ERUPTION STYLE SENSITIVITY TO CRYOMAGMA-VOLATILE COUPLING IN CONDUITS ON ENCELADUS AND OTHER OCEAN WORLDS. K. L. Mitchell[1], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109-8099. (Karl.L.Mitchell@jpl.nasa.gov).

Introduction: The discovery and characterization of cryovolcanic plumes on Enceladus presents us with an opportunity to gain insight into a process that might be fundamental to various ocean worlds, and play a critical role in connecting potentially habitable zones (subsurface oceans) to surface environments. However, if we are to use cryovolcanic plumes to study these potentially habitable environments it is critical to understand the extent to which the plumes sample them, which depends on the transport process.

Previous studies have described ascent and eruption on Enceladus in which a liquid-gas water interface exists within a conduit system, either at isostatic depths [1] or closer to the ocean ice-shell interface [2], feeding vapor into the plume via boiling. However, under those circumstances the static pressure at this interface should be low, in which case dissolved volatiles would effervesce and grow throughout the conduit. This should lead to either: (1) work done by expanding bubbles to the liquid if they remain dynamically coupled, leading to continuum flow and explosive eruption analogous to fire fountaining on Earth or Io; or (2) non-H_2O volatile phases decoupling from the liquid, and either lost diffusively through walls leading to fumarolic activity or bubbles accumulating and lead to a non-steady eruption, leading to enrichment of non-H2O components, potentially analogous to strombolian style activity [3]. Whether decoupling of volatile gases and liquid magma occurs depends primarily directly on bubble growth characteristics and rise speeds, and indirectly on the evolution of the conduit system.

The role of (super)saturated volatiles in determining eruption style on Enceladus: Cassini revealed volatile concentrations in Enceladus' plume [4]. H_2 alone (0.4-1.4%) stands out as likely supersaturated relative to ocean saturation of 0.3-0.6% (assuming Henry's Law, 8 x 10^{-4} mol kg^{-1} bar^{-1}, 20-30 km ocean depth and excess pressure of 0-1 MPa [5]. This (super-)saturated situation lends itself to analogy with terrestrial silicate volcanism, in which CO_2 concentrations often exceed magma reservoir solubilities, in which much of the degassing occurs pre-eruptively (often diffusively), with bubbles nucleating throughout the conduit, usually establishing continuum flow if conduits are near-vertical. Remaining magmatic CO_2 fractions tend to approximate saturation solubilities at the magma source plus supersaturation overpressure (typically a few MPa for silicates if nucleation sites exist [3]; likely far less for water).

Stokes' flow describes the buoyant motions of at least smaller bubbles, and so it is clear that the lower viscosity of water than silicate magmas will tend to lead to faster bubble migration and a greater likelihood of dynamic decoupling. However, another relevant analogy can be drawn with the 1986 eruption of Lake Nyos, in which supersaturated CO_2 ascending from the lake base (~2 MPa) to shallower depths, causing a devastating limnic eruption of CO2 gas and water droplets [6]. The implication is that, even a non-continuum starting point is invoked, then ascending supersaturated water will tend to establish continuum flow easily even on Earth. Also note that Enceladus' lower gravity should, according to Stokes' law, suppress bubble migration rates by up to about two orders of magnitude, enhancing dynamic coupling.

Conclusions: Ocean-saturated H_2 likely results in dynamically coupled cryovolcanic activity, analogous to basaltic fire-fountaining on Earth and Io. In the context of negatively buoyant water within an ice shell, this may critically enable ascent and eruption. Given observed plume and jet longevity [7], quasi-steady multi-phase solutions of the Navier-Stokes equation may best describe eruption dynamics, with gradual evolution towards a series of tubes with nozzles. The high observed H_2O vapor fractions [8] can be explained as a result of enhanced sublimation due to elevated temperatures in close proximity to the tiger stripes [9]. Freezing of H_2O in the conduit is largely mitigated due to retardation of ascent velocities below the Mach shock, as work done by expanding bubbles is converted back into heat. If correct, eruptive compositions broadly representative of ocean composition are predicted, with a superimposed sublimated water vapor plume. It is unclear whether sufficient dissolved volatiles exist to fuel coupled ascent in a similar manner from the higher pressure oceans of larger ocean worlds.

References: [1] Kite E. S. & Rubin A. M. (2016) *PNAS, 113,* 3972; [2] Postberg F. et al. (2009) *Nature*, *459*, 1098; [3] Gonnerman H. M & Manga M. (2012) In *Fagents et al.*, CUP; [4] Waite J. H. et al. (2017) *Science, 356,* 155; [5] Manga M. and Wang C.-Y. (2007) *GRL*, *34*, L07202; [6] Zhang Y. and Kling G. W. (2006) *AREPS*, *34*, 293; [7] Porco C. et al. (2014) *Astron. J.*, *148*, 45; [8] Ingersoll A. P. & Ewald S. P. (2011) *Icarus*, *216*, 492; [9] Goguen J. D. et al. (2013) *Icarus*, *226*, 1128.

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