Glaciology
Life and Ice

Group 3

April 3, 2012

I. Introduction

Although to the casual observer ice appears barren and devoid of life, you would be surprised to discover the variety of life that exists on ice, inside of ice, and beneath ice. In our presentation today we would like to introduce you all to the connections we have found between life and ice. By understanding how life can survive in such harsh conditions today we can then try to understand theories that involve life beginning in ice as well as the possibility that life is present in ice on other planets.

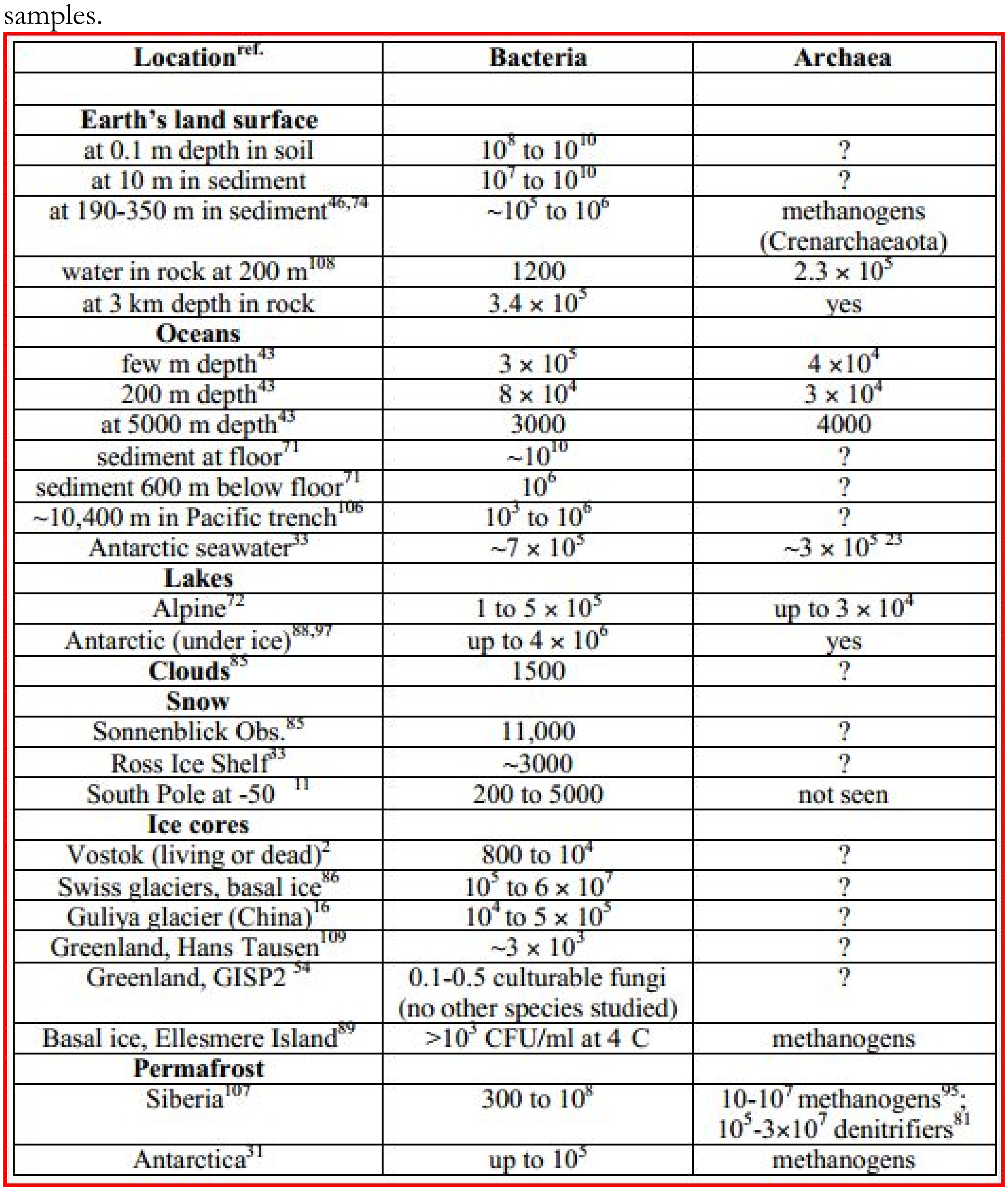
II. Life On Ice, In Ice, and Under Ice

By researching on top of the glaciers in Denali National Park, scientists were able to discover the existence of life forms that were unable to be detected at first sight. Wind carries many organisms onto glaciers but only the strong and small can survive. Glaciers in Denali National Park, for example, are covered in algal cells so small they cannot be seen without a microscope. The algae discovered on top of glaciers is understood to be food for other organisms on top of the ice. Although small and simple, glaciers can provide a perfect example of a food chain.

Algae (produces food for itself) -> Springtail eats algae -> Beetles eat springtail -> Springtail and beetles die and decompose leaving nutrients in the ice for algae to thrive on

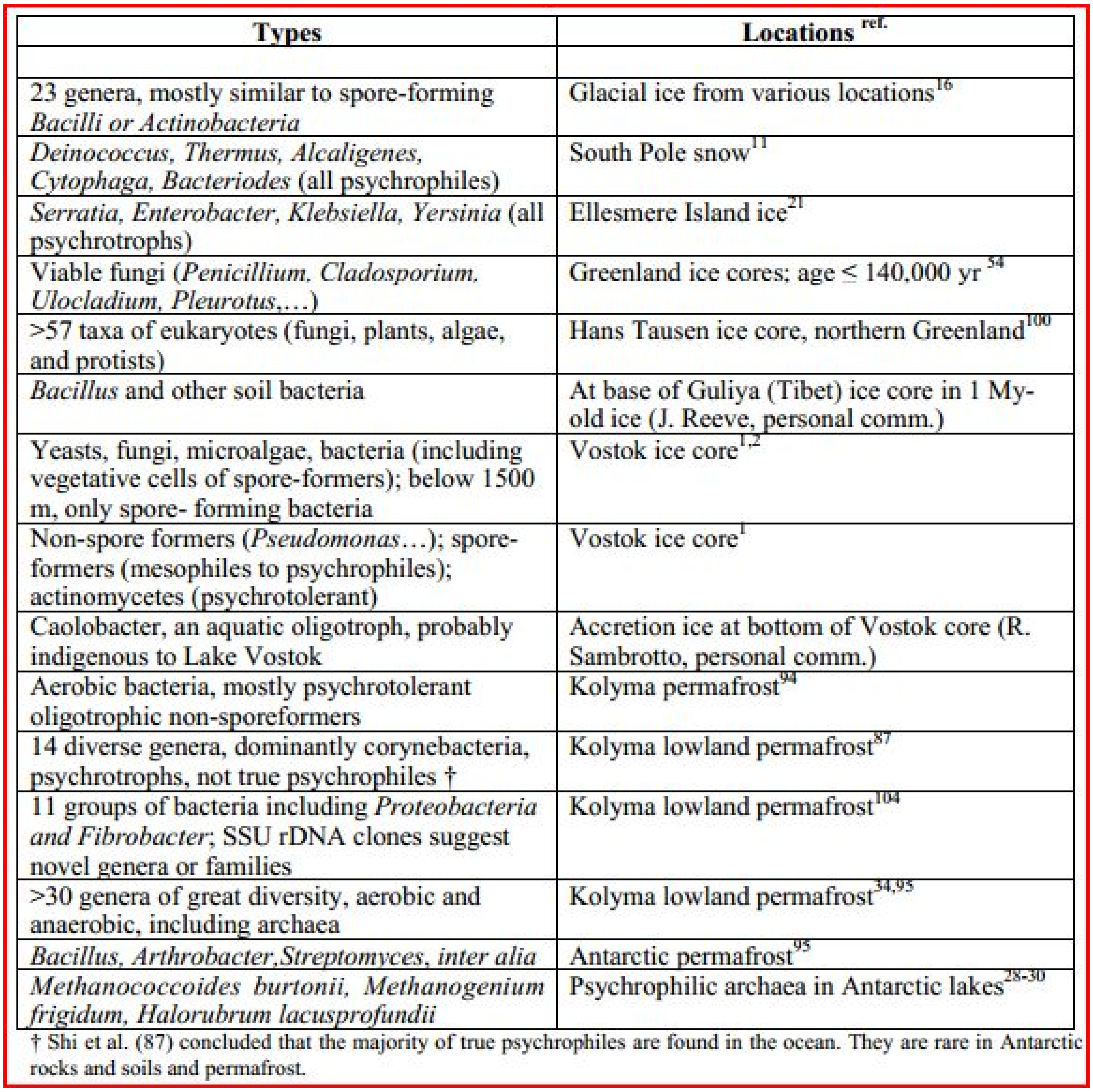
"One thing all organisms living on the glaciers share in common is size. They are all tiny! This is because resources, such as nutrients, are in short supply. Larger animals could not survive on such meager rations. Temperatures on the ice and snow are always at or below freezing. This means that there is usually very little free water. All organisms need water to survive. But if ice forms inside an animal's body it can cause tissue damage or death. Glacier organisms have many adaptations that help them to cope with freezing temperatures. When the temperature drops, some types of invertebrates can isolate water in their bodies and cause it to form ice crystals in non-critical areas of their system. This prevents their tissues from being damaged. They may also produce a type of glycerol that acts as an antifreeze in the cells, keeping them from freezing completely."

Life does not merely exist on top of ice, but in it as well. In P. Buford Price's unpublished report titled "Life in Solid Ice?", he explains the factors that halt many forms of life from thriving in ice. "Challenges to survival include extremes of temperature, pressure, pH, dryness, salinity, oxygen concentration, radiative flux (including sunlight), and availability of nutrients and bioelements." However, just because there are so many hurdles to life in ice, does not mean that ice is completely devoid of life. In the chart below, taken from "Life in Solid Ice?" we can see the concentrations of prokaryotes (cells cm^-3) in various environments including ice core samples.



Location[ref.]	**Bacteria**	**Archaea**
Earth's land surface		
at 0.1 m depth in soil	10^8 to 10^{10}	?
at 10 m in sediment	10^7 to 10^{10}	?
at 190-350 m in sediment[46,74]	~10^5 to 10^6	methanogens (Crenarchaeaota)
water in rock at 200 m[108]	1200	2.3×10^5
at 3 km depth in rock	3.4×10^5	yes
Oceans		
few m depth[43]	3×10^5	4×10^4
200 m depth[43]	8×10^4	3×10^4
at 5000 m depth[43]	3000	4000
sediment at floor[71]	~10^{10}	?
sediment 600 m below floor[71]	10^6	?
~10,400 m in Pacific trench[106]	10^3 to 10^6	?
Antarctic seawater[33]	~7×10^5	~3×10^5 [23]
Lakes		
Alpine[72]	1 to 5×10^5	up to 3×10^4
Antarctic (under ice)[88,97]	up to 4×10^6	yes
Clouds[85]	1500	?
Snow		
Sonnenblick Obs.[85]	11,000	?
Ross Ice Shelf[33]	~3000	?
South Pole at -50 [11]	200 to 5000	not seen
Ice cores		
Vostok (living or dead)[2]	800 to 10^4	?
Swiss glaciers, basal ice[86]	10^5 to 6×10^7	?
Guliya glacier (China)[16]	10^4 to 5×10^5	?
Greenland, Hans Tausen[109]	~3×10^3	?
Greenland, GISP2 [54]	0.1-0.5 culturable fungi (no other species studied)	?
Basal ice, Ellesmere Island[89]	>10^3 CFU/ml at 4 C	methanogens
Permafrost		
Siberia[107]	300 to 10^8	10-10^7 methanogens[95]; 10^5-3×10^7 denitrifiers[81]
Antarctica[31]	up to 10^5	methanogens

Another interesting chart that the "Life in Solid Ice?" paper provided showed the specific types of microbial life found in permafrost, snow, and lakes as well as glacial ice.



Types	**Locations** [ref.]
23 genera, mostly similar to spore-forming *Bacilli or Actinobacteria*	Glacial ice from various locations[16]
Deinococcus, Thermus, Alcaligenes, Cytophaga, Bacteriodes (all psychrophiles)	South Pole snow[11]
Serratia, Enterobacter, Klebsiella, Yersinia (all psychrotrophs)	Ellesmere Island ice[21]
Viable fungi (*Penicillium. Cladosporium. Ulocladium, Pleurotus,…*)	Greenland ice cores; age ≤ 140,000 yr [54]
>57 taxa of eukaryotes (fungi, plants, algae, and protists)	Hans Tausen ice core, northern Greenland[100]
Bacillus and other soil bacteria	At base of Guliya (Tibet) ice core in 1 My-old ice (J. Reeve, personal comm.)
Yeasts, fungi, microalgae, bacteria (including vegetative cells of spore-formers); below 1500 m, only spore- forming bacteria	Vostok ice core[1,2]
Non-spore formers (*Pseudomonas…*); spore-formers (mesophiles to psychrophiles); actinomycetes (psychrotolerant)	Vostok ice core[1]
Caolobacter, an aquatic oligotroph, probably indigenous to Lake Vostok	Accretion ice at bottom of Vostok core (R. Sambrotto, personal comm.)
Aerobic bacteria, mostly psychrotolerant oligotrophic non-sporeformers	Kolyma permafrost[94]
14 diverse genera, dominantly corynebacteria, psychrotrophs, not true psychrophiles †	Kolyma lowland permafrost[87]
11 groups of bacteria including *Proteobacteria and Fibrobacter*; SSU rDNA clones suggest novel genera or families	Kolyma lowland permafrost[104]
>30 genera of great diversity, aerobic and anaerobic, including archaea	Kolyma lowland permafrost[34,95]
Bacillus, Arthrobacter,Streptomyces, inter alia	Antarctic permafrost[95]
Methanococcoides burtonii, Methanogenium frigidum, Halorubrum lacusprofundii	Psychrophilic archaea in Antarctic lakes[28-30]

† Shi et al. (87) concluded that the majority of true psychrophiles are found in the ocean. They are rare in Antarctic rocks and soils and permafrost.

Beyond life that exists on top of and in glaciers, we must also account for life that exists beneath glaciers. Subglacial life is the hot topic of conversation to many scientists today with the recent intrusion into the subglacial lake, Lake Vostok. Since scientist have found microbial life that exists within the ice core from Lake Vostok, they have reason to believe that there is life in the actual lake as well. Discovery of life beneath ice in such isolated conditions will be a scientific breakthrough that could confirm theories we will later discuss about life on other planets' ice.

However, subglacial lakes are not the only place to look for life under ice. Beneath the ice sheets, as we have seen from the Planet Earth clip, many marine species exist. From mussels to starfish the variety of species living below ice in the frigid ocean is immense. As expected the diversity of marine creatures beneath and around ice increases during the summer months due to the warmer temperatures and melting ice that gives way for more animals to move about.

III. How Life Exists under Ice

Life existing without sunlight

Regular life is derived by photon acceptance and transfer to create sugars; while this works for surface creatures, it does not work in all places.

Chemosynthesis

Chemosynthesis is the preferred method for life in many remote areas that have access to hot sulphur vents. It works by using the hydrogen sulfide that comes out of the vents as an electron donor and is used to convert carbon dioxide into sugars. In the case of some forms of bacteria, it can even convert methane into sugars rather than carbon dioxide. This is a plausible example of how life could exist under ice.

Blood Falls

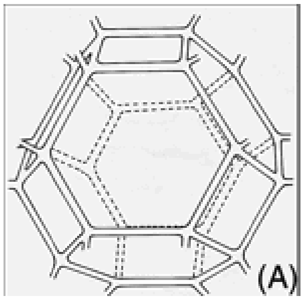
One way that we have found evidence of life existing under glaciers is in the case of Blood Falls. In a remote area of Antarctica there is an isolated body of water that contains an ecosystem of chemosynthetic bacteria that live off of reactions between iron(3) and sulphur. This ecosystem is relatively unexplored and still remains in many ways a mystery. The reaction occurring is one of relatively low energy, yet it has been able to sustain the system for well over the 1.8 million years that it has been isolated.

IV. Theories Regarding Origins of Life in Ice

Current studies suggest that life on Earth could have originated in frozen environments. Though the formation of life forms once seemed impossible in these conditions, we now know that is not so.

It was previously believed to be impossible for life to survive in glaciers due to extreme conditions including:

- Low temperatures
- High pressure
- Dilute chemical environment
- Lack of sunlight
- Lack of liquid water



As we now know, microbial life does exist within ice. Liquid water can actually exist at extremely low temperatures, especially with the aid of salts and other impurities depressing freezing temperature. In tiny veins in Arctic Ice, the high concentration of salt can maintain liquid water down to -65F (-53.9C). Tiny veins exist on the edges of ice crystals where they meet one another (Fig. A), meeting in curved tetrahedral pockets or bubbles at triple junctions; it is within these microscopic pockets and veins that liquid water can persist and provide a home to microorganisms.

Eutectic freezing

Eutectic freezing occurs in bubbles in the ice. As an ice crystal grows, only molecules of water join the growing crystal while impurities are excluded. As the space between crystals grows smaller and smaller, activity within the pores increases and the molecules of the excluded elements collide with one another and react. The bubbles can be thought of as tiny test tubes.

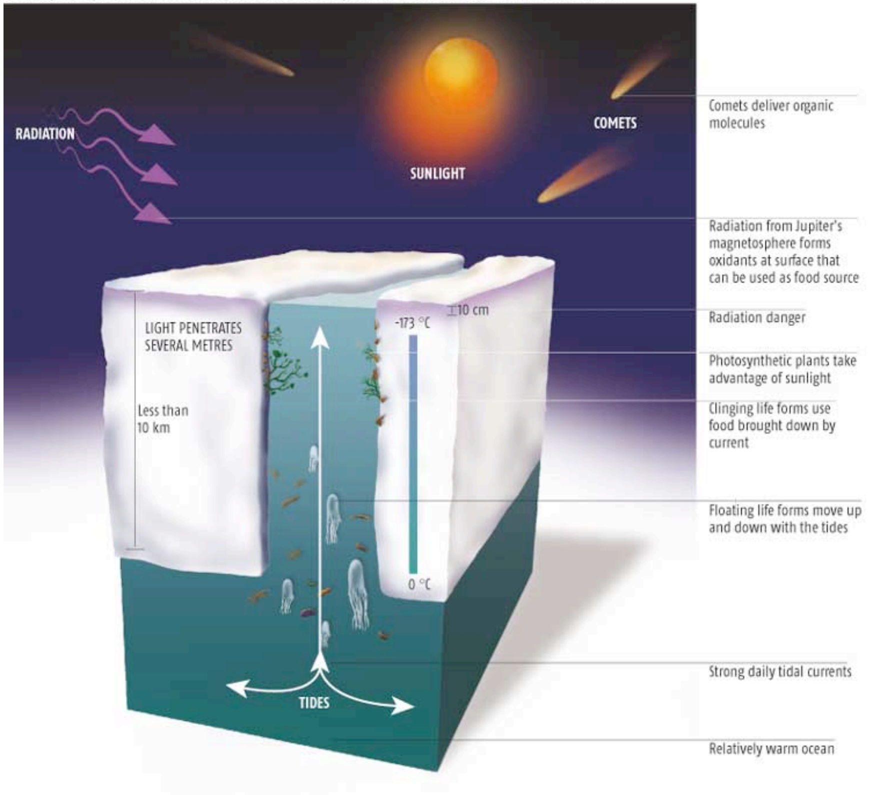
Research on this topic was somewhat pioneered by a man named Stanley Miller, who combined chemicals thought to exist on early Earth and froze them at extreme temperatures for 25 years. Thawing of his ammonia and cyanide samples revealed the formation and nucleobases and amino acids, thus prompting additional research by other scientists. Trinks measured drops in voltage on crystals' surfaces, suggesting an electric field capable of orienting molecules. Biebricher froze RNA nucleobases with seawater and studied the growth of RNA chains up to 700 bases long. Finally, Vlassov discovered the constructive ability of "hairpin" RNA at freezing temperatures as it pieces RNA chains together. When chains are joined, a water molecule is expelled. As ice removes water molecules, the reactions are prompted to only move in one direction-- towards growth of RNA.

So, it is possible that enzymes on early Earth could have acted in the same way as the above RNA, joining small segments together to form longer chains. In ice, pockets of air could have connected and formed channels in which contents might mix during freeze-thaw cycles. When the ice refreezes, the channels close off and the pockets are then separated as their own tiny experiments. When Earth warmed, the molecules may then have been delivered to ponds or seas where further development may have occurred.

V. Theories Regarding Life and Ice On Other Planets

We know of the existence of ice elsewhere in the universe, and we are currently learning of the presence of liquid water. If there is liquid water, it could hold life if we get in more energy and nutrients.

The 3 main candidates for where we could find life are Mars, Europa and Titan. There are also other icy bodies where we suspect the presence of liquid water (Ganymede, Callisto, Pluto, Charon, Triton, etc...). Mercury and Earth's moon have ice as well, but do not have all the other elements necessary for life.
On the following picture we can see a theory of how life can be on the other planets (here with Europa as an example), with the presence of liquid water, a source of energy (raylight, comets...), and nutrients necessary delivered by the comets.



IS THERE LIFE ON EUROPA?

If Europa's icy crust is thin enough, cracks would provide a habitat where life could thrive

http://astrobioloblog.files.wordpress.com/2011/03/greenberg.jpg

NASA had planned a mission on Jupiter and its moons to study under the ice, but they encountered some problems. For the moment, even on Earth we cannot drill deeper than 10 km. The ice layer on Europa is around 100 km and for Ganymede is 1000 km. There is also the problem of Earth contamination. So it's not tomorrow that we are going to know if there is life or not in the universe.

VI. Resources

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