Sea Ice microstructure
Oil migration through brine channels

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Marc Oggier
Geophysical Institute
University of Alaska Fairbanks
Fairbanks, AK 99775-7320, USA
e-mail: marc.oggier@gi.alaska.edu

Outline

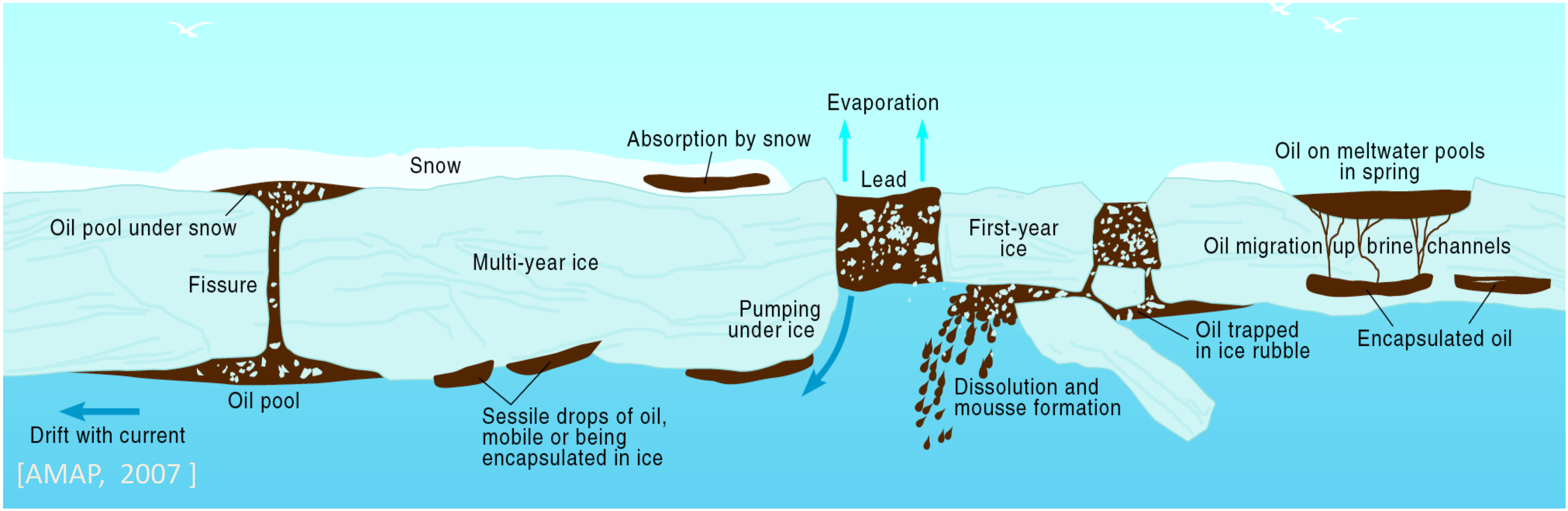
- Oil/sea ice interaction
- Sea-ice microstructure
  - Growth
  - Porosity & permeability
  - Brine movement
- Oil entrainment in ice
- Conclusions

Sea Ice Group (GI|UAF)

- Hajo Eicken
- Chris Petrich
- Jonas Karlsson
- Daniel Pringle

.... and other collaborators

Oil & sea ice interactions



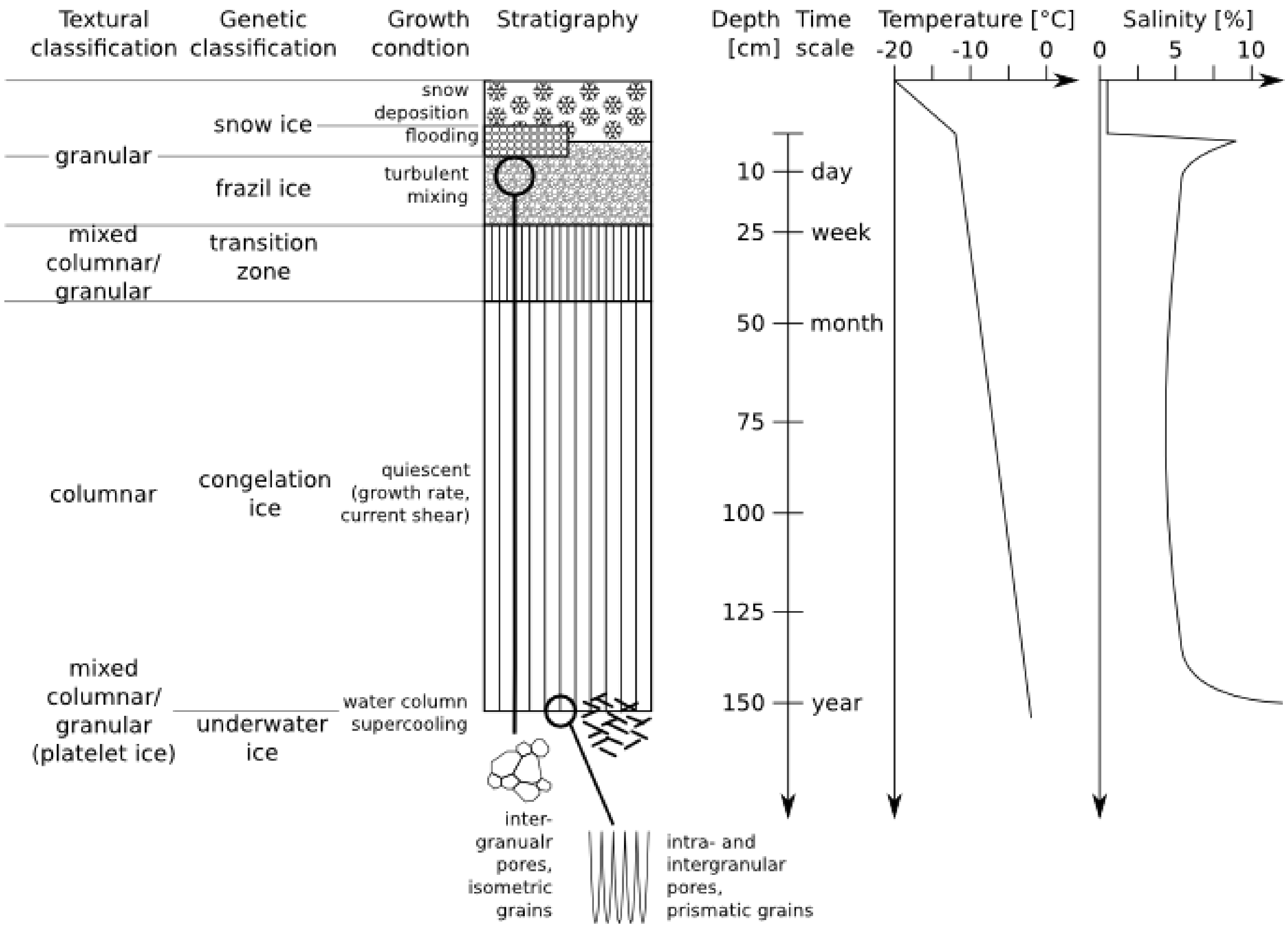
Oil encapsulation

- Under-ice spreading
- Encapsulation in growing ice
- Mobilization and migration in spring
- Surfacing and weathering
- Release with ice break-up

Potential mitigation

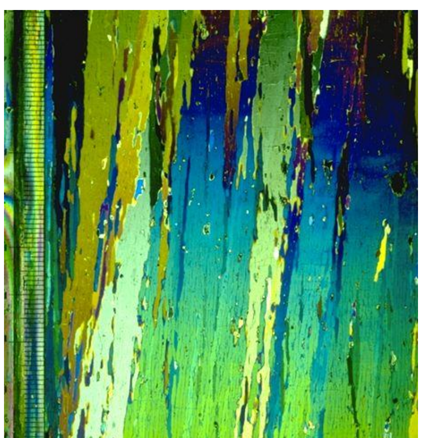
- Limited access
  - Both under- and in-ice
- Remediation
  - After oil have migrated toward the surface

Sea ice microstructure properties and structure profiles

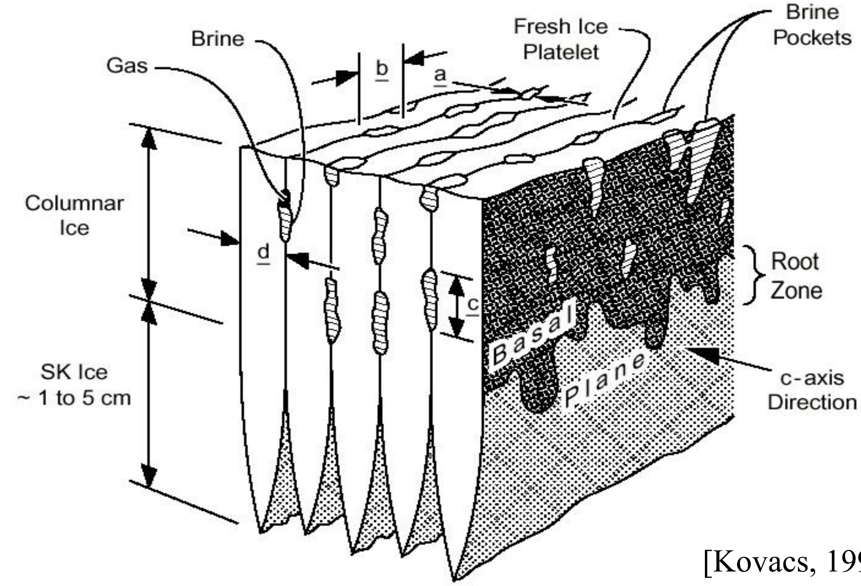


Sea ice microstructure

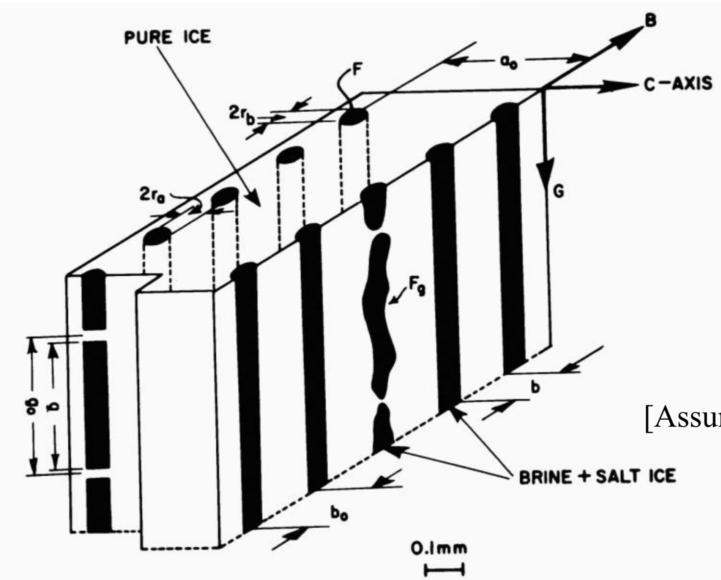
- Brine entrapped at the bottom of sea ice
- Constriction & segregation of pore space
  - During thickening & cooling
  - Brine layer > brine tube > brine pockets
  - Depends of salinity & temperature (porosity)



[Eicken]



[Kovacs, 1996]



[Assur, 1960]

Sea ice microstructure

Brine channel system (BCS)

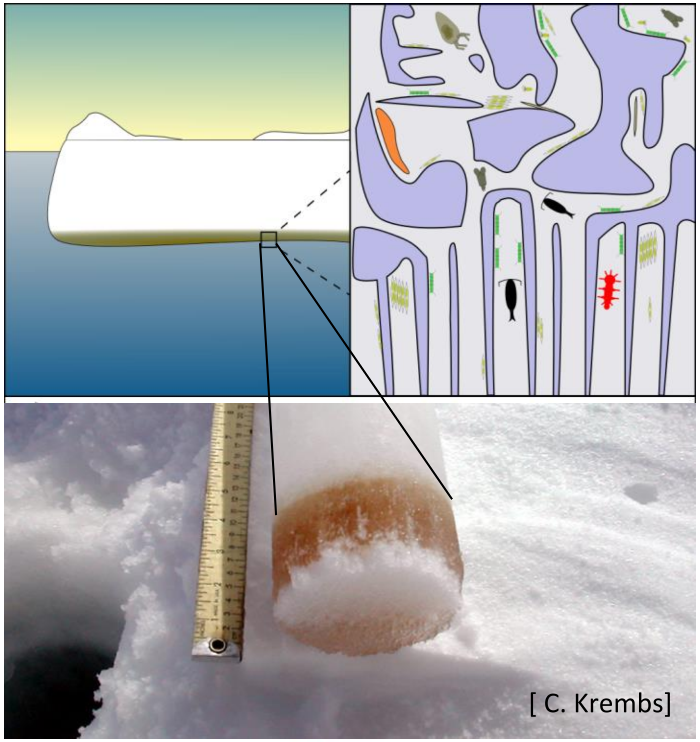
- Winter (March)
  - Number density
    0.5±0.1 dm^{-2}
  - Aerial fraction
    0.10±0.04 cm^{-2}
  - Mean spacing
    11±4 cm

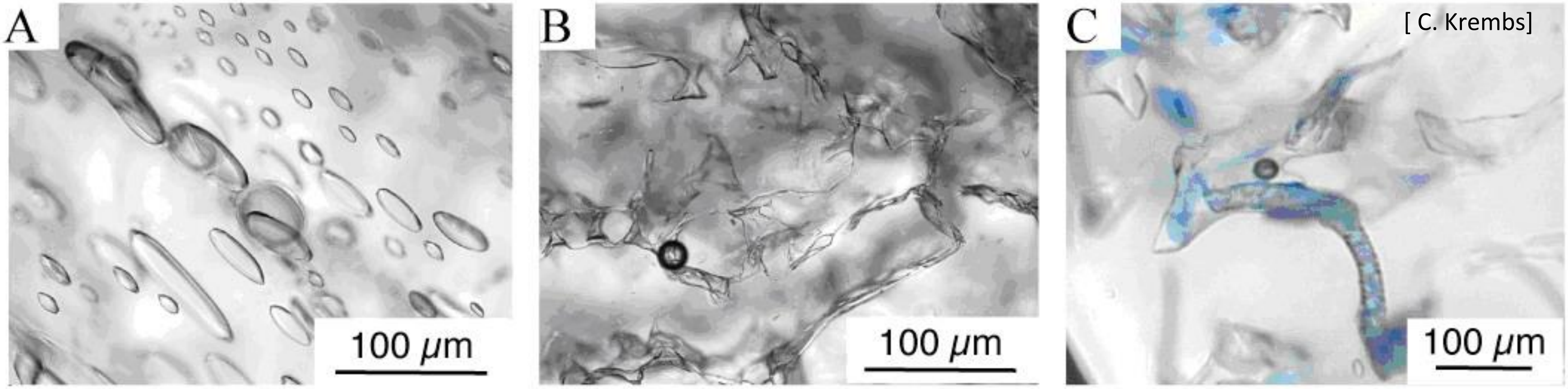
vertical section

horizontal section (D=9cm)

Sea ice microstructure

- Host of multitude of organisms
- Release of extracellular polymeric substance (EPS)
  - Influence ice growth & microstructure
- Biota would be influence by oil spill



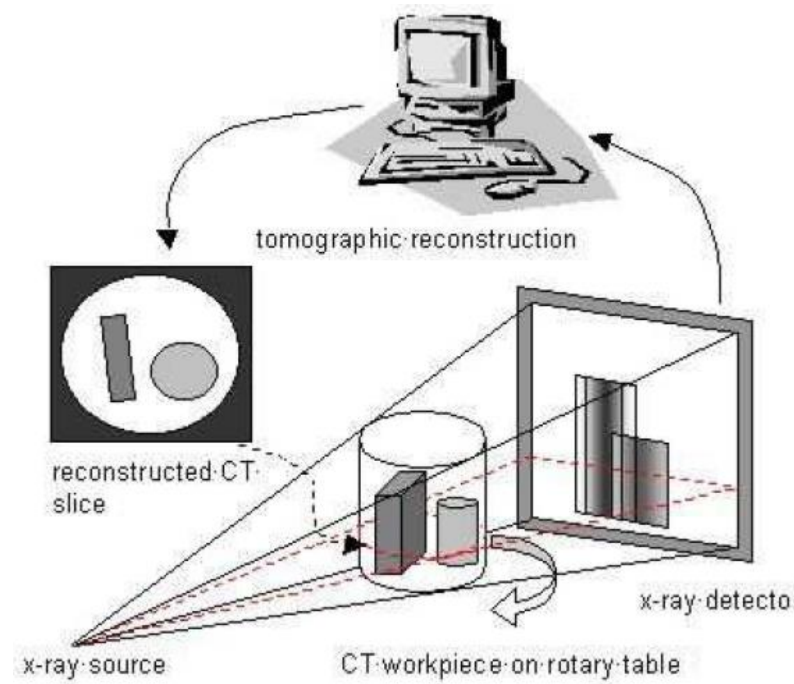


No EPS *EPS* *Blue colored EPS*

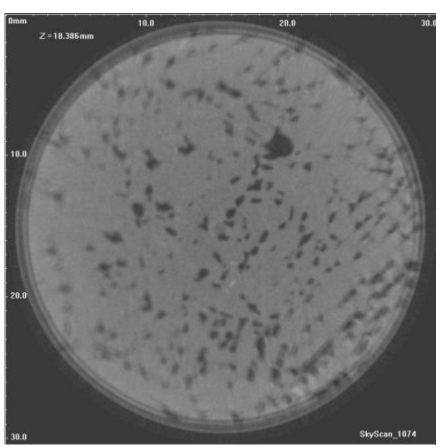
Sea ice microstructure — X-ray computed tomography

- X-ray imaging
  - Multiple projections of a same object
  - Every projection at a slightly different angle
  - Contrast based on density

- Computed tomography
  - 2D slices
  - 3D model reconstruction



[D. Pringle]

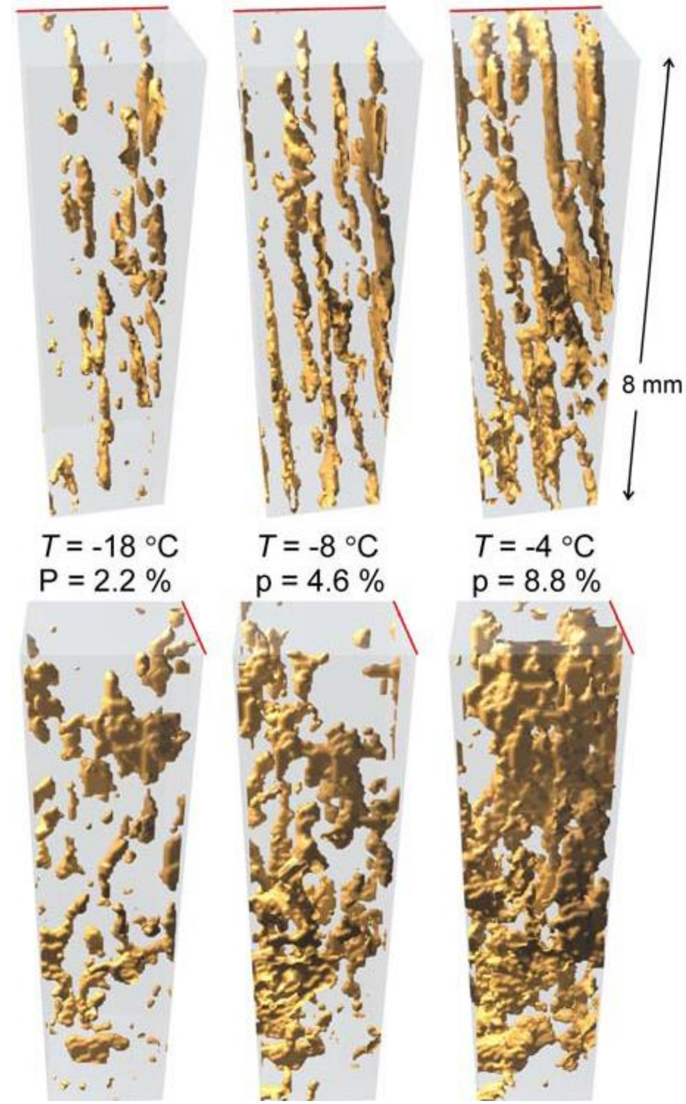


Porosity

- Winter growth
  - Columnar sea ice
  - Brine channel
    - V_f: 2-3% in January
    - Segregated

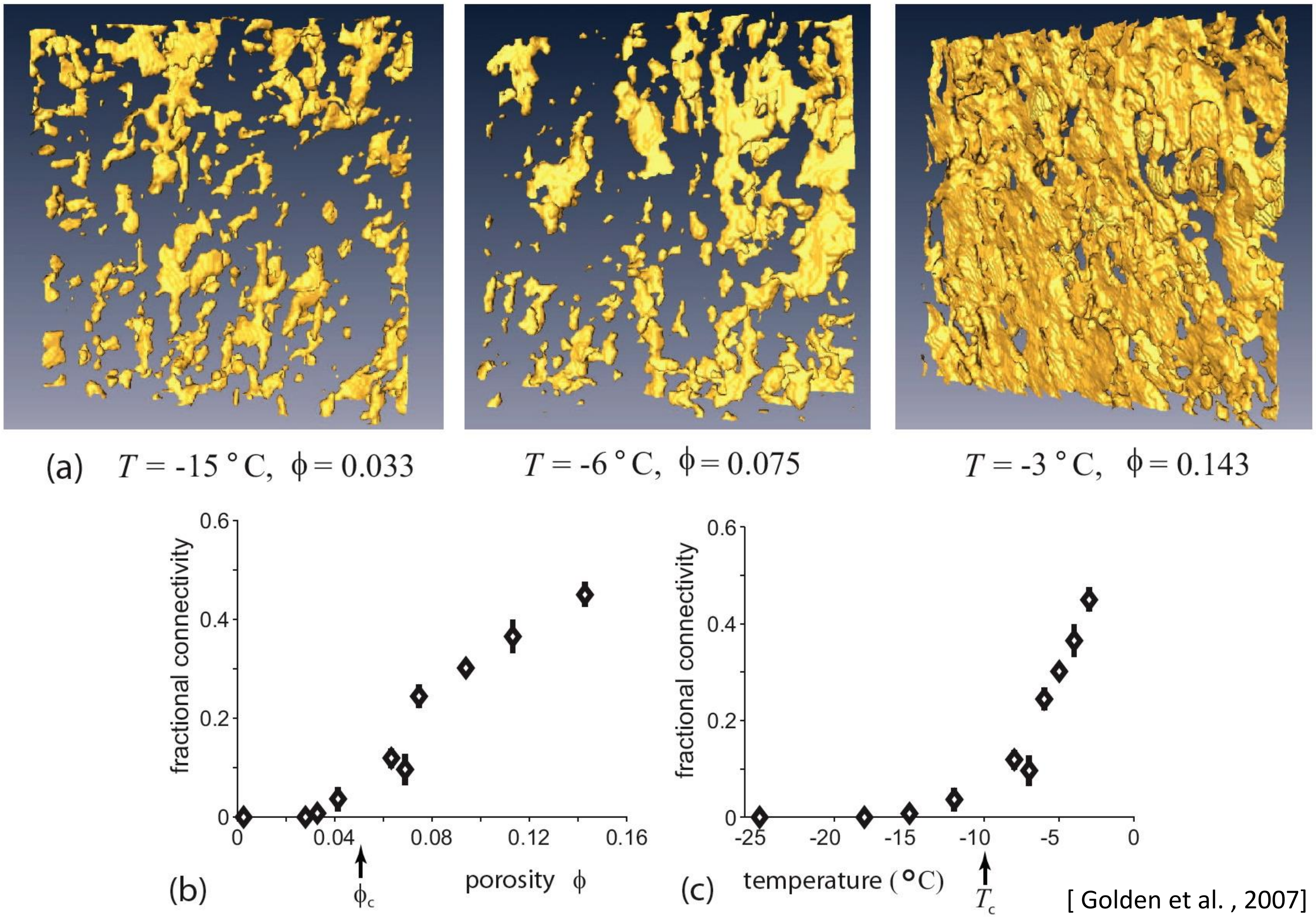
- Spring
  - Warming event
  - Increasing porosity
    - Increasing channel diameter
    - Interconnection
  - Salinity change

- Volume occupied by brine
  - Dependant of temperature and salinity



Brine channel evolution
[Pringle, 2009]

Connectivity is function of temperature

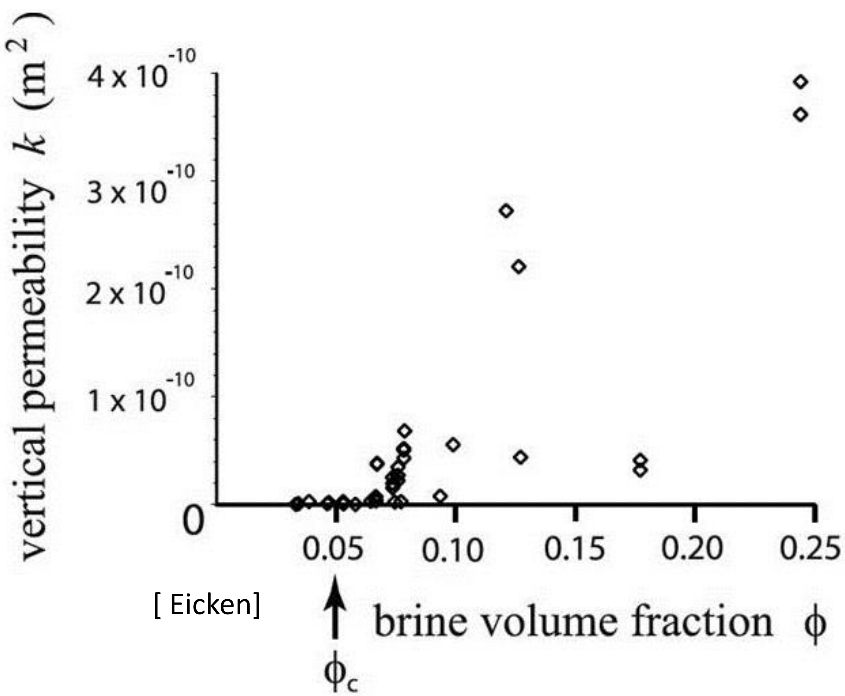


[Golden et al. , 2007]

The fractional connectivity is the proportion of inclusions intersecting the upper surface which are also connected to the lower surface.

Porosity Porosity- permeability linkage

- Intrinsic permeability
  - Mathematical model (Golden et al., 2007)
  - Difference between cold & warm ice
- Percolation threshold ϕ_c=0.05
  - T = -5°C
  - S = 5 PSU



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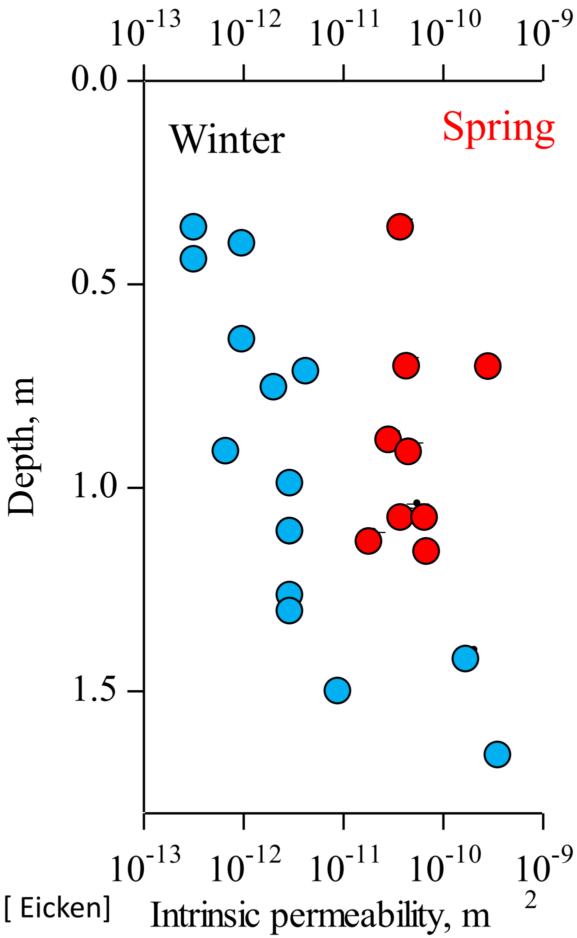
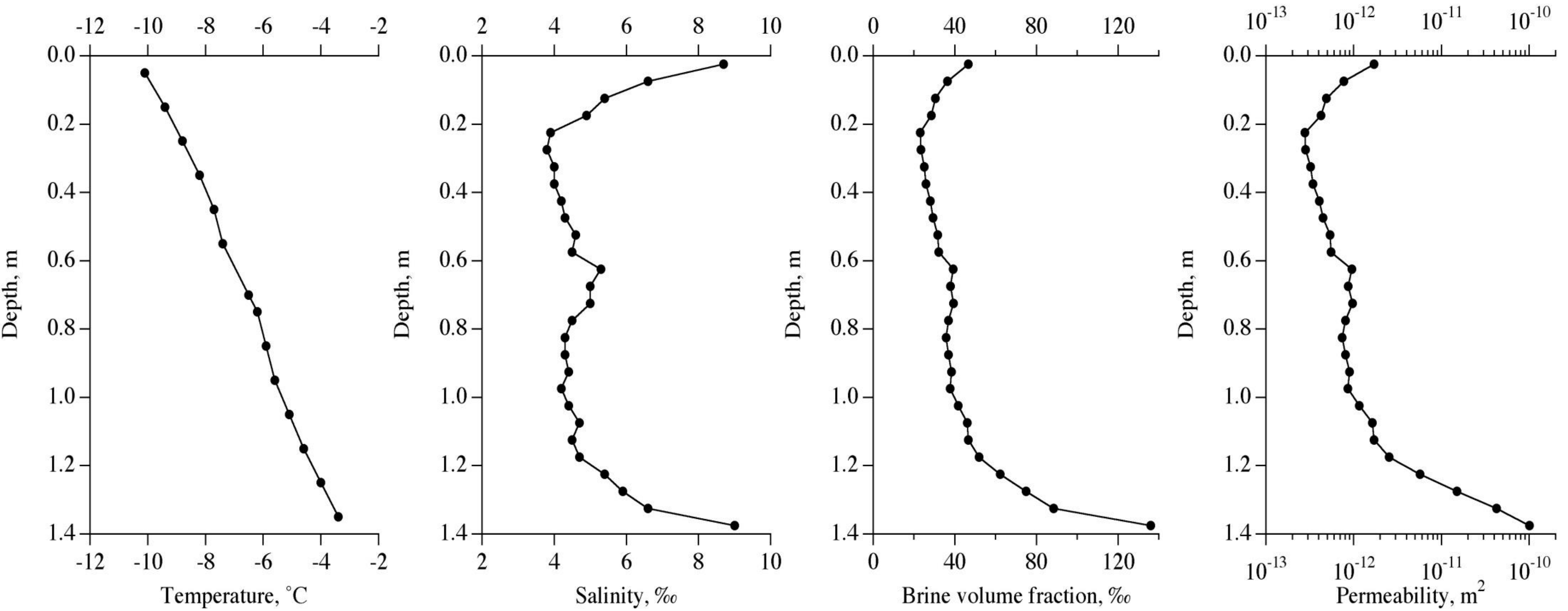


[Eicken]

Porosity

Measurement

- Ice core data
- *In situ*



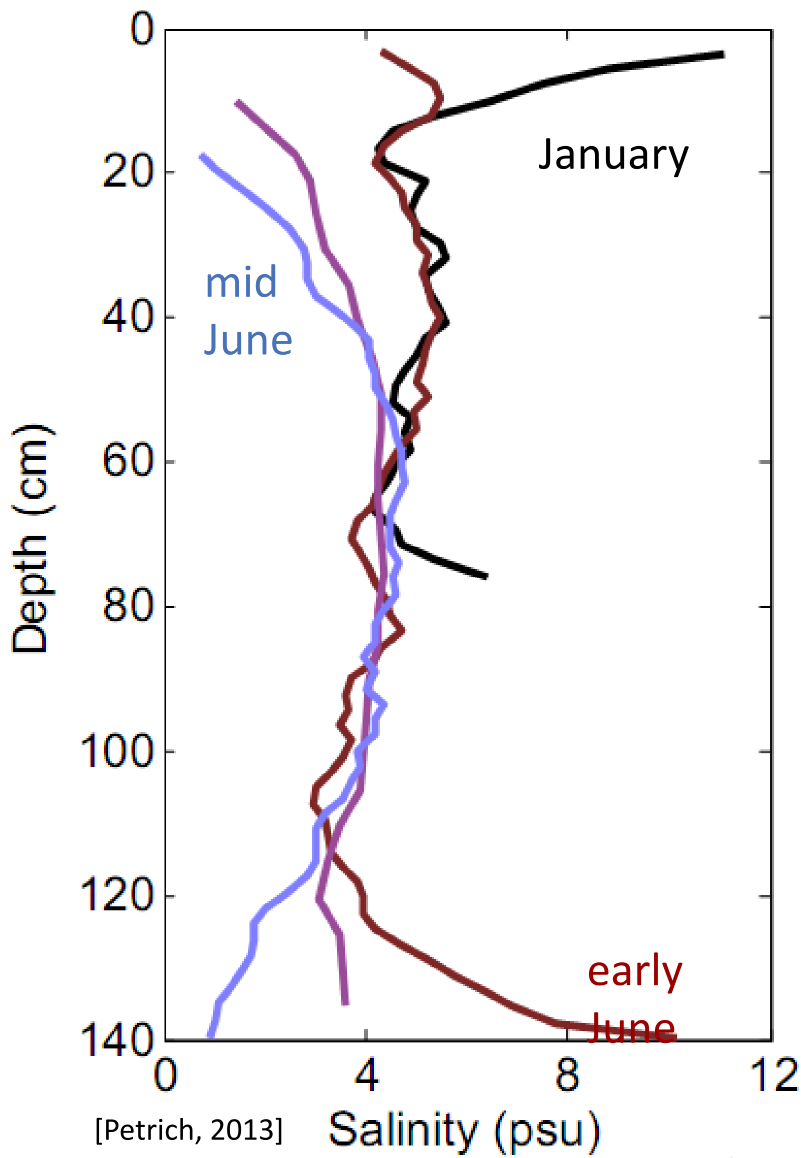
[Eicken]

Calculated

- Simple relationship
- Mathematical model

Brine movement

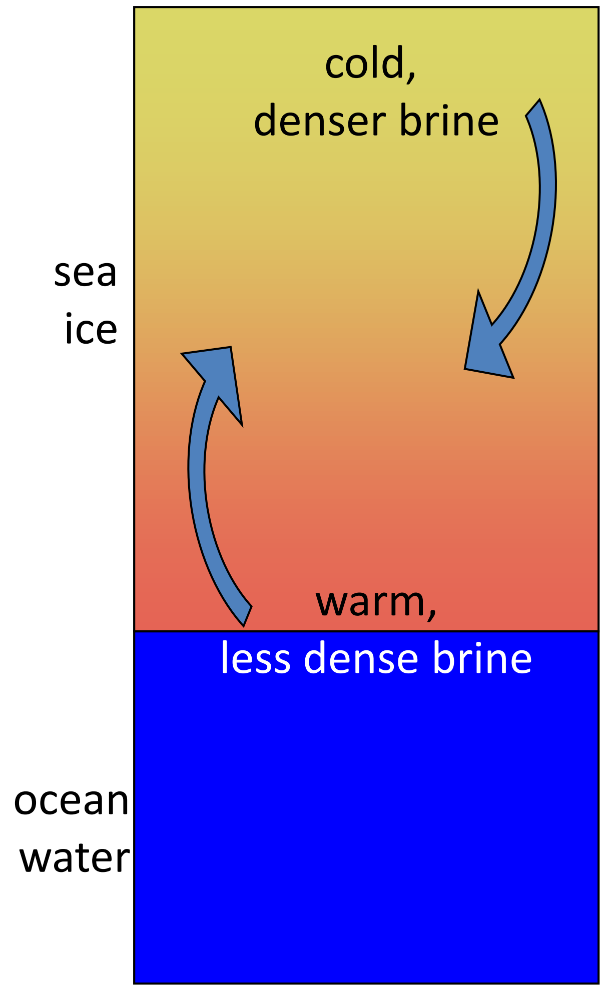
- Ice core data from Barrow, Ak
- Higher salinity at bottom
  - Winter C-Shape curve
- Surface melting
  - Late May / early June
  - S-Shape curve
- Downward flushing of meltwater
  - Higher permeability
  - Brine drainage



[Petrich, 2013]

Brine movement

- Force balance
  - Driving force
    - Density difference $\partial\rho / \partial z$
    - Limited by
      - Medium permeability K_z
      - Fluid viscosity μ
  - Retarding motion
    - Thermal diffusivity α_{si}
    - Phase transition



- Porous medium
  - Rayleigh number

$$Ra_p = g \frac{\partial\rho / \partial z \, K_z \Delta z}{\mu \alpha_{si}}$$

  - If Ra > $Ra_{p,c}$: convection

1st experimental study

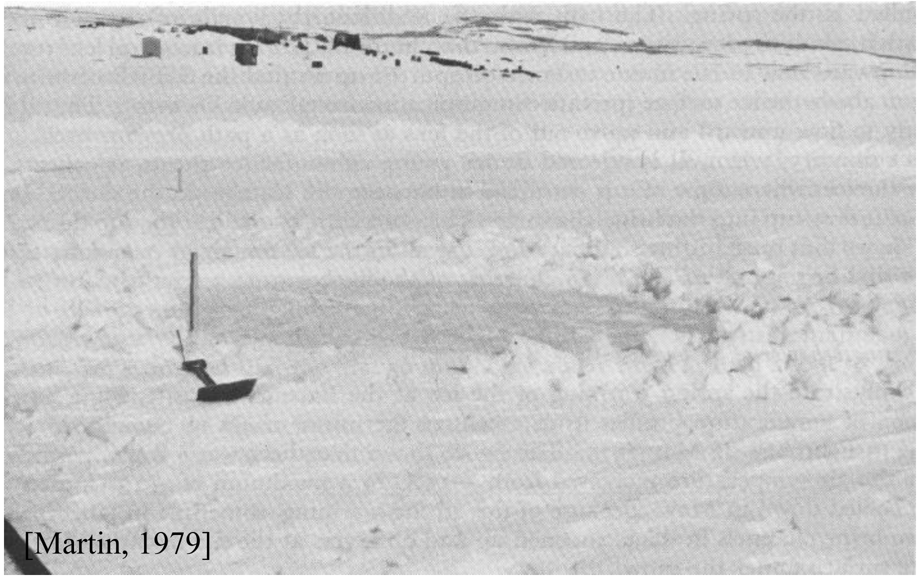
Winter oil spill

- Landfast ice
- Oil spilled 15 February
- Migration to surface in April / early May

Spring oil spill

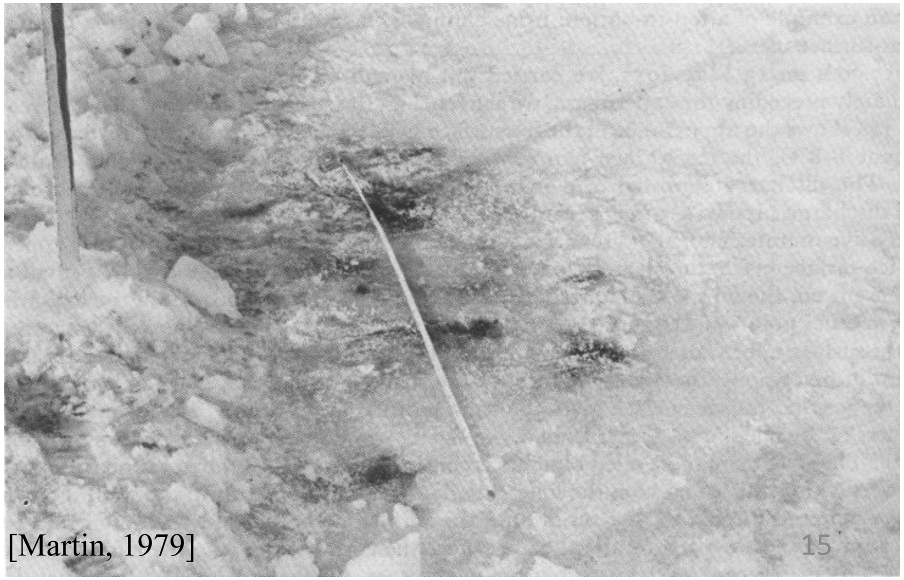
- Landfast ice
- Oil spilled 15 May
- Migration to surface within 1 hour

Ice surface prior to under-ice spill



[Martin, 1979]

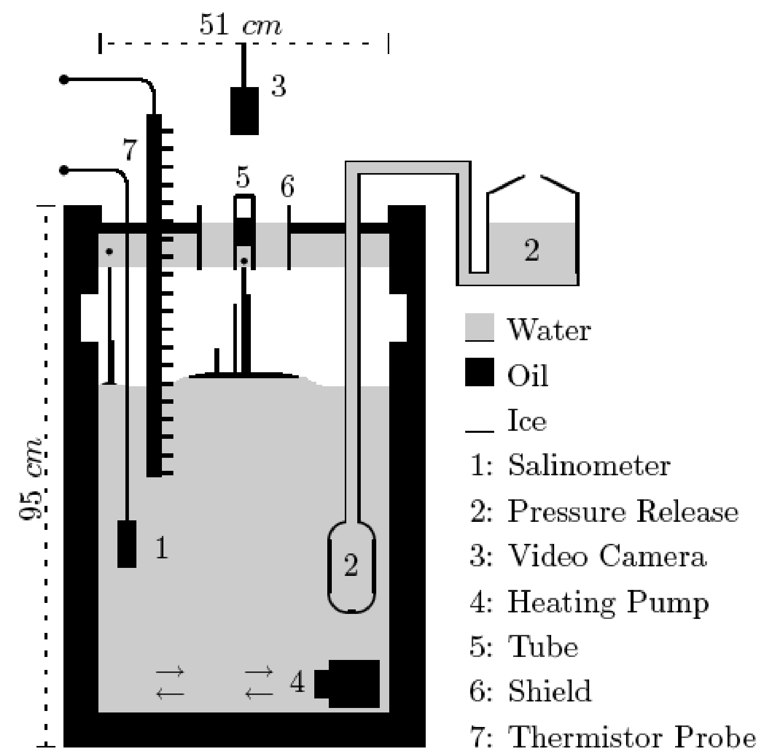
Ice surface 2 h after under-ice spill



[Martin, 1979]

Oil movement in ice

- Ice tank
  - Mimic natural sea ice growth
  - Insulated ice tank
    - Prevent ice formation along the wall
  - Pressure release
    - Avoid tank deformation
  - Pump
    - Break saline convection cell
    - Provide similar ocean heat flux

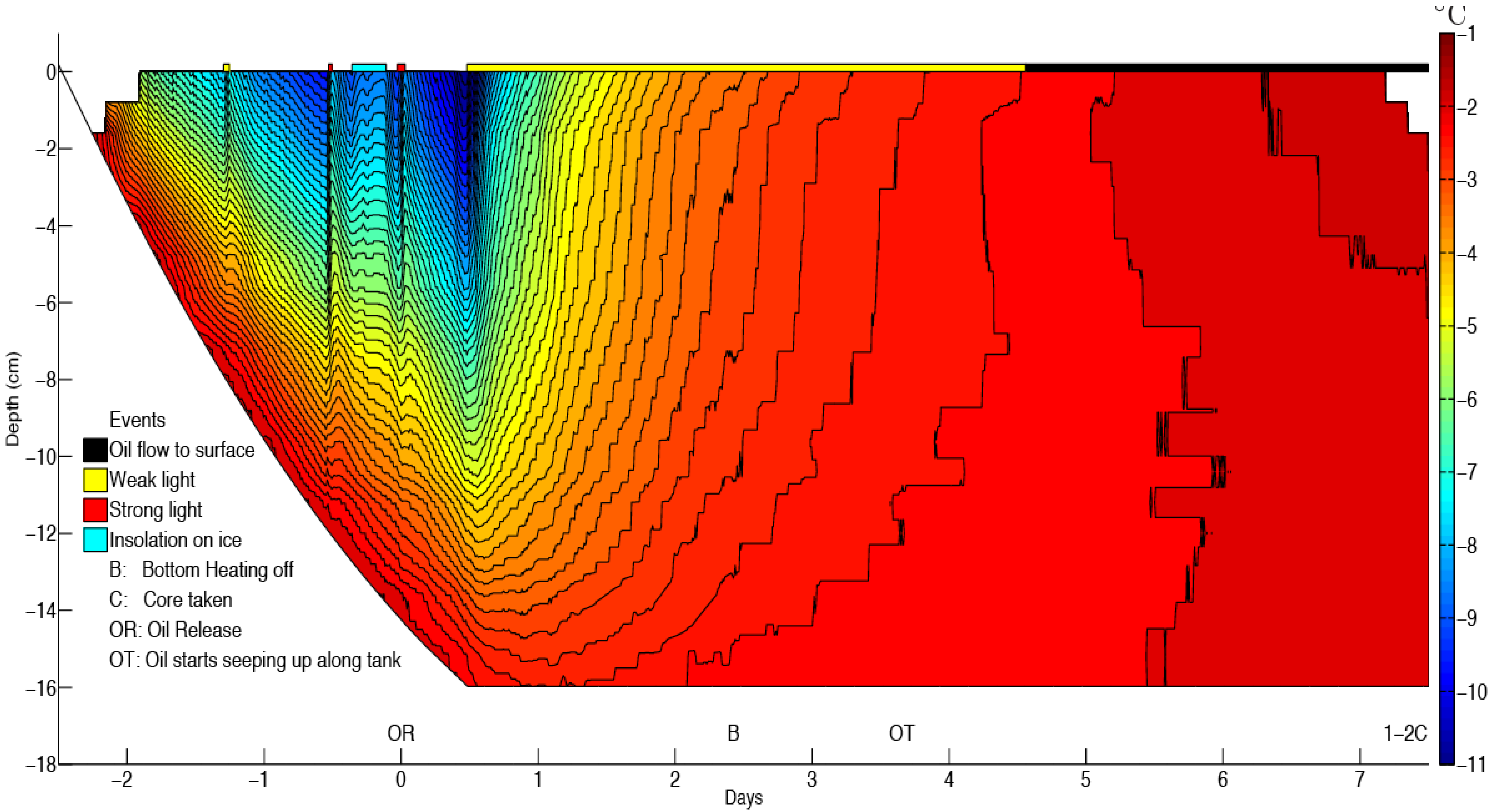


[Karlsson, 2011]

- Oil entrainment & migration
  - Temperature & salinity data
  - Oil flow
  - Oil content & distribution

Oil movement in ice

Temperature profile



[Karlsson, 2011]

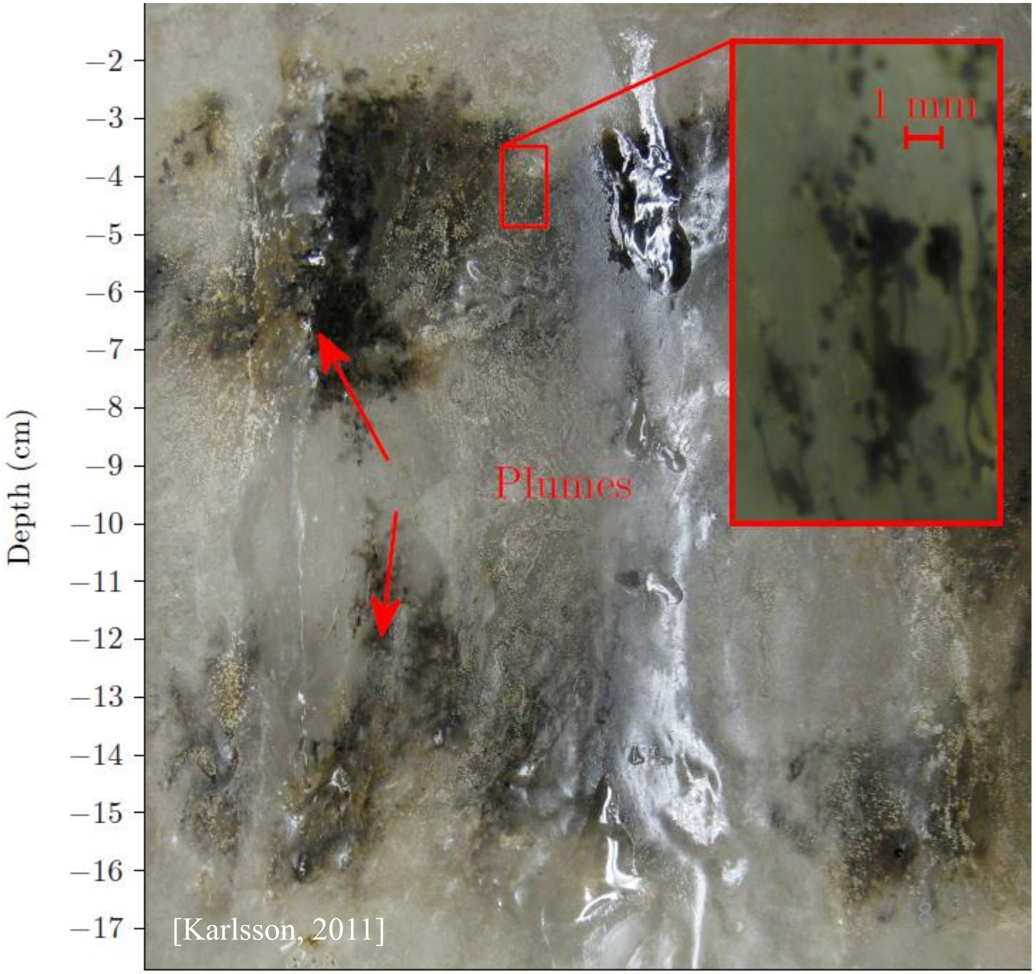
Growth season experiment

- No warming event
- Oil confined at the bottom

[Karlsson, 2011]

Melt experiment

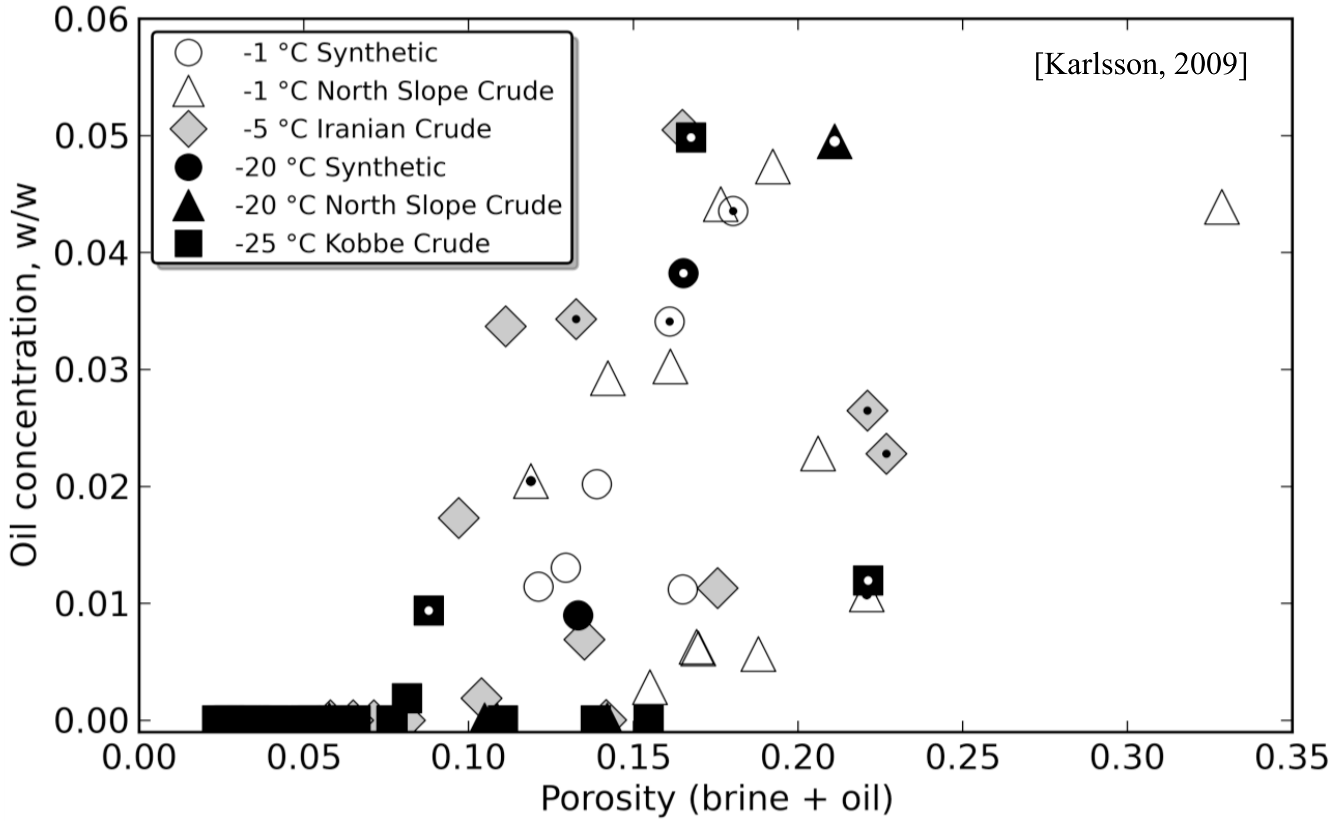
- Simulated warm spelt
- Oil migration within the ice



[Karlsson, 2011]

Oil movement in ice

- Brine movement
  - Critical threshold : ϕ_c=0.05
- Oil movement
  - Critical threshold $\phi_{c,oil}$=0.10-0.15

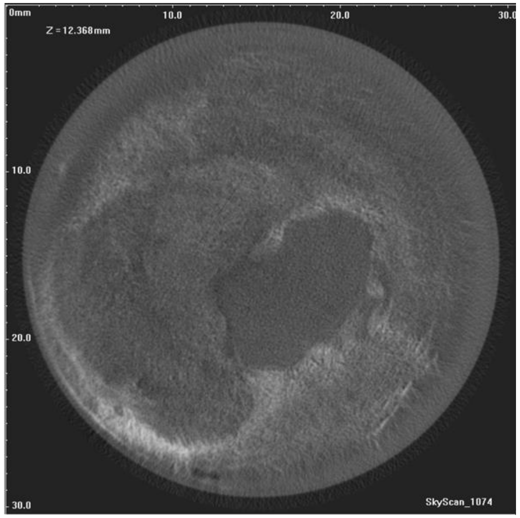


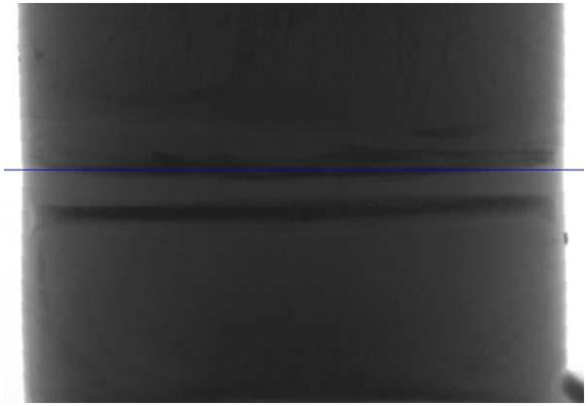
Conclusion

- Oil migration
  - Encapsulated into pore space
  - Entrained during spring
- Microstructure & brine inclusion morphology
  - Controlling factors of depth penetration
  - Determine entrainment and mobilization in Spring
- Fluid exchange with underlying ocean
  - Controlled growth rate
  - Interface morphology
  - Feedback biota-oil

Further work

- Linkage with biota
  - Ongoing work
  - Indoor experiment
- X-Ray observation of oil/ice
  - Similar density
    - $\rho_{ice} = 0.92$ [gcm^{-3}]
    - $\rho_{oil} \approx 0.87$ [gcm^{-3}]
  - Possible to distinguish oil layer
  - Possibility to follow
    - Oil distribution ?
    - Oil content ?
- Modeling
  - Simple 1D model
  - Fluid flow in porous media





Question ?

Thank you

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