Abstract: Volatiles on Vesta indicated by Dawn observations and the HED meteorites

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The Dawn mission observed spatially localized indications of volatiles on Vesta's surface, in the form of pitted terrain and curvilinear gullies/lobate deposits, interpreted respectively as the product of impact-induced degassing of volatiles (Denevi et al., 2012) and impact-induced, transient debris-flow-like processes (Scully et al., 2015). Here we examine further the evidence for or against the presence of volatiles on Vesta, by means of: (1) detailed morphological studies of Vesta's Marcia region and potentially analogous regions on Ceres, (2) a review of recent studies of the howardite-eucrite-diogenite (HED) meteorites, and (3) laboratory experiments about the behavior of water at low pressures ($<<10^{-3}$ atm).

Our detailed morphological study focuses on the Marcia region, which contains some of the clearest examples of pitted terrain, curvilinear gullies and lobate deposits. Further indications of volatiles in this region include a landslide whose runout distance indicates a low coefficient of friction (~0.35), which can be explained by basal entrained volatiles. We also analyze the distribution and thermal properties of the pitted terrain, which are consistent with an impact melt with ~10% of the volatile content of typical terrestrial magmas. Impact-deposited carbonaceous chondrites and sub-surface ice-bearing deposits are evaluated as possible sources of the volatiles. In addition, we discuss the significance of potential pitted terrain, curvilinear gullies and lobate deposits observed by Dawn on Ceres, which is the largest object in the asteroid belt and widely accepted to be ice-rich in comparison to Vesta (e.g. McCord et al., 2011).

Our study is enhanced by analyses of the HED meteorites, whose compositional link to Vesta was proposed on the basis of telescopic and laboratory spectra (McCord et al., 1970), and confirmed by Dawn's compositional analyses of Vesta (e.g. De Sanctis et al., 2012, Prettyman et al., 2012). While the aforementioned indications of volatiles on Vesta's surface were unexpected, these observations are consistent with a few recently analyzed eucrite meteorites, whose late stage alteration products are plausibly deposited from aqueous fluids (Barrat et al., 2011). In particular, the eucrite NWA 5738 contains complex, multistage alteration that is attributed to percolation of fluids through the rock (Warren et al., 2014). Similarly, quartz veins in the Serra de Magé eucrite are interpreted as deposits from liquid water solutions, analogous to terrestrial quartz veins (Treiman et al., 2004). Further eucrites contain apatites with relatively high OH contents (~0.4 wt.%), which may also be indicative of past interior water (Sarafian et al., 2013). Moreover, clasts of carbonaceous chondrite are the source of ~0.5-6 wt.% mineralogically-bound water in select howardites (Herrin et al., 2011).

Previous laboratory experiments at Vestan post-impact surface temperatures and pressures (~293 K and $<10^{-3}$ atm) indicate that liquid water, especially when mixed with particulates, as in a debris flow, would be quasi-stable for the minimum time required to form the curvilinear gullies/lobate deposits (~24 minutes, Scully et al., 2015). We will briefly outline additional experiments that will investigate the behavior of liquid water at lower pressures ($<<10^{-3}$ atm), and investigate the impact of salts on the loss rate of water.