Synchrotron-based X-ray Tomographic Microscopy of Sea Ice

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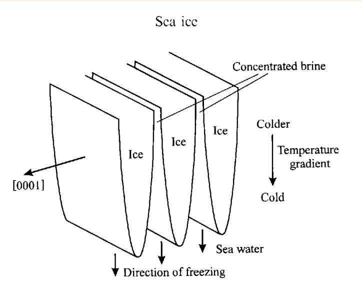
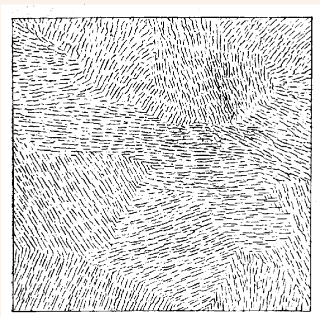
1 Sea Ice Skeleton



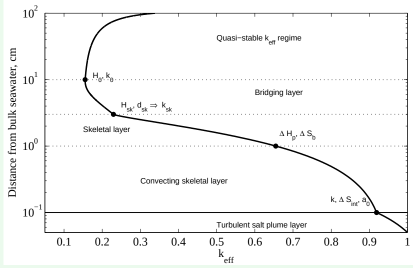
Principal sub-grain sea ice structure near the freezing interface; from Petrenko and Whitworth (1999).



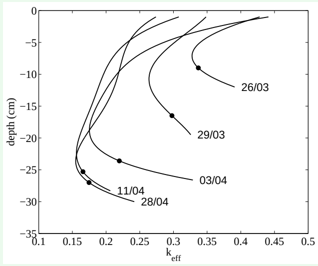
Tinfoil replica from the bottom of sea ice obtained in 1897 by E.v. Drygalski (6 cm on a side, 1-2 cm grain size)

Columnar sea ice grows with a lamellar interface of vertically oriented plates, typically spaced by 0.3-1 mm, and parallel within each grain. Its macroscopic properties depend on how this initial *skeleton* transforms into pore networks and disconnected inclusions.

2 Microstructure and Bridging



Conceptual regimes of sea ice desalination



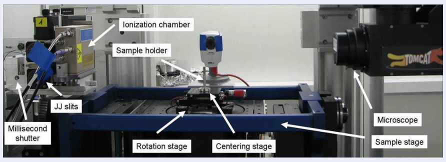
Young ice salinity profiles

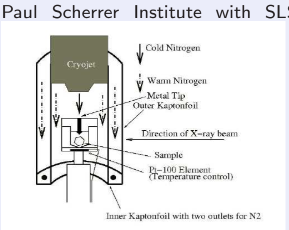
The near-bottom transition regime from brine layers to pore networks may be termed the *Bridging Layer*:

- Macroscopically it may be associated with ceasing desalination and a salinity minimum $\approx 10-15$ cm from the interface
- Microscopically it is, due to difficulties in sampling, storage and image technique limitations, not well understood.

3 Synchrotron-based X-ray tomography

Paul Scherrer Institute with SLS

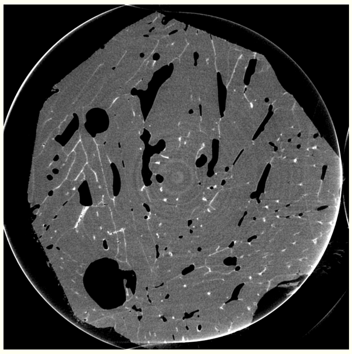




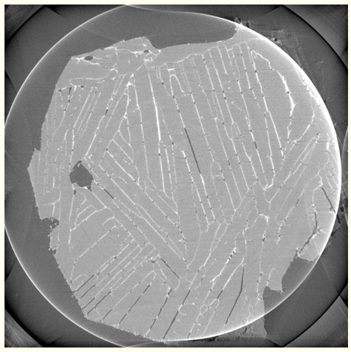
We have imaged the microstructure of laboratory-grown seawater ice by synchrotron-based X-ray tomography (SXRT). After rapid centrifugation of brine at in situ temperature samples were transported on dry ice to the TOMCAT tomography beamline of the Swiss Light Source (SLS). A special stage keeps the sample cold and prevents condensation on the sample holder.

$\Rightarrow$ Three-dimensional images with micrometer resolution

4 Imaging the Salt and Pore Space



Centrifuged, ≈ 12 mm, voxel size 5.6 μm



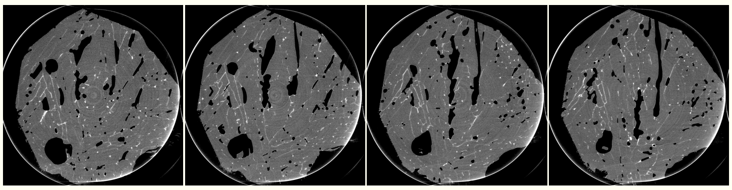
No centrifuge, ≈ 12 mm, voxel size 5.6 μm

Imaging at $\approx -35^o$C allows us to distinguish air (dark) solid salts (bright) and pure ice (grey).

- Centrifuged $\Rightarrow$ interconnected and disconnected pore space
- Rapidly frozen samples $\Rightarrow$ pattern of original brine layers

Many of the air pores (emptied by centrifugation) have diameters less than 50 μm.

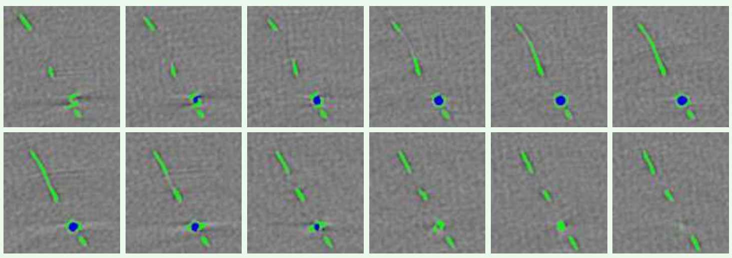
5 Details of Brine Channel Architecture



Horizontal images, ≈ 12 mm, voxel size 5.6 μm, spaced vertically by 220 μm.

While limited to ≈ 1 cm sample size, this was sufficient to reveal the main architecture of O(1 mm) brine channels. Already on a vertical scale of 0.2 mm these show high complexity and variability.

6 Very High Resolution Imaging



≈ 10 μm air bubble (blue) in a precipitated salt layer (green), voxel and spacing 1.4 μm

Imaging at the highest resolution (0.7 μm, binned two times) lets us retrieve fractionation details and the most tiny inclusions. Meanwhile the TOMCAT beamline allows for improved resolution of 0.35 μm, appropriate to resolve single salt crystals.

7 Conclusions

Synchrotron-based X-ray tomography (SXRT) has been applied to obtain three-dimensional images of laboratory-grown sea ice with one to two orders of magnitude higher resolution than hitherto realised. The results illustrate the importance to retrieve microstructural details of natural sea ice with micrometer resolution.