The potential for horizontal gene transfer in sea ice

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Although 'follow the water' has long been a mantra in astrobiology, the dominant state of water in our solar system is not as a liquid but as a solid. Water ice is present in abundance on the satellites of Saturn and Jupiter, including Titan and Europa, on Mars, on the Moon, and it may have played a prominent role in the evolution of life on Earth during putative 'snowball Earth' episodes.

One form of solid water present on Earth today is sea ice, an extreme environment characterized by low temperature (-2 to $-35°$C) and high salinity (35 to 270 parts per thousand) in its brine inclusions, where microbes have been observed to reside. The physical concentration of microorganisms and the subsequent imposition of physical, chemical, and biological stresses in autumn and winter sea ice brine may favor the occurrence of horizontal gene transfer there, which in turn is expected to aid in the adaptation of microorganisms to this seasonally and epochally dynamic environment.

As part of the International Polar Year (IPY) Circumpolar Flaw Lead System Study (CFL) we found high concentrations of bacteria, viruses, and extracellular free DNA in sea ice brine relative to underlying seawater (Fig. 1), each a proxy for the raw materials required for horizontal gene transfer by conjugation, transduction, and transformation, respectively. Transduction is suggested as a prominent form of horizontal gene transfer in sea ice due to extremely high virus-to-bacteria contact rates predicted in sea ice brine (Fig. 2) and the presence of stressors, like rapid changes in temperature and salinity, that have been shown to promote the induction of prophage into the lytic cycle.

Horizontally transferred genes with particular utility in sea ice may include those encoding for the production, degradation, or alteration of extracellular polymeric substances or compatible solutes, compounds thought to have utility as cryoprotectants and osmoprotectants. Complete genome comparisons using a sea ice affiliated psychrophilic gammaproteobacterium, *Colwellia psychrerythraea*, revealed evidence for the horizontal acquisition of genes necessary for the complete catabolism of glycine betaine (Fig. 3), a common compatible solute used for protection against salt stress by members of all three Domains of life. Growth experiments using a defined medium indicated that sarcosine (an intermediate in the catabolism of glycine betaine) was utilized by *Colwellia psychrerythraea* and several other isolates of *Colwellia* as a sole source of organic carbon and nitrogen, suggesting that the horizontally transferred operon was expressed in vitro.

Figures

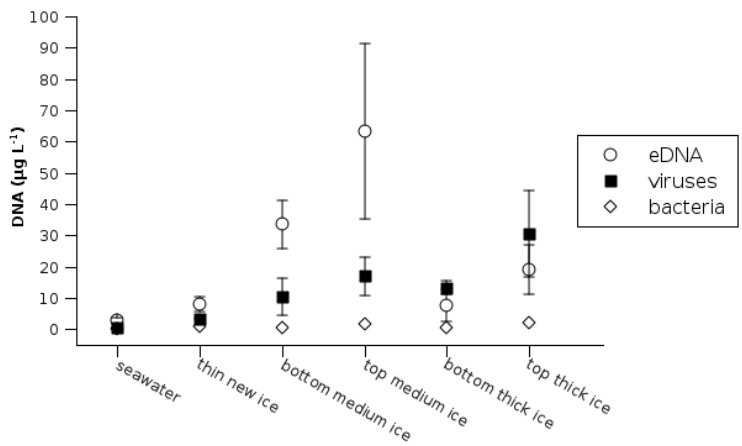

Figure 1: Concentrations of DNA in bacteria, viruses and extracellular DNA in seawater and sea ice from Amundsen Gulf and Beaufort Sea, Canadian Arctic sector.

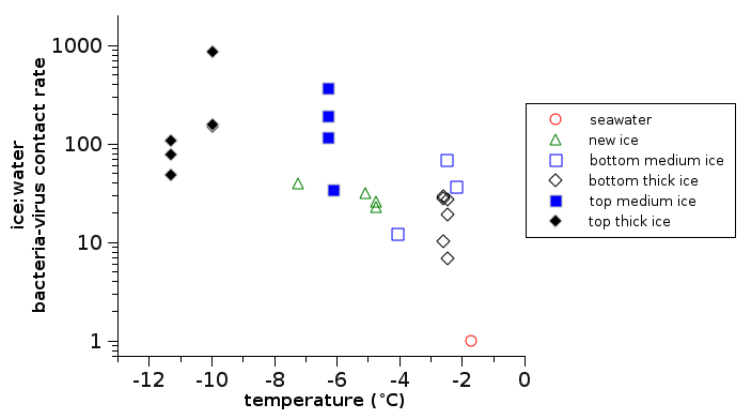

Figure 2: Virus-bacteria contact rates relative to seawater at $-1.7°$C in sea ice from Amundsen Gulf and Beaufort Sea, Canadian Arctic sector.

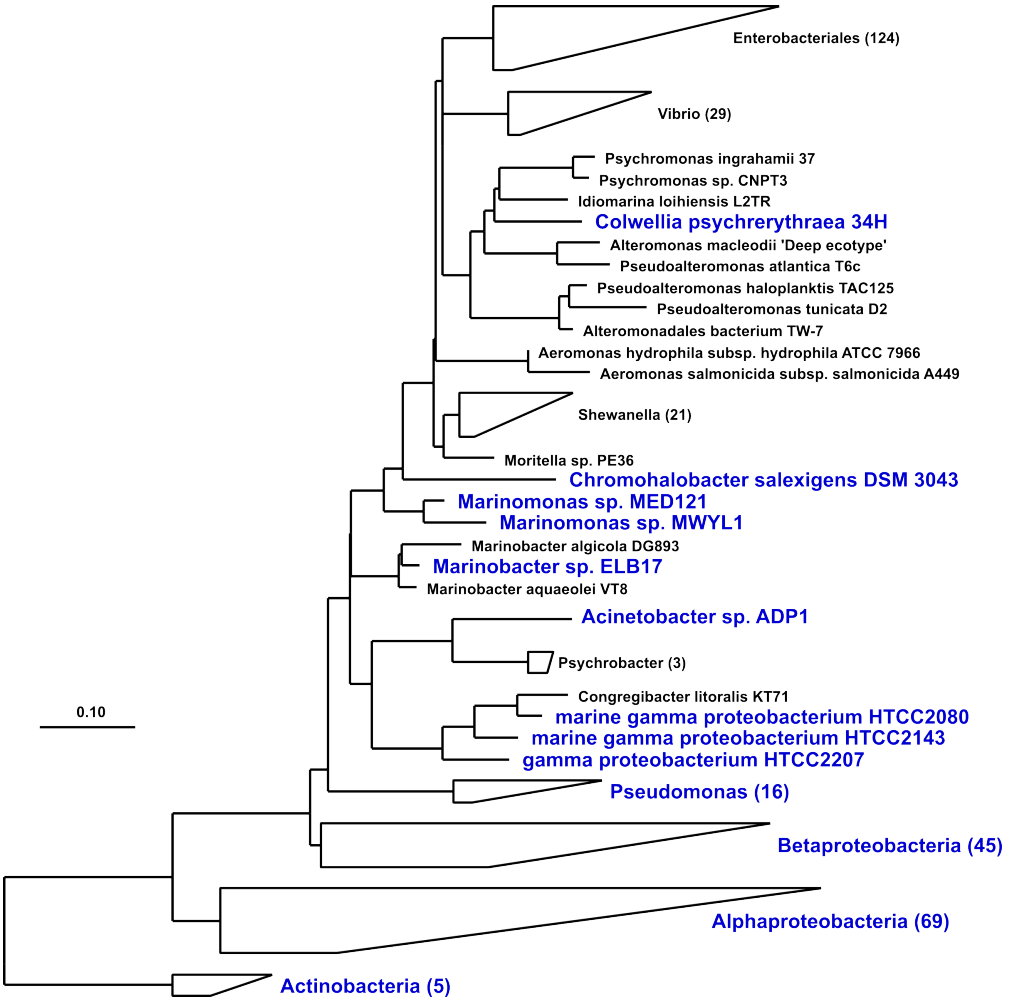

Figure 3: Phylogeny of 16S rRNA gene sequences from selected genomes in the Joint Genome Institute Integrated Microbial Genomes database. Alignment and neighbor-joining tree were acquired from SILVA version 98. Large blue leaf font indicates the genome included at least one copy of the genes encoding heterotetrameric sarcosine oxidase.