Microstructure and solutal boundary layer at the sea ice - ocean interface

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EGU - Sharing Geoscience Online 2020

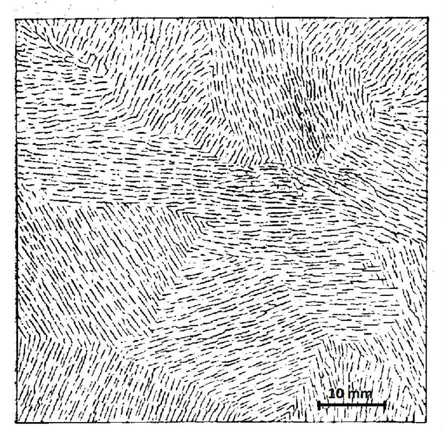
OS1.13 Under cover: ice-ocean interactions from the boundary layer to the Southern Ocean

Overview

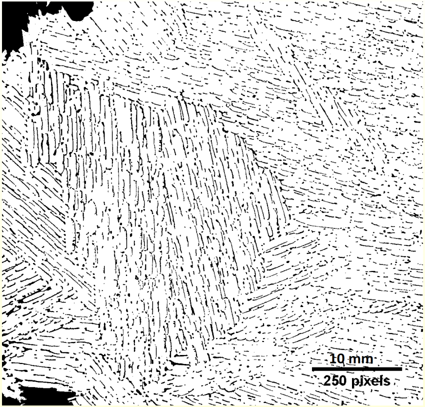
- Motivation: Sea ice and some marine ice shelves freeze with a cellular interface.
  - How does this microstructure change with growth conditions?
  - Growing sea ice rejects brine into a solutal boundary layer. How does this layer evolve and interact with microstructure?
  - How does the microstructure shape ice-ocean interaction?
- Approach/methods
  - Morphological stability analysis of a growing sea ice interface
  - Brine rejection and salt finger fluxes
  - Microscopic X-ray imaging of the sea ice interface
- Key results[1]
  - Microstructure (plate spacing) scales with growth velocity
  - Salt finger convection implies a BL thickness $D_s/V < 1$ mm
  - Relevance for growth of sea ice and marine ice shelves

[1] from "The plate spacing of sea ice", S. Maus, March/2020, in re-review at Annals of Glaciology

2-D imaging of the sea ice – ocean interface

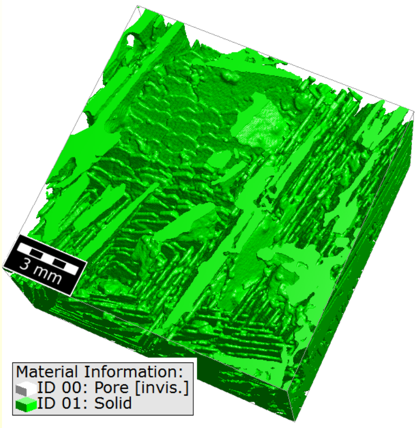


Drawing after a tinfoil replica from the bottom of sea ice (Drygalski, "Grönlands Eis und sein Vorland", 1897)

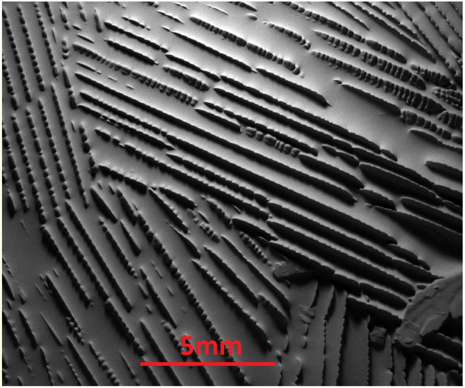


Slice from a 3-D X-ray micro-tomographic image near the bottom of laboratory grown sea ice (S. Maus, unpubl.)

3-D imaging of the sea ice – ocean interface

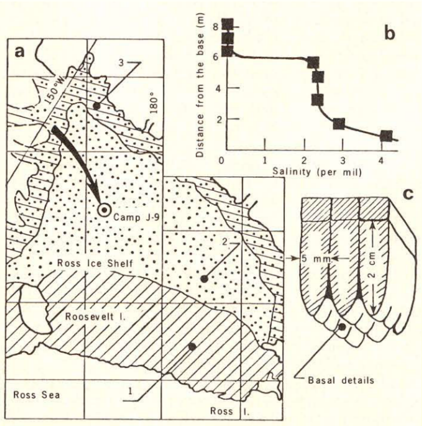


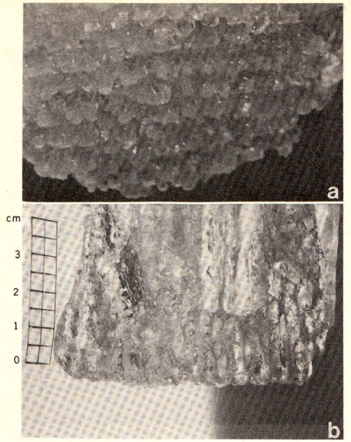
3-D X-ray tomographic image of the ice-seawater interface of laboratory grown sea ice.



2.5-D image of the ice-seawater interface of laboratory grown sea ice, obtained with an elastomeric sensor (www.gelsight.com).

Imaging of an ice shelf – ocean interface

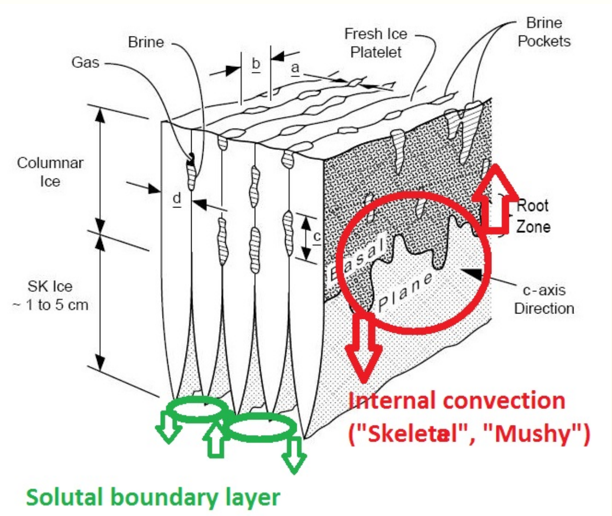




Lammelar plate spacing (10 times larger than for sea ice) was also observed at the bottom of the Ross Ice shelf.

(from Zotikov et al., 1980, DOI: 10.1126/science.207.4438.1463)

The plate spacing – a fundamental microstructure scale



How do plate spacing and solutal boundary layer interact?

Modified after Kovacs (CRREL Rep. 96-7, June 1996)

Key Result 1: Plate spacing a_0 versus growth velocity V

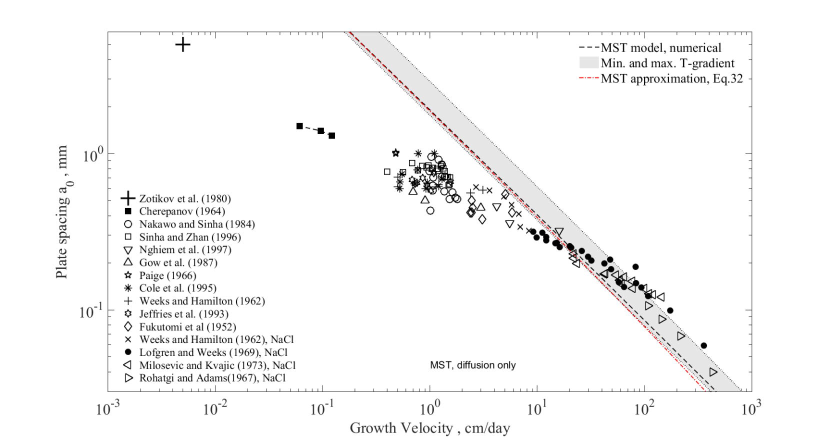


Plate spacings from the laboratory to the bottom of ice shelves. Morphological stability theory (MST) based on solute diffusion only implies $a_0 \sim V^{2/3}$ and only explains the lab regime.

Key Result 2: Plate spacing a_0 versus growth velocity V

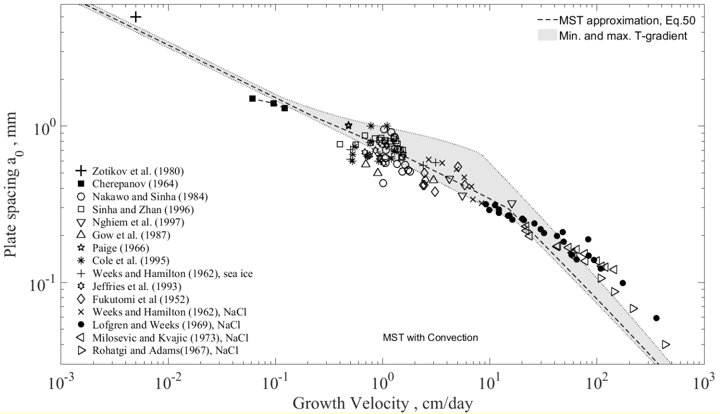
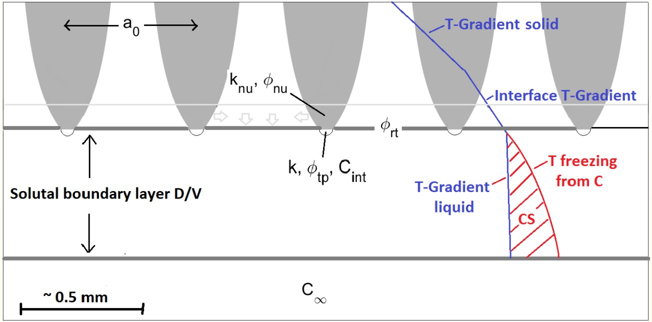


Plate spacings from the laboratory to the bottom of ice shelves. MST based on solutal BL convection model implies $a_0 \sim V^{1/3}$ and explains also the sea ice and marine ice regimes.

Key Result 3: Supercooling and solutal boundary layer



Sketch of the freezing interface with plate spacing a_0 and the solutal boundary layer ahead. Within the solutal boundary layer the solute concentration is changing from C_{int} to C_∞. The corresponding freezing temperature is lower than the actual temperature which implies that this layer is constitutionally supercooled (CS). Solid fraction ϕ_{tp} and C_{int} within the tip regime relate to k that sets this supercooling. The boundary layer D/V decreases with ice growth velocity V. At a critical BL thickness salt finger convection starts and the BL thickness becomes constant ($\approx$ 0.5 mm according to the present model, where this transition takes place below $V \approx$ 15 cm/day.

Acknowledgements

I like to thank

- Margret Matzl, Martin Schneebeli (WSL-SLF Davos) for XRT imaging support
- Andreas Wiegmann, Jürgen Becker (Math2market): For support with 3-d image analysis using GeoDict
- The Research Council of Norway (NFR) for funding through grants 218407 (MIPHASICE) and 243812 (MOSIDEO)