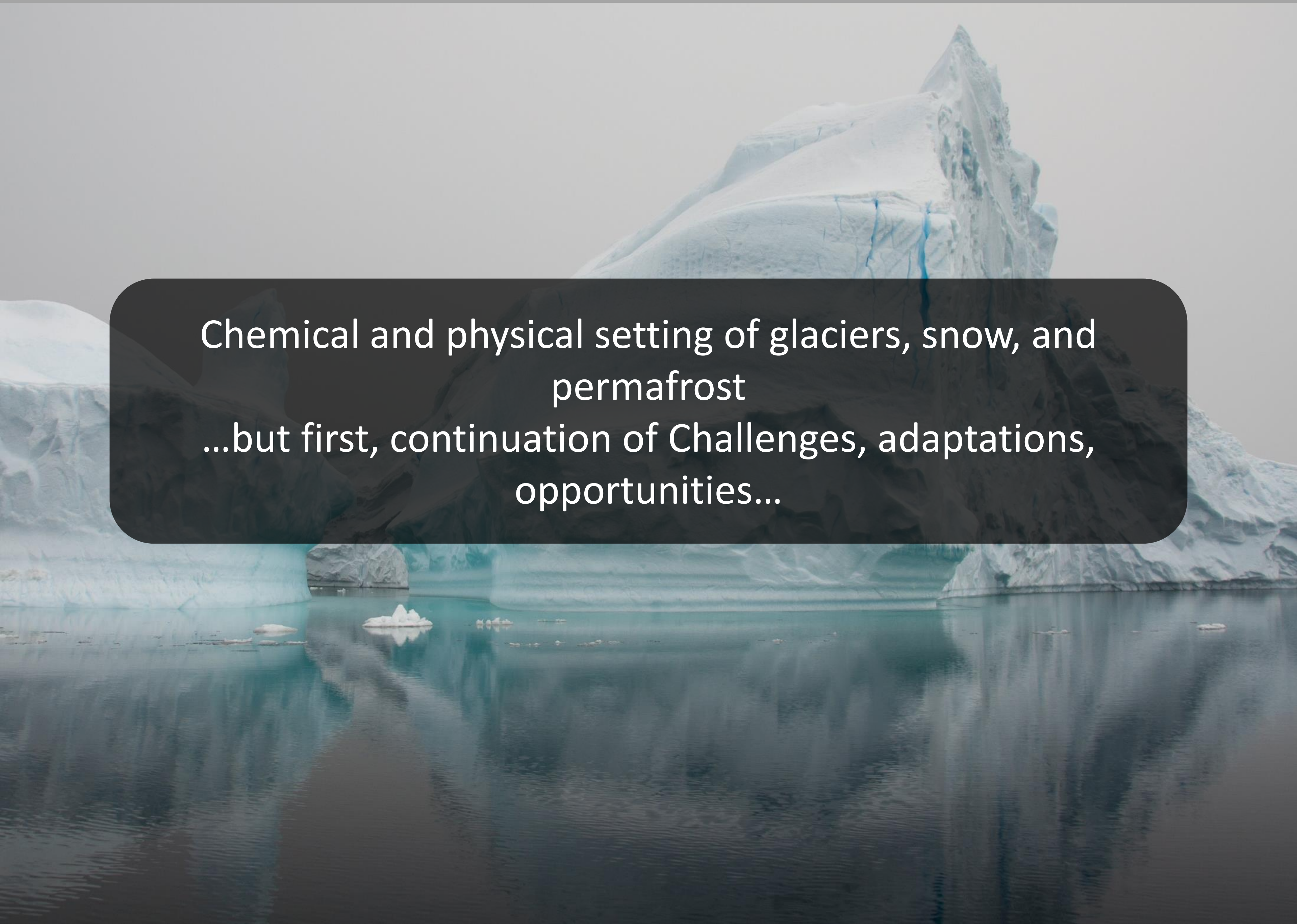


Chemical and physical setting of glaciers, snow, and permafrost
…but first, continuation of Challenges, adaptations, opportunities…

Three possible topics due in class on Tuesday!

- Topics will define groups for presentations
- Final topics for bibliography and final paper should be related to group topic
- Annotated bibliography pushed back due to heavy reading

1. Which of the following features likely has the highest brine salinity: frost flowers, columnar sea ice close to the atmosphere, columnar sea ice close to the water.

   Frost flowers

2. Rank the following in order of highest to lowest albedo: open water, snow, bare sea ice.

   Snow, bare sea ice, open water

3. At what temperature do pore spaces in “typical” sea ice lose connectivity?

   -5 C, remember the “rule of fives”!

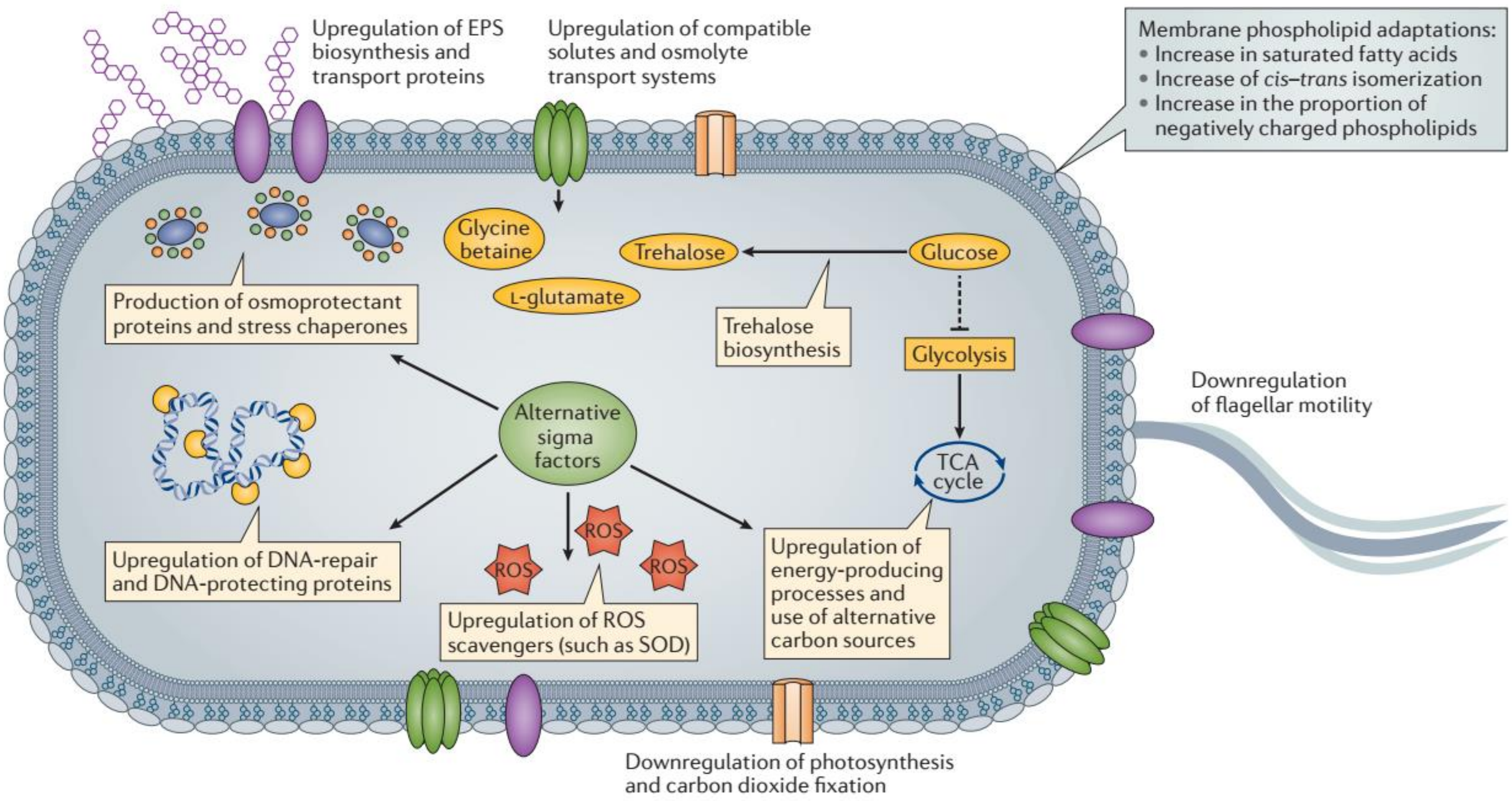
1. Do sterols have a stabilizing or destabilizing effect on the lipid membrane?
2. What is the approximate lower limit of water activity for cellular life?
3. EPS is largely composed of what macromolecule?

Ice crystal formation also presents challenges for life

- If cytosol freezes the cell will lyse due to expansion
- The cell surface can be impinged by growing ice crystals
- Some organisms have evolved the ability to control the formation of ice
  - Depress the intracellular or extracellular freezing point
  - Nucleate ice crystals to control the formation process

Many of the high salt responses also help prevent the cell against freezing

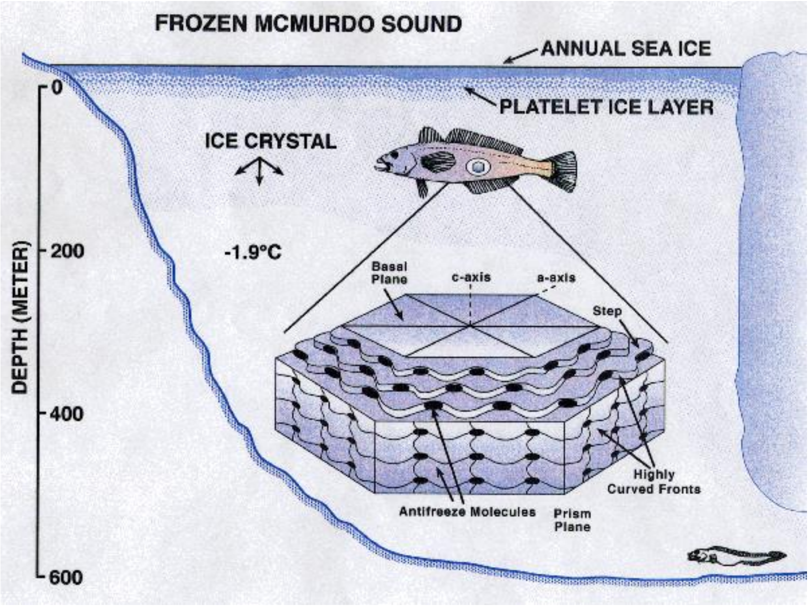
- EPS
- Compatible solutes



Production of antifreeze proteins and compounds

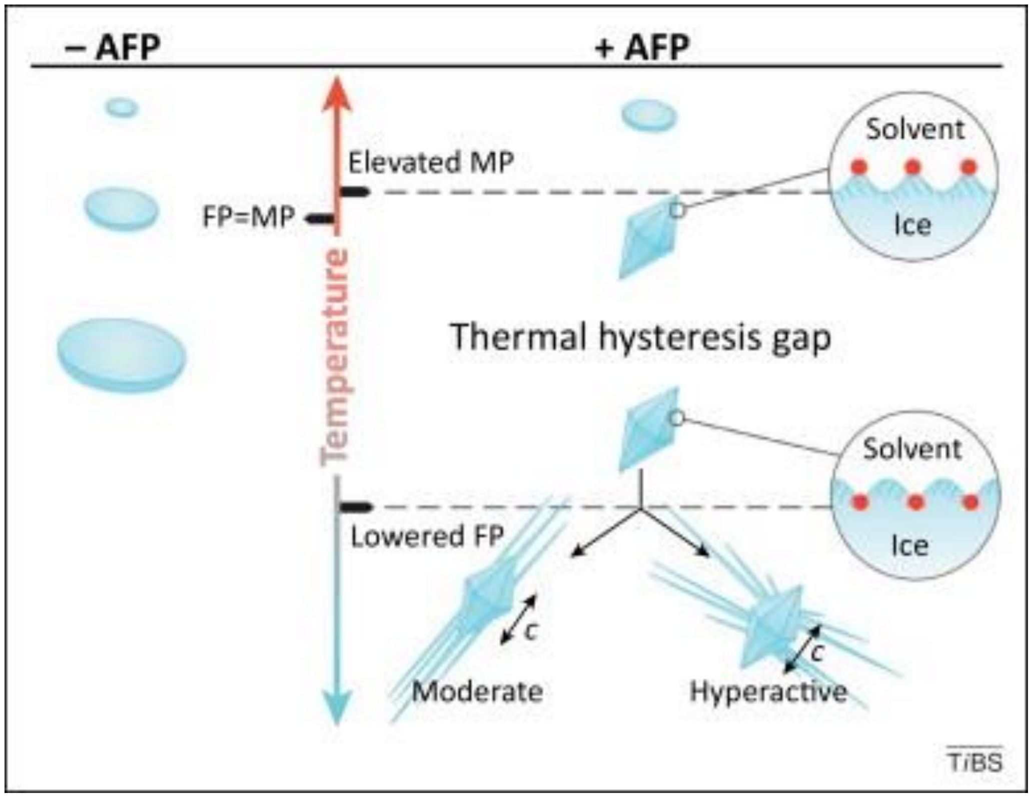
- Ice binding proteins such as those produced by icefishes of the family Channichthyidae bind to newly formed ice crystals to halt their growth

Q: Icefish are the only vertebrates that lack the protein hemoglobin. Why?
A: Oxygen is very soluble in cold water, reducing the selective pressure to maintain an oxygen-binding protein.



Production of antifreeze proteins and compounds

- Ice binding proteins such as those produced by icefishes of the family Channichthyidae bind to newly formed ice crystals to halt their growth
- Ice binding proteins create a *thermal hysteresis gap* by elevating the melting point and depressing the freezing point
- This allows them to serve multiple (contrasting) ecological functions.



Davies et al., 2014

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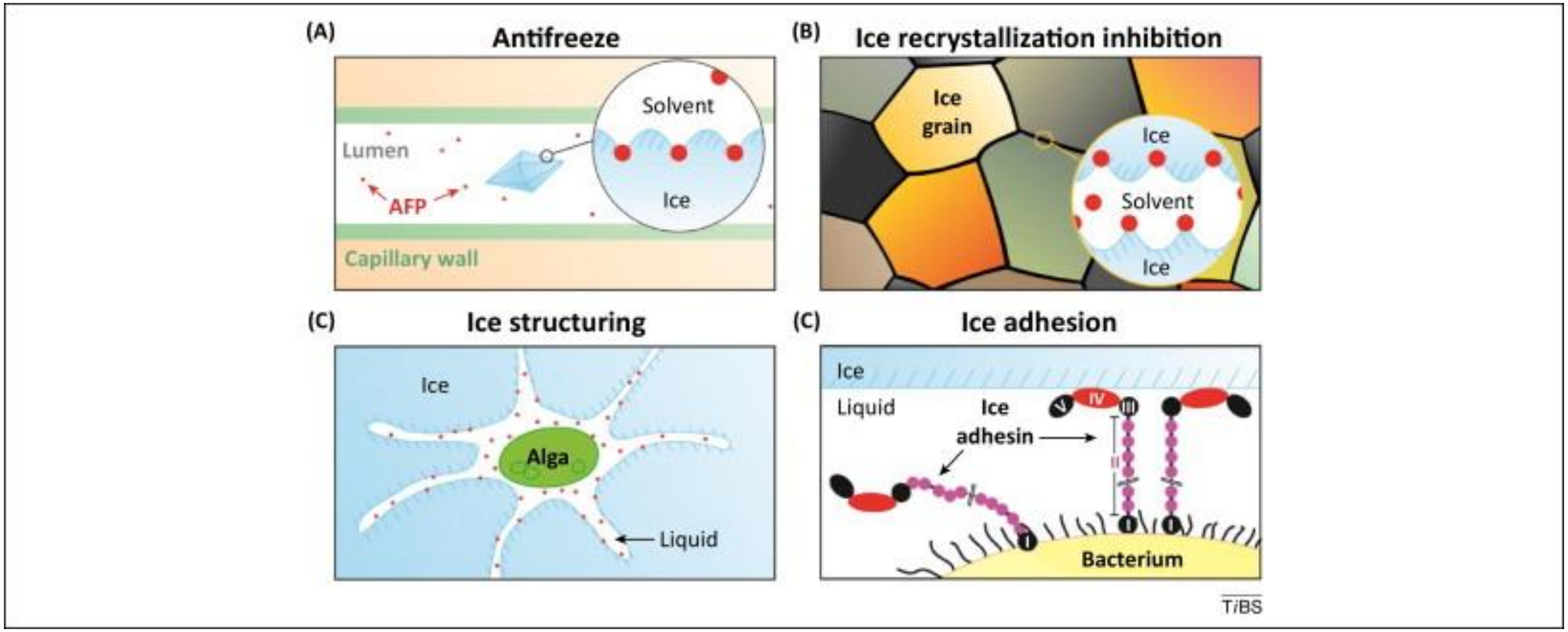

Davies et al., 2014

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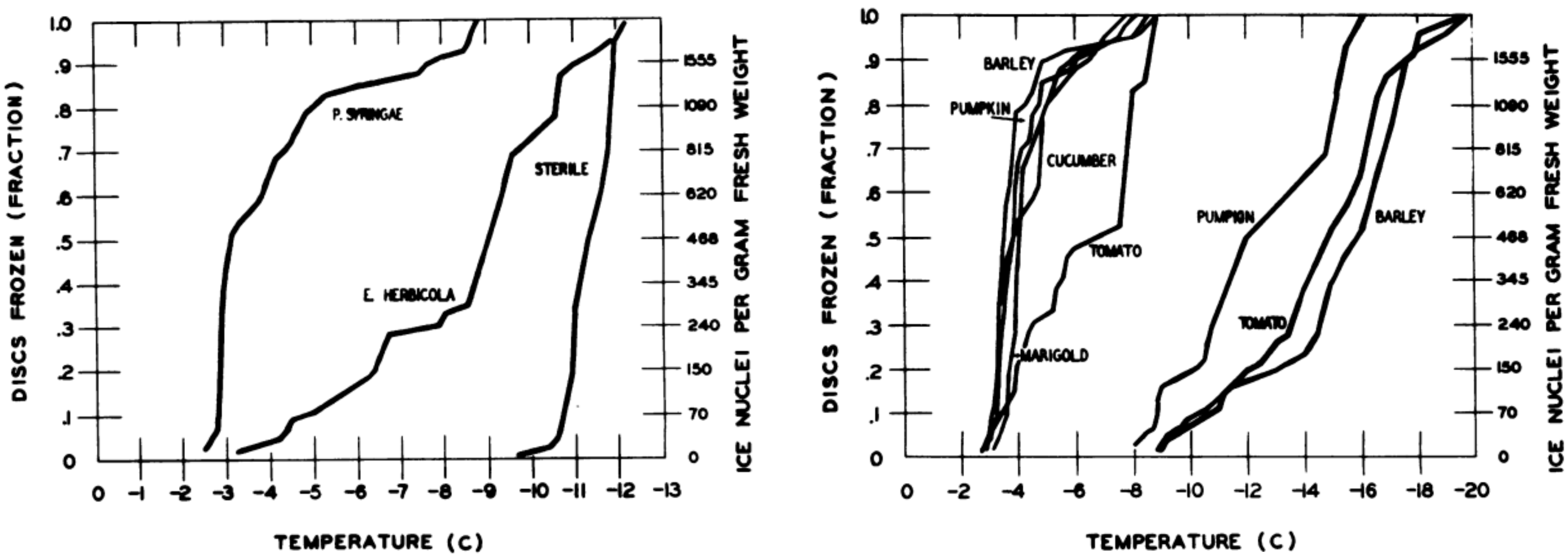


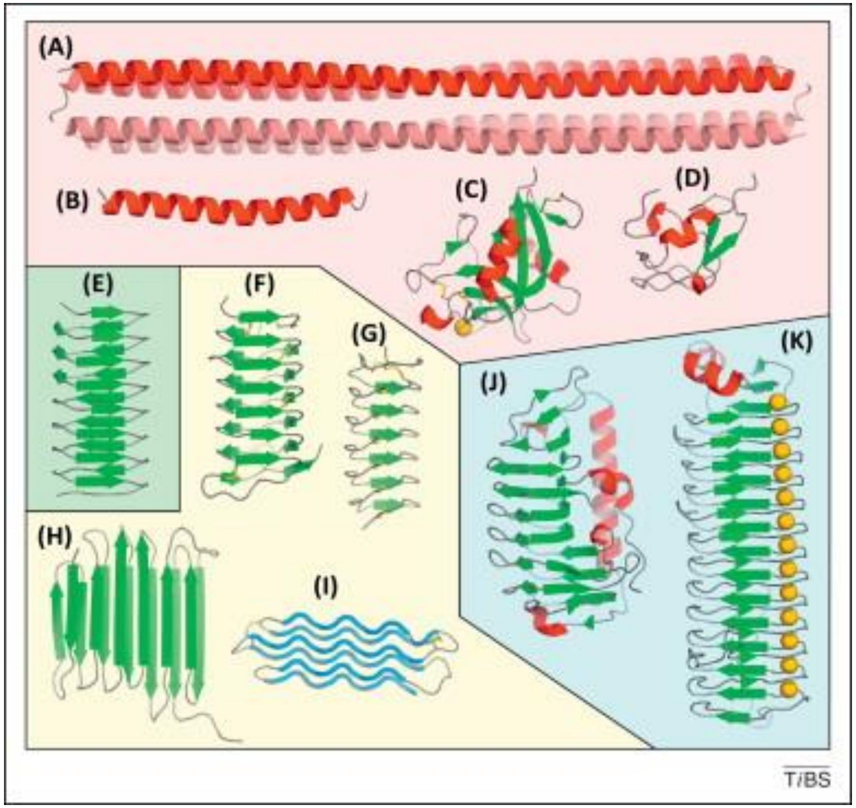
Lindow et al., 1982

Water does not spontaneously freeze until -40 C. Freezing above this point is caused by *nucleation*.

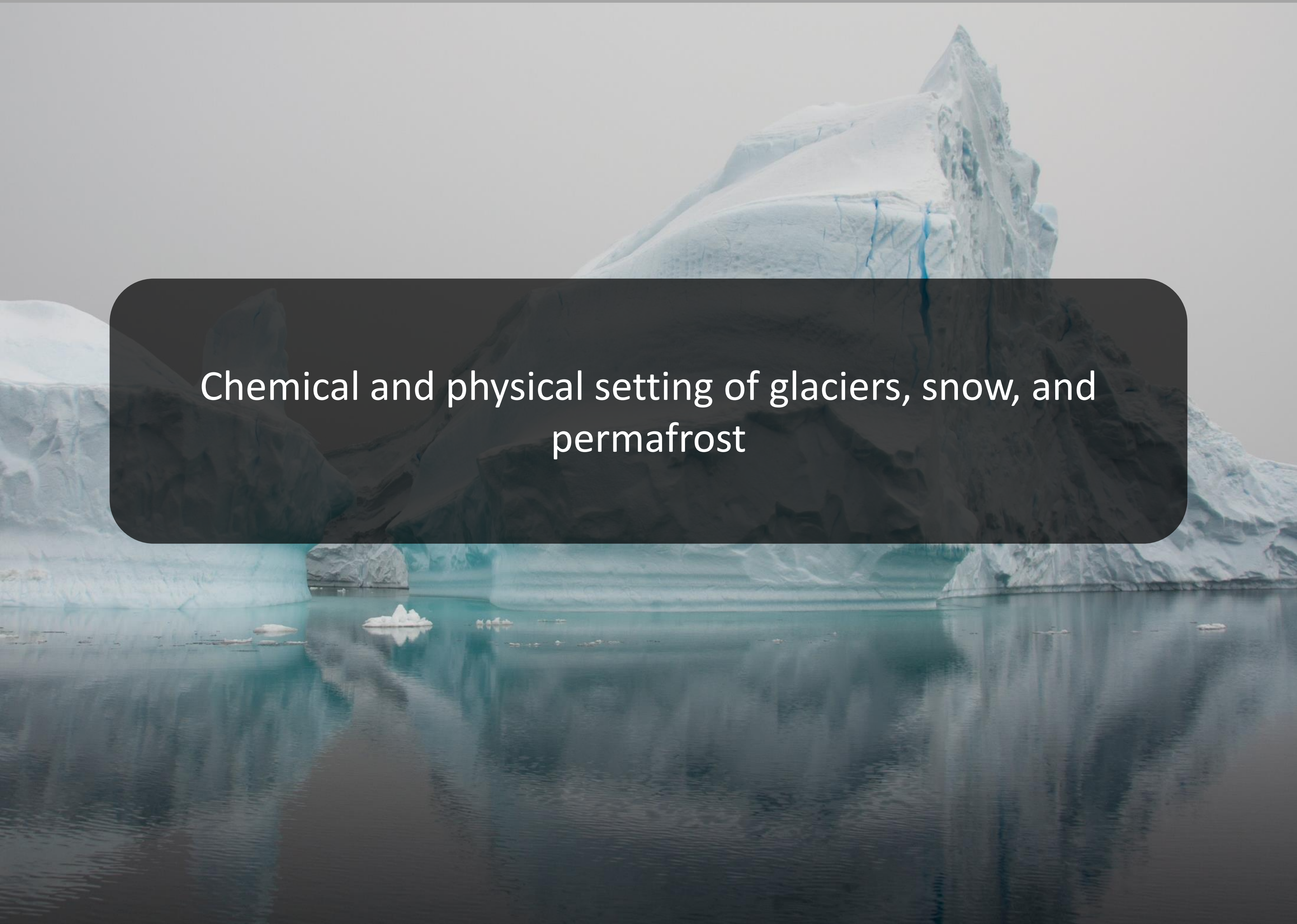
- Some common, temperate, plant-associated bacteria have ice binding proteins
- This may be an effective mechanism for them to attack plant cells

Production of antifreeze proteins and compounds

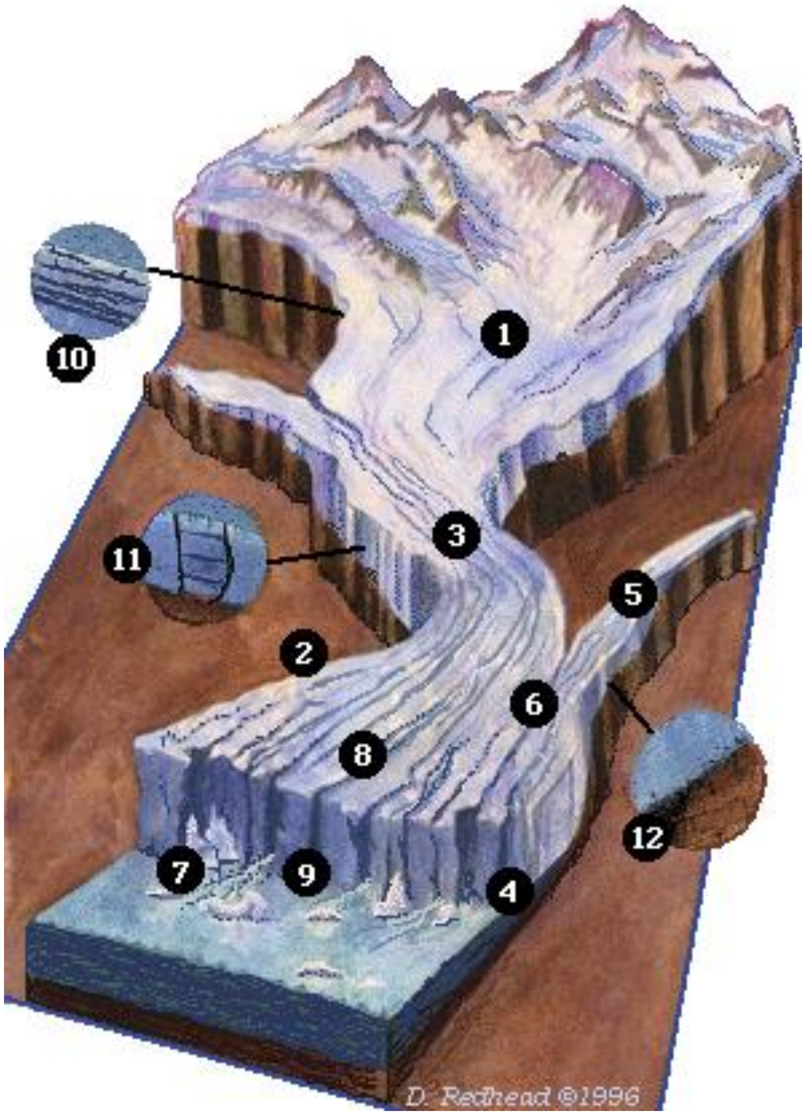
- Ice binding proteins such as those produced by icefishes of the family Channichthyidae bind to newly formed ice crystals to halt their growth
- Ice binding proteins create a *thermal hysteresis gap* by elevating the melting point and depressing the freezing point
- This allows them to serve multiple (contrasting) ecological functions.
- Structural diversity suggests recent evolution in response to freezing conditions.



Davies et al., 2014



Chemical and physical setting of glaciers, snow, and permafrost

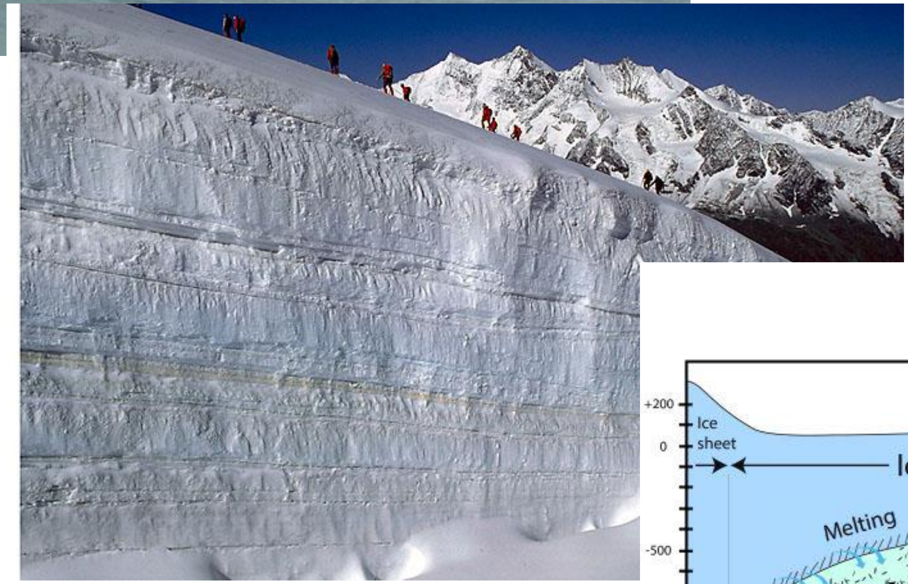


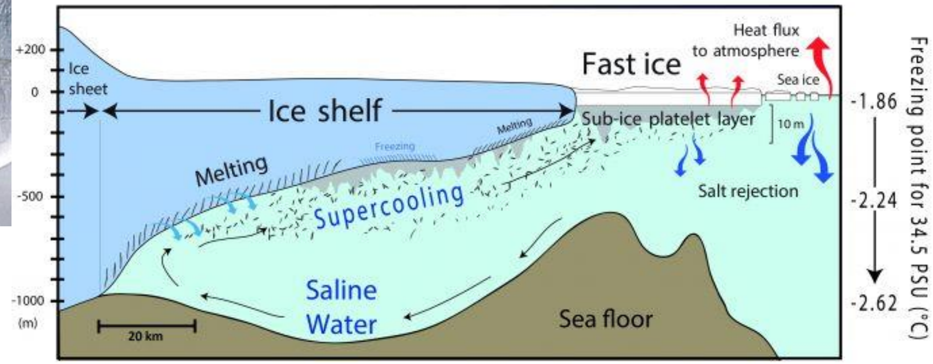
1. Accumulation zone
2. Ablation zone
3. Equilibrium line
4. Terminal moraine
5. Tributary glacier
6. Medial moraine
7. Calving
8. Terminus
9. Meltwater (also – moulin)
10. Water lenses and glands
11. Internal deformation
12. Glacier bed

Red = you should know!

13. Basal ice
14. Glacial firn
15. Accretion ice

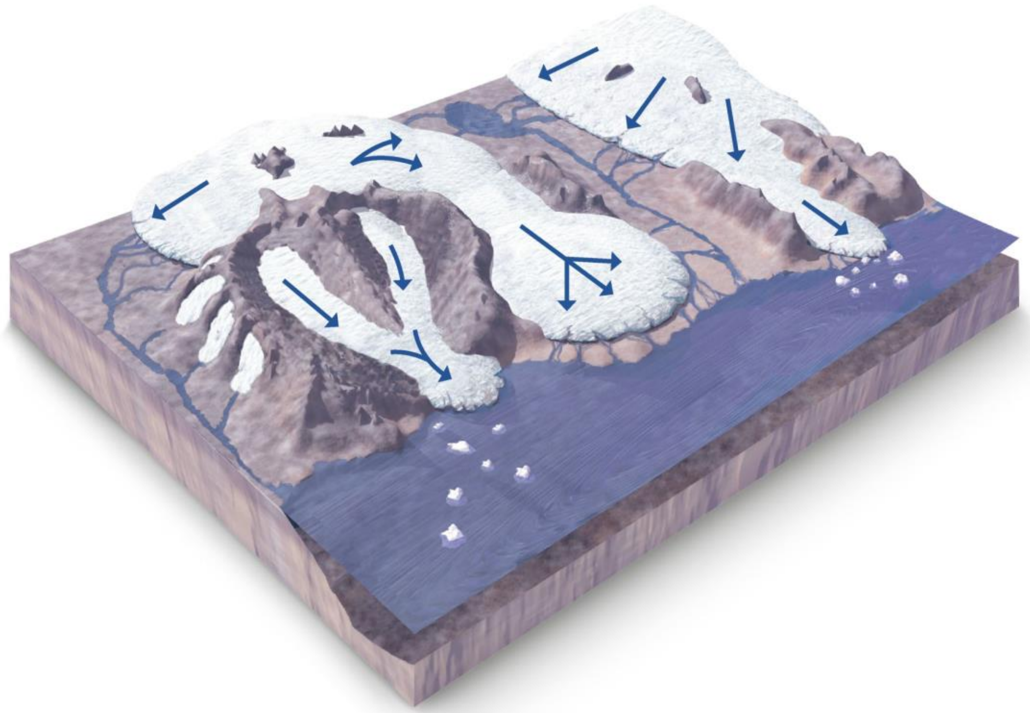
Red = you should know!





Glaciers come in a huge variety:

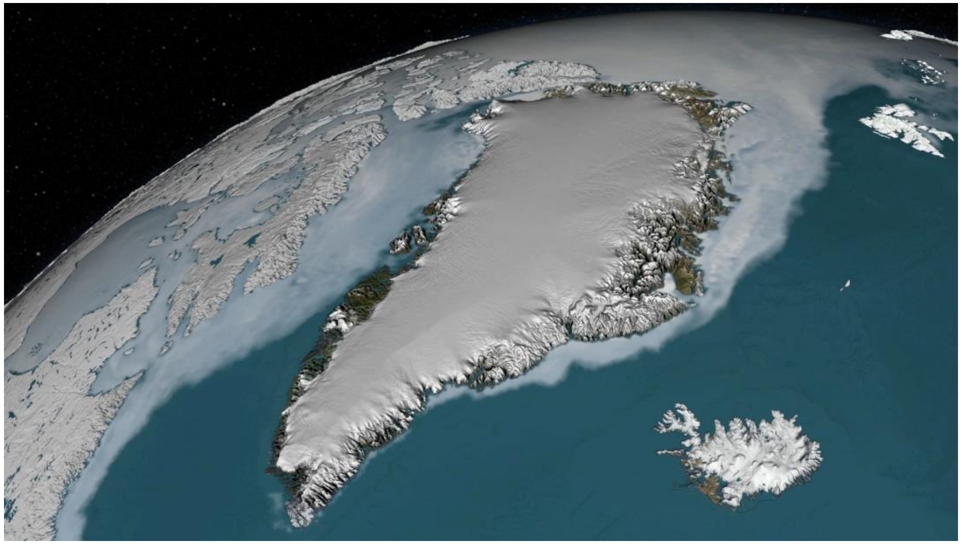
- Mountain glaciers
- Valley glaciers
- Tidewater glaciers
- Piedmont glaciers
- Hanging glaciers
- Ice shelves
- Ice caps and sheets



For the purpose of our discussions will only distinguish between *ice shelves*, *ice caps/sheets*, and all other glacier types. Just keep in mind that there are many important differences.

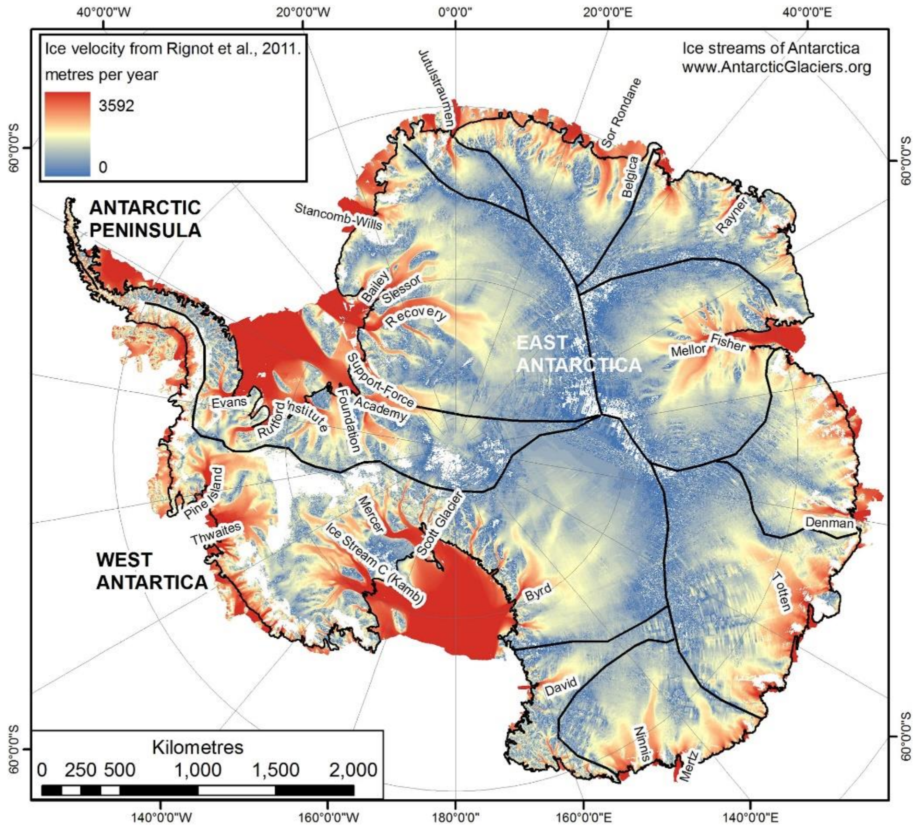
Ice cap/sheet: "permanent" mass of ice that covers an extensive area; a glacier system


Agassiz ice cap in Canada


3D model of the Greenland ice sheet

- At this time ice sheets are found only in Greenland, Antarctica, and Patagonia
- Ice caps can be found in the Himalaya, Iceland, Canada, and Alaska

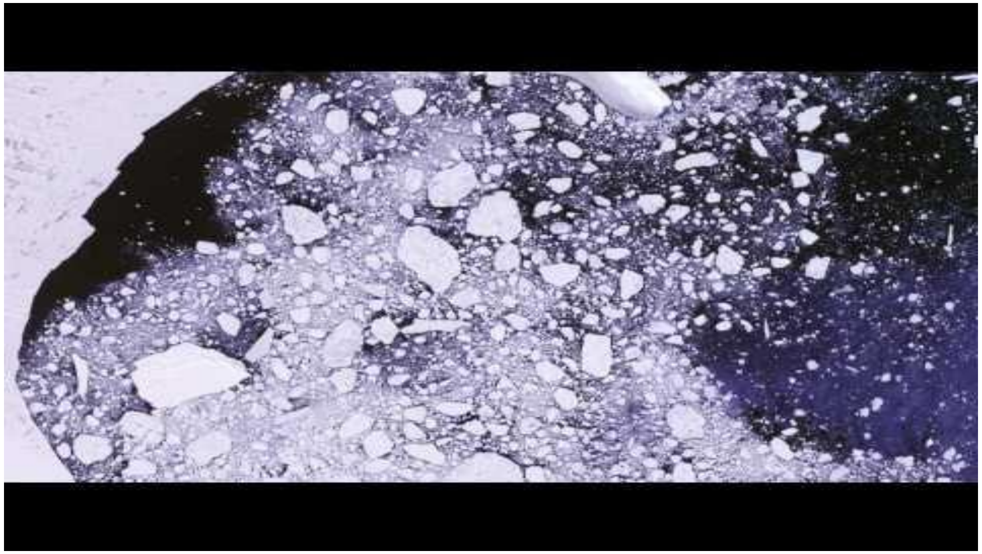
Ice cap/sheet: "permanent" mass of ice that covers an extensive area; a glacier system



- Although they look static, ice sheets and caps are dynamic!
- Fast moving regions are known as *ice streams*

Q: What are the highest velocity features on this map?
A: Ice shelves

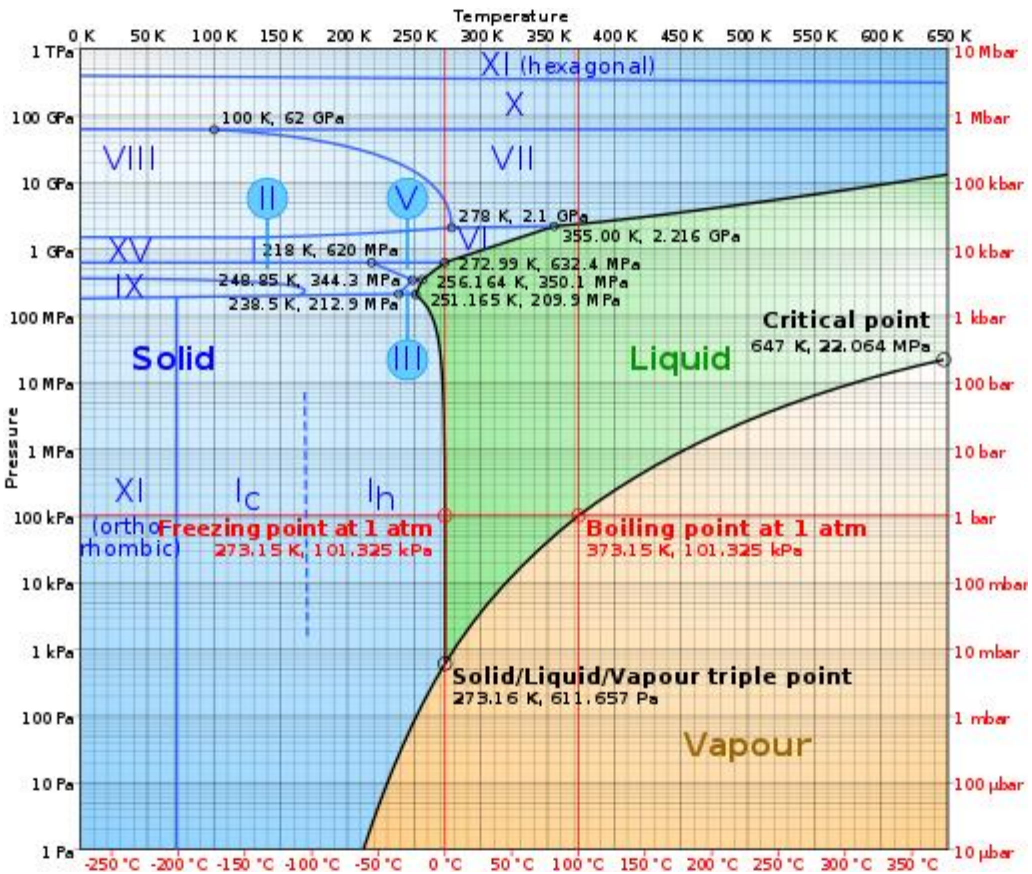
Ice shelf: a floating ice sheet, currently only found in Antarctica



SIO 121, Lecture 4: Glaciers, snow, and permafrost: Glaciers

Glaciers can also be separated by temperature class

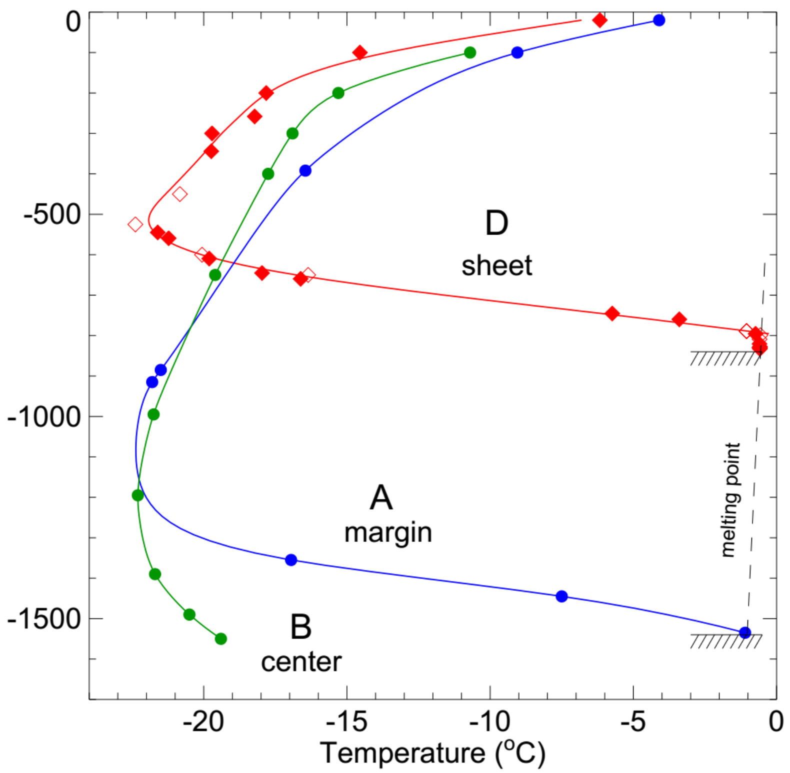
- Cold: glacier is below the pressure melting point
- Temperate: Whole glacier is at the pressure melting point, except for surface
- Polythermal: A mixture of cold and temperature, e.g., base of glacier may be above pressure melting point
- *Pressure melting point*: pressure lowers the melting point of ice. This is independent of any heating effects of pressure!

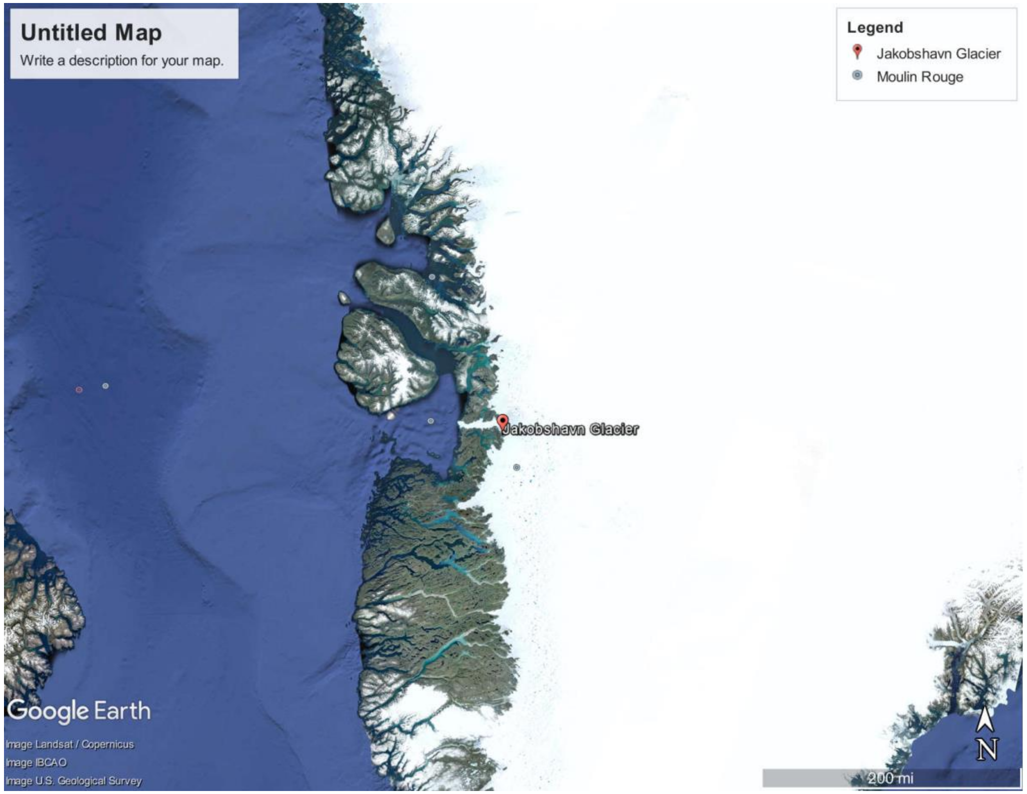


Q1: If a cubic meter of ice weighs 900 kg, and a 1 m^2 column of the atmosphere equals 10,330 kg, how many meters of ice equal one atmosphere?
A: 11.47 m = 1 atm

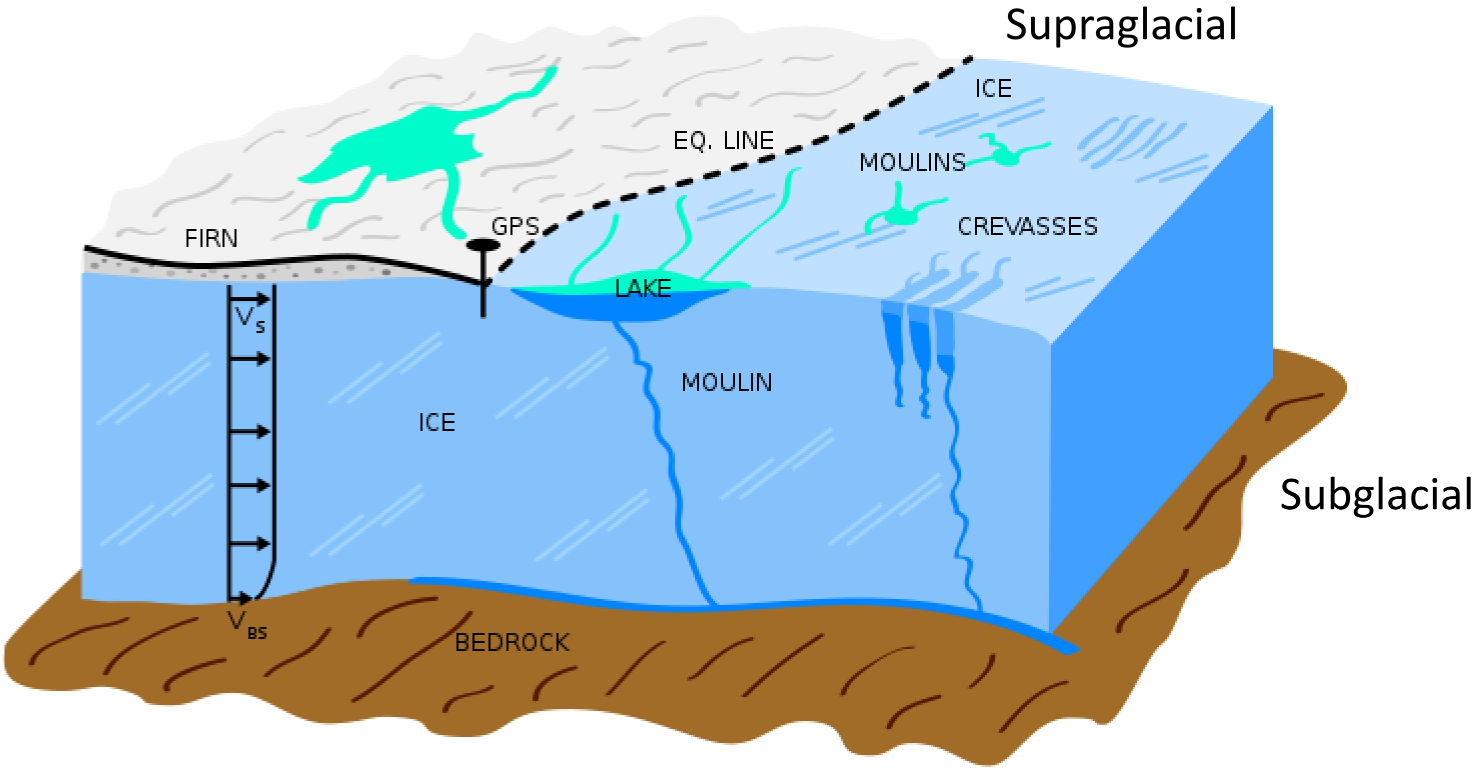
Q2: How many atmospheres of pressure are present below 4,776 m (max depth AIS)?
A: 416.4 + 1 atm – that's a lot!

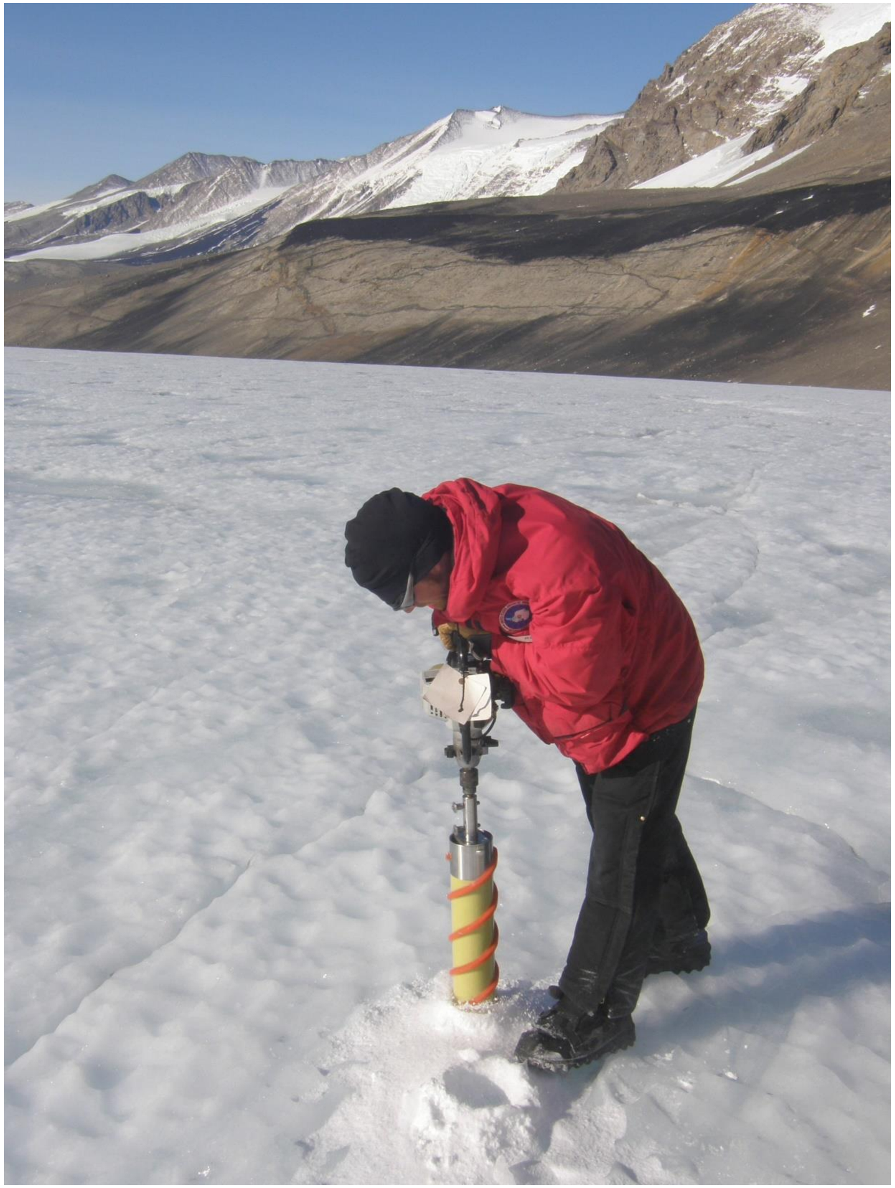
Temperature profiles for Jakobshavn, a polythermal glacier in Greenland



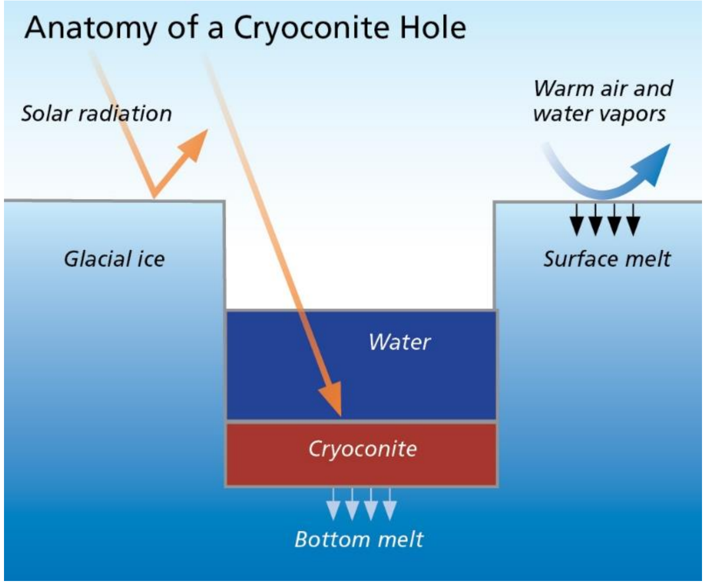


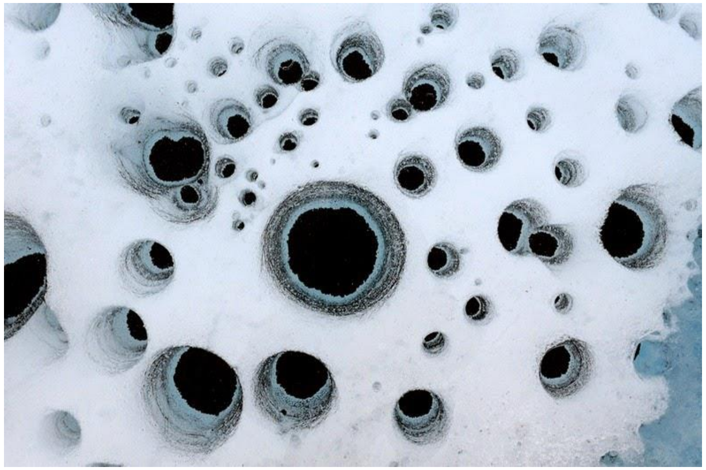
Q: Based on your knowledge so far, where do you expect to find life in this glacier?
A: At the glacier surface and at the glacier bed.


Supraglacial
ICE
EQ. LINE
MOULINS
CREVASSES
FIRN
GPS
LAKE
V_S
ICE
MOULIN
V_{BS}
BEDROCK
Subglacial



Taylor glacier in 2011. Am I in the accumulation zone or the ablation zone?


Anatomy of a Cryoconite Hole
Solar radiation
Warm air and water vapors
Glacial ice
Surface melt
Water
Cryoconite
Bottom melt

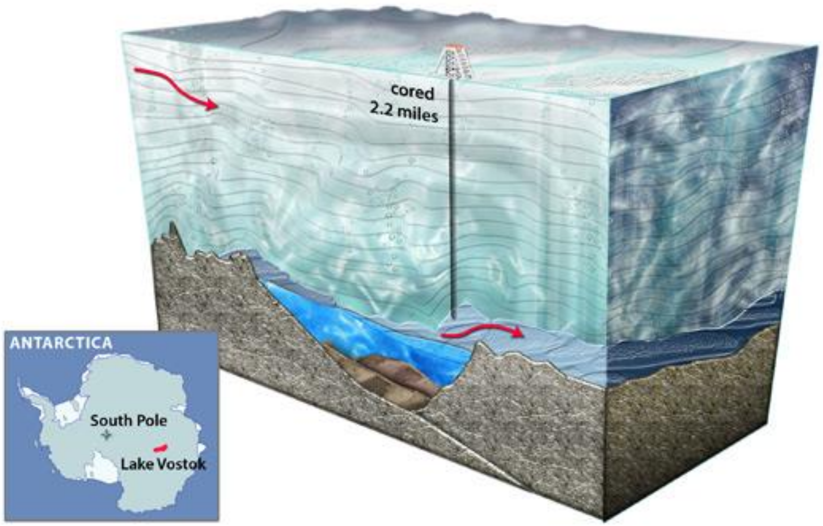


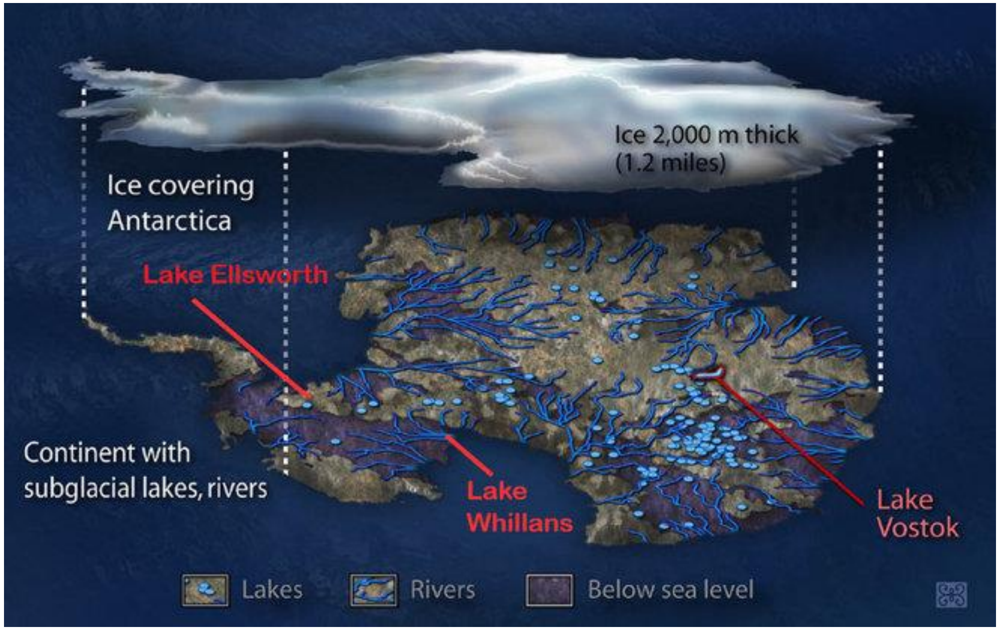
Greenland surface melt ponds

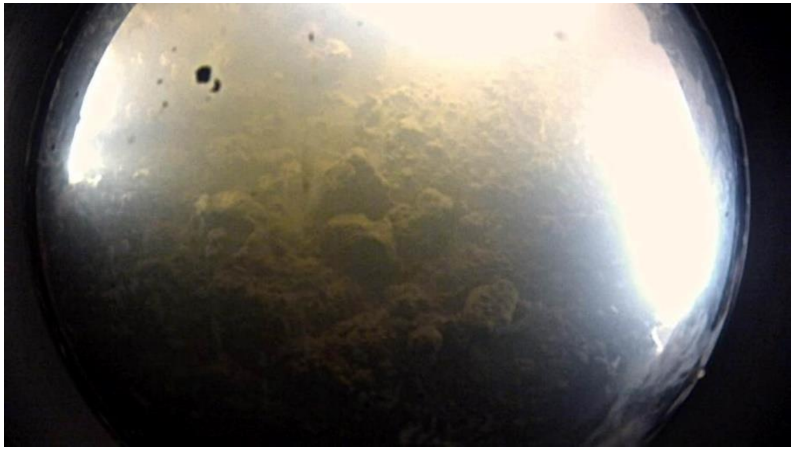
- Extensive melt observed in the summer
- Melt ponds and lakes also found in Antarctica, but much reduced

Q: What happens to the surface energy budget after extensive melting?
A: Surface absorbs more heat, leading to more melting

Subglacial environments

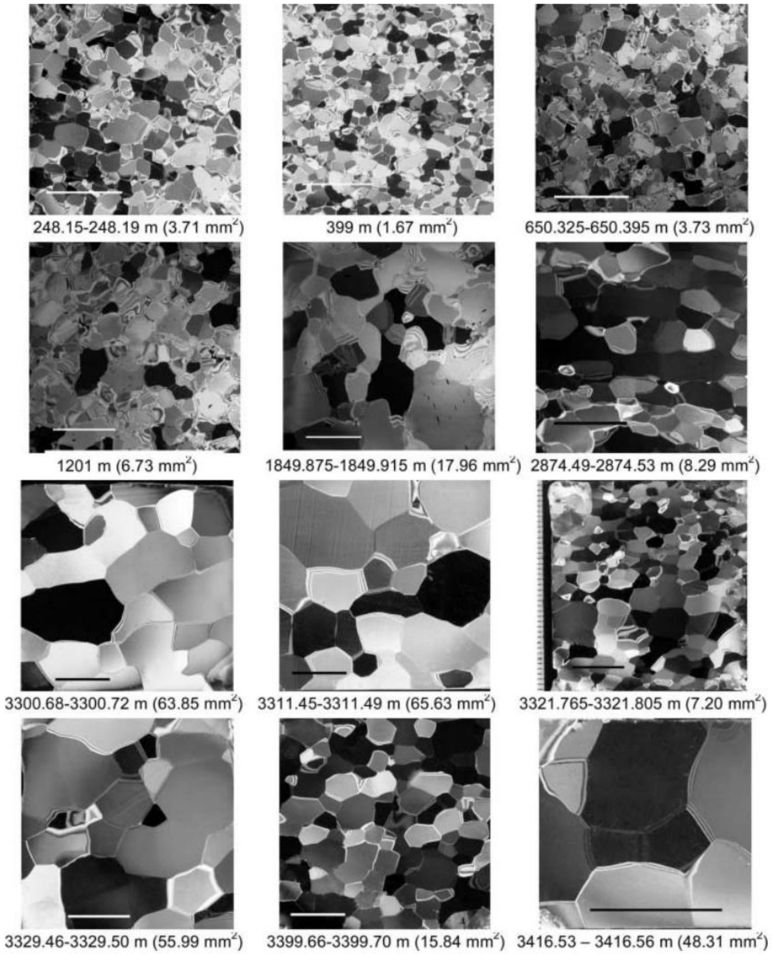


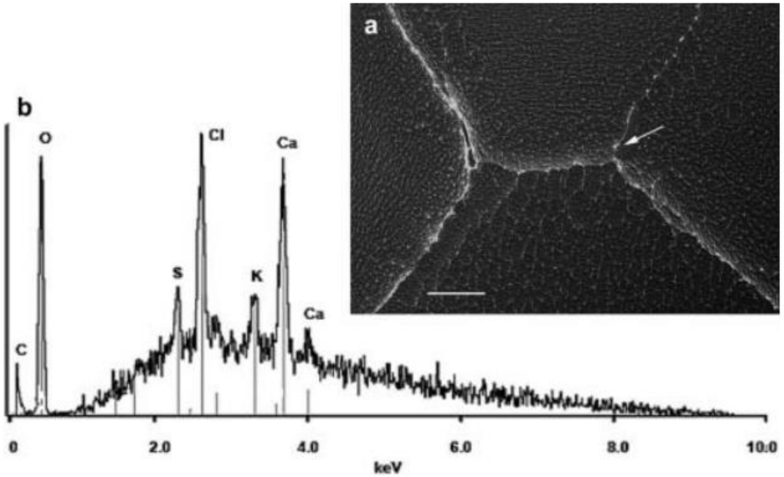




What about the glacier interior? Is there a viable microbial habitat?

- For all practical purposes glaciers contain little salt
- There are however, some solutes present which prevents total freezing
- Unlike sea ice glacier ice grains grown large during recrystallization, thus the resulting brine channels are larger than sea ice, though the brine volume fraction remains the same.



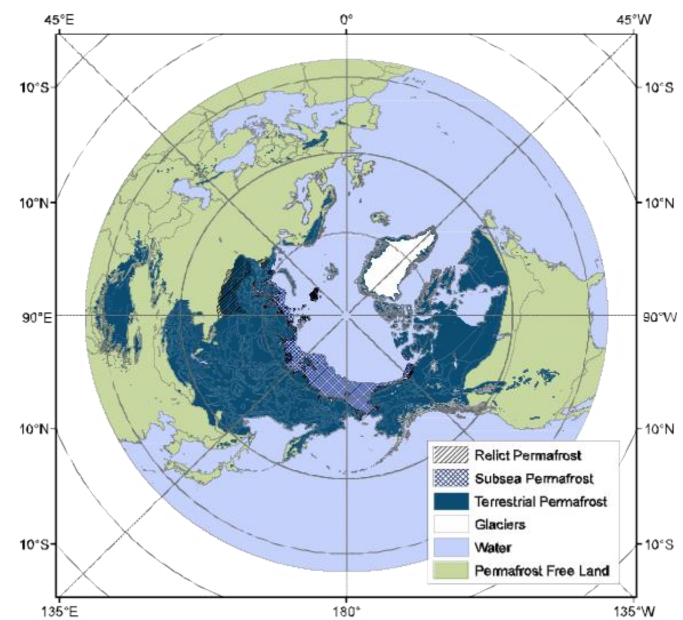


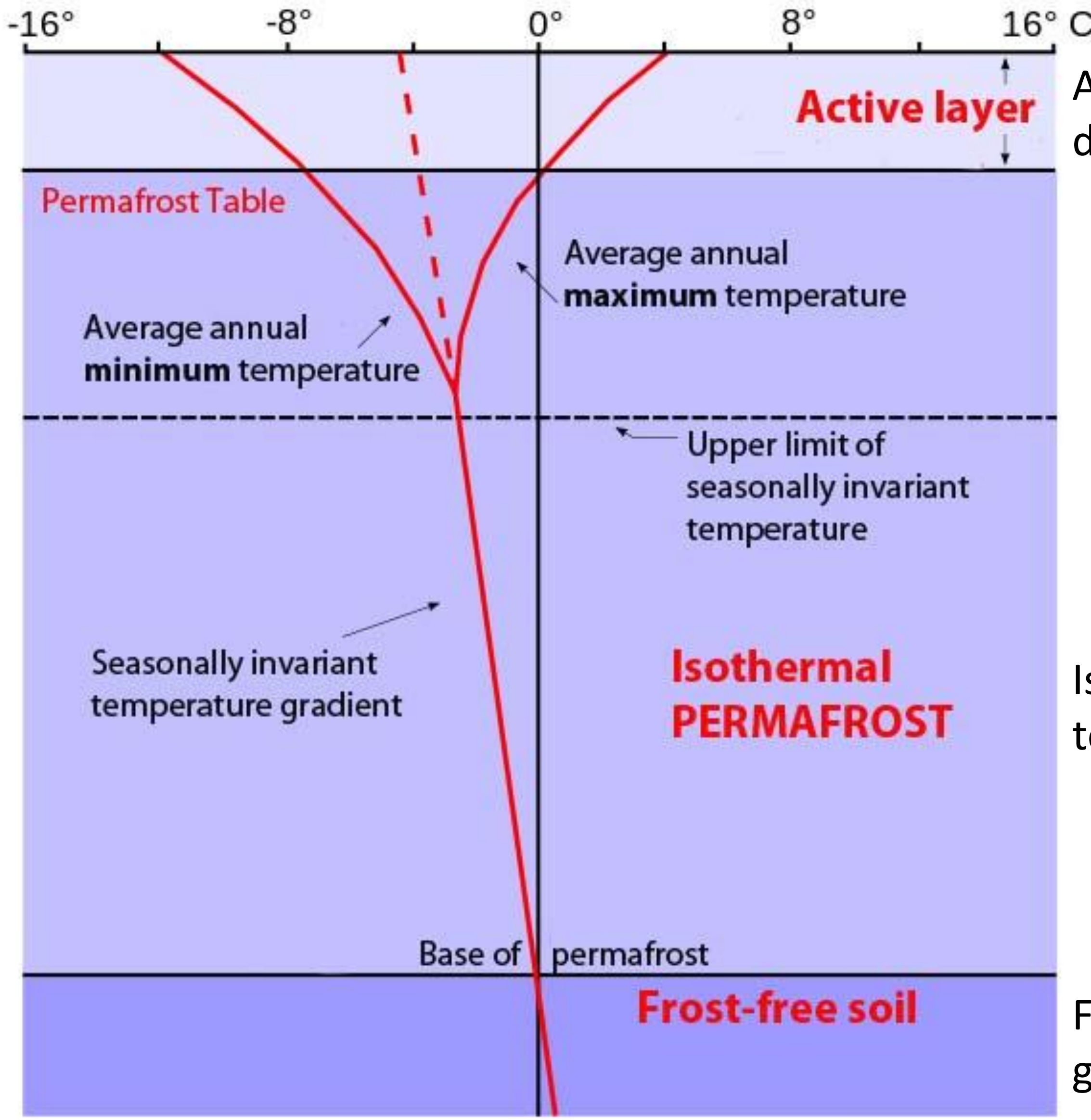
Obbard and Baker, 2007

Source: International Permafrost Association, 1998. Circumpolar Active-Layer Permafrost System (CAPS), version 1.0.

Permafrost: soil frozen for more than two consecutive years

- More widespread in the northern hemisphere
- Present at the periphery of the Antarctic, and at high latitudes throughout the world



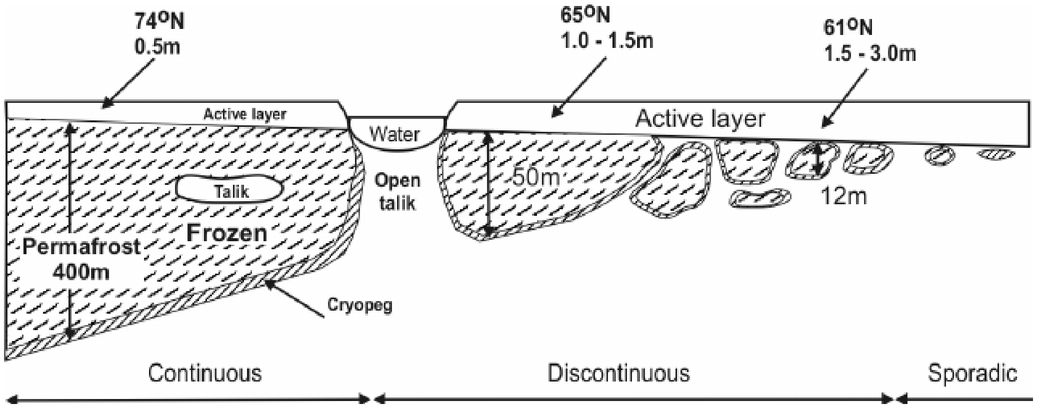


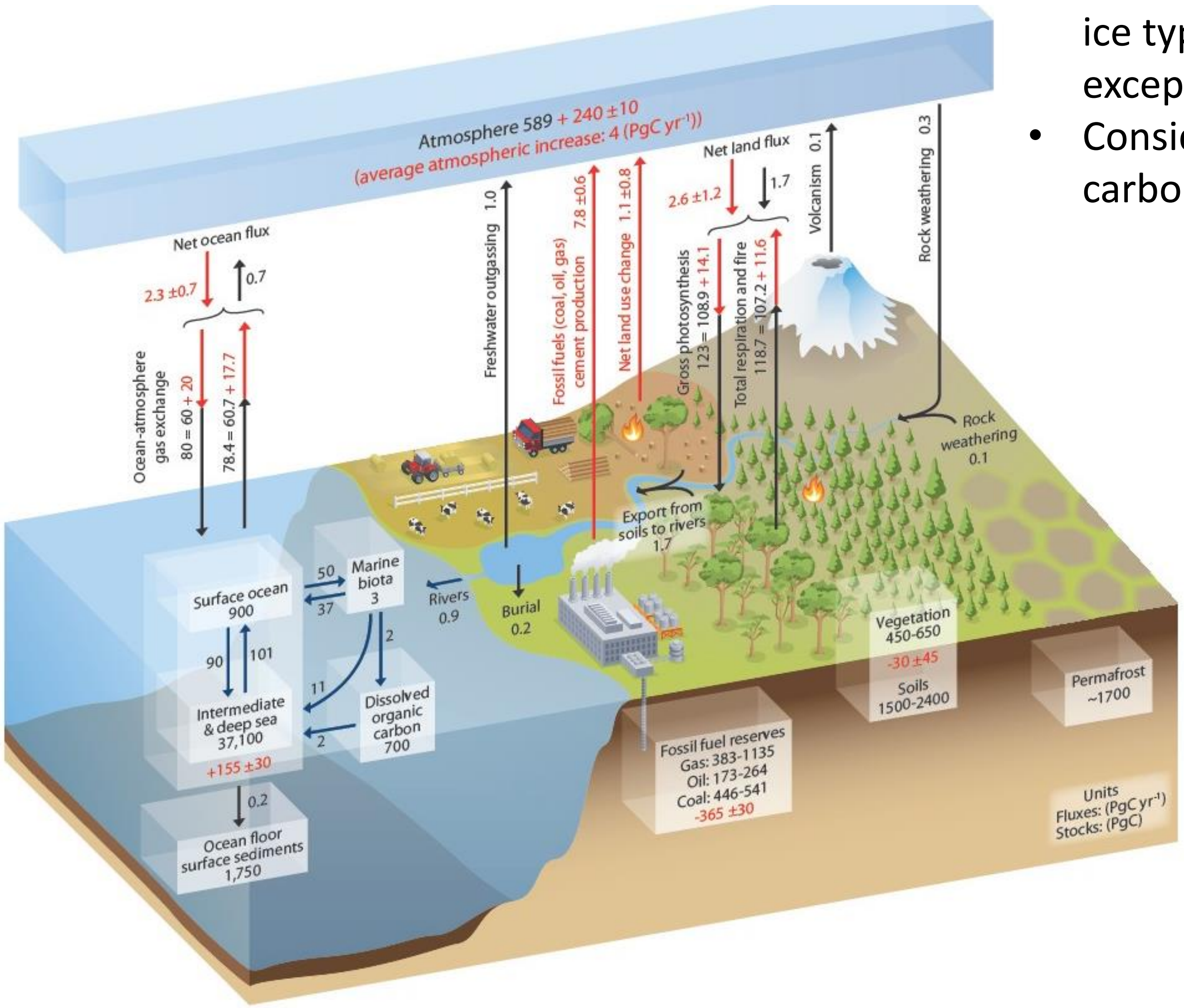
Active layer: warms above freezing during the summer

Isothermal permafrost: not prone to season warming.

Frost-free soil warmed by geothermal energy.


© Mark Wasson, MarkHitsTheRoad.com

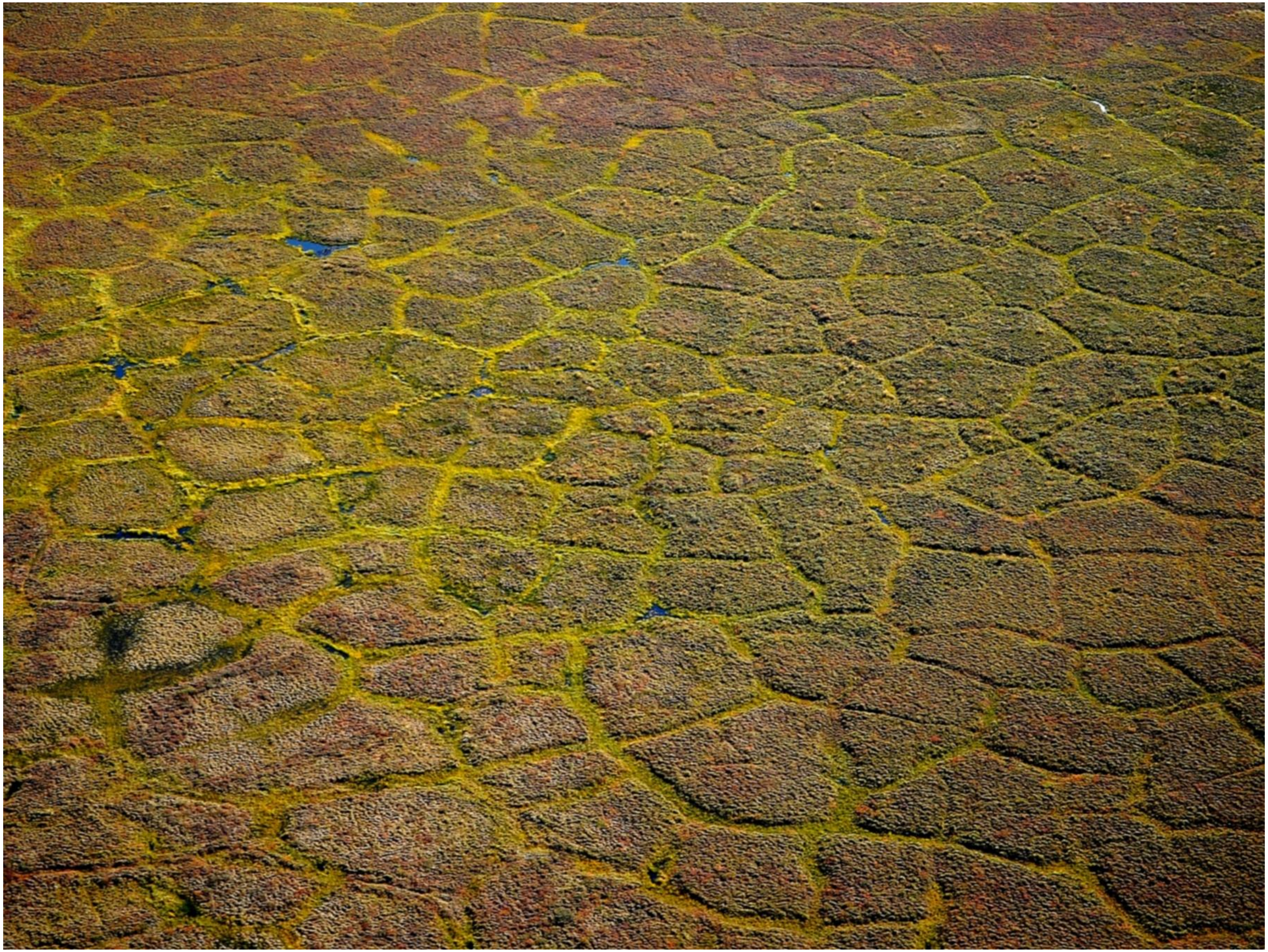

74°N
0.5m
Active layer
Water
Talik
Open
talik
Frozen
Permafrost
400m
Cryopeg
65°N
1.0 - 1.5m
61°N
1.5 - 3.0m
Active layer
50m
12m
Continuous
Discontinuous
Sporadic



- Permafrost is similar to other ice types we've discussed, except:
- Considerably more organic carbon

Features of permafrost landscapes include:

- Polygons



Features of permafrost landscapes include:

- Polygons
- Thermokarst lakes

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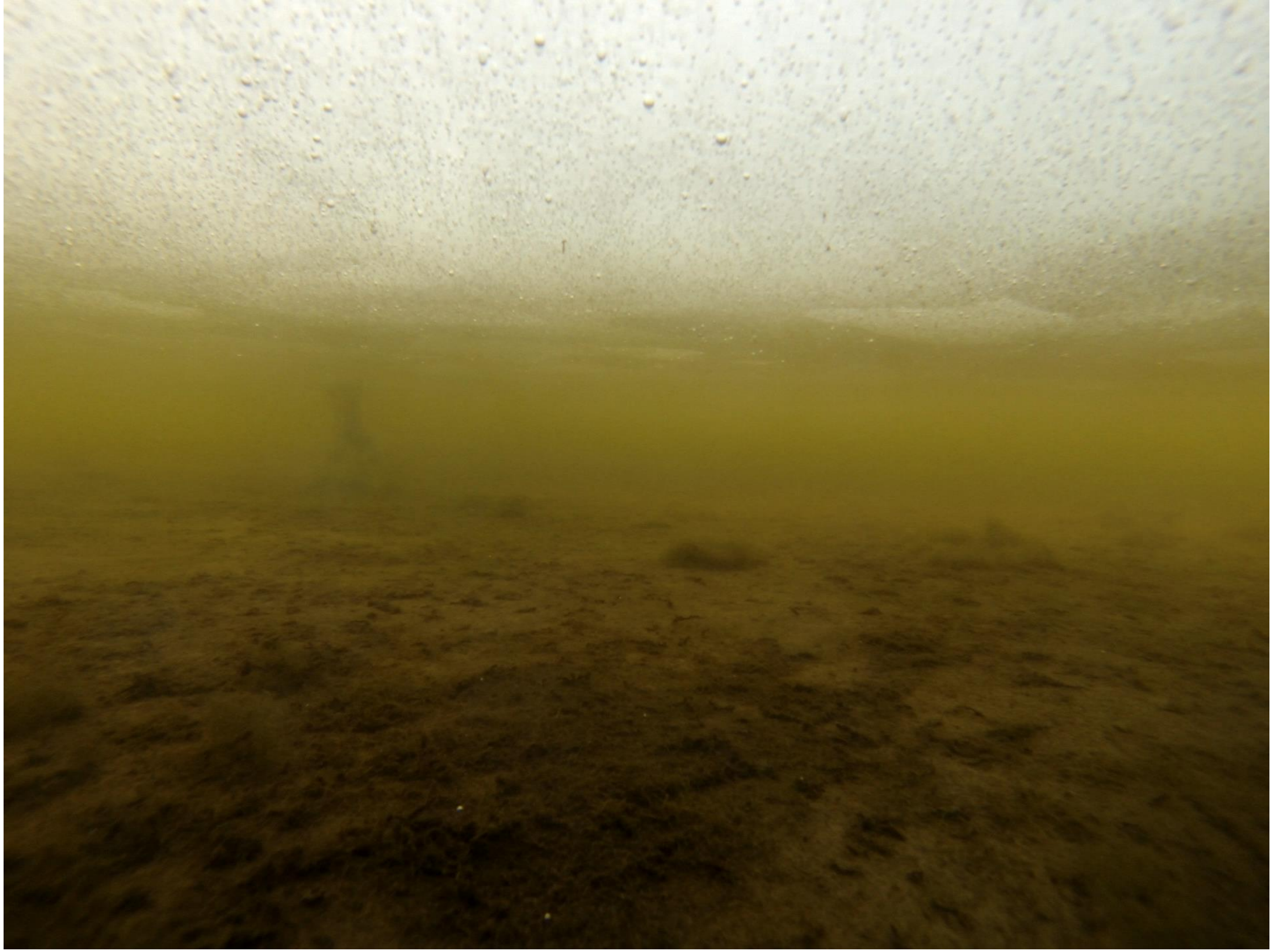
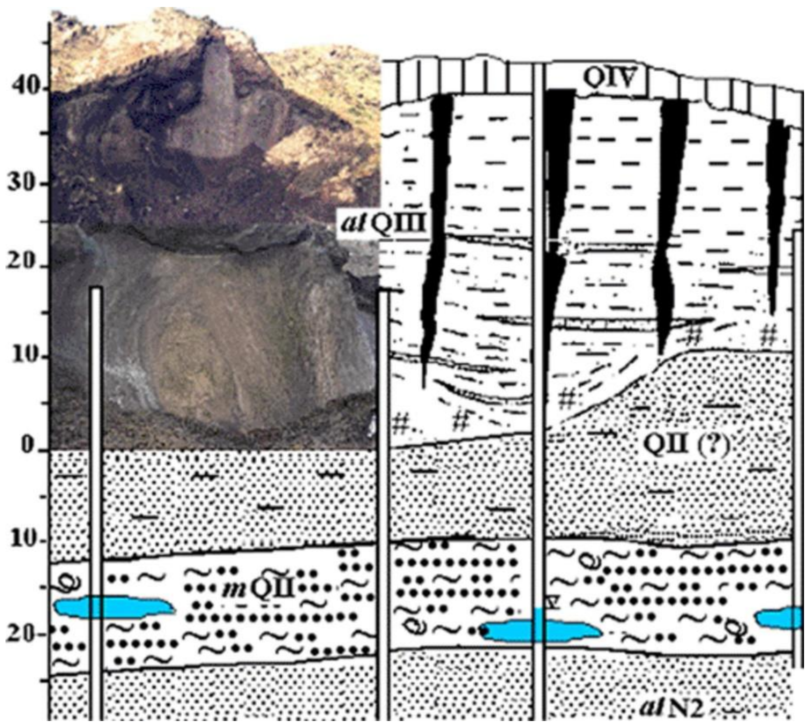


Features of permafrost landscapes include:

- Polygons
- Thermokarst lakes
- Cryopegs: frozen, remnant marine sediments



Gilichinsky et al., 2005

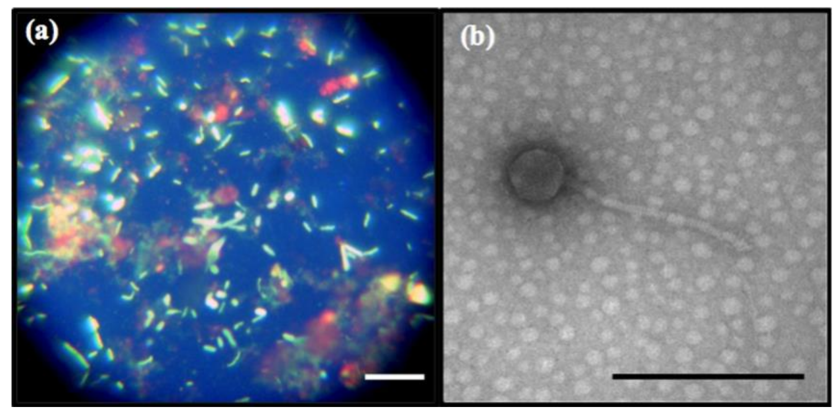


Table 1. Comparative concentration of main ions (mM) and total mineralization (g/L) in cryopegs and standard seawater

Ion, mM	Sampling Site				
	Yakutskoe Lake	Chukochii Cape	Varandei Cape	Barrow Cape	Seawater
K^+	20	10	6.2	23.5	10.2
Na^+	2000	1520	99.5	1680	469
Ca^{2+}	30	40	8.9	52.4	10.3
Mg^{2+}	310	195	28.5	357	52.8
Cl^-	2630	1940	111	1930	546
SO_4^{2-}	35	31.5	23.8	64.4	28
Mineralization (‰)	150–200	150–200	6–18	115	35

Spirina et al., 2017

Features of permafrost landscapes include:

- Polygons
- Thermokarst lakes
- Cryopegs: frozen, remnant marine sediments

Colangelo-Lillis et al, 2016