THE PONDS ON EROS: POSSIBLE NEW INSIGHTS FROM EXPERIMENT, VESTA, MARS, AND TERRESTRIAL ANALOGS.
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Introduction: One of the most intriquing features of the surface of near-Earth asteroid Eros are the so-called "ponds", smooth areas at the bottom of craters (Fig. 1) [1]. Similar smooth areas have been observed on other asteroids [2]. The major properties of the Eros Ponds are that they (1) have distinctive flat floors sometimes showing non-central downside movement, (2) have sharp boundaries, (3) have uniform morphology, color and albedo, (4) typically have a radius ~1/3 the diameter and a ~5% of the depth of the host crater diameter and that they are not concentrations of a uniform widespread ejecta, and (5) can be seen on other (noncrater) depressions [3]. Additionally, (6) the Eros depressions appear preferentially at locus of sub-solar point and they are more abundant in regions of lower gravity. Regions of ponded regolith on asteroids were predicted by Cintala *et al*. [4] as a result of seismic shaking and this interpretation has been applied to the Eros ponds [5]. It has also been suggested that they are due to electrostatic processes occurring on the dry dusty microgravity environment [1]. With the recent discovery of water on Vesta's surface, and its behavior during energetic events like impact, we suggest a role for volatiles in the formation of the Eros ponds.

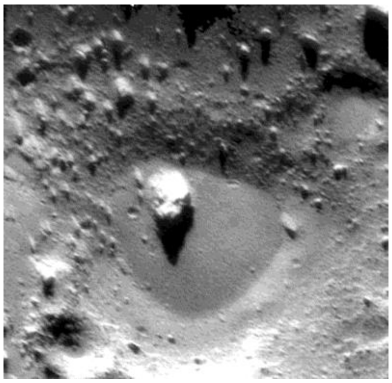

Fig. 1. *Example of an Eros pond.*

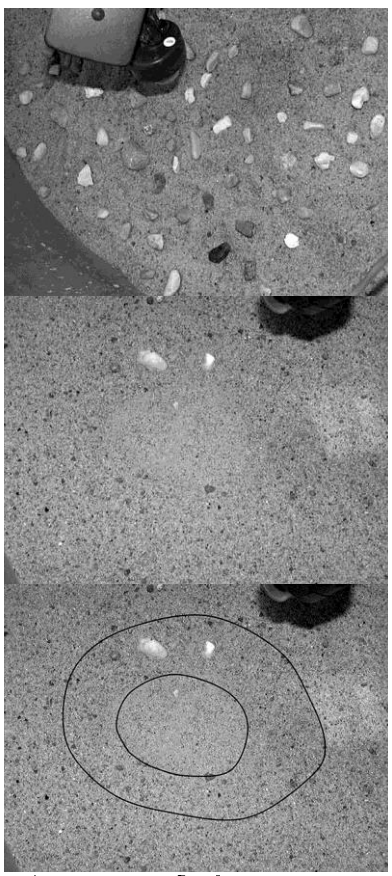

Fig. 2. *One-g fluidization experiments on the surface of loose unconsolidated sand. Top, before. Middle, after. Bottom, crater-like depression (outer curve) and fine-grain "pond" (inner curve) shown.*

Laboratory Simulations: Kareev et al. [6] and Hasseltine et al. [7] have reported experiments in which regolith simulats have been placed in a vacuum chanber and water or nitrogen allowed to flow through to the surface as the pressure was reduced (Fig. 2). Ice and water were placed 10 cm below the surface or nitrogen gas was bled in from a cylinder. The regolith simulant was an Hawaiian tephra or sand, of diverse grain size. Crater-like depressions were formed by the explosive release of volatiles or slow decrease in flow rate, and areas of flat fine-grained "pools" were made as the flow rate slowed and finally ended. The final features had a close resemblance to the Eros ponds and even "streaks" forming on "crater" walls.

Possible Martian Analog Observations: The recently observed pits observed on Mars may not be exactly analogous to the Eros ponds, but are features proposed to form when volatiles are released from impact melt-bearing deposits (Fig. 4) [8,9]. In this case the target surface contains a considerable amount of ice and there is a measureable atmosphere, although the latter is unimportant for pit formation based on current formation models.

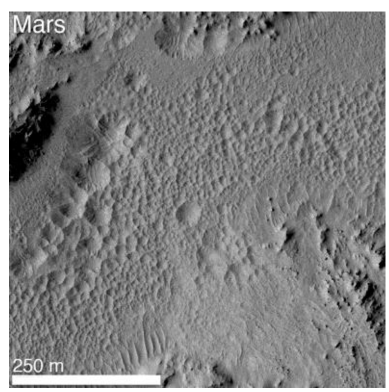

Fig. 4. *Pitted terrain on Mars [9].*

Possible Vesta Analog Observations: It came as a considerable surprise when pits and pitted terrain [10] (and gullies [11]) were discovered on Vesta, as well as water-bearing regions [12] and dark areas [13]. These two observations were explained in terms of infall of CM chondrite material (which are a common meteoritic xenolith and can contain up to 10 vol% water). The Vesta pits, which resemble the pitted terrain on Mars, are interpreted as being caused by the release of volatiles from impact melts. The gullies may similarly be evidence for fluid-abetted mass wasting [11], but may also be explained as dry flows [14].

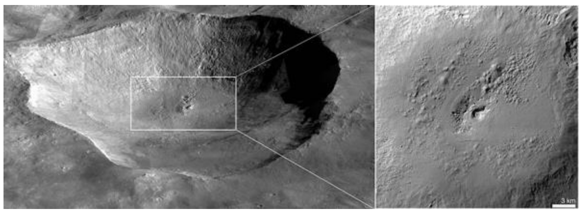

Fig. 5. *Marcia crater on Vesta with a smooth plain at the bottom with numerous pits [10].*

Possible Impact Analog Observations: Additional work over the last few years supports that volatiles can play a major part in the formation of impact craters on Earth [15,16]. One of the pioneering studies on this subject by Newsom et al. [17] indicated that volatiles were released during the formation of 'suevite' – clay-rich impact melt-bearing breccias – at the Ries Crater in southern Germany (Fig. 6). Fieldwork carried out by one of us (GRO) has shown that these features are not distributed evenly around the Ries structure and these 'pipe structures' are typically dm across and extend vertically for several m. We do not know the original scale of these features and their surface manifestations, as active meteorology and vegetation may have removed them in the case of the Ries, but clearly volatile release during impact is a process to be considered on impacted surfaces.

Possible Volcanic Analog Observations: Phreatic pits are formed when lavas flow over water-bearing sediments and are well-documented at the Craters of the Moon National Monument and Preservev [18]. They are usually formed explosively and there are numerous boulders scattered around the pit. Some have been smoothed over by loess and surrounded by subsequent flows (Sugar Bowl), some show evidence for multiple events (Split Butte), while others are deep rooted and expose underlying strata (King's Bowl). All represent an interaction between volatiles and surface materials during energetic events.

Fig. 6. *Channels caused by the release of volatiles during impact that formed the Ries Crater.*

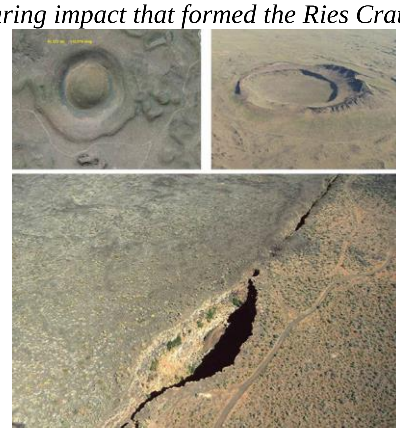

Fig. 7. *Phreatic pits at the Crater of Moons National Monument and Preserve, Sugar Bowl, Split Butte, and King's Bowl.*

Discussion: At this point we are not inferring that the Eros ponds are simple analogs of the pits and phreatic structures, but we do point out that if Vesta contained sufficient exogenous water to produce these textures then S asteroids should also. Seismic shaking and electrostatic processes might well explain the Eros ponds, but in view of the prevalence of volatile interactions on these diverse planetary bodies we suggest that volatile driven processes should also be investigated in the case of the Eros ponds.

References: [1] Robinson et al., 2001. Nature **413**, 396-400. [2] Fujiwara et al., 2006. Science 312, 1330-1334. [3] Robinson et al., 2002. MAPS 37, 1651-1658. [4] Cintala et al., 1979. In Asteroids, 579-600. [5] Cheng et al. 2001. MAPS 37, 1095-1105. [6] Kareev et al. 2002. LPSC #1610. [7] Hasseltine et al. 2006. LPSC #1103. [8] Tornabene et al. 2012. Icarus 220, 348–368. [9] Boyce et al. 2012, Icarus 221, 262-275. [10] Denevi et al. 2012. Science 338, 246-249. [11]Scully et al 2013. LPSC #1578. [12] McCord et al., 2012. Nature 491, 83-86. [13] De Sanctis et al. 2012. Science 336, 697-700. [14] Jaumann et al. 2013. EPSC #2013-307. [15] Kirsimäe and Osinsky, 2013. In Impact Cratering, 76-89. [16] Stöffler et al., 2013. MAPS 48, 525-589. [17] Newsom et al. 1986. JGR 48, E239-E251. [18] Hughes et al 1999. In Guidebook to the Geology of Eastern Idaho, 143-168.