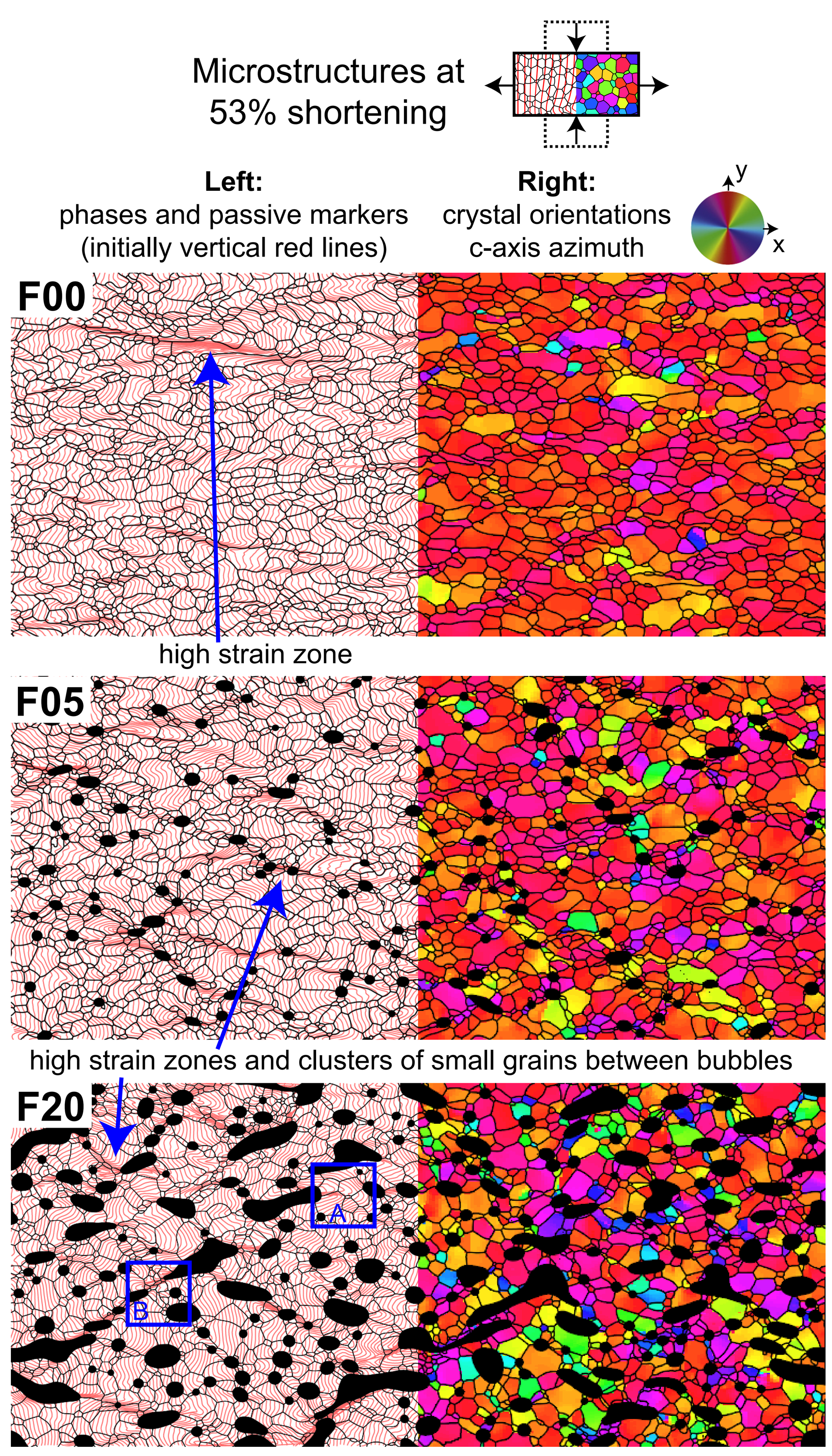
Pure shear conditions up to 53% vertical shortening ≈ 1x2 box ➔ 2x1 box



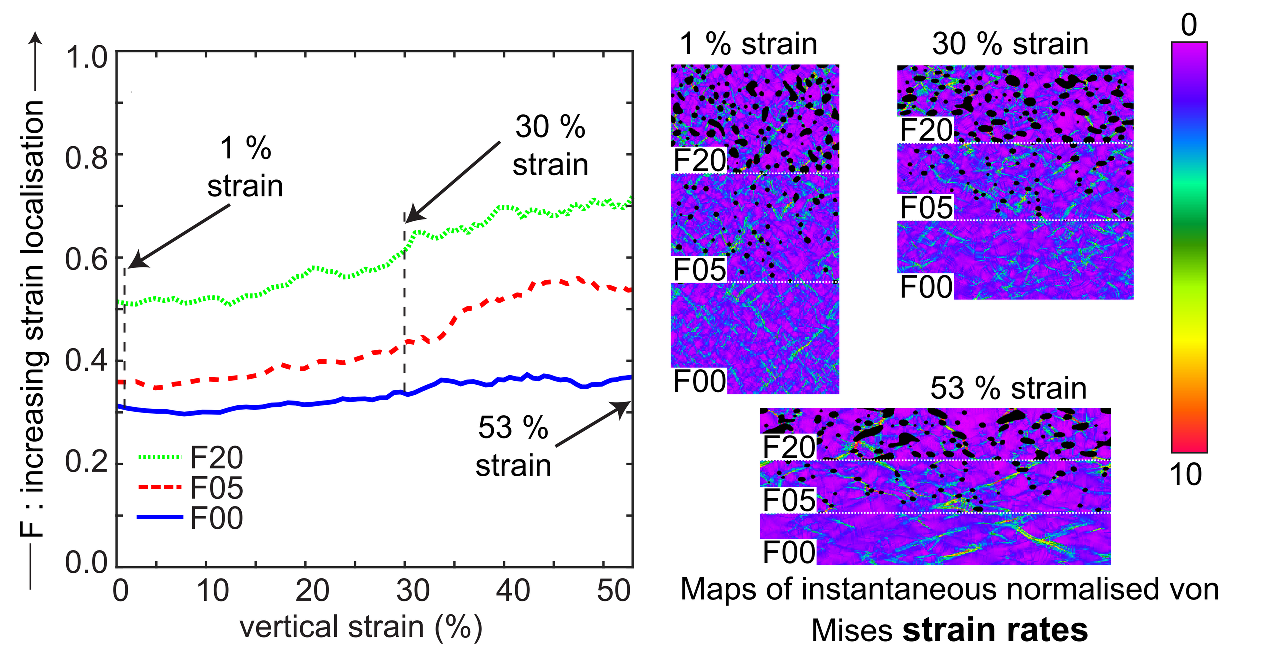
Initially 20x10 cm 2D box, mean ice grain area ≈ 6 mm² using a grid of 256x256 unodes

Basal slip set 20x easier than non-basal, air is set 5000x softer (incompressible and isotropic)

Results:

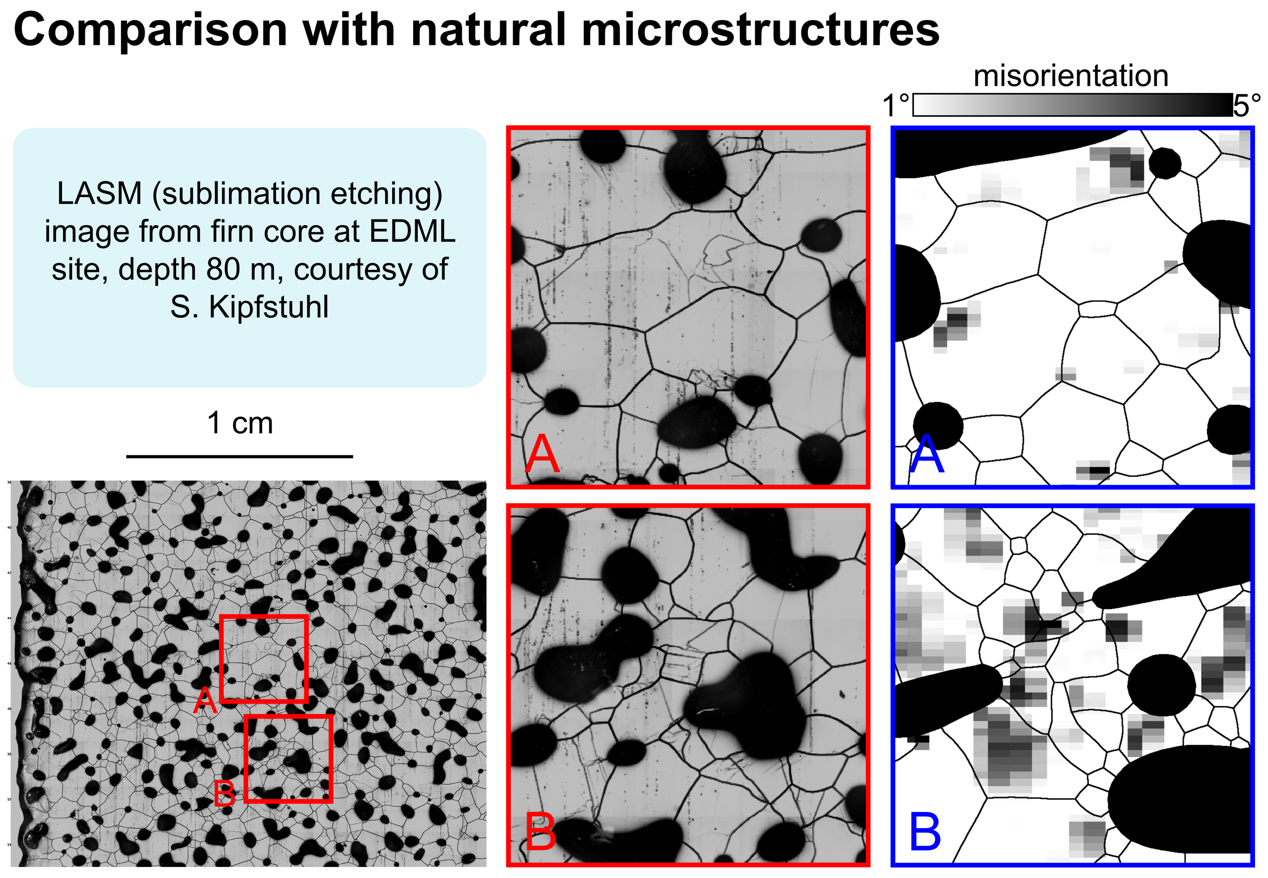


Localisation factors and strain rate maps: **Intensified strain localisation** with increasing amount of bubbles



Maps of instantaneous normalised von Mises **strain rates**

Comparison with natural microstructures



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Publications associated with the project

Bons, P.D., et al. (2016) Nature Communications, 7, doi: 10.1038/ncomms11427
Jansen, D., et al. (2016) The Cryosphere, 10, 359-370, doi: 10.5194/tc-10-359-2016
Steinbach, F., et al. (2016) The Cryosphere, doi: 10.5194/tc-10-3071-2016
Llorens M.G., et al. (2017) Philosophical Transactions of the Royal Society A, doi: 10.1098/rsta.2015.0346

Scan for simulation movies