Lessons Learned From Drilling Through the Antarctic Ice Sheet: The WISSARD and SALSA Projects

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Goals:

- How do we know the subglacial water cavities are there?
- How do we know that life exists in them?
- WISSARD
- SALSA

} Vostok

- Contamination Control (PP and sample integrity)
- “CLEAN” access drill

Similarities between subglacial lake and exploration of icy worlds beyond Earth

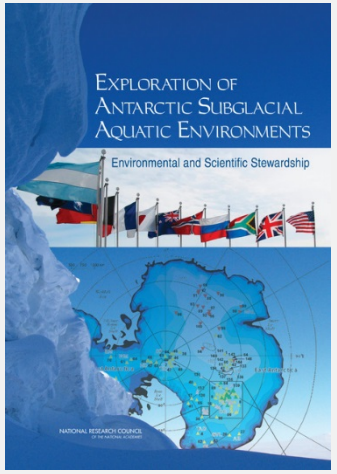
Subglacial Exploration on Earth:

--Until ~15 years ago Antarctica was thought to be a "dead" continent

--13 years of indirect measurements implied the presence of subglacial water and life in these waters. Direct sampling of Subglacial Lake Whillans in 2013 proved this to be true.

--Environmental stewardship and sample contamination issues have to be addressed for any mission

NAS review



Coordination

ICSU formed SCAR (Scientific Committee on Antarctic Research) in 1957

SCAR is charged with initiating, developing and coordinating high quality international scientific research.

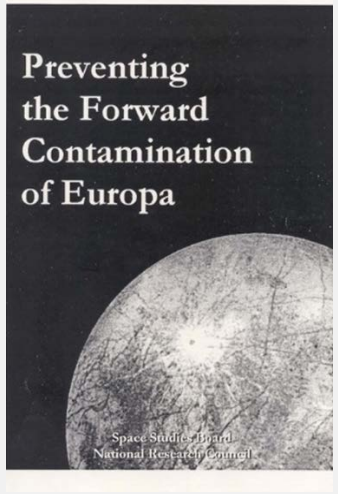
Solar System Exploration:

--60 years ago the outer Solar System was largely seen as an icy planetary graveyard

--indirect measurements on icy moons in the outer Solar system imply the presence of sub-ice oceans that have the capacity for life to evolve and multiply. Direct sampling is required to provide unequivocal evidence for life.

--Environmental stewardship and sample contamination issues have to be addressed for any mission (and sample return)

NAS review



Coordination

ICSU formed COSPAR (Committee on Space Research) in 1958

COSPAR's objectives are to promote on an international level scientific research in space

Subglacial Lakes: How do we know they are there?

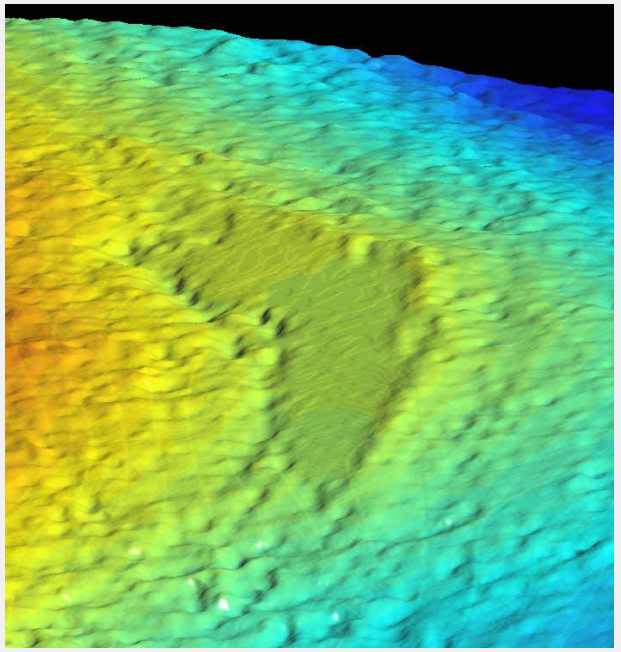
Use radar, seismic's, and examine surface ice features to understand sub-ice dynamics

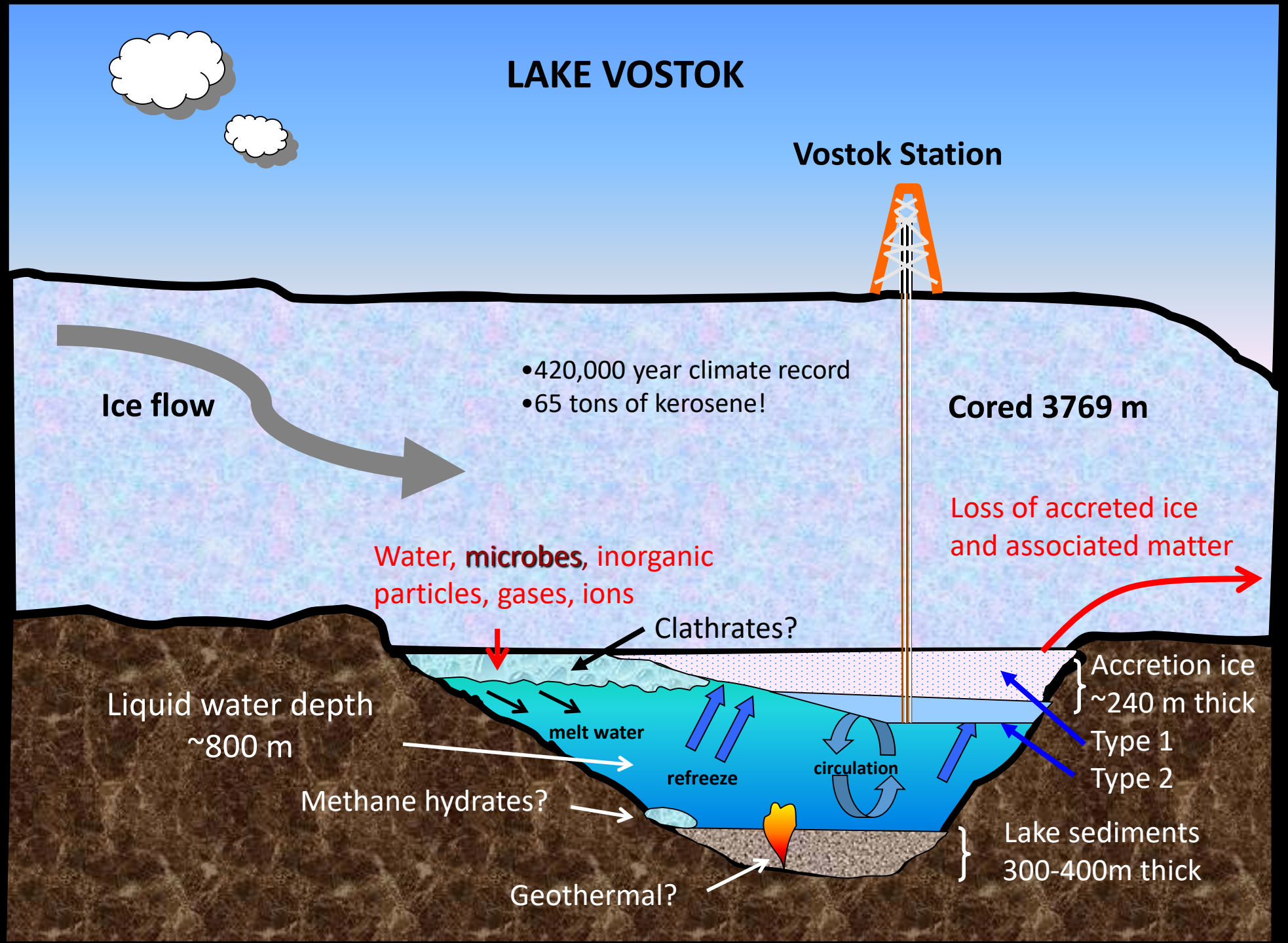
Maybe we should put a bunch of CubeSats on Europa to help understand surface ice dynamics!

Lake Vostok from space

Subglacial Lake Vostok morphometry and ice data

Parameter	Value
Lake	
Volume	5,400 km^3
Area	14,000 km^2
Maximum length	240 km
Mean width	50 km
Maximum depth	~1000 m
Sediment depth (Russian data)	~300 m
Geothermal heat flux	0.05 W m^{-2}
Ice Cover	
Ice thickness (N-S)	4,300-3,700 m
Ice thickness difference (N-S)	**600 m**
Pressure freezing point at N-end	-2.83 ^oC
Pressure freezing point at S-end	-2.53 ^oC
Range of ice ceiling temperature (pressure freezing pt)	**0.30 ^oC**




LAKE VOSTOK
Vostok Station
Ice flow
•420,000 year climate record
•65 tons of kerosene!
Cored 3769 m
Loss of accreted ice
and associated matter
Water, microbes, inorganic
particles, gases, ions
Clathrates?
Liquid water depth
~800 m
melt water
refreeze
circulation
Accretion ice
~240 m thick
Type 1
Type 2
Methane hydrates?
Lake sediments
300-400m thick
Geothermal?

Reprint Series
10 December 1999, Volume 286, pp. 2141–2144

Science

"Microbes within a liquid water habitat deep below a frozen surface provide an analog for possible life on Europa, one of the Galilean moons of Jupiter. Galileo spacecraft results imply that a subsurface ocean exists on Europa. Although the thickness of the overlying ice in Europa is unknown, ice would accrete to the bottom of the ice cover and would also form in cracks, possibly extending close to the surface. Similar to Lake Vostok accretion ice, this ice may retain evidence for life, if present, in the europan ocean."

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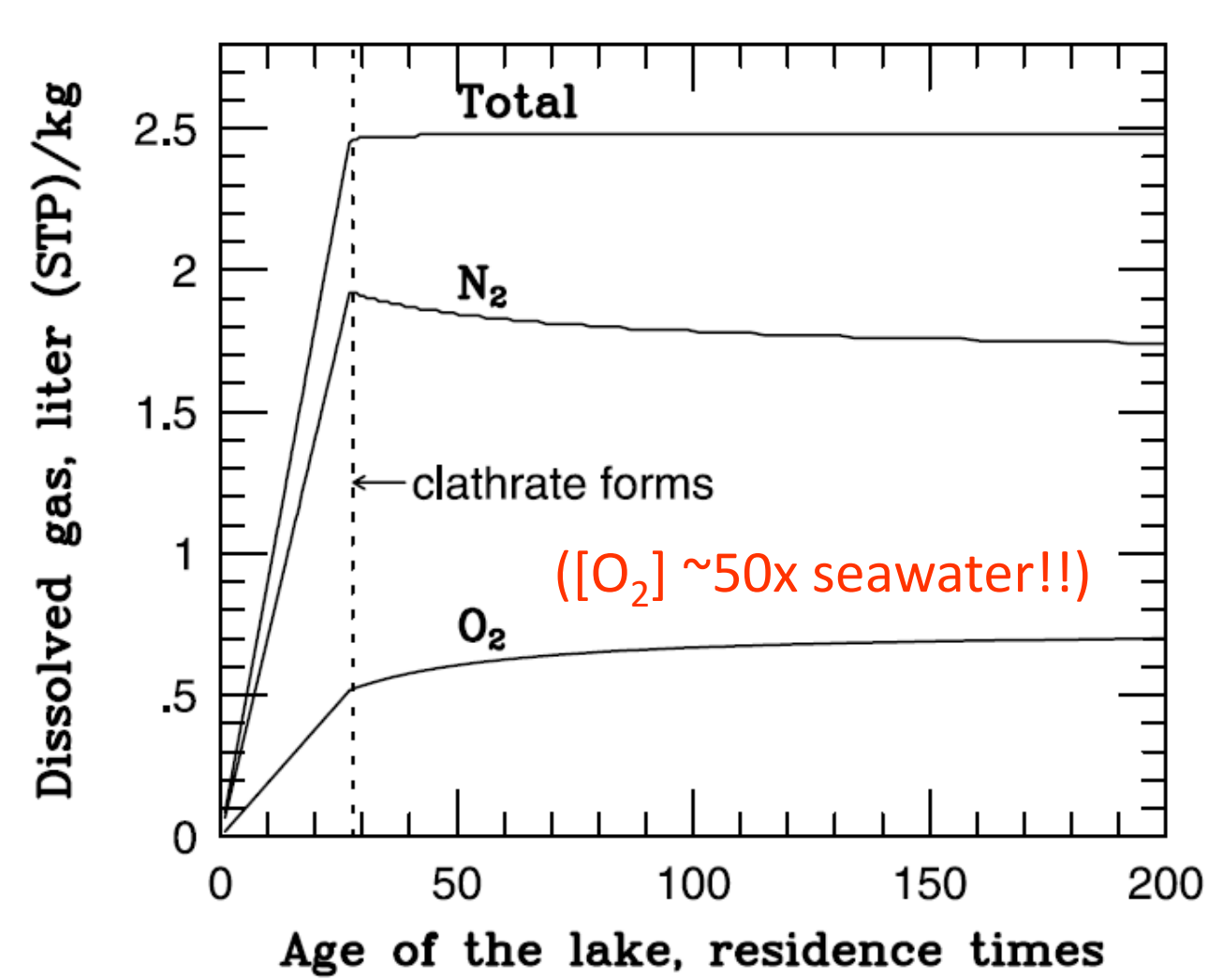
Vostok Gas Dynamics

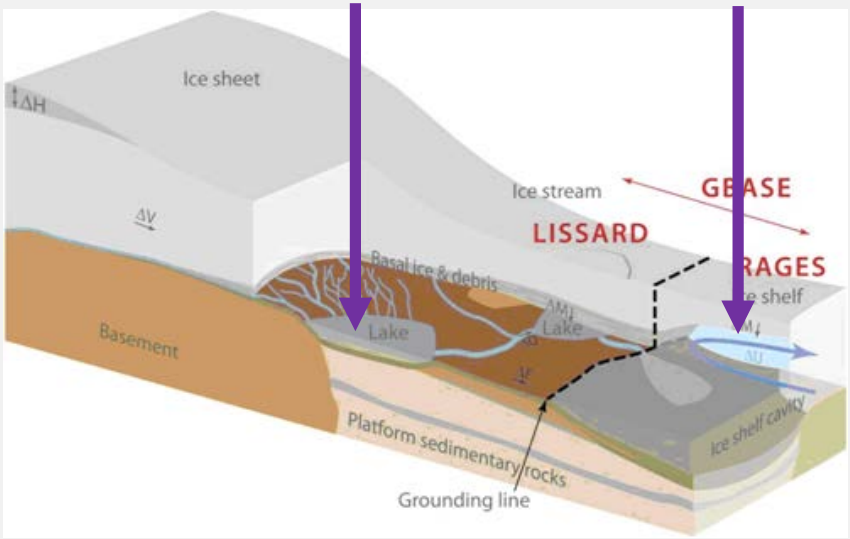


Lake Vostok is supercharged with gases (2.5 l/kg); similar to a bottle of Coca-Cola!

Dissolved N_2, O_2 and total gas amount in water of Lake Vostok as a function of the age of lake, with age expressed in units of residence time. One residence time is ~10,000 years.

McKay, C.P., K.P. Hand, P. Doran, J.C. Priscu. 2003. Clathrate formation and the fate of noble and biologically useful gases in Lake Vostok, Antarctica. Geophys. Res. Lett. 30(13):1702.

The Whillans Ice Stream Subglacial Access Research Drilling (WISSARD)



WISSARD.ORG

The WISSARD project applied an "integrated systems" approach **driven by biology** to one region of the ice sheet that contains an intersection of the subglacial environment, the sub-ice shelf cavity and the grounding zone itself, the northern section of Whillans Ice Stream (WIS) in West Antarctica. We studied these environments using a combination of geophysical imaging, GPS surveying, satellite data, in-situ measurements and laboratory experiments to test the overarching hypothesis: ***"The dynamic glaciology, sedimentological, and biochemical processes combine to stabilize the ice shelf and control the structure and function of microorganisms inhabiting the region."***

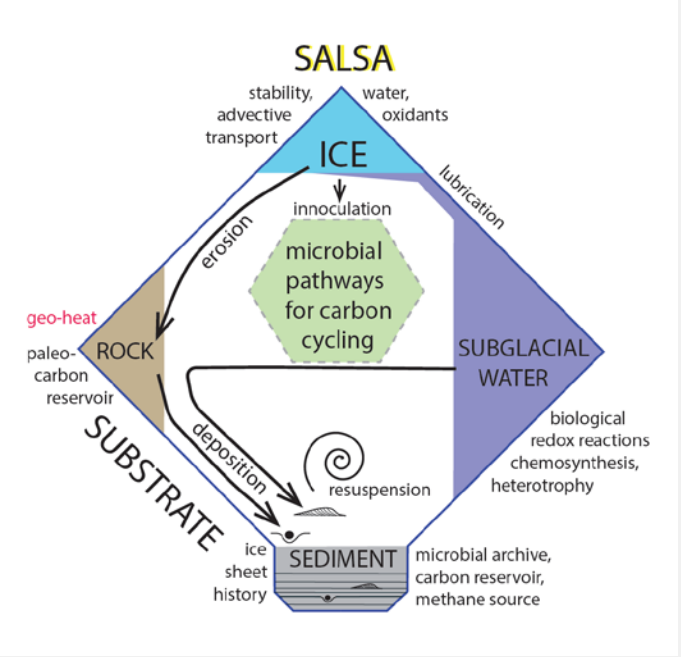
WISSARD: Key Findings

WISSARD.ORG

- GPS data revealed cascading subglacial floods and resulting ice-velocity changes.
- A process model showed that flow channels are mechanically eroded into deformable subglacial sediment rather than melted into the overlying ice.
- The geothermal heat flux is 285 ± 80 mW/m2, significantly higher than the continental and regional averages estimated for this area.
- Genomic analysis revealed that the diverse (4000 species) bacterial and archaeal communities inhabiting the water column and underlying sediments were compositionally distinct from those in the drilling and borehole water.
- Many of the microorganisms inferred to be abundant were most closely related to species found in deep sea habitats including cold seeps and basalts.
- The prevalence of taxa phylogenetically related to microbial species that derive energy from the oxidation of reduced sulfur or nitrogen compounds (chemolithoautotrophs) implies an important role for sulfide and ammonia oxidation in these ecosystems.
- Subsurface geogenic and biogenic CH_4 fuels an active population of CH_4-oxidizing bacteria that reduces O_2 levels within the lake.
- Our clean drilling approach was successful.

SALSA: Overarching hypothesis:

"Contemporary biodiversity and carbon cycling in Subglacial Lake Mercer is regulated by the cycling of relict marine organic matter and through interactions among ice, rock, water, and sediments"

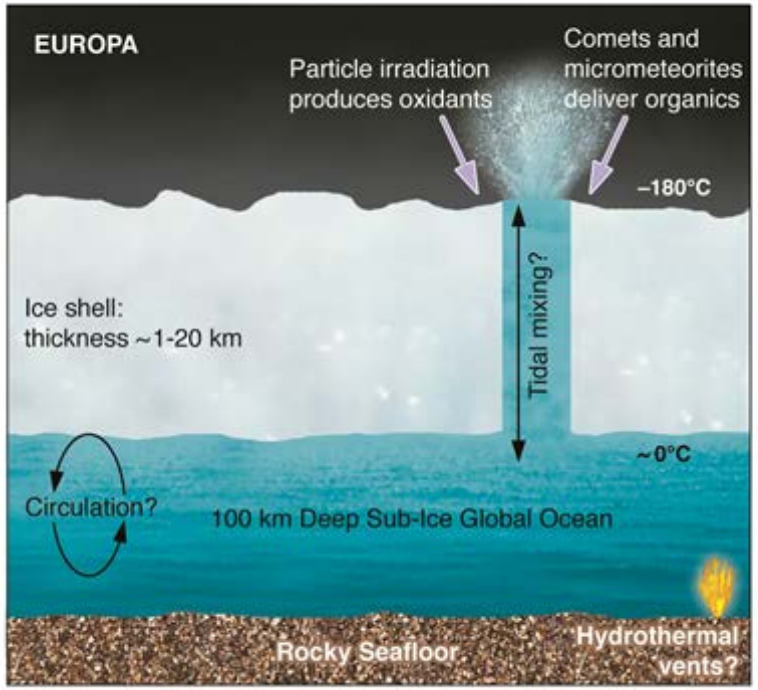


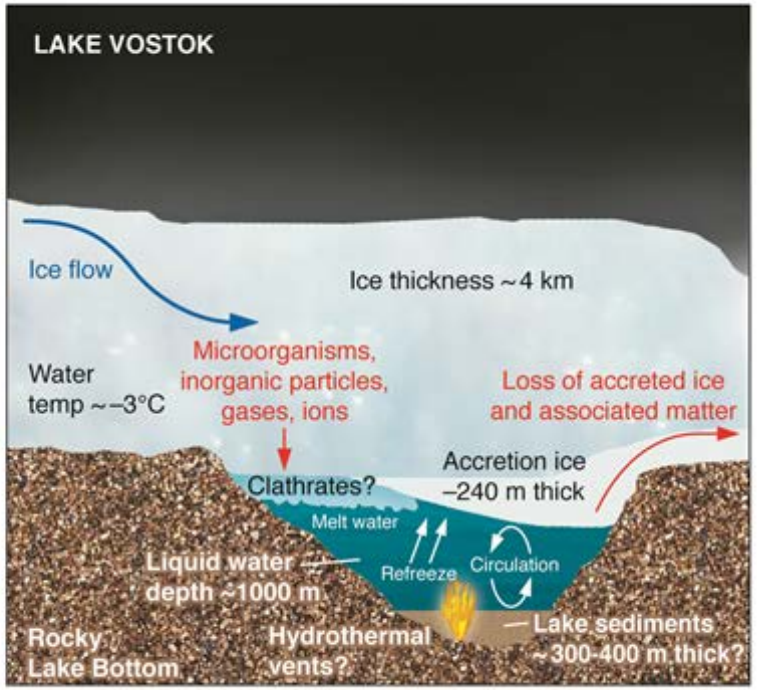
In January 2019 SALSA will drill through 1200 m of ice into SLM to address key questions relating to:

- the stability of the ice sheet by determining the extent and timing of past marine incursions,
- the subglacial hydrological system,
- the deep-cold subglacial biosphere.

Hot-water-drilled boreholes will be used to collect basal ice samples, provide access for direct measurement of subglacial physical, chemical, and biological conditions in the water column and sediments, and to explore the subglacial water cavities using a remotely operated vehicle equipped with sensors, cameras, and sampling equipment.

The Microbial Habitability of Extraterrestrial Icy Worlds: A View From Earth based on Antarctic Subglacial Environments

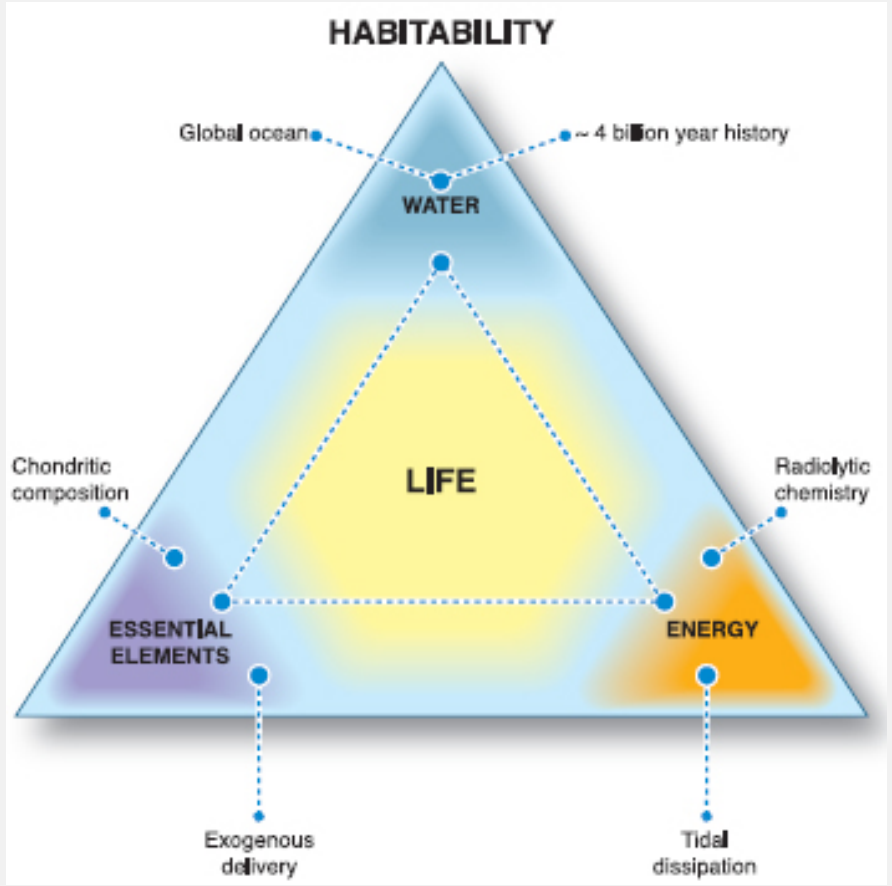




Priscu and Hand 2012

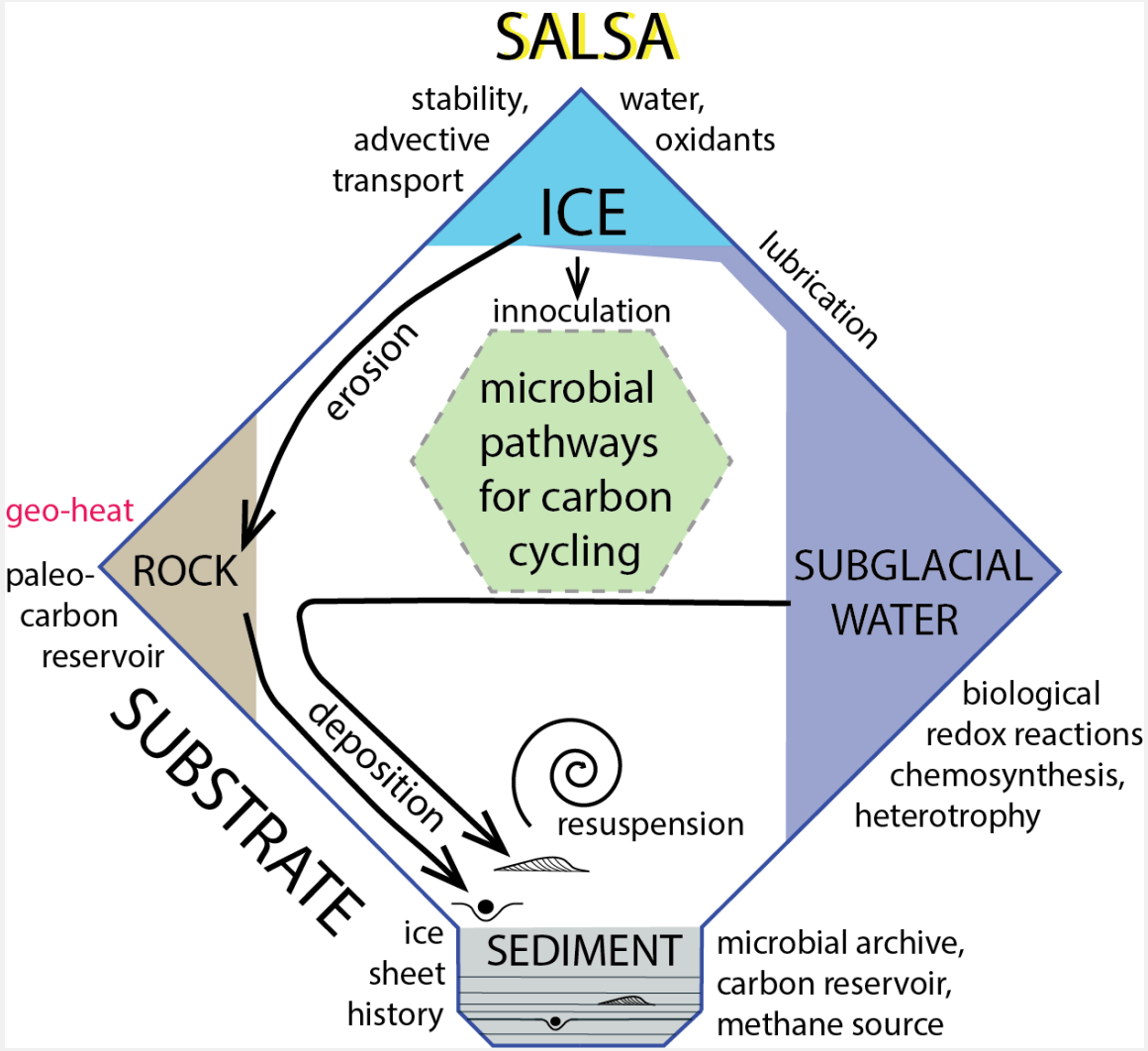
We need a detailed conceptual model for what we expect to find in the Europan ocean and the ice shell

Europa



From Priscu & Hand 2012

Subglacial



WISSARD clean access hot water drilling

Priscu et al. 2013. A microbiologically clean strategy for access to the Whillans Ice Stream subglacial environment. Antarctic Science, 25(5):637-647

Environmental stewardship and sample integrity

National Research Council Report. *Exploration of Antarctic Subglacial Aquatic Environments: Environmental and Scientific Stewardship* (The National Academies Press, 2007)

Subglacial Lake Whillans: 0.5 miles beneath the ice surface