Extreme Environment Microbiology in Ices

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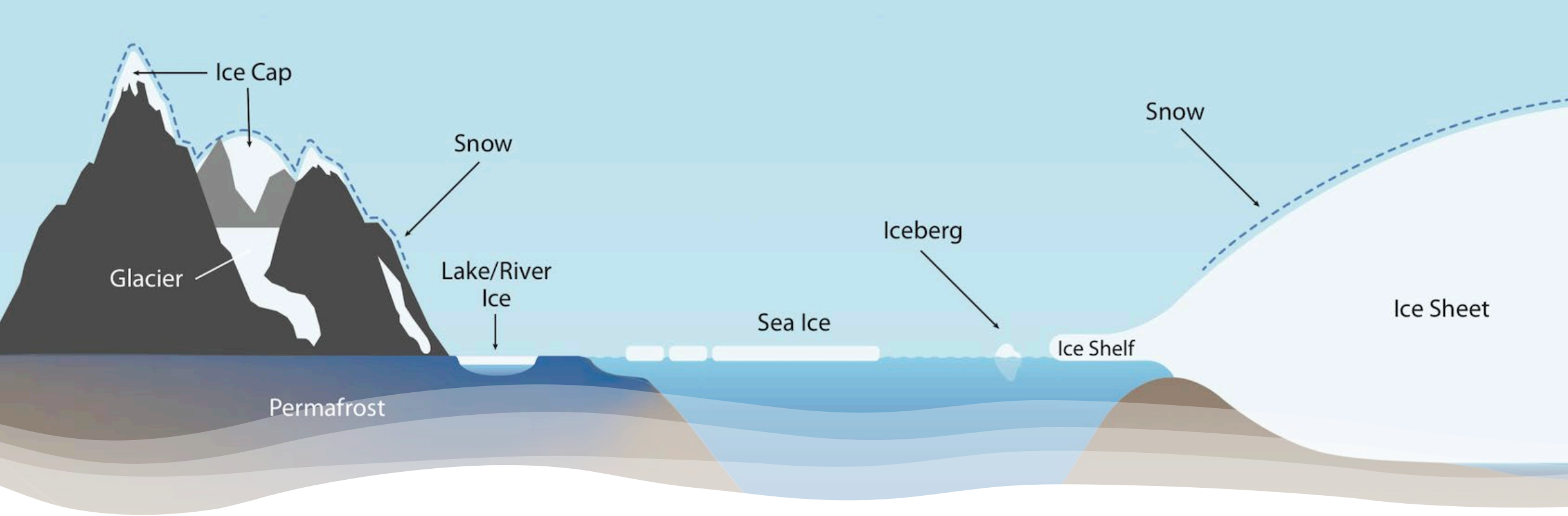
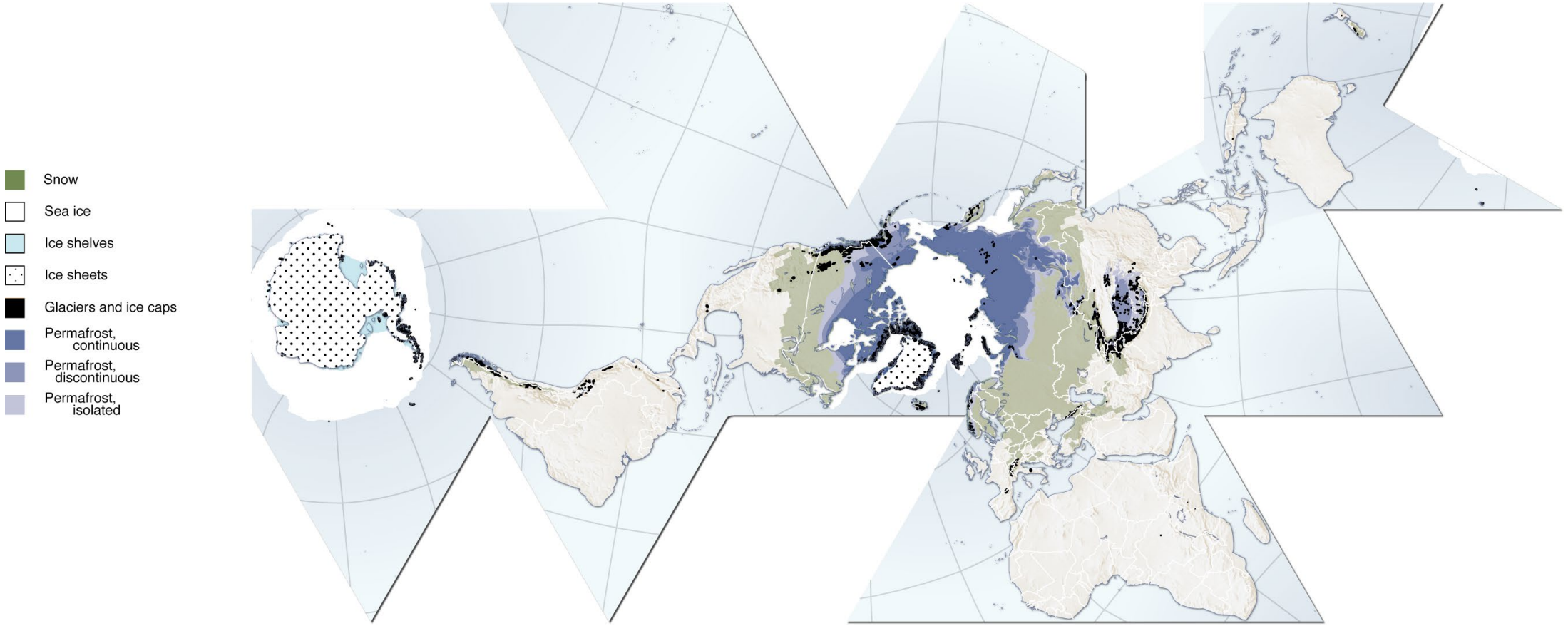


The Cryosphere

Image from CryoConnect.com

From a biological perspective, Earth is a cold planet

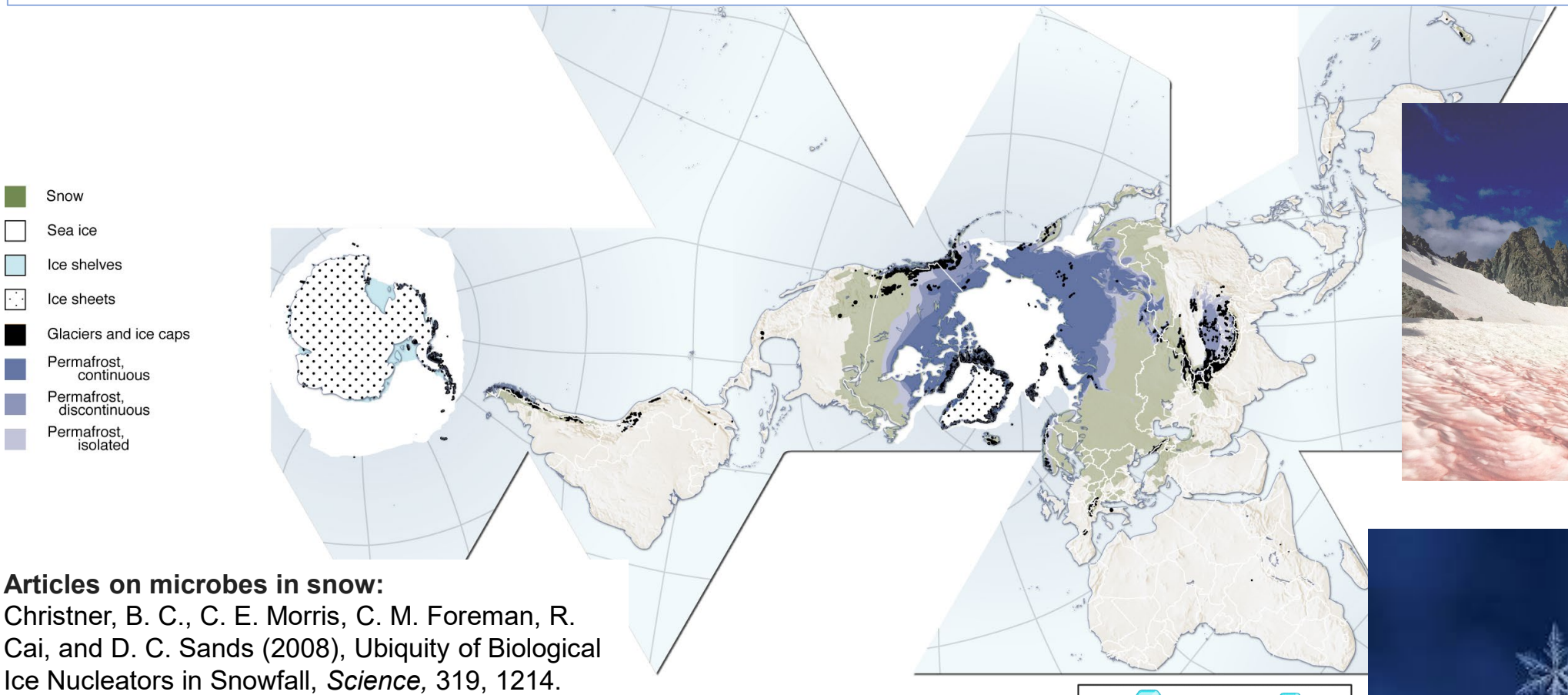
Cryosphere: portions of Earth's surface where water is in solid form. Includes sea ice, lake ice, river ice, snow cover, glaciers, ice caps, ice sheets, and frozen ground

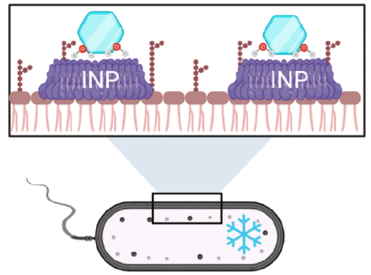


UNEP/GRID-Arendal, Cryosphere, *UNEP/GRID-Arendal Maps and Graphics Library* (2007) http://maps.grida.no/go/graphic/cryosphere

Snow: microbes can be transported in the atmosphere and facilitate the nucleation of snow crystals.

Some microbes use special ice nucleating proteins to grow the crystal lattice at temperatures above freezing.





Articles on microbes in snow:

Christner, B. C., C. E. Morris, C. M. Foreman, R. Cai, and D. C. Sands (2008), Ubiquity of Biological Ice Nucleators in Snowfall, *Science,* 319, 1214.

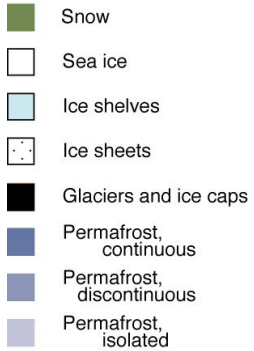
Miteva V. (2008). Bacteria in Snow and Glacier Ice. In Psychrophiles: from Biodiversity to Biotechnology. Springer, Berlin, Heidelberg.

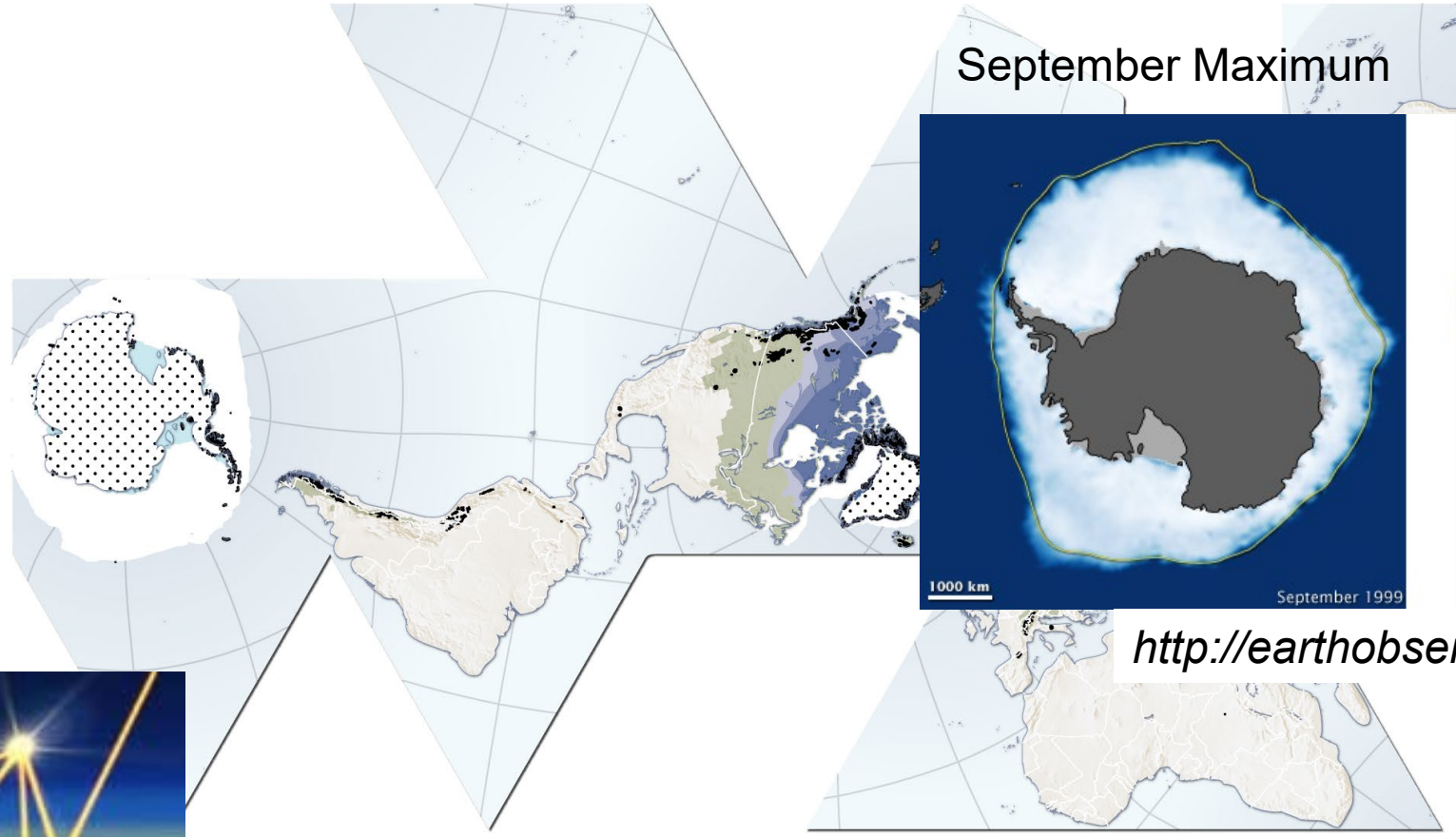
Maccario, L., L. Sanguino, T. Vogel and C. Larose. (2015). Snow and ice ecosystems: not so extreme. Research in Microbiology, 166:10: 782-795.

UNEP/GRID-Arendal, Cryosphere, *UNEP/GRID-Arendal Maps and Graphics Library* (2007) http://maps.grida.no/go/graphic/cryosphere

Sea Ice: frozen ocean water; forms, grows, and melts in the ocean. Covers ~25 million km^2 of the Earth

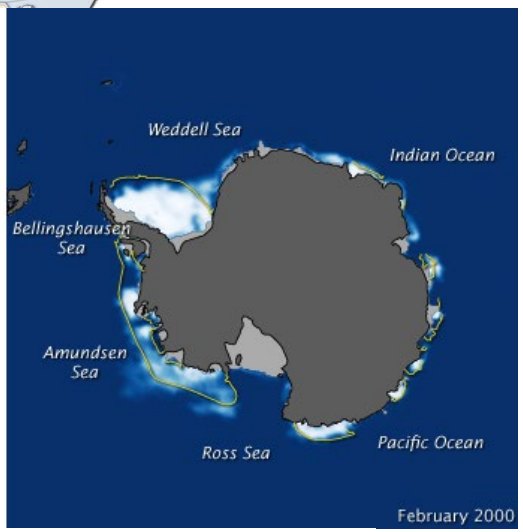
~15% of the world's oceans are covered with sea ice at some point





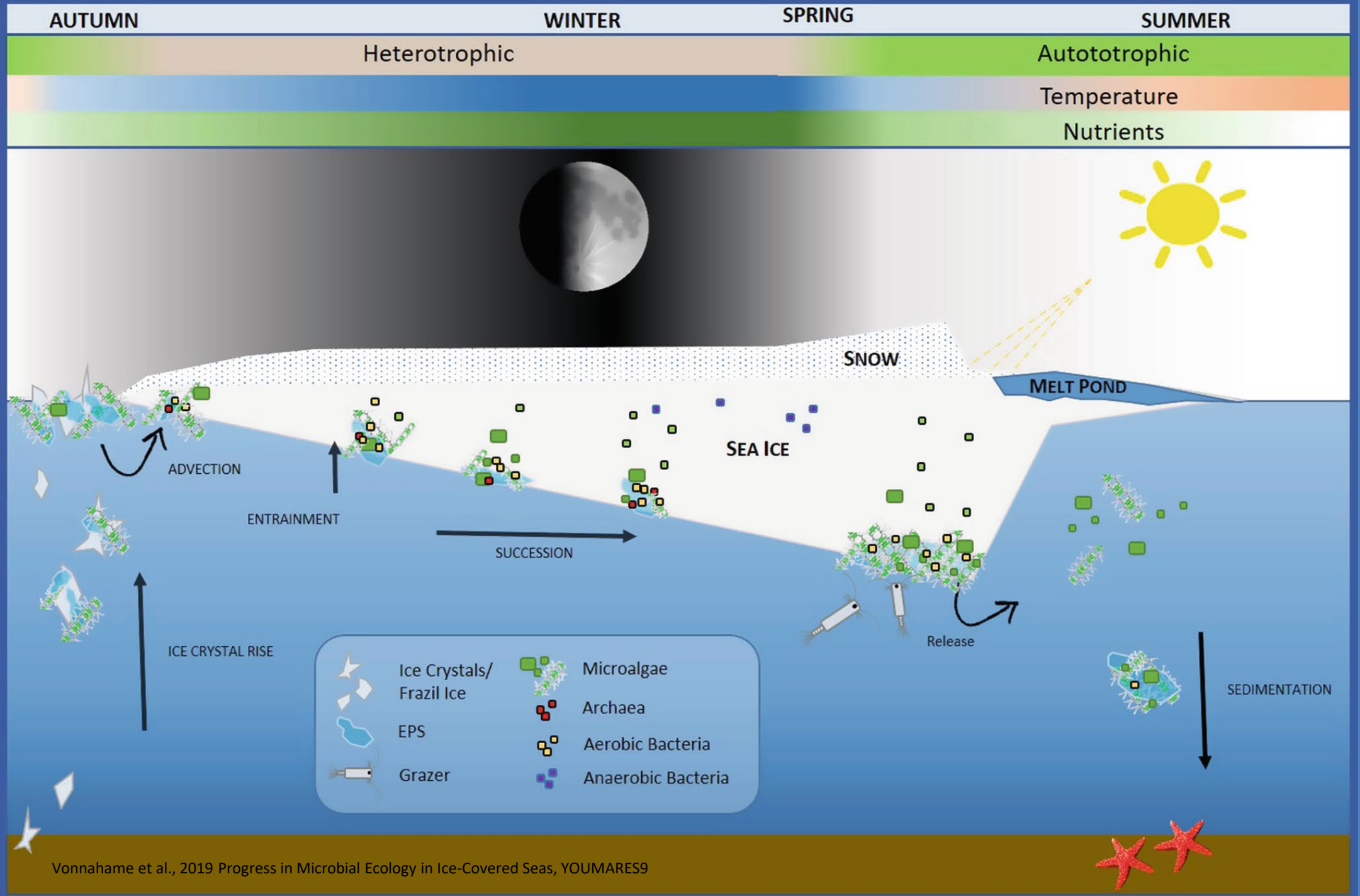
September Maximum

February Minimum



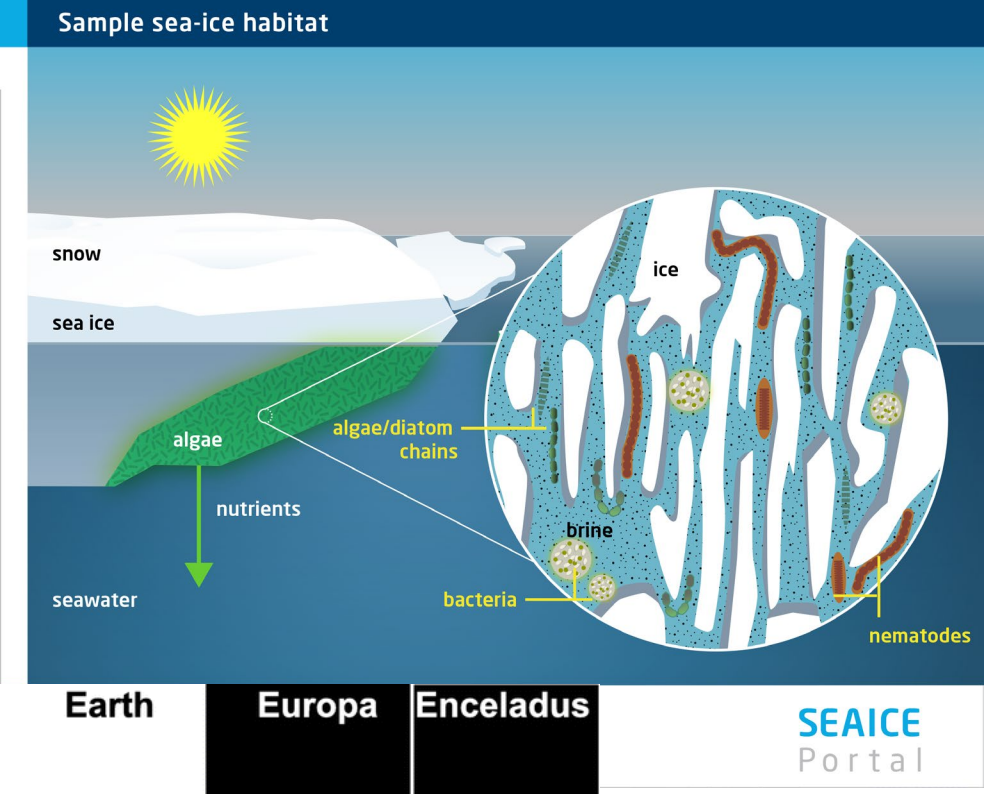
http://earthobservatory.nasa.gov

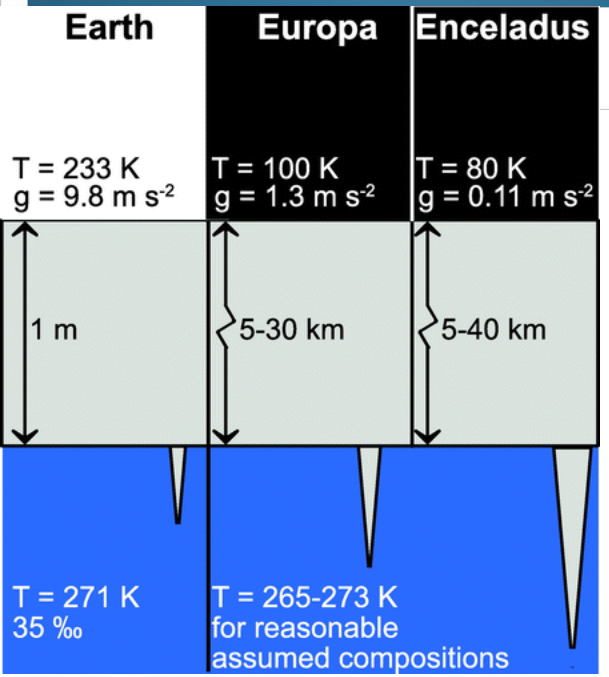
UNEP/GRID-Arendal, Cryosphere, *UNEP/GRID-Arendal Maps and Graphics Library* (2007) http://maps.grida.no/go/graphic/cryosphere



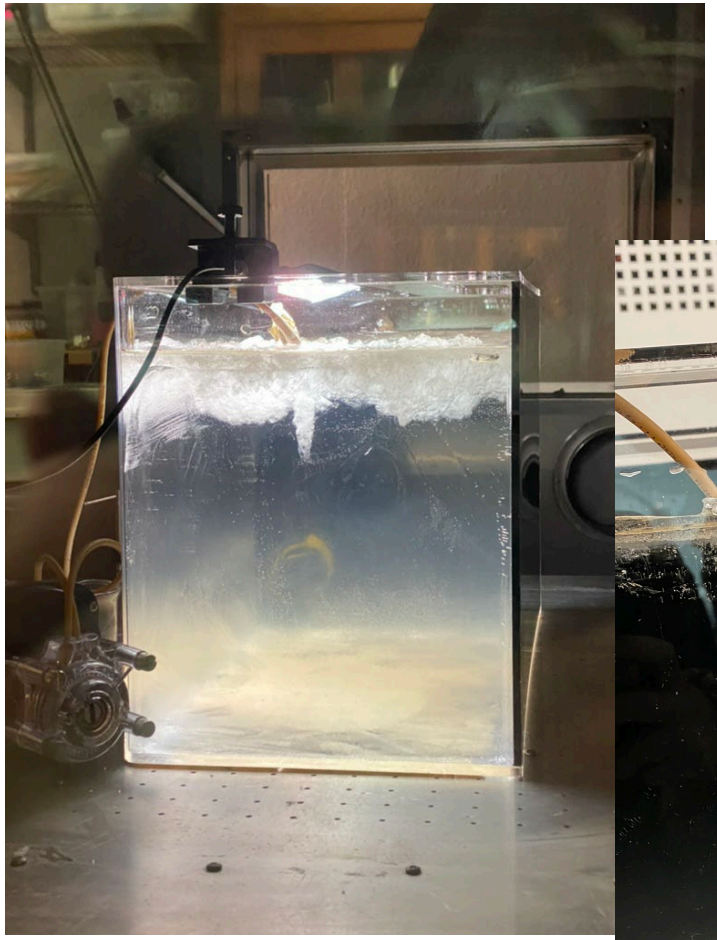
Vonnahame et al., 2019 Progress in Microbial Ecology in Ice-Covered Seas, YOUMARES9

Brinicles- inverse chemical gardens

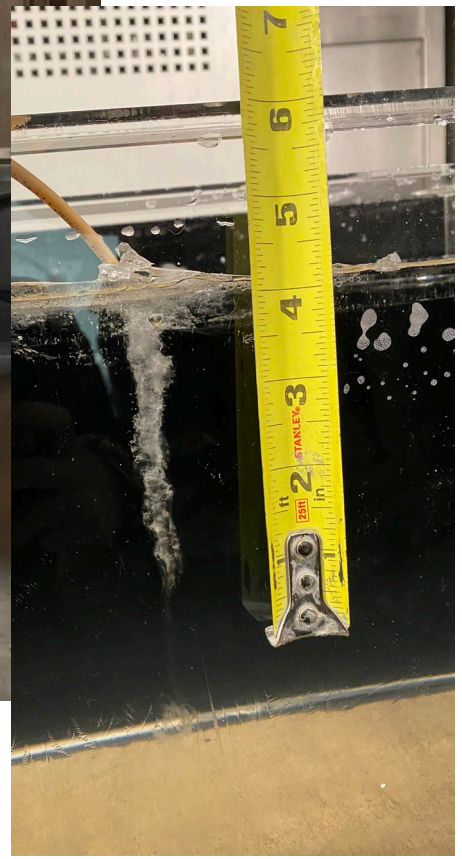




Vance et al., 2018, *Astrobiology*



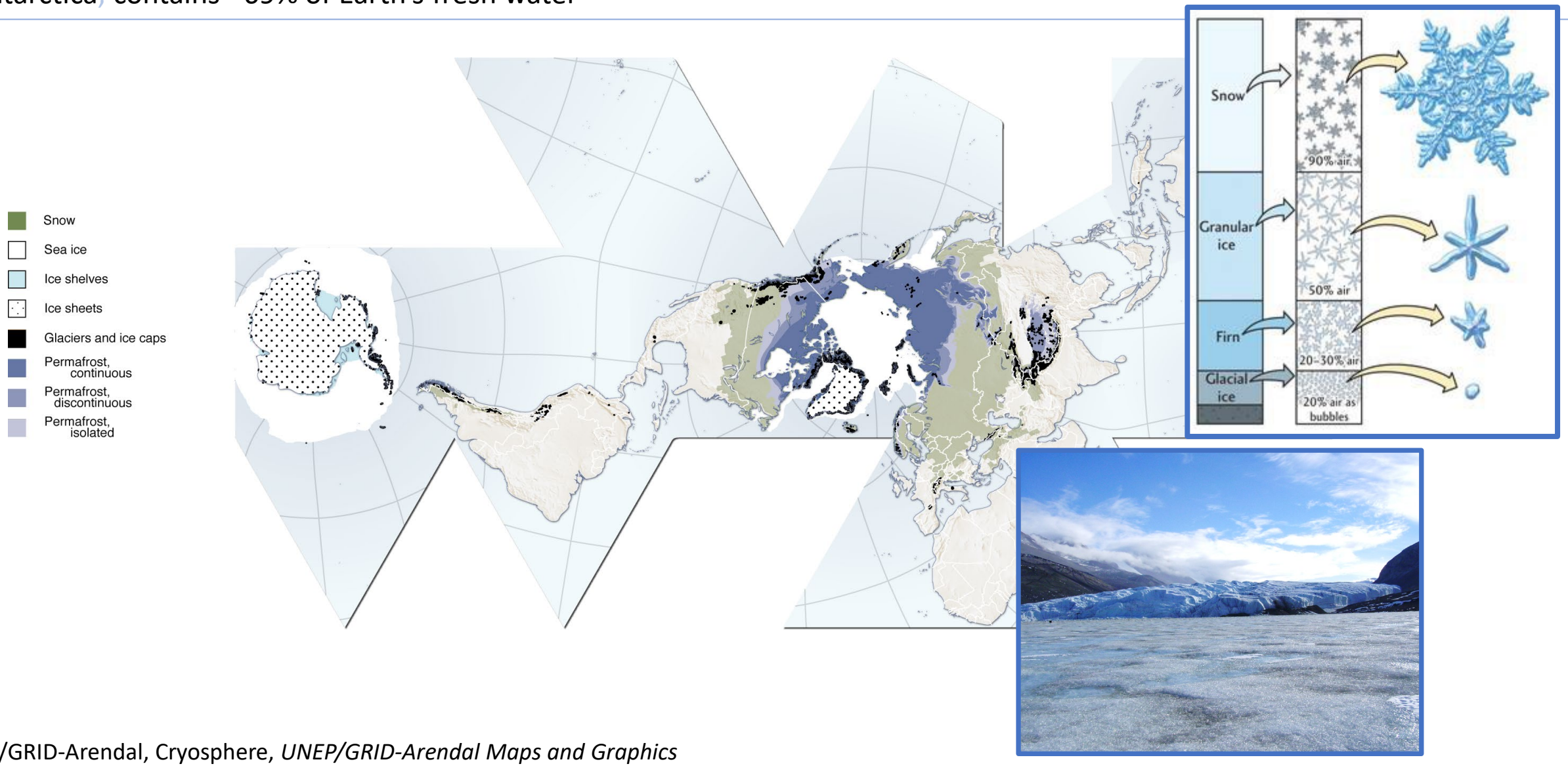
Maddie Garner, Foreman Research Group



Cartright et al., 2013, *Langmuir*.

Glaciers and Ice Caps: Form when snow accumulates long enough to compress into thick ice masses.

~10 percent of land area on Earth is covered with glacial ice, including glaciers, ice caps, and ice sheets in Greenland and Antarctica, contains ~69% of Earth's fresh water



UNEP/GRID-Arendal, Cryosphere, *UNEP/GRID-Arendal Maps and Graphics Library* (2007) http://maps.grida.no/go/graphic/cryosphere

The glacier/ice sheet ecosystem can be divided into 3 broad realms:

Supraglacial: situated or occurring at the surface of a glacier.

Englacial: occurring, or formed inside a glacier.

Subglacial: occurring underneath a glacier or ice sheet.

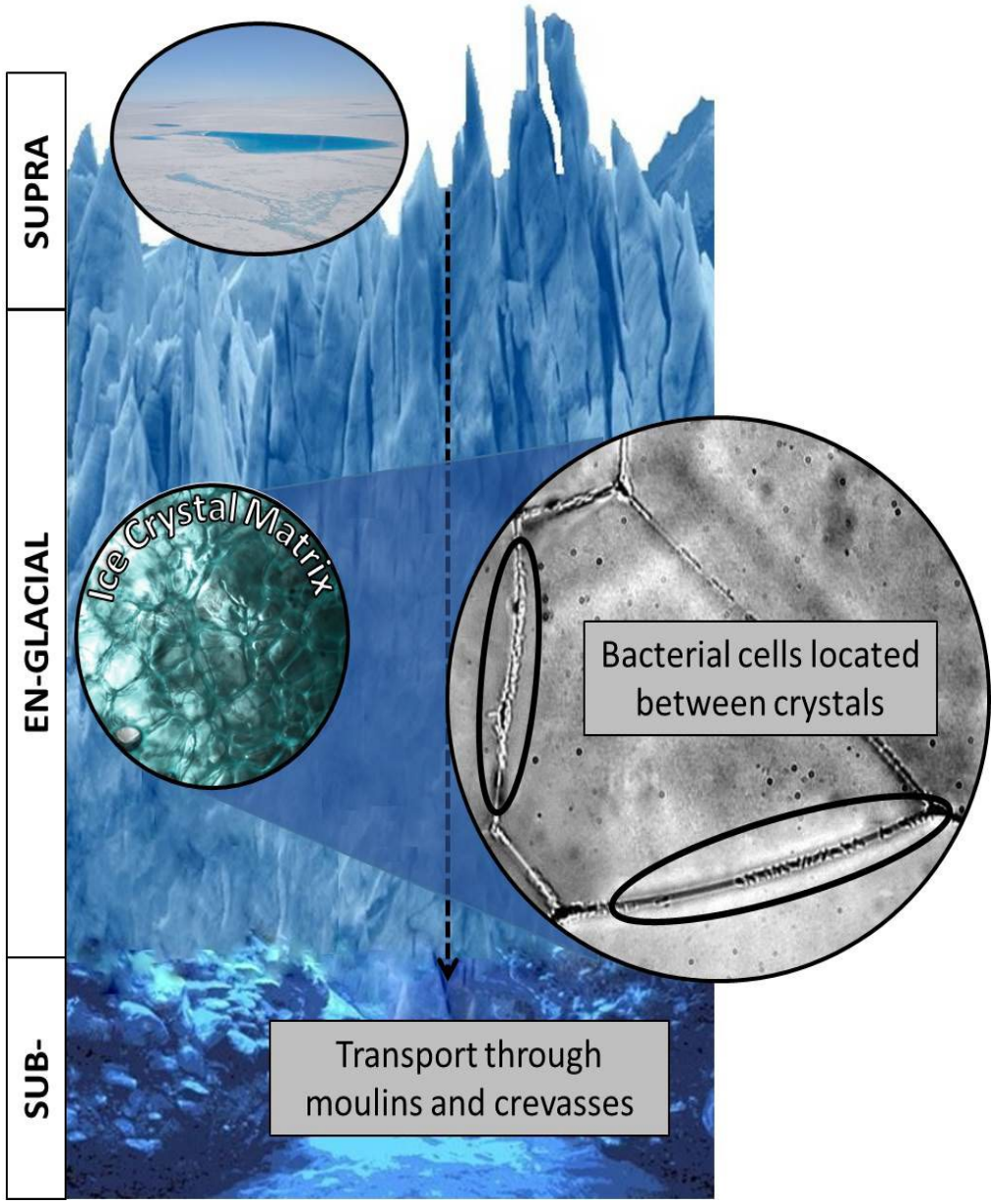


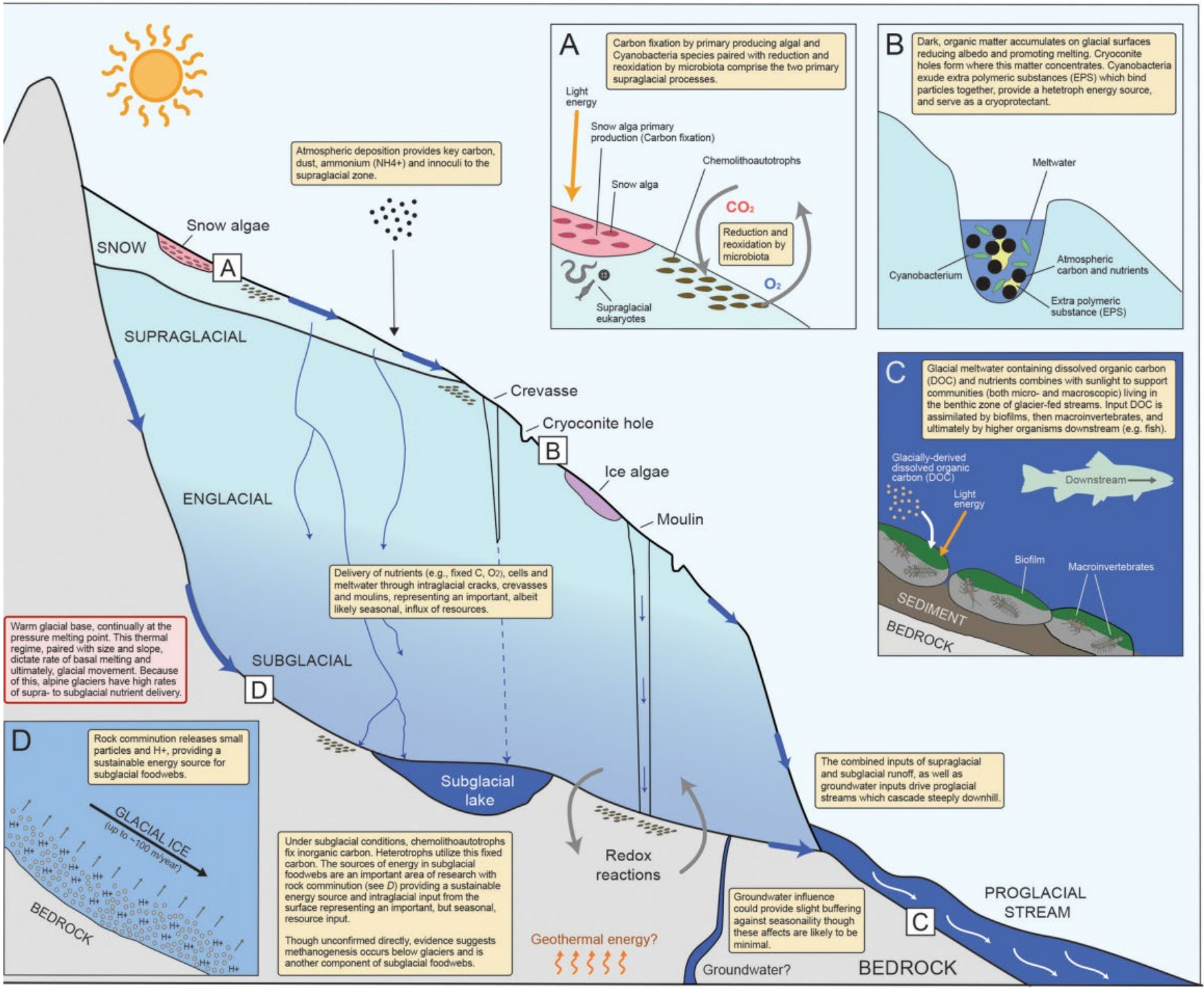
Image: M. Dieser, Foreman Research Group

Review articles on glacier microbiology:

Boetius et al., 2015. Microbial ecology of the cryosphere: sea ice and glacial habitats. *Nature Reviews Microbiology*, *13*(11), pp.677-690

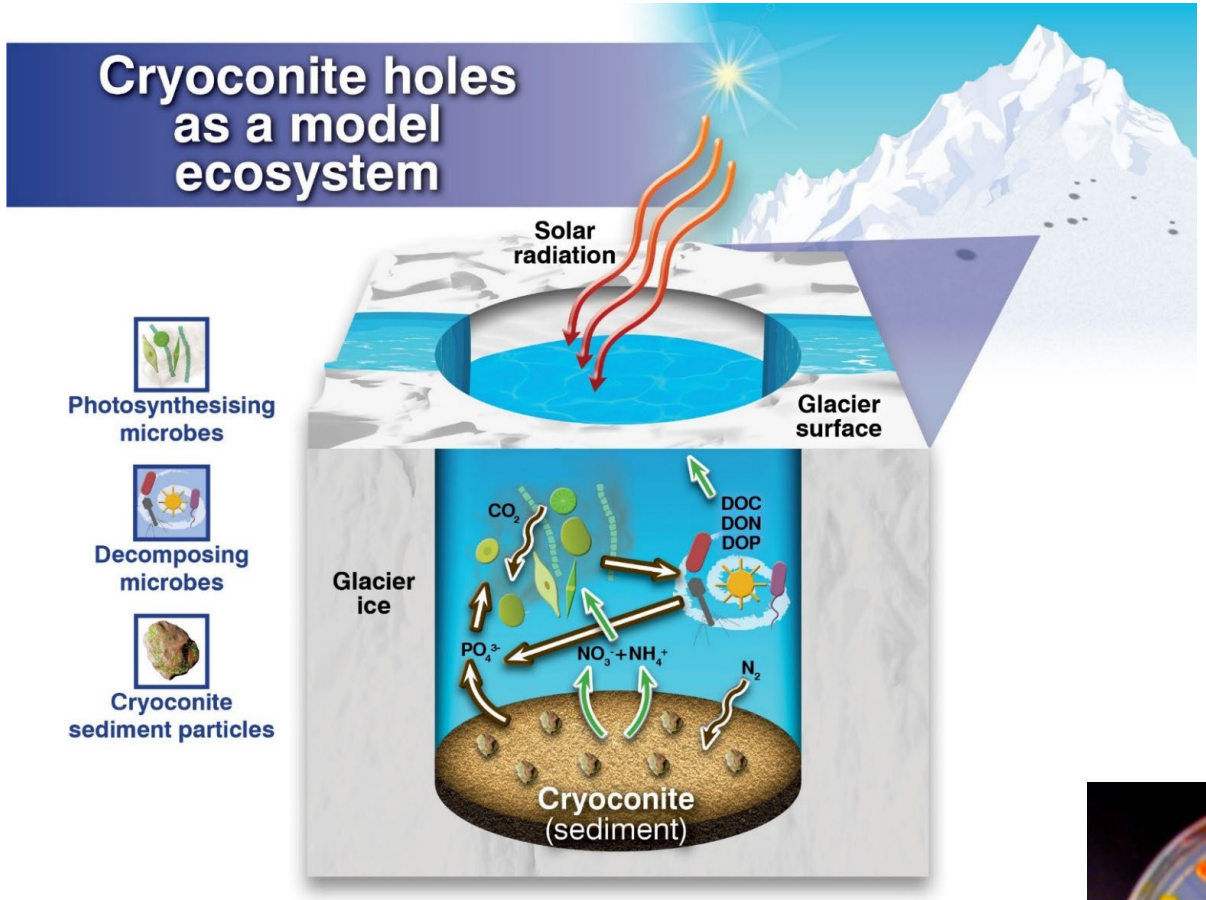
Anesio, A.M. and Laybourn-Parry, J., 2012. Glaciers and ice sheets as a biome. *Trends in ecology & evolution*, *27*(4), pp.219-225.

Hodson et al., 2008. Glacial ecosystems. *Ecological monographs*, *78*(1), pp.41-67.

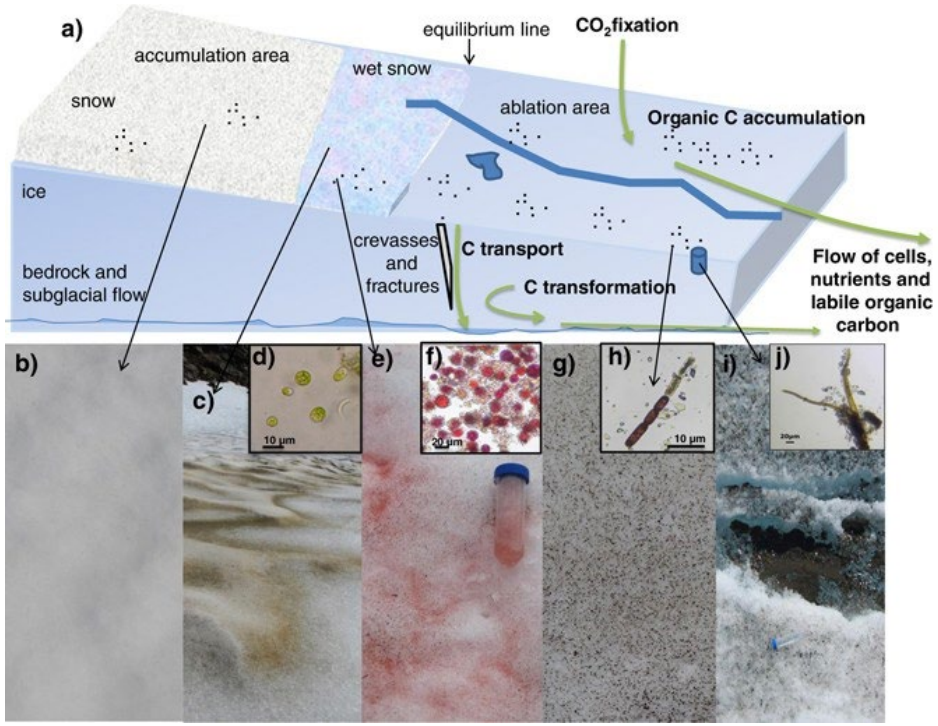


Hotaling, S., E. Hood and T. Hamilton (2017). Environmental Microbiology, 19(8): 2935-2948.

Supraglacial: Pigmented organisms occupy glacier surface niches & impact albedo



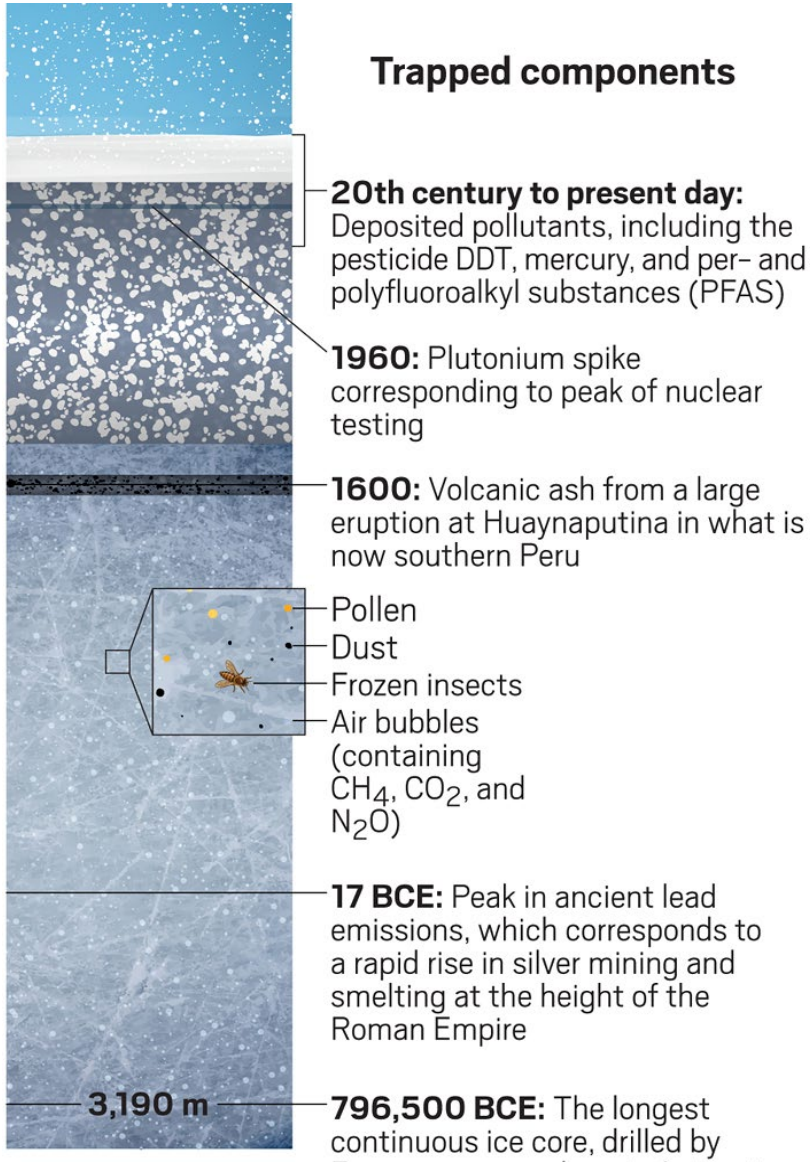
Smith et al., 2016 *Nature Biofilms and Microbiomes*



Anesio et al., 2017 *Nature Biofilms and Microbiomes*

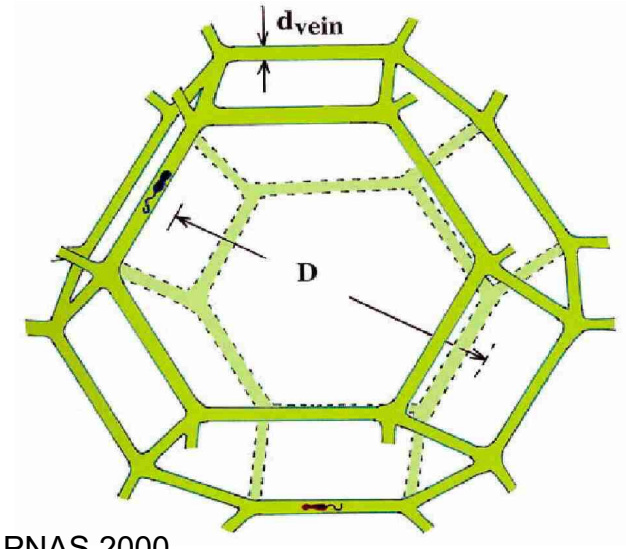
Pigmented glacier isolates. Dieser et al., 2010. *Arctic, Antarctic & Alpine Research*

Englacial environment- deep cores are important, understudied, microbial habitats



Bourzac 2020, Chemical and Engineering News

Image: WAIS Divide



Price, PNAS 2000

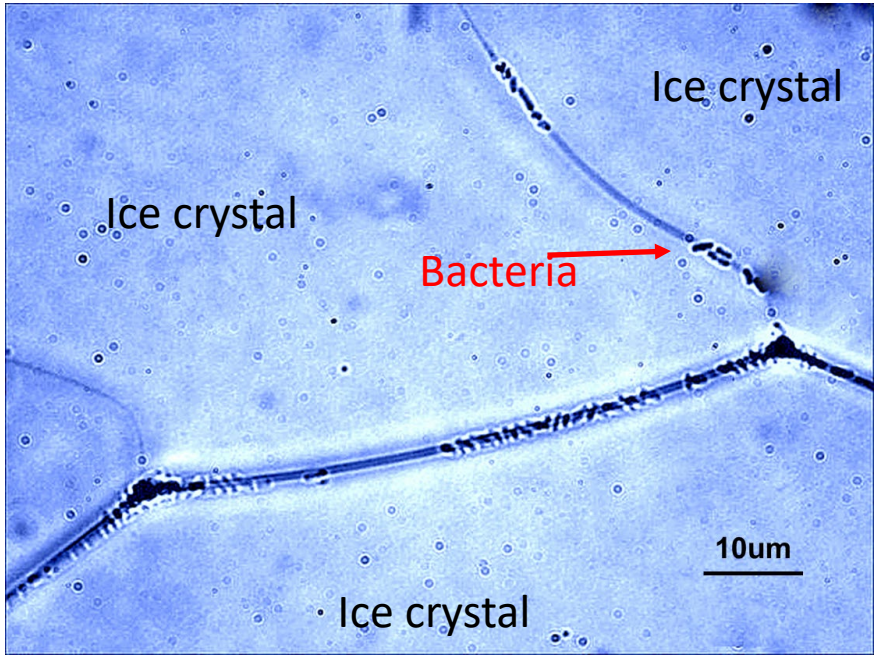
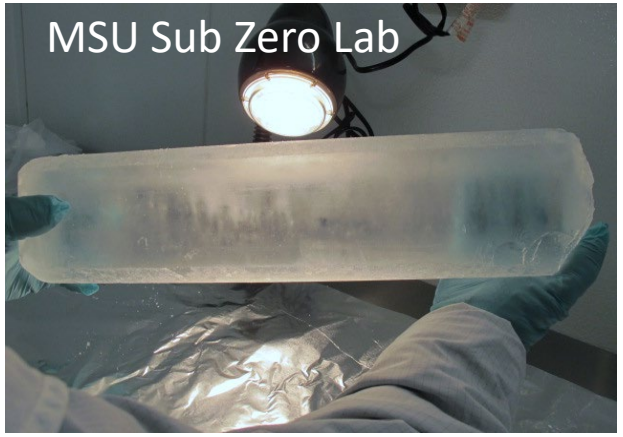
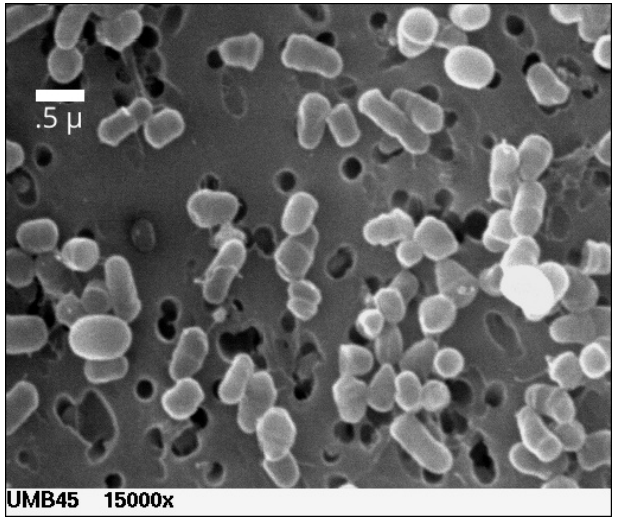


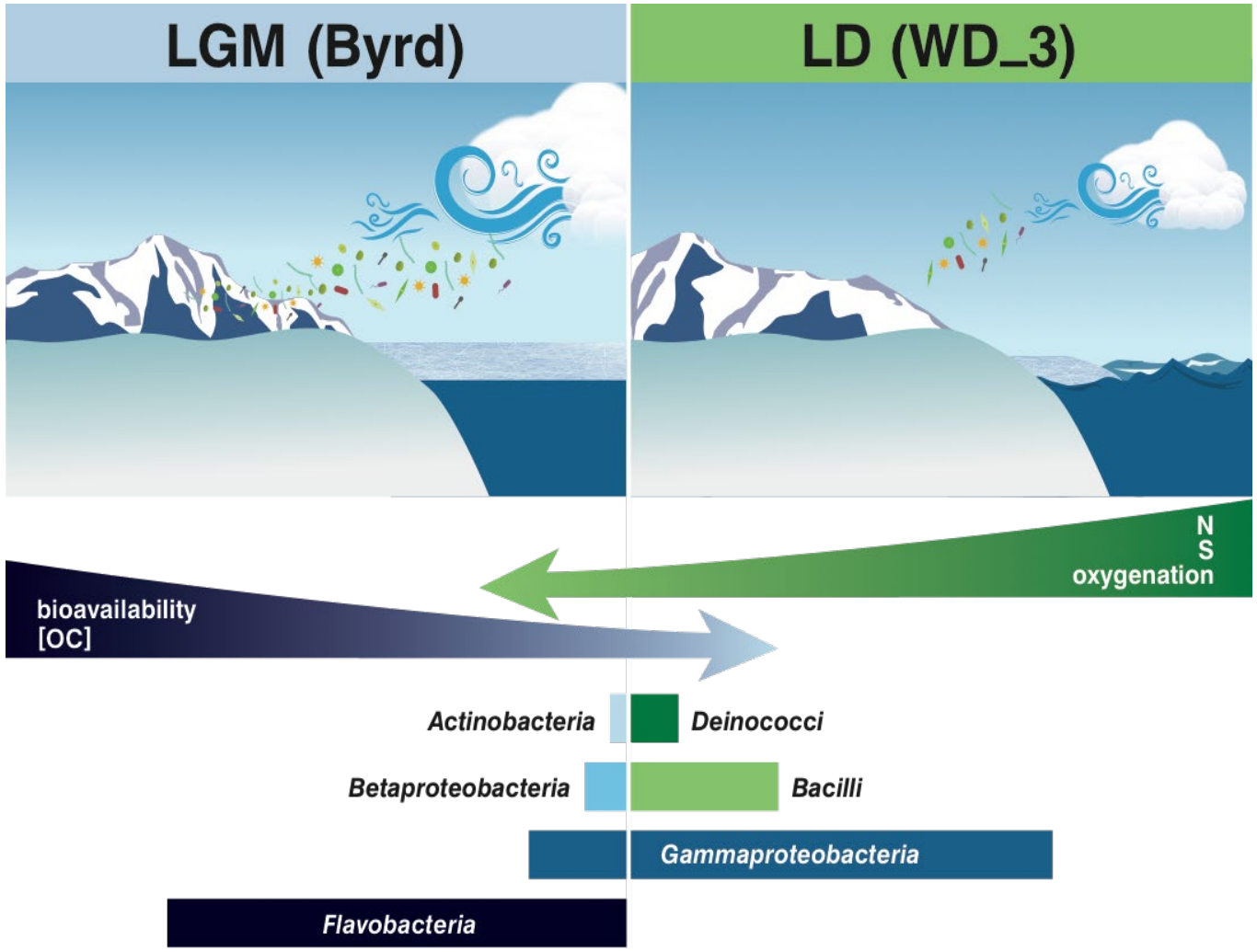
Image: Dieser & Foreman

Microbial components of ice core records





Ultramicrobacteria, Miteva and Brenchley, *Appl Env Micro* 2005

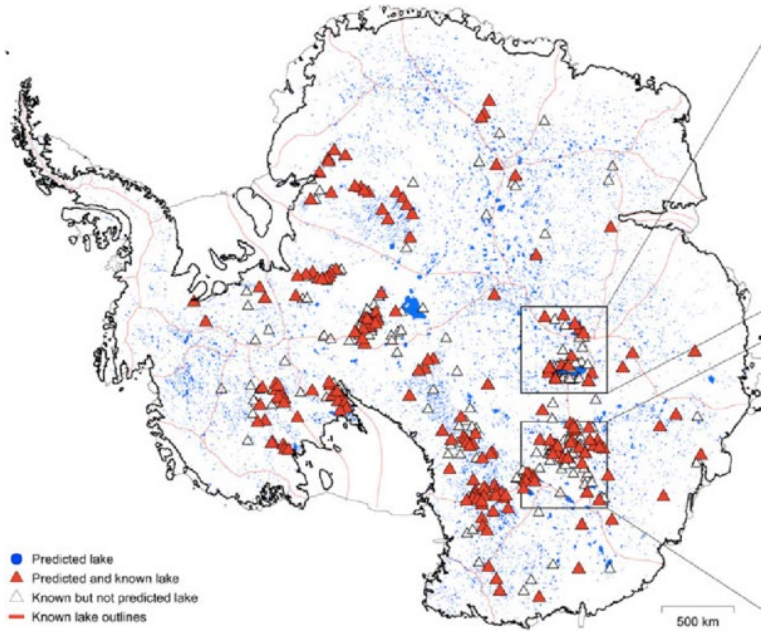


D'Andrilli, Smith, Dieser & Foreman 2017 *Geochemical Perspectives Letters*

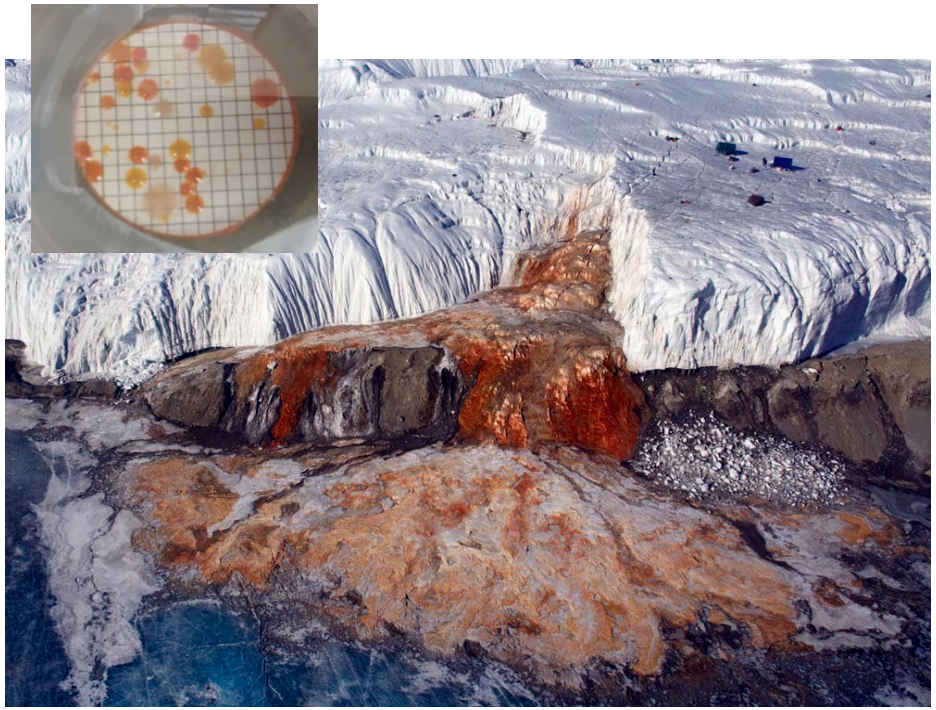
Diversity of sub-ice environments

Hypersaline **subglacial** lake
– Devon Island, Canada
Rutishauser et al. 2018, *Science Advances*

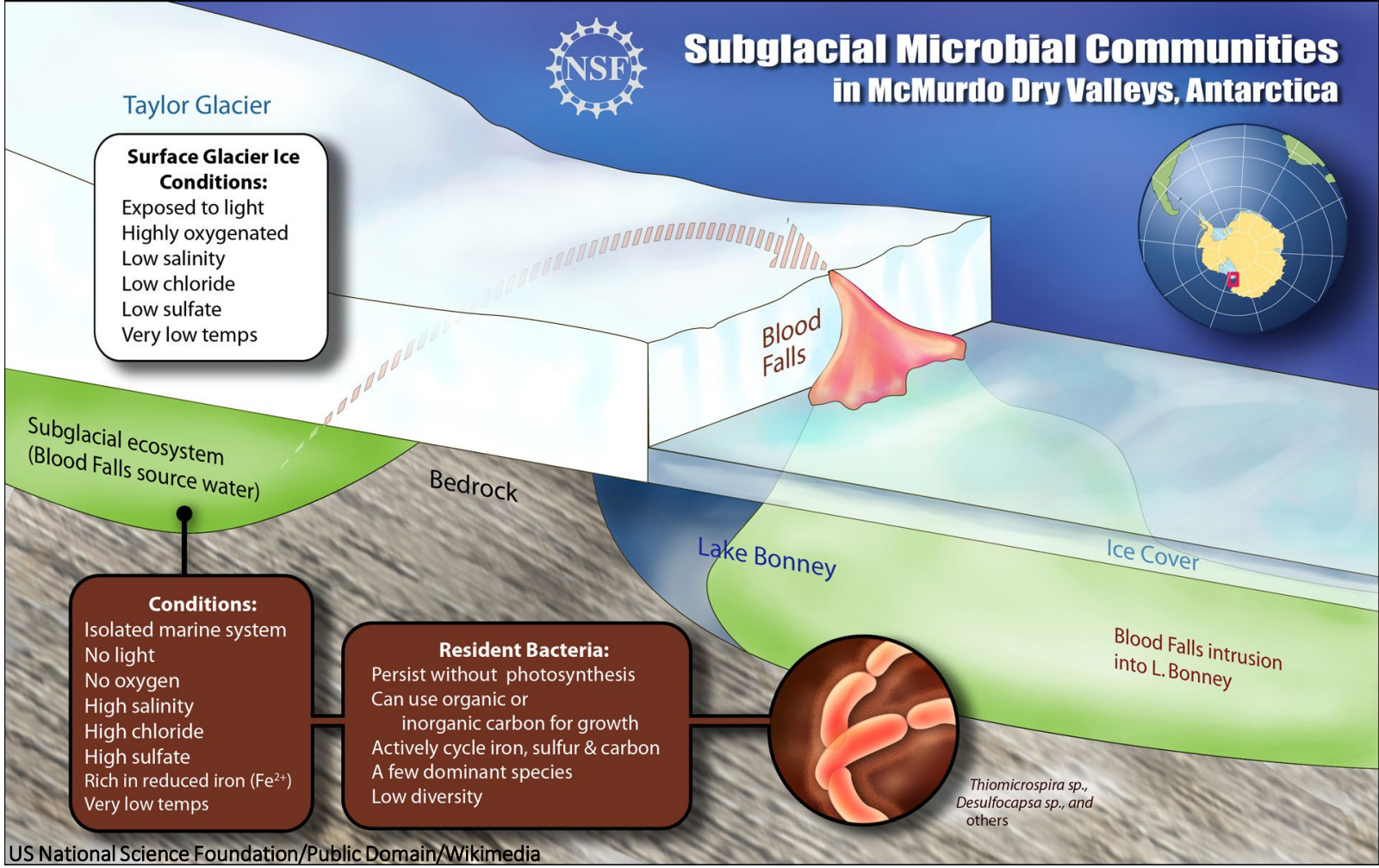
Grímsvötn subglacial **caldera** lake (Iceland)
Crafford et al (2022), Gaidos et al (2004), Astrobiology



~400 subglacial **Antarctic** subglacial lakes detected …so far (Wright and Siegert (2011)



Blood Falls, Antarctica episodically discharges subglacial ancient marine brine to an icy surface. J. Mikucki

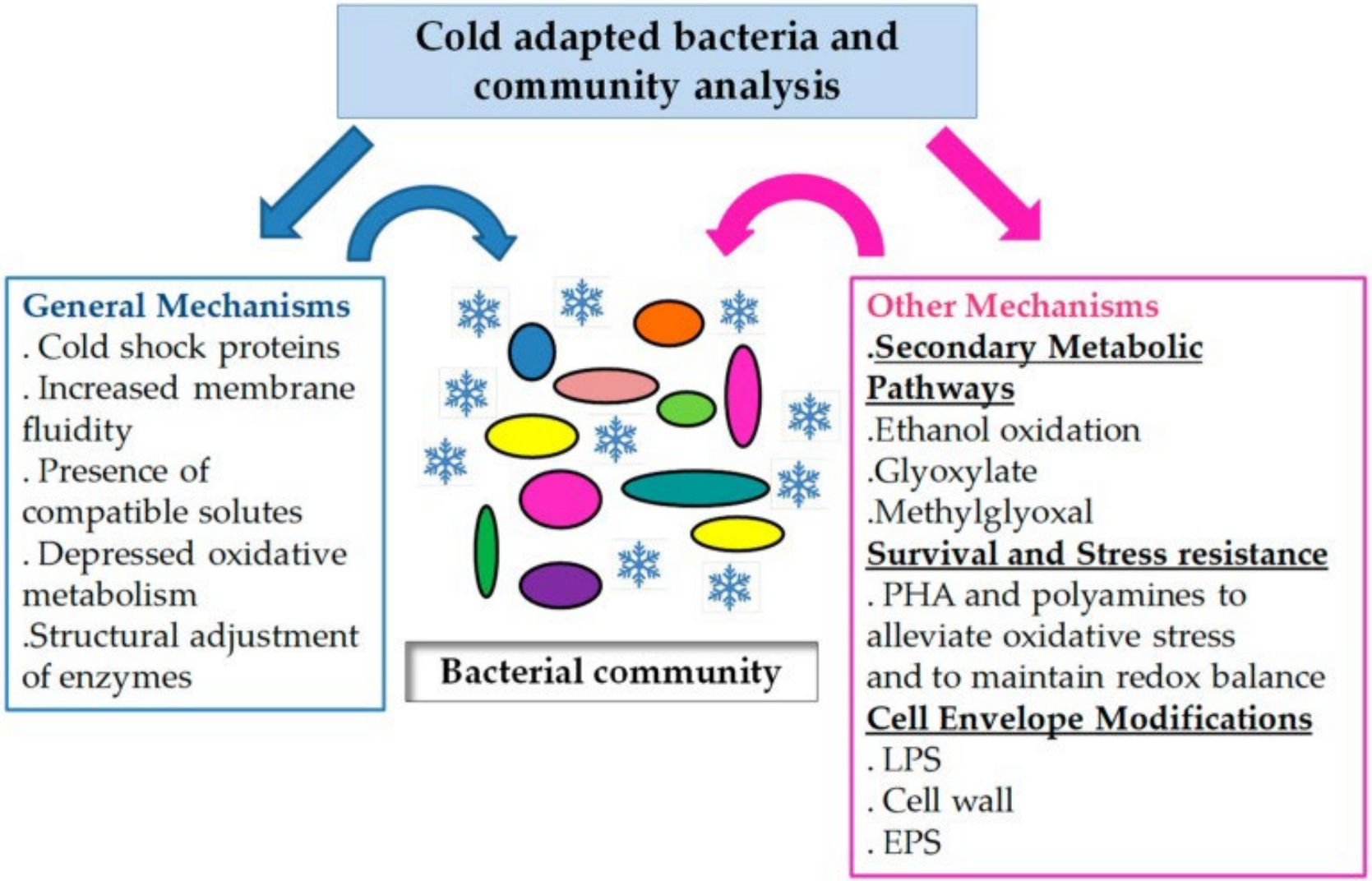


Articles on Blood Falls subglacial environment:

Mikucki et al., 2005 Geomicrobiology of Blood Falls: an iron rich saline discharge at the terminus of the Taylor Glacier, Antarctica. *Aquatic Geochemistry,* 2004

Mikucki et al., 2016. Subglacial Lake Whillans microbial biogeochemistry: a synthesis of current knowledge. *Phil. Trans. R. Society*.

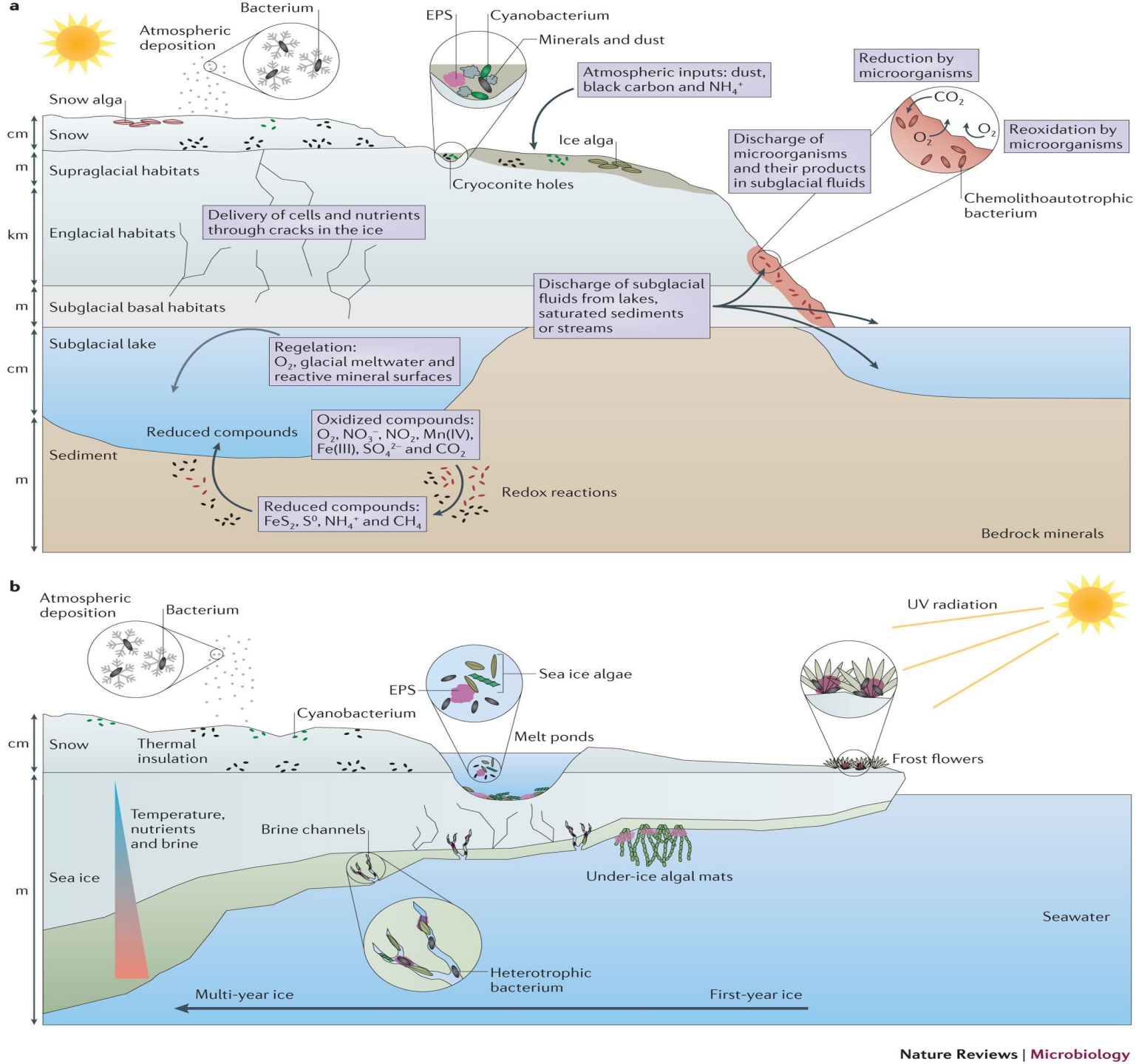
Sklute et al., 2022. A Multi-Technique Analysis of Surface Materials from Blood Falls, Antarctica. *Astron. Space Science*



Tribelli and Lopez, 2018. Reporting key features in cold-adapted bacteria. *Life*.

“Great God! This an awful place…”
Robert Falcon Scott

Diary January 17, 1912



Nature Reviews | Microbiology

Microbial ecology of the cryosphere: sea ice and glacial habitats. Boetius et al., 2015

Life in Ice Beyond Earth

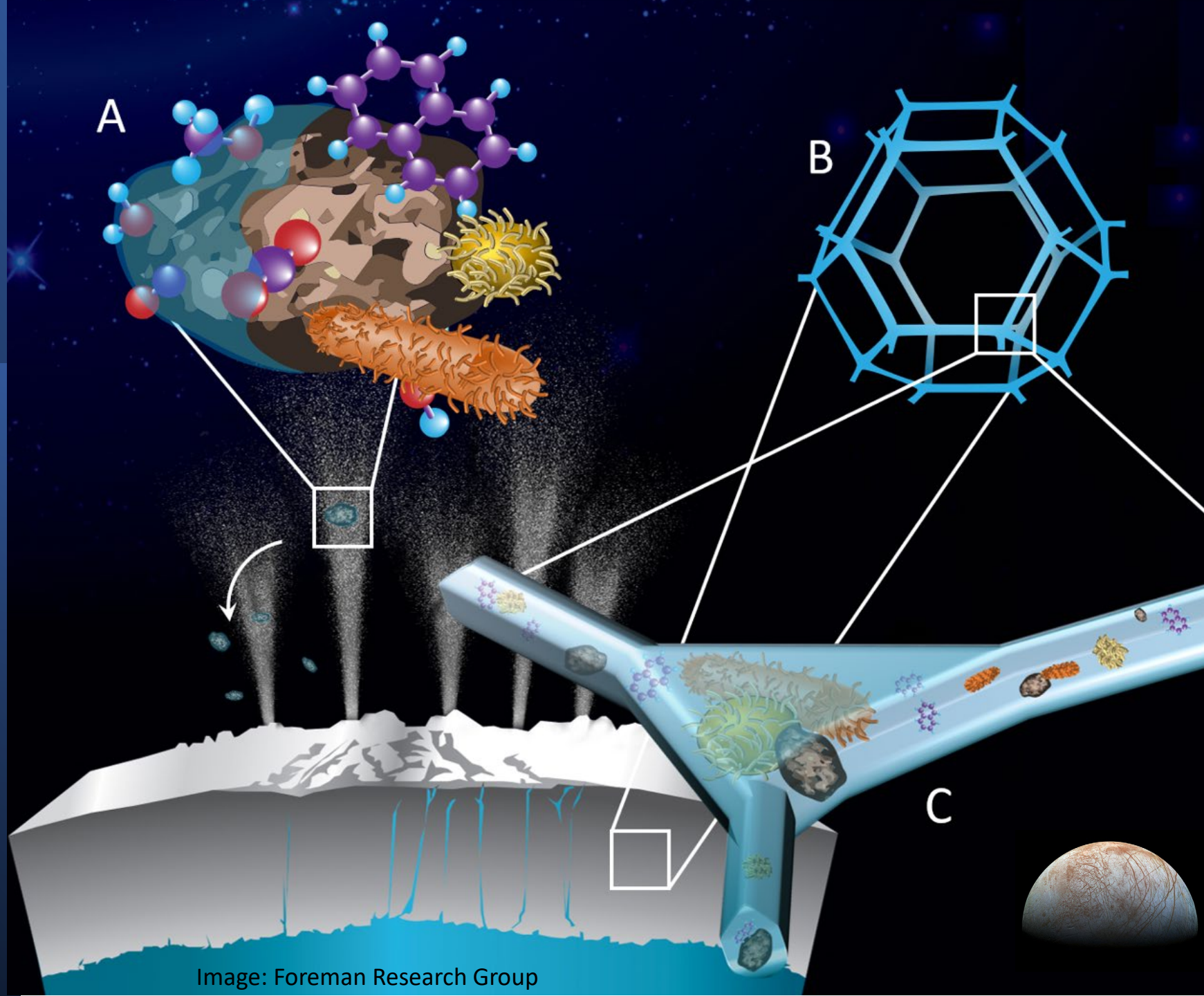
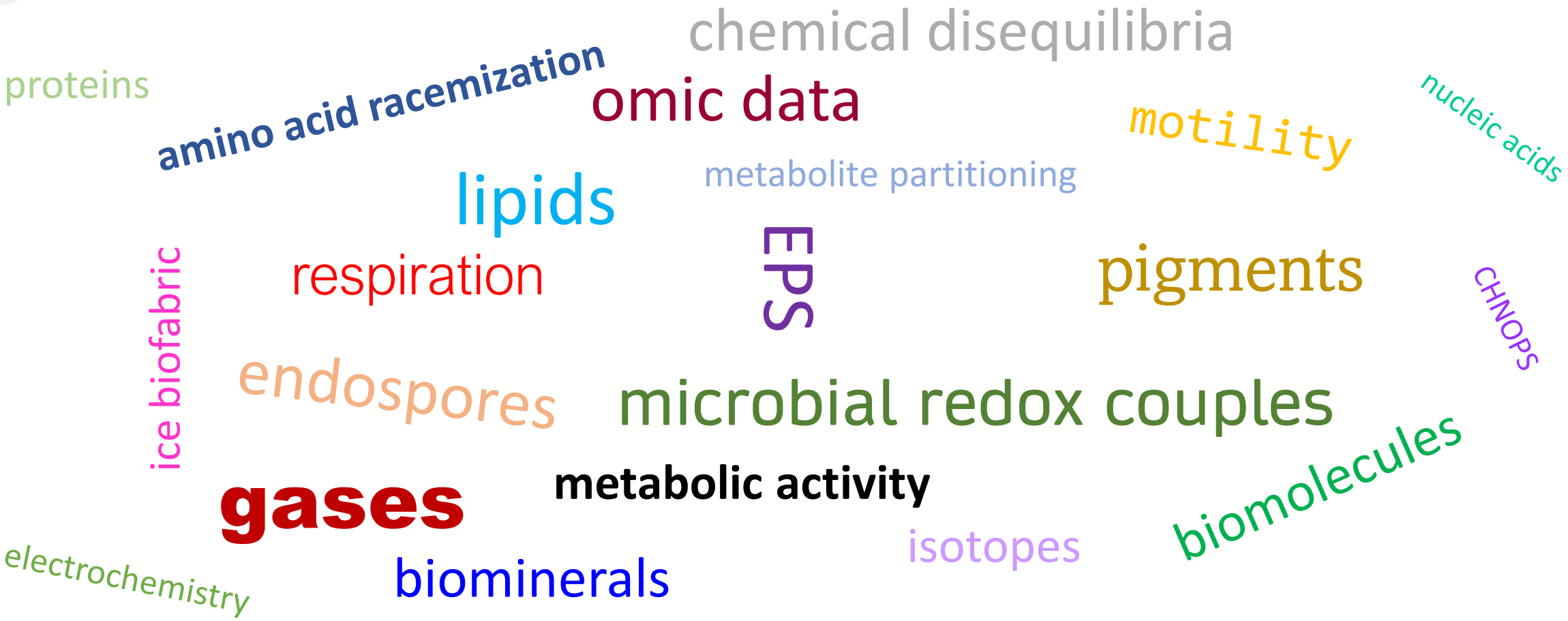


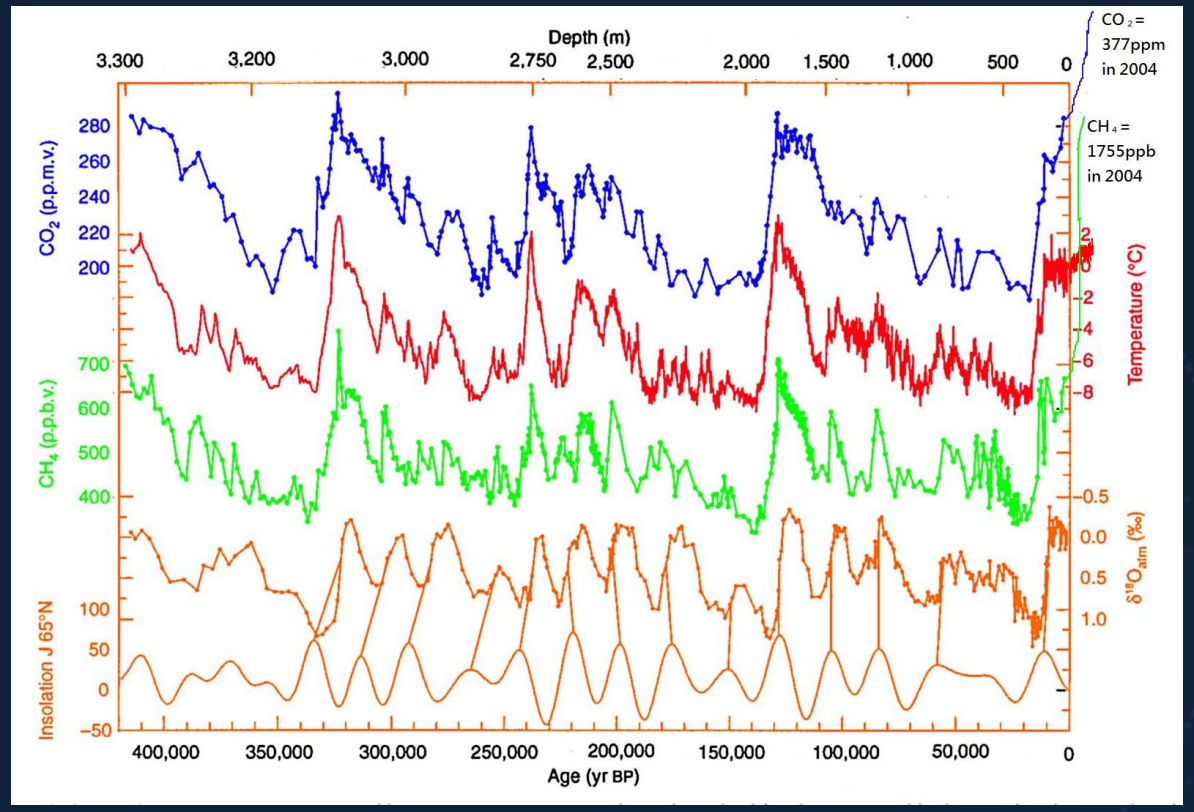
Image: Foreman Research Group

Microbial bioindicators in ice



Cryospheric Microbial Bio-Indicators: changes to chemical equilibria

Image: Foreman Research Group

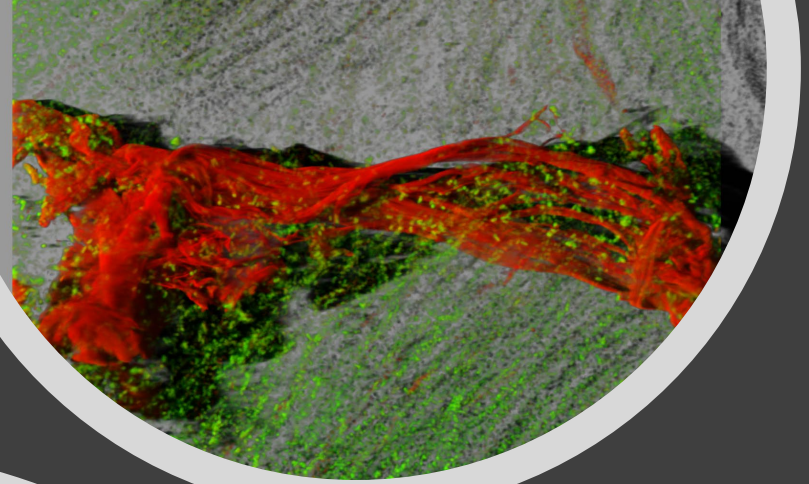


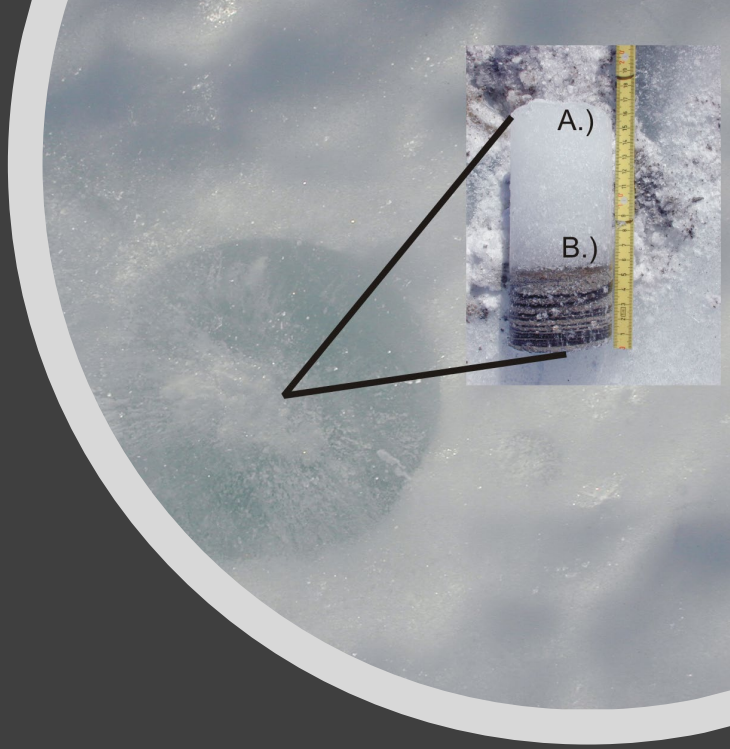
420,000 yrs of ice core data from Lake Vostok, Wikimedia Commons

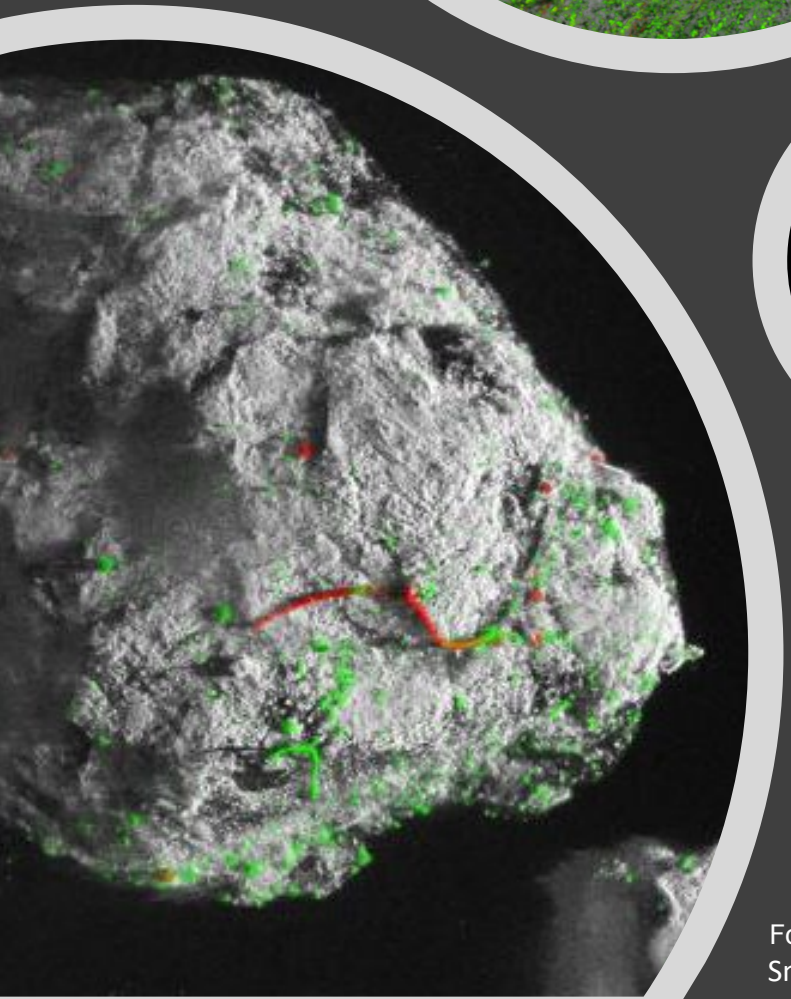
Articles on gases:

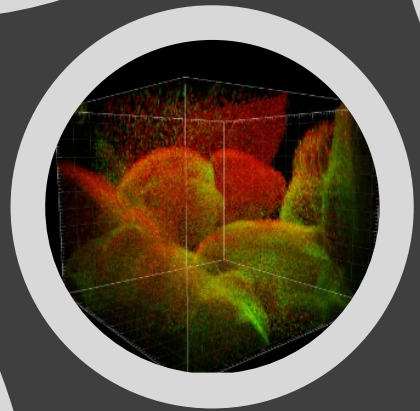
Lee et al. (2020). Excess methane in Greenland ice cores associated with high dust concentrations. *Geochemica et Cosmochimica Acta*, 270:409-430.

Seager et al., (2016). Toward a List of Molecules as Potential Biosignature Gases for the Search for Life on Exoplanets…..*Astrobiology*, 16, 465





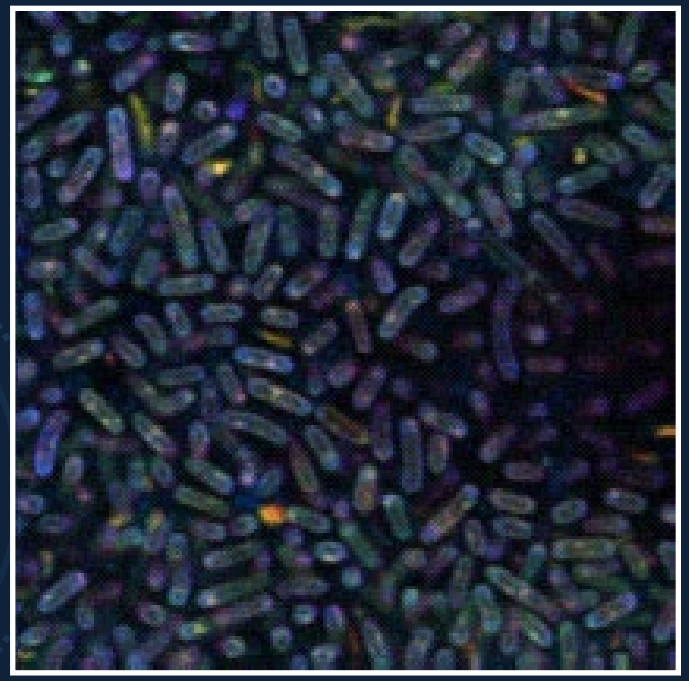


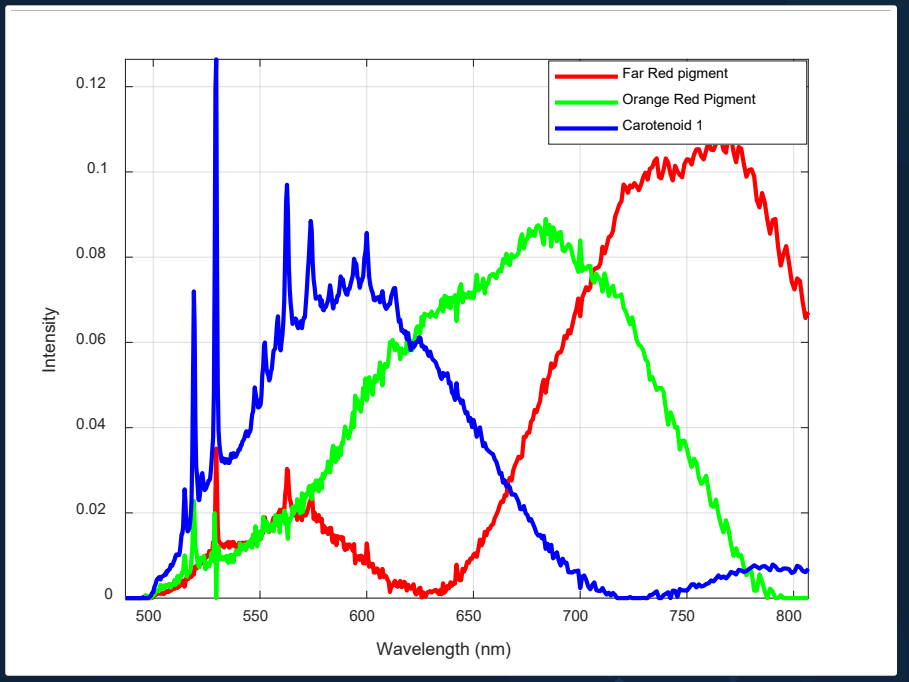


Cryospheric Microbial Bio-Indicators: *Biofilms on Ice*

Foreman et al., 2007 *Aquatic Geochemistry*
Smith et al., 2016 *Nature Biofilms and Microbiomes*

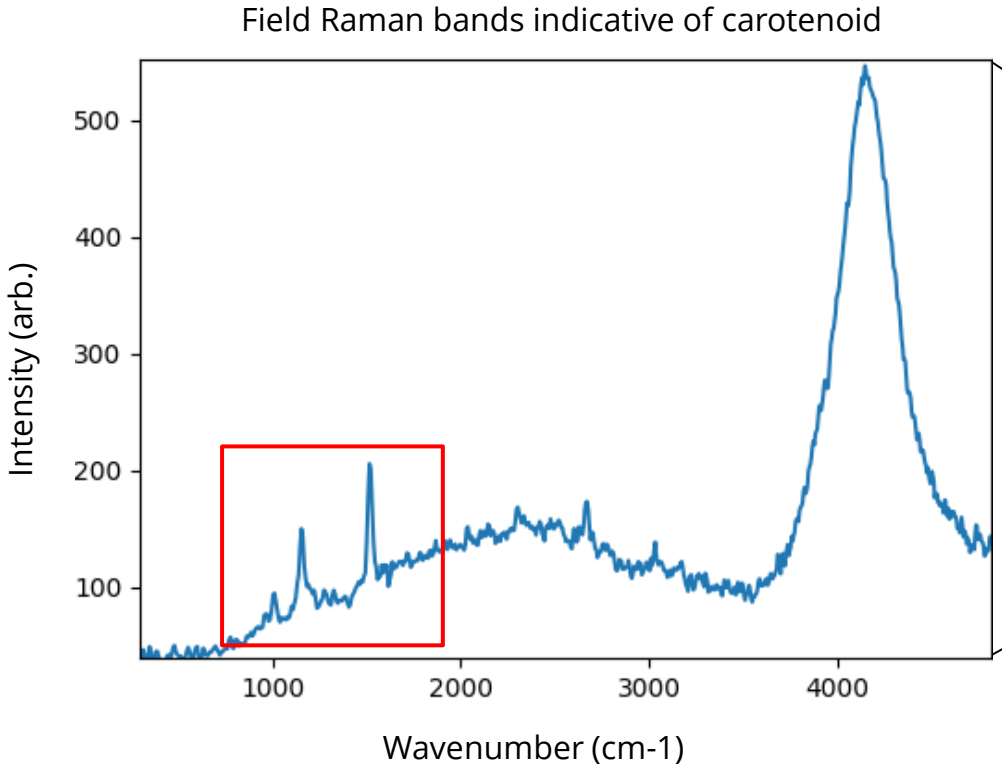
Cryospheric Microbial Bio-Indicators: Pigments





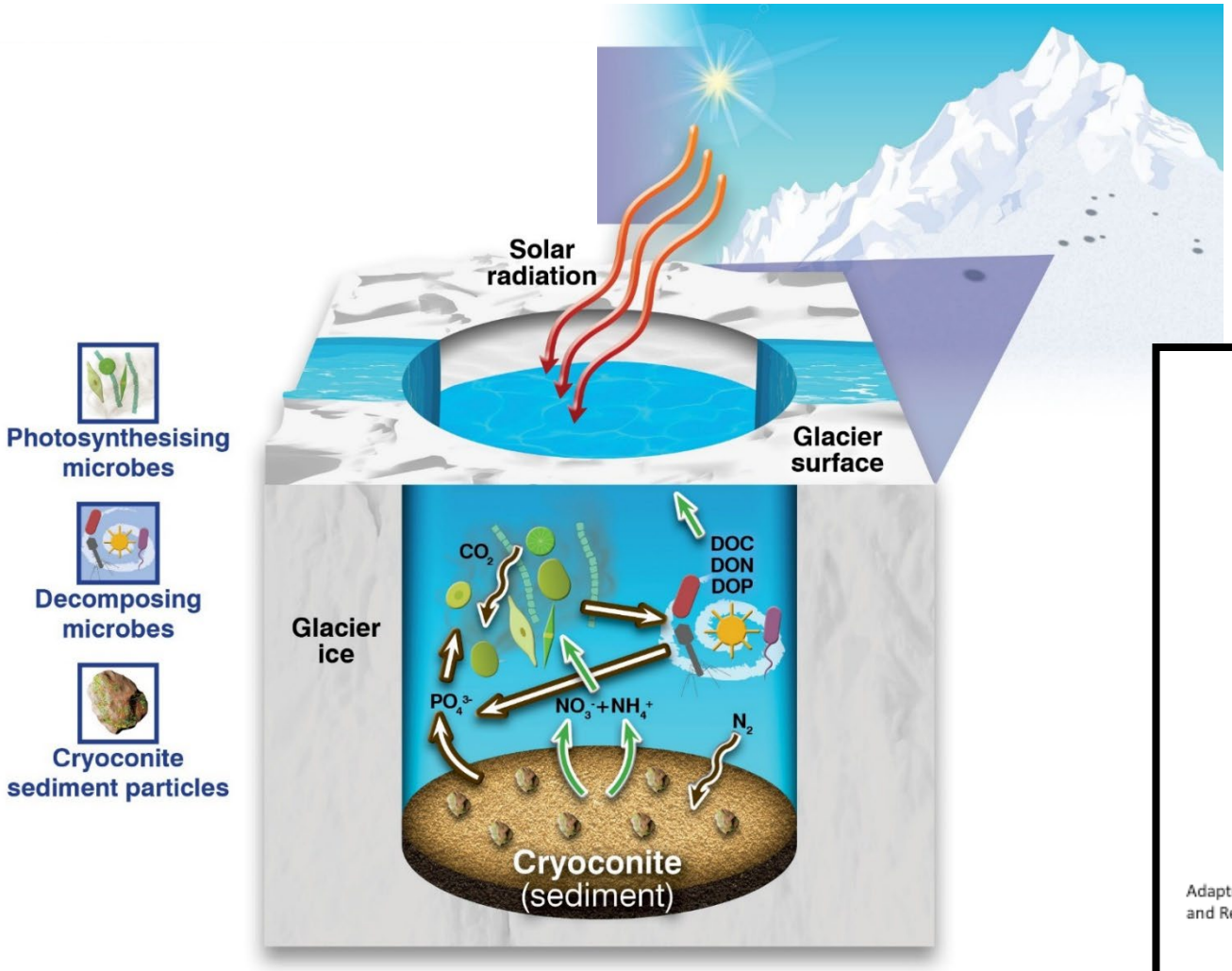
Images: Foreman Research Group

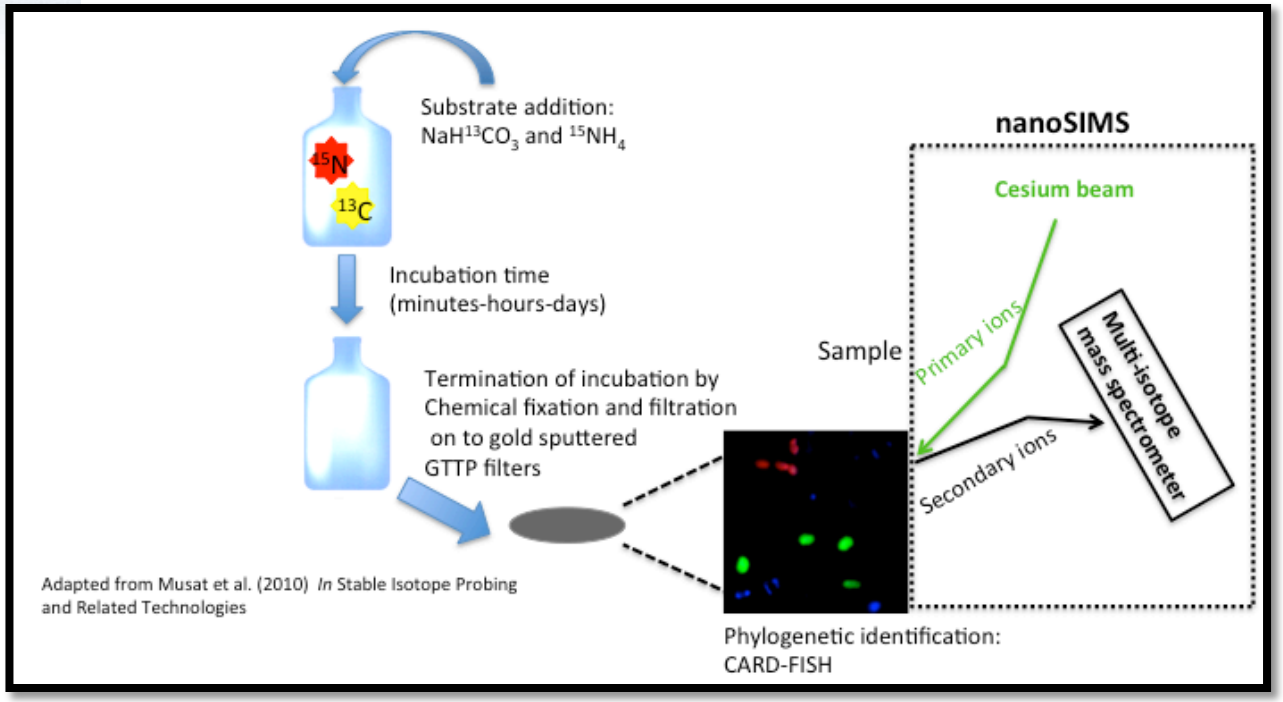
Field detection



Madie Willis, Juneau Icefields 2022

Cryospheric Microbial Bio-Indicators: metabolic activity

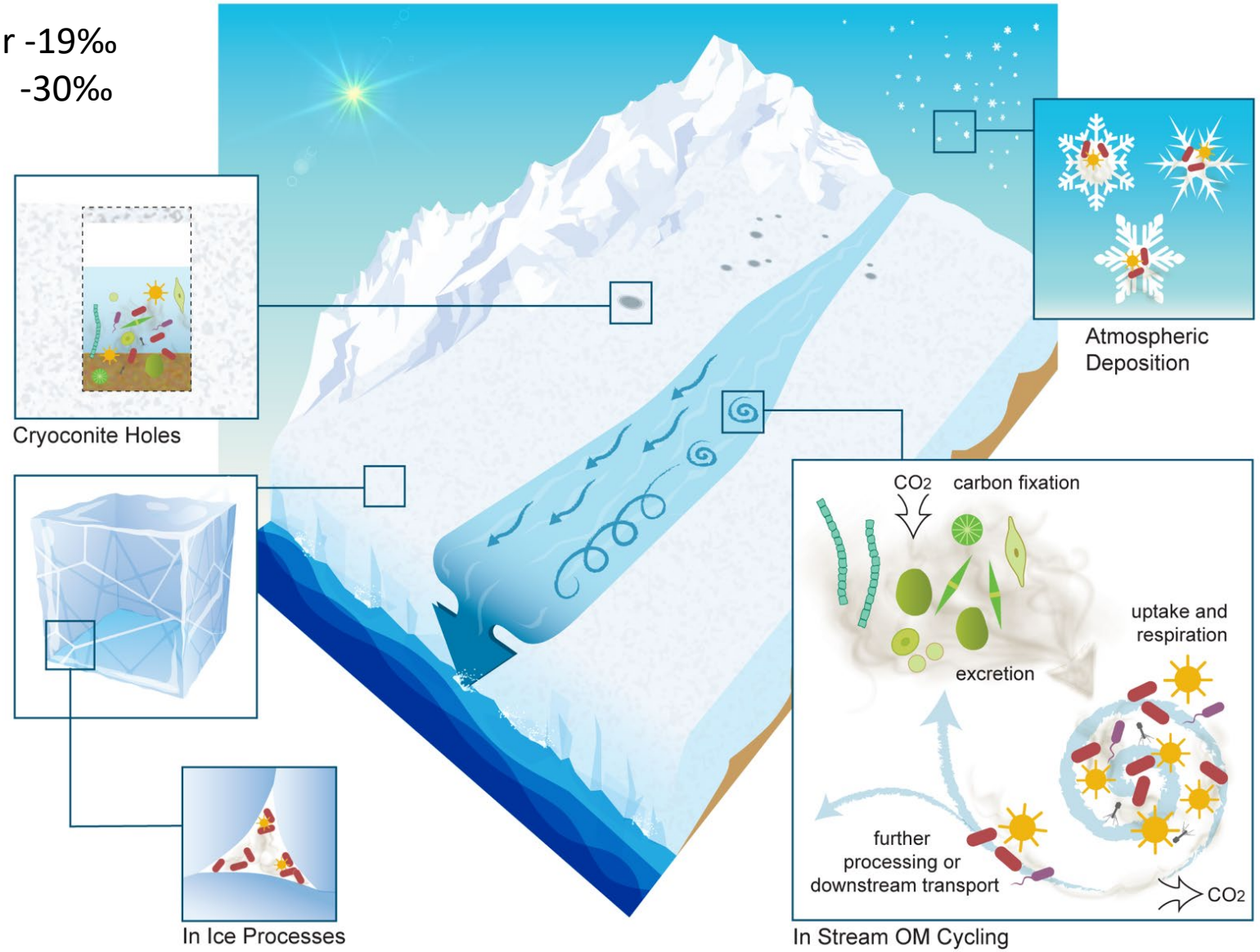




Foreman et al., 2007 Aquatic Geochemistry; Smith et al., 2016 Nature Biofilms and Microbiomes

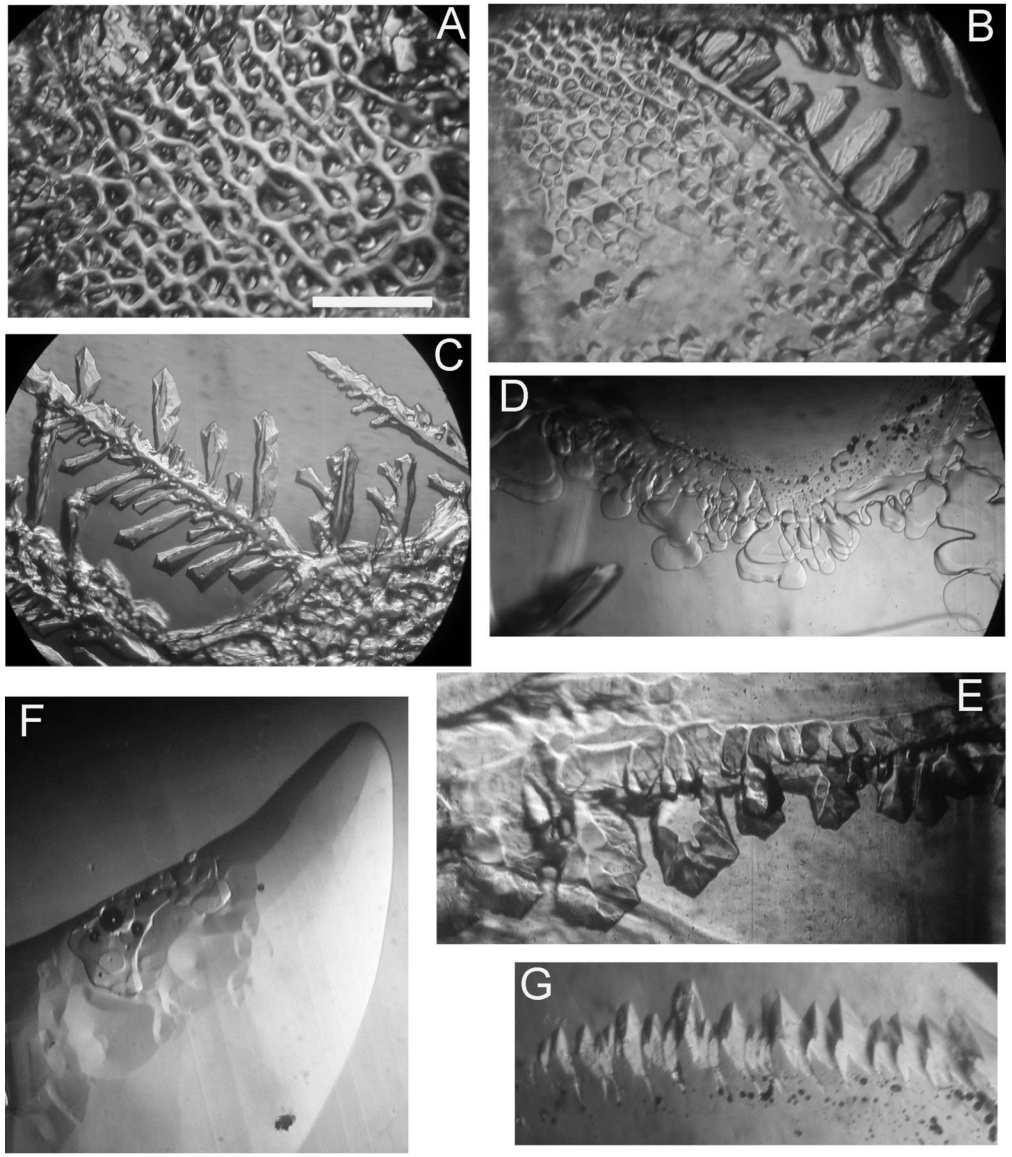
Cryospheric Microbial Bio-Indicators: Isotopes and OM

$\delta^{13}C$ stream water -19‰
$\delta^{13}C$ ice -30‰

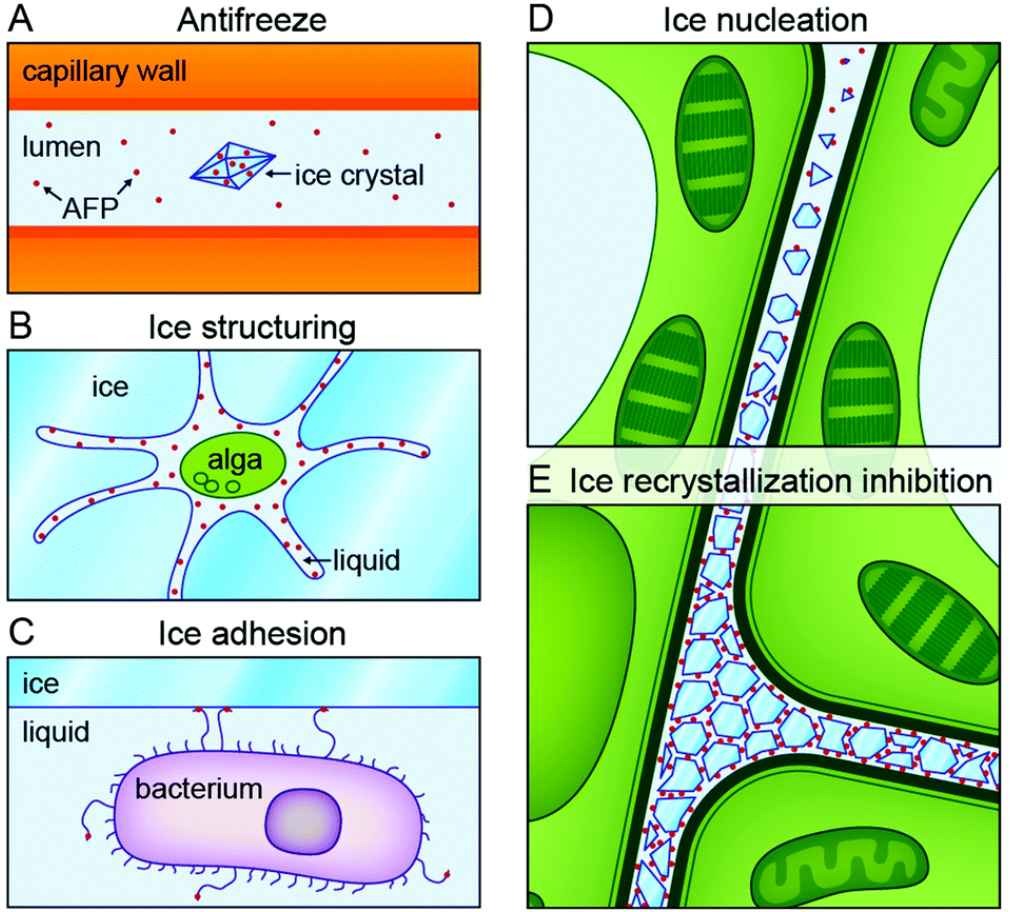


Smith *et al.*, 2017 *Nature Geoscience*

Cryospheric Microbial Bio-Indicators: Ice biofabric



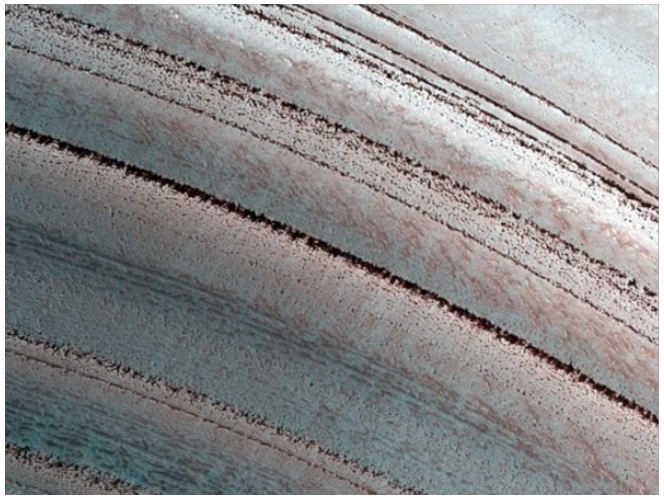
Raymond et al., (2021) *Applied and Env Microbiology*



Oude Vrielink *et al.*, *Biointerphases*, 2016, 11

Survivability of life in ice- what do we know that can help guide life detection and biological validation?

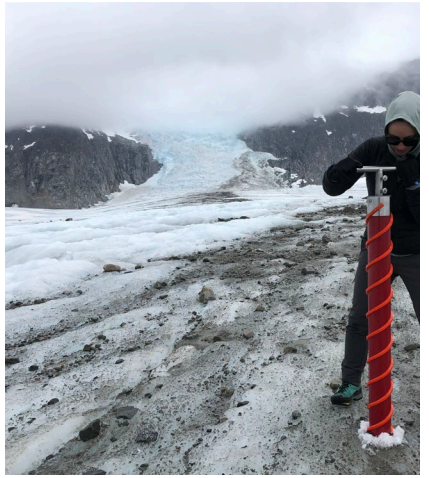
North Polar Layered Deposits on Mars



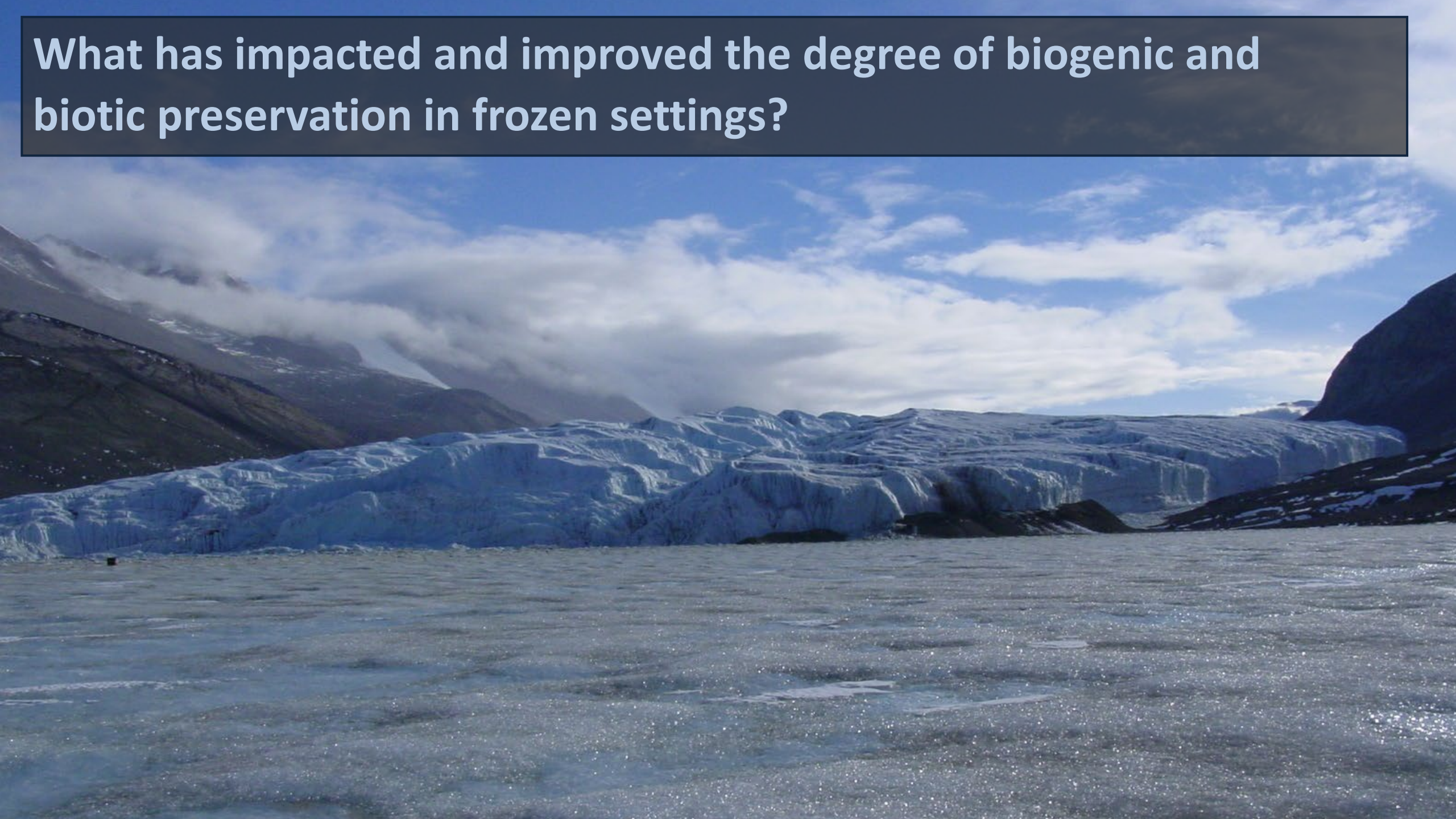
NASA/JPL/UArizona

Glacial ogive bands in Alaska

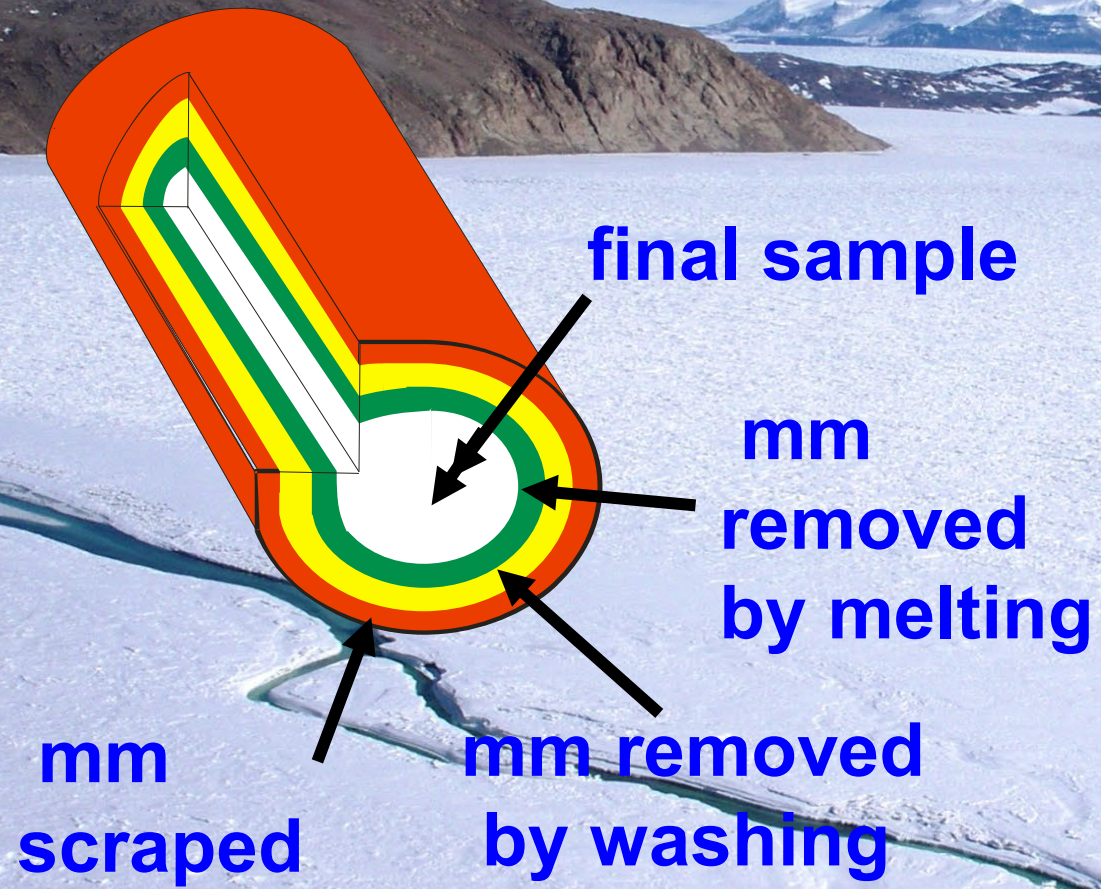
Joel Wilner, the JIRP blog

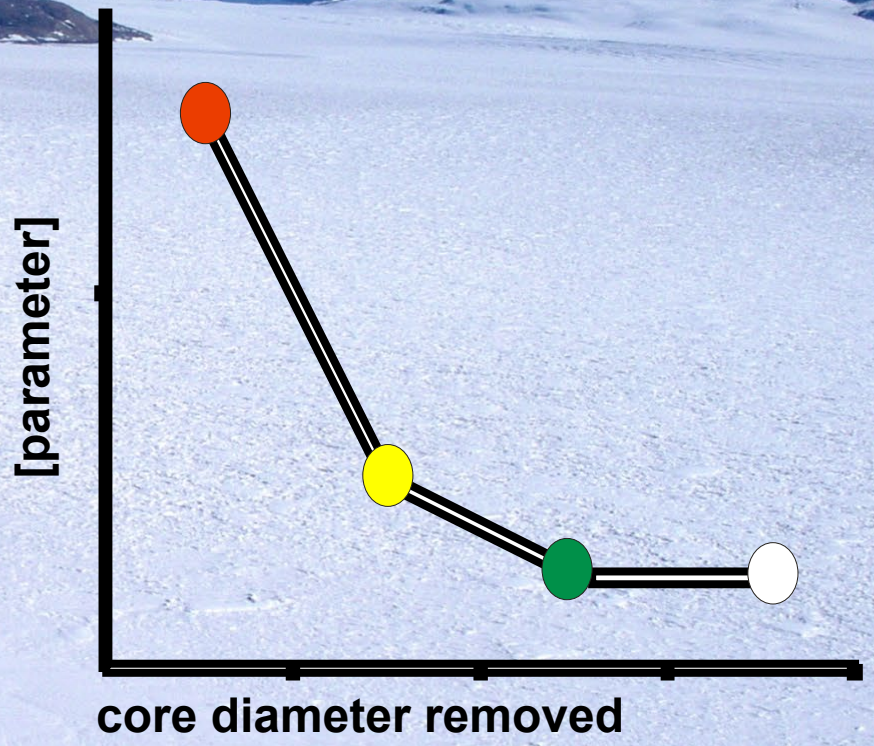


What has impacted and improved the degree of biogenic and biotic preservation in frozen settings?



What are best practices in the design of experiments for assessing cellular communities in ice?





Christner et al (2005) *Icarus*

Questions to consider

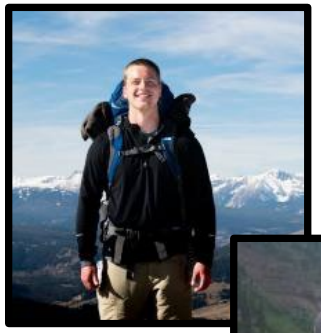
- What is the longevity of microbes while frozen?
- What is the lowest temperature at which metabolic activity is possible?
- Which life-detection approaches yield unequivocal results?
- Is there metabolism in solid ice?

Questions?

ACKNOWLEDGEMENTS





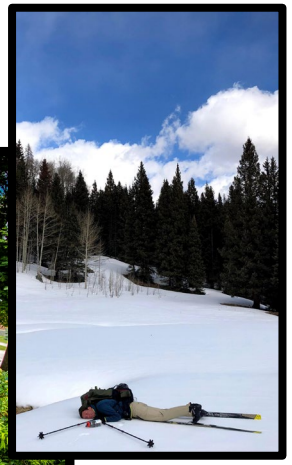












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- 2 environmental chambers with temperature-gradient and solar radiation controls
- a class 1000 cold clean room
- a steel-reinforced concrete structural testing chamber
- a snowmaking/hydrodynamics laboratory
- a dedicated -30 storage room for polar ice cores and snow samples
- a sub-zero machine shop for working with ice and snow
- a microstructural characterization lab with micro-CT, optical and epifluorescence microscopy, a biological microtome for thin sectioning