Volatile-driven cryovolcanic eruption on asteroid Ceres as a probe to its interior

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Introduction: Imageries from NASA's DAWN mission revealed the presence of localized bright spots (or faculae) exhibiting brighter materials with likely composition of anhydrous sodium carbonate (De Sanctis et al., 2016) within the dark Ceres surface. These materials are assumed to be remnants of cryovolcanic ejecta which ascended from brine reservoirs thorough impact induced fractures. Quick et al., (2018) showed that excess pressure caused by the gradual freezing chamber could be a driving source for its ascent. However, DAWN image revealed the presence of both explosive (e.g. Vinalia faculae) and effusive (i.e. Cerealia facula and Ahuna Mons) eruptions, implying the possibility that fragmentations of cryomagma are induced by exsolved volatiles and this could be a primal driving source.
Objectives: Volatile exsolution are known to play an important role in ascent dynamics of silicate volcanism, and it enables ascent of relatively high density cryomagmas, but their contributions to cryovolcanism are not well understood. This study attempts to obtain new constraints on the properties of a subsurface brine reservoir and conduit geometry based on phase equilibria and model calculations.
Model: The equilibrium composition of CO_2-H_2O-NaCl system by Akinfiev & Diamond (2010) was used as the cryomagma composition. The cryomagma is assumed to have a viscosity of 10^5-10^8 Pa s (Quick et al., 2018), and this slurry-like rheology constrains the temperature within the solidus and liquidus curves along decompression. If we assume ascents to be isothermal at velocity >10^{-3} m/s (Quick et al., 2018) and salinity lower than the stability region of hydrohalites, then the temperature of cryomagma should be within ~260 - 270 K, consistent with impact simulation (Bowling et al., 2018), and salinity <~20 wt%. One-dimensional 2-phase (i.e. cryomagma and exsolved gaseous volatile) steady flow in a cryovolcanic conduit was modelled with the theory developed by Kozono & Koyaguchi (2009) for terrestrial volcanoes. Major modifications in our model were, adjustment of the henry's law, application of choking condition at the surface, and the liquid stability of CO_2. The depth, volatile content, viscosity of brine reservoir, and conduit radius were constrained from the estimated explosive eruption velocity of Vinalia faculae 26 - 54 m/s (Quick et al., 2018) derived from its emplaced radius.
Result and Discussion: Calculation results indicated that for a given viscosity (e.g, 10^5 Pa s), a series of combinations of conduit radius and volatile content, ranging from 10 m and 4 - 7 wt% to 50 m and 0.8 - 3 wt%, 200 m and 0.7 - 3 wt%, can achieve the above eruption velocity. Note that plausible conduit radii should lie within 1 - 100 m (Fagents 2003) and robust upper limit is given by observed radii of vent-like feature ~200 m. We found that reservoir depths have little influence on eruption velocities. For a given viscosity (10^6 Pa s), similar combinations of conduit radius and volatile content ranging from 50 m and 2 - 3 wt% to 200 m and 0.7 - 3 wt% can achieve the eruption velocity. Although higher viscosity >10^7 Pa s can achieve similar eruption velocity when a larger conduit radius >100 m is assumed, such large conduits are not consistent with estimations (Quick & Marsh, 2016). Results for explosive eruptions experienced fragmentation at >100 m depth and showed that volatiles could drive the ascent and cause fragmentation of cryomagmas. If effusive eruptions occurred from the same reservoir, conduit radii should be <1 m. However, the probable abundance of such conduits is inconsistent with the lack of effusive eruptions on Ceres and thus could have formed differently, such as diapiric ascents (Buczkowski et al., 2018). Our model calculations showed that cryomagmas could be volatile-driven and may cause fragmentations to erupt explosively. Also, constraints from our calculation showed that Ceres subsurface could be volatile-rich than previously assumed.

Keywords: Ceres, cryovolcano, DAWN, facula, eruption