

GULLIES ON VESTA, RELATED GEOLOGIC FEATURES AND POSSIBLE FORMATION MECHANISMS. J. E. C. Scully¹, C. T. Russell¹, A. Yin¹, R. Jaumann², H. Y. McSween³, C. A. Raymond⁴, V. Reddy⁵, L. Le Corre⁵, ¹Department of Earth and Space Sciences, University of California, Los Angeles, California 90095-1567, USA (jscully@ucla.edu), ²DLR, Institute of Planetary Research, Berlin, Germany, ³University of Tennessee, Knoxville, TN, USA, ⁴Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, ⁵Max Planck Institute, Katlenburg-Lindau, Germany.

Introduction: Since its arrival at Vesta, NASA's Dawn spacecraft and its three instruments, the Framing Camera (FC) [1], Visible and Infrared Spectrometer (VIR) [2] and Gamma Ray and Neutron Detector (GRaND) [3], have collected spectacular imaging, compositional and geophysical data. Vesta is a differentiated asteroid with no atmosphere and a gravitational acceleration of 0.22 m/s^2 [4]. Thermal modeling predicts that about 50% of Vesta's surface has an average temperature of $<145 \text{ K}$, which suggests that water ice could be stable within the top few meters of regolith [5]. Dawn acquired data [e.g. 6,7] consistent with the earlier theory that the howardite, eucrite and diogenite (HED) meteorites originate from Vesta [e.g. 8].

Data: This work primarily uses FC images and mosaics from the Low Altitude Mapping Orbit (LAMO), which have a pixel scale of $\sim 20 \text{ m/pixel}$. FC images and mosaics from the first and second High Altitude Mapping Orbits (HAMO and HAMO 2) are also used, but at $\sim 70 \text{ m/pixel}$ they often do not provide the required detail. Additional compositional data is provided by VIR [e.g. 6,9] and GRaND [7], along with topography maps derived from the FC data [e.g. 10,11].

Gullies: Gullies are observed in relatively fresh, young craters on Vesta's surface and can be divided into two morphologically distinct categories: type L and type C. Type L are the most common, occurring in 48 craters, and type C are less common, occurring in 11 craters. This catalogue of gully-containing craters is essentially complete; the only areas that have not been examined are some of the most northerly latitudes that unfortunately were not observed under favorable illumination conditions.

Type L (linear) gullies. These gullies often originate at spurs of material near the crater rims, which are positive topography features and appear to consist of competent material. The gullies themselves are reasonably straight, linear depressions, parallel to one another and have a lower length:width ratio than the type C gullies. They are often bounded by levees of mass-wasted material. Type L gullies are morphologically similar to lunar gullies, which are thought to form by dry mass-movement processes [12].

Type C (curvilinear) gullies. These gullies often originate from V-shaped, headward alcoves, which are negative topography features near the crater rims. The

gullies themselves form discrete channels, are sinuous, merging, have higher length:width ratios than the type L gullies and often end in lobate deposits that are morphologically similar to the aprons of terrestrial debris flows. Type C gullies intersect more than type L gullies, resulting in more complex patterns, and form relatively steep lobate deposits. Type C gullies are morphologically similar to gullies in Meteor Crater on Earth [13] and to Martian gullies [e.g. 14]. It has been proposed that Martian gullies are inconsistent with a fluid formation mechanism and that dry flows of eolian material are the more likely [e.g. 15]. However, many others view the morphologies of the Martian gullies as being more akin to those associated with modification due to fluid flow [e.g. 16] and presently, the general consensus is that erosion by liquid water formed the Martian gullies [17].

Other geologic features: The gullies are found alongside a suite of varied geologic features both inside and outside impact craters, such as mass-movement deposits, boulders, linear features and pitted terrain, which is interpreted to form by the degassing of volatile-bearing material after impact heating [18]. Understanding the level of interconnectedness between these features, and how they tie together a number of aspects of Vesta's geology and composition, leads to a fuller understanding of the geological history and evolution of this body.

Hydration and Vesta: Confirmation of Vesta's igneous differentiation [19], and the fact that igneous rocks formed in a vacuum are thought to be mostly anhydrous [20], suggest that Vesta is a dry body. However, there are indications from the HED meteorites of local hydration on Vesta. Carbonaceous chondrite material in howardites [e.g. 21] is evidence for mineralogically bound water and Vesta's dark material has been interpreted as carbonaceous chondrite material [e.g. 22, 23]. Hydrogen, in excess of $400 \mu\text{g/g}$, was found by the GRaND instrument to correspond to the broad locations of Vesta's likely carbonaceous chondrite dark material [7]. There is also limited evidence for liquid water in the form of quartz veinlets found in a eucrite meteorite, which are interpreted to be most likely deposited from aqueous solution due to their similarity to terrestrial quartz veinlets [24]. Further, a few eucrites containing apatites with relatively high OH contents suggest that there may have been some amount of wa-

ter in magmas on Vesta [25]. Moreover, remote sensing observations indicate local Vestan hydration. [20] interpreted 3 μm and 3.4 μm absorption bands in Vesta's spectrum to be due to OH and/ or H₂O bearing minerals. VIR detected a widespread, heterogeneously distributed 2.8 μm OH absorption on Vesta's surface [9].

Formation mechanisms: Study of possible formation mechanisms for the gullies and other features is done by analysis of: a) morphologies, b) relative locations of features with respect to topography, pitted terrain etc., c) compositional and physical properties of Vesta, d) compositional and physical properties of possible crater-forming impactors and e) analogs elsewhere in the solar system. The feasibility of dry granular flow and fluid flow, in the form of impact melt and transient water flow, are considered. Water flow is considered because: a) the type C gullies are morphological similar to gullies on other bodies that are thought to form by liquid water erosion, b) there is meteorite and remote sensing evidence that Vesta may not be as dry as once thought and c) water is such a common volatile in the inner solar system. Water flow would be transient because of the lack of atmosphere and the low average surface temperature of Vesta.

References: [1] Sierks H. et al. (2011) *Space Sci. Rev.*, 163, 263. [2] DeSanctis M. C. et al. (2011) *Space Sci. Rev.*, 163, 329. [3] Prettyman T. H. et al. (2011) *Space Sci. Rev.*, 163, 371. [4] Thomas P. C. et al. (1997) *Science*, 277, 1492. [5] Stubbs T. J. & Wang Y. (2012) *Icarus*, 217, 272. [6] DeSanctis M. C. et al. (2012) *Science*, 336, 697. [7] Prettyman T. H. et al. (2012) *Science*, 338, 242. [8] McCord T. B. et al. (1970) *Science*, 168, 1445. [9] DeSanctis M. C. et al. (2012) *ApJL*, 758, L36. [10] Gaskell R. W. et al. (2012) *44th DPS*, 209.03. [11] Preusker F. et al. (2012) *45th AGU*, P43E-05. [12] Bart G. D. (2007) *Icarus*, 187, 417. [13] Kumar P. S. (2010) *Icarus*, 208, 608. [14] Malin M. C. & Edgett K. S. (2000) *Science*, 288, 2330. [15] Treiman A. H. (2003) *J. Geophys. Res.*, 108, 8031. [16] McEwen A. S. (2007) *Science*, 317, 1706. [17] Carr M. H. (2012) *Phil. Trans. R. Soc. A*, 370, 2193. [18] Denevi B. W. (2012) *Science*, 338, 246. [19] Russell C. T. et al. (2012) *Science*, 366, 684. [20] Hasegawa S. et al. (2003) *GRL*, 30, 2123. [21] Herrin J. S. et al. (2011) *42nd LPSC*, 2806. [22] Reddy V. et al. (2012) *Icarus*, 221, 544. [23] McCord T. B. et al. (2012) *Nature*, 491, 83. [24] Treiman A. H. et al. (2004) *EPSL*, 219, 189. [25] Sarafian A. R. et al. (2012) *43rd LPSC*, 1175.

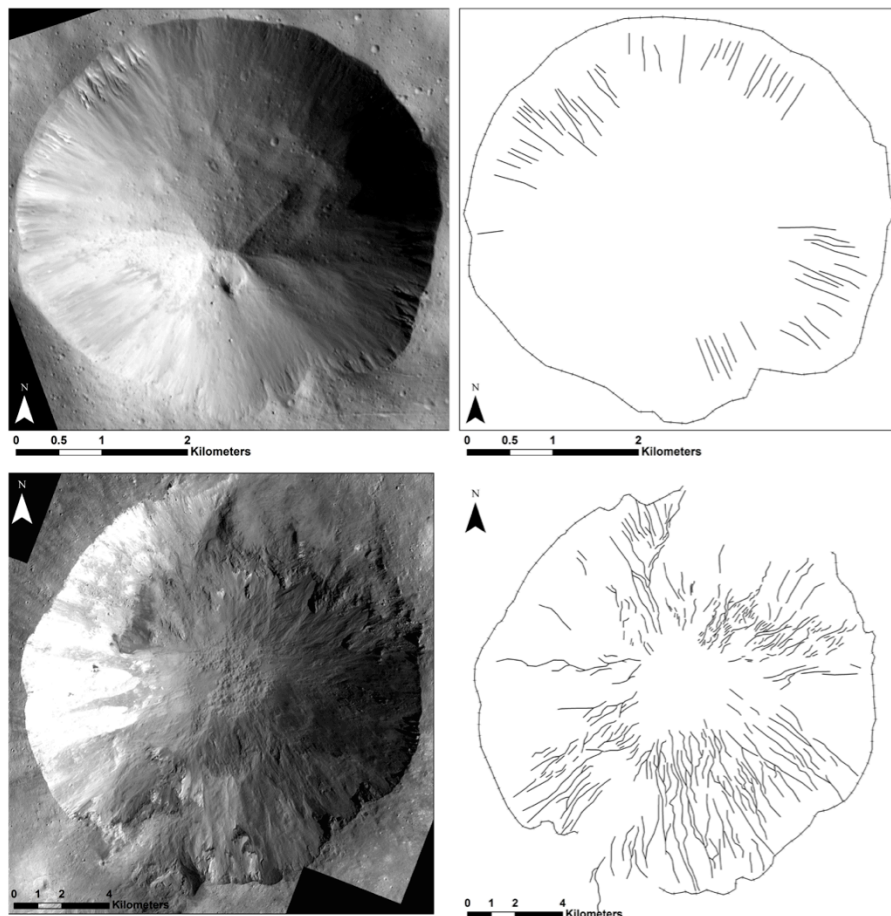


Figure 1: Top: unmapped (left) and mapped (right) images of type L gullies in Fonteia crater. Bottom: unmapped (left) and mapped (right) images of type C gullies in Cornelia crater.