BREAKING THE BBC (BUOYANCY BARRIERS TO CRYOVOLCANISM). P. J. McGovern[1] and O. L. White[2], [1]Lunar and Planetary Institute, Universities Space Research Association, 3600 Bay Area Blvd., Houston, TX 77058 (mcgovern@lpi.usra.edu), [2]NASA Ames Research Center.

Introduction: The term "volcanism" refers to transport of liquid-phase material melted in the interior of a planet to another location, either a more elevated location within the planet or to its surface ("eruption"). The most voluminous manifestations of volcanism in the inner solar system occur as partial melting of silicate mantles to produce basaltic magmas in mid-ocean ridge and intraplate hotspot settings on Earth, and in large igneous provinces (LIPs) on the Moon, Mars, Venus, and Mercury. For planets with icy (generally water ice) materials in solid-phase outer shells, including asteroids (e.g., Ceres), outer planet satellites (e.g., Europa, Enceladus), and Kuiper belt objects (e.g., Pluto, Charon), the prefix "cryo" is added to distinguish the phenomenon from the silicate-driven process.

Why So Serious? Cryovolcanism has been considered difficult to produce because of the higher density of the fluid phase relative to the solid phase. Nonetheless, arguments from observation and theory suggest that these difficulties have been exaggerated.

Arguments from Observation: Cryovolcanism is observed in plume activity at Enceladus and Europa [1,2]. Cryovolcanism is inferred from the presence of potential edifice structures on Ceres (Ahuna Mons [3]) and Pluto (Wright Mons [4]) and potential lava flow features on Europa [5], Dione [6], and Triton [7,8].

Arguments from Analogy: On planets dominated by basaltic volcanism, major buoyancy deficits have been overcome. The GRAIL Mission revealed that the bulk density of the porous (impact-beaten) anorthositic lunar crust averages near 2500 kg/m^3 [9]. However, liquidus densities for mare basalt magmas range from 2800-3050 kg/m3, depending on iron and titanium content [10]. The resulting large negative buoyancy force did not prevent the eruption of the broad mare basaltic provinces; such magmas can reach the surface via a combination of mechanisms including crustal thinning, in-mantle buoyancy, volatile generation, and lithospheric stress gradients [11, 12]. Further, a reexamination of Mars gravity data [13] reveals a similar low density for the bulk martian crust, and yet the presence of immense LIPs like Tharsis, Alba, and Elysium reveals that the dense basalt flows there [e.g., 14] were able to overcome the large negative buoyancy.

Stress-driven Magma Ascent at Pluto: We model the filling of an impact basin underlying Sputnik Planitia on Pluto with carbon monoxide or nitrogen ice (density 1000 kg/m3) and the subsequent flexural and membrane responses of a water ice lithosphere via an analytical model [15] to evaluate the potential to enhance cryomagmatism in regions surrounding the basin (for example, Wright Mons). We calculate ascent velocity u_z in a dike [16]:

$$u_z = (1/3\eta)\, w^2\, (d\Delta\sigma_T/dz + \Delta\rho g + d\Delta P/dz) \quad (1)$$

where $\Delta\sigma_T$ is the difference of horizontal and vertical normal stresses, $\Delta\rho$ is the rock-magma density contrast, g is gravity, w is dike width and η is viscosity, and $d\Delta P/dz$ is the gradient of magmatic overpressure (neglected). The loading stresses give us the first term in (1) which is used to calculate u_z, and the first term can be equated to the second term (buoyancy) to calculate an "effective buoyant density" $\Delta\rho_{efb}$ to effectively offset the negative buoyancy inherent to cryovolcanism.

Results: Our model predict an annular zone of enhanced cryomagma ascent surrounding Sputnik Planitia, with magnitudes of effective buoyant density significantly in excess of the expected ~ -100 kg/m3 buoyancy of liquid water in water ice. The magnitudes and locations of enhanced magma ascent regions will depend on parameters such as lithosphere thickness and others listed above, to be explored...

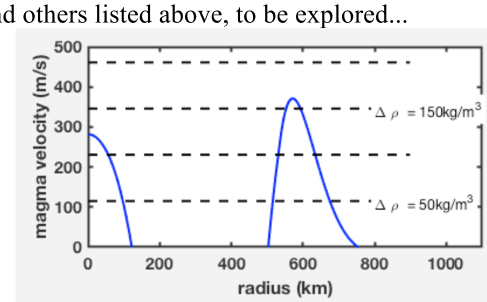

Figure 1. Ascent velocity u_z vs. radius for loading of Sputnik Planum basin (r = 550 km) with CO ice layer of maximum 5 km thickness. Dashed lines indicate $\Delta\rho_{efb}$. Model parameters tuned to produce u_z comparable to estimated plume velocities at Enceladus [1].

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