SELF-ASSEMBLING ICE MEMBRANES: BRINICLE PROPERTIES, FIELD EXAMPLES, AND POSSIBLE ENERGETIC SYSTEMS IN OCEAN WORLDS.

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Introduction: We discuss the physical, chemical, and electrochemical properties of ice chemical gardens and their similarity to other more well-understood self-assembling chemical systems. We will discuss how ice membranes may act as energy conduits and habitats for life on Earth and on other worlds such as Europa.

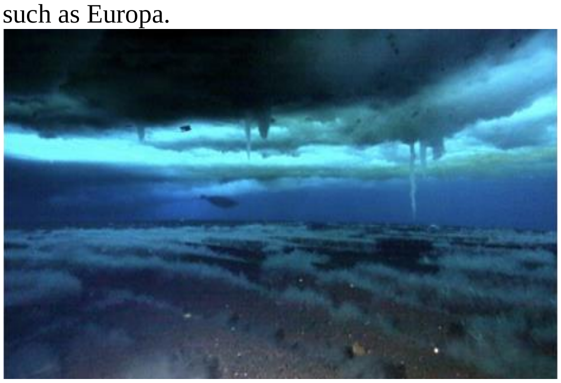

Figure 1: Brinicles under sea ice near McCurdo Station of the US Antarctic Survey.

1) Ice membrane structures as habitats? Chemical-garden structures are a general phenomenon that emerges from fluid interfaces in far-from-equilibrium chemical systems, and they can occur at all scales [1]. They can be formed in a test tube, and in natural systems they range from submicrometre-sized (e.g., cement tubes) to tens of meters tall with decimeter internal diameter (e.g., black smokers). The scale of the tubular structure that forms is related to the physical and chemical parameters of the system, including the reactant concentrations, fluid flow and internal pressure, precipitation conditions and the solubility of membrane material. Precipitated structures guide the further flow of fluid, and if the membrane precipitate can isolate the inner fluid from the exterior reactants for some distance, then the inner solution will continue to flow through the structure until it can emerge at the top and precipitate. Thus the huge chemical gardens that grow at hydrothermal vents – such as the 60-meter tall (but with micrometer scale tubes) carbonate chimneys at the Lost City hydrothermal vent field – are products of tens of thousands of years of chemical gradients maintained through geological processes. They can serve as habitats and gradient-mediating structures for a very long time. The ice tubular structures discovered so far in Antarctica [2] are smaller (meter(s) in length and ten or more cm in external diameter) and more fragile (they are dislocated by strong ocean currents and thus can only form below the sea ice closer to land). They are also not long-lived; they depend on the winter air temperature to produce the supercooled brine that feeds growth of the tube, so they disappear with seasonal changes.

By anology to the large mineral precipitates at hydrothermal vents, one can imagine a scenario in which tubular ice structures growing down from an ice sheet become thicker, stronger, and more stable. The ice membrane wall grows via heat loss from seawater directly interfacing the brine stream. The temperature gradient between the seawater and brine, along with the thermal conductivity of the ice, determines how thick the wall will become and correspondingly how far the brinicle will grow. Heat from the interior brine fluid must be dissipated through the ice wall (thus freezing additional seawater and making the wall grow thicker) or as the brine reaches the outlet of the tube, thus lengthening the whole tube from that outlet point. In Antarctica the tubes can reach all the way from the ice sheet to the seafloor.

3) Brinicle structures in icy world oceans. The extended length scales and comparatively weaker gravity and fluid-flow regimes of icy-world oceans may support the existence of more widespread, larger, and longer-lived structures. Fundamentally, brinicles come about due to the expulsion of brine pockets in ice. We will discuss how the physical magnitude of such expulsions on icy worlds may lead to brinicle structures that persist over geologically significant time scales.

Implications: When humankind eventually goes to Europa, where should we look for evidence of life? Oxidants percolating down from near surface fluids could create strong redox gradients where they meet the ocean [3]. Just as in the deep oceans on Earth, life is found on entire ecosystems huddled around hydrothermal vents on the ocean floor, so on Europa we argue that the vicinity of the icy vents that are brinicles would be ideal place to seek out life.

References: [1] Barge et al. (2015) *Chemical Reviews*, **115** (16): 8652–8703. [2] Cartwright et al. (2013) *Langmuir* **29**, 7655–7660. [3] Vance, S. D., K. P. Hand, and R. T. Pappalardo (2016), *Geophys. Res. Lett.*, **43**, 4871–4879, doi:10.1002/2016GL068547.