EPSC Abstracts
Vol. 6, EPSC-DPS2011-1306-1, 2011
EPSC-DPS Joint Meeting 2011

Life *in* Ice: Defining the Habitability of Europa

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Abstract

The science surrounding missions to the outer planets has been dominated by geophysics. However, a mission to Europa, the top mission priority from the last decade and a uniquely compelling mission for flight in this decade, represents a search explicitly for a “habitable world.” A comprehensive dialogue about life *in* the ice is critical since habitability is not singularly defined by shell thickness or the existence of water. Here, we present evidence from the Earth’s cryosphere for life adapted to ice and how habitability can be remotely quantified, discuss implications for the ice shell, and demonstrate how radar sounding opens the door for answering the question: can life exist in Europa’s ice?

1. Introduction

On Earth, ice is a stronghold for life, both at interfaces with water and within the ice itself (e.g. 1). The underside of sea ice for example, represents the most concentrated zone of life along a column thousands of meters in length, from the atmosphere to the sea floor (2). The reason for the concentration is energy. If life exists on Europa we may expect a similar scenario, with life concentrated at the first ice-water interface. Here ice cycling may provide oxidants to the Europan ocean, itself a source of reduced material. Pores, cracks and grain boundaries in the ice near this interface may be habitats.

2. Habitability of Ice

The temperature distribution of multi-year ice (MYI), low levels of nutrients, and microstructure make it a useful analogue for the Europan ice shell. Despite the seemingly dilute nature of MYI, calculations of pore space bacterial populations and carbon concentration demonstrate that MYI environment hosts a dense community. In particular the concentration of biomass at the interface between MYI and seawater is a distribution likely in a Europan ecosystem.

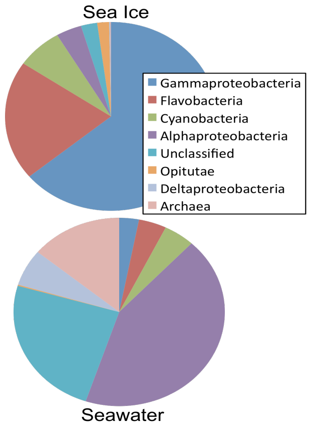

Figure 1: Analysis of 454 sequencing reads illustrates the dramatic differences between the MYI and seawater microbial communities (3).

Brine rejection during ice formation reduces salinity in the upper ice horizons. In the springtime melting at the ice surface flushes the ice, reducing both bulk salinity and nutrients. The loss of nutrients is compensated for by the increased concentration factor resulting from the loss of salt and subsequent ice growth. This process carries over as the ice becomes MYI. The pore space environment of ice of a constant salinity is governed exclusively by temperature. Cooling the ice reduces the volume of liquid contained within it, raising the concentration of dissolved and particulate matter partitioned into pore spaces, and reducing the potential for ice growth.

Many of the clades observed within MYI are copiotrophic, meaning they perform well under high nutrient conditions. Additionally sea ice hosts an abundance of psychrophilic and psychrotolerant clades (4), that perform best under cold conditions. The surface seawater community by contrast is dominated by oligotrophic bacteria that perform best under low nutrient conditions. In terms of bulk chlorophyll A concentration, a proxy for dissolved organic carbon (DOC), the MYI environment appears oligotrophic. When the partitioning of DOC into pore spaces is taken into account however, MYI is observed to be extremely nutrient rich. This explains the dominance of copiotrophic bacteria in this environment. This finding has is important for Europa: while bioavailable carbon may be limited, DOC concentrations may be amplified within the ice by 2 or 3 orders of magnitude, given the right temperature and salinity conditions.

3. Where to Look on Europa

The role of ice penetrating radar is to characterize the ice structure, including any subsurface water reservoirs and ice-water interfaces. Where might these interfaces be found?

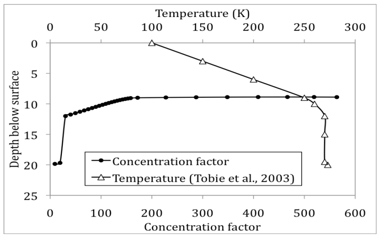

Figure 2: The concentration factor for nutrients overlaps Europa's temperature profile near 10 km for conservative salinity estimates. Shallower interfaces in the ice may be viable for higher impurity content.

Ice at the Ocean Interface: Ice thickness variations and ocean circulation beneath ice controls the distribution of accreting ice, ice that forms by salinity rejection at the base of the shelf. The topography of the bottom of the ice shell thus is unlikely to be flat, and the variation in topography can control and be diagnostic of the distribution of pure and impure ices at the interface. The habitability of accreting ice, in terms of its salinity, pressure, temperature and thus concentration factor will be discussed.

Melt Lenses in the Ice Shell: Schmidt & Blankenship (5) suggest that large water lenses form by pressure melting within the ice shell. Such lenses may be a sweet spot for habitability because of the flux of pure ice from below, impure ice from above, an evolving thermal environment and brine percolation into the ice, creating chemical and energy gradients from the lens through the ice above. The longevity and connectivity of these environments will affect their long-term habitability. Europa's surface age is less than 100 Myr, and chaos covers ~50% of the surface indicates that features forming near or over one another may allow for transfer of biomass between lenses, preserving the habitat. These new possibilities will be quantified

4. Dual-Frequency Radar

Radar sounding is a well-established technique optimized for the detection of interfaces in ice bodies. (6). In particular, a dual-frequency approach can be used to quantify the scattering environment and is especially well-suited for determining habitability. 1) Buried scatterers are indications of porosity—space is a requirement for life. 2) Scattered energy can be used to study water-filled cracks—fractures are likely locations for chemical gradients that life can exploit. 3) Dual-frequency radars can quantify the dielectric response of an ice body constraining its chemistry and temperature—brine and bioavailable nutrients are key to ice habitats. Single frequency radar cannot make such detections unequivocally, and thus while interfaces may be imaged, the biopotential of these regions may remain unquantified.

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