VESTAN GULLIES AND THEIR FORMATION MECHANISMS. J. E. C. Scully[1], C. T. Russell[1], A. Yin [1], R. Jaumann[2], E. Carey[3], H. Y. McSween[4], C. A. Raymond[3], V. Reddy[5,6], L. Le Corre[5,6,], J. Castillo-Rogez[3], [1]Dept. of Earth and Space Sciences, University of California, Los Angeles, CA, USA (jscully@ucla.edu), [2]DLR, Berlin, Germany, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [4]University of Tennessee, Knoxville, TN, USA, [5]Max Planck Institute, Katlenburg-Lindau, Germany, [6]PSI, Tuscon, AZ USA.

Introduction: The view that airless solar system bodies are completely dry is changing with the discovery of water on the Moon [e.g. 1] and Mercury [e.g. 2]. Vesta too has evidence for water: its meteorites contain evidence for aqueous alteration [3,4] and water in primitive melts [5]. Furthermore, Dawn's observations detected a 2.8 μm OH absorption [6] and mineralogically bound OH and/ or H_2O [7]. Also, pitted terrain, interpreted as evidence for degassing of volatile-bearing material, is found in some recent craters [8].

Flow conditions and morphology: Morphology of terrestrial flow features is used to indicate the flow conditions under which they formed [9]. This approach is adopted by planetary geologists, who have used surface morphology, amongst other characteristics, as an indicator of the formational flow conditions of gullies on the Moon and on Mars [10,11,12].

Lunar gullies are straight, parallel to one another and do not intersect to form networks, which is indicative of their formation by dry flow of granular material [11,12]. Martian gullies have a generic form of a head alcove, curvilinear channels and a depositional apron [10] and many formation mechanisms for them have been proposed [e.g. 13]. A specific set of young Martian gullies, called surficial gullies, are located in and around Gasa crater and are proposed to form by the flow of impact-melted water sourced in ice-rich mantle deposits [14]. These surficial gullies have some morphologies that are different from generic Martian gullies: they are shallowly incised and can originate in the crater walls without alcoves [14].

Observations: Gullies on Vesta are classified, based on morphology, into two types: linear, identified in 50 locations, and curvilinear, identified in 8 locations. Both are chiefly found on the sloping walls of young impact craters.

Linear gullies. Linear gullies are straight, parallel to each other, rarely intersect and have simple network geometries that form parallel networks. They typically originate in alcoves below spurs of more coherent material and are often bounded by talus material levees.

Curvilinear gullies. The type area curvilinear gullies are found in two craters: Cornelia and Marcia. In these craters the gullies are sinuous, frequently intersect and have complex network geometries that form sub-dendritic and sub-parallel networks. They typically originate below slumped deposits or in the crater walls and commonly end in deposits that are lobate in shape. These lobate deposits partially superpose one another and are morphologically similar to terrestrial alluvial fans formed by debris flows.

Pitted terrain: The four craters with pitted terrain on their floors [8] also contain curvilinear gullies in their walls. Sometimes, pitted terrain is observed on the lobate deposits of curvilinear gullies as well as on the rest of the crater floor. Pitted terrain is not observed in craters containing only linear gullies. Pitted terrain is morphologically similar to Martian pitted terrains [15] and both are interpreted to form by impact-heated degassing of volatile-bearing material [8,15].

Quantified observations: The morphologic dissimilarity between the two gully types can also be quantified. The length to width ratio of curvilinear gullies, on average 30, is higher than that of the linear gullies, on average 13. Also, the junction angles between connecting gullies, on average 33° for curvilinear gullies, is higher than that of the linear gullies, on average 16°. The number of connections between gullies is also highest for curvilinear gullies.

Interpretations: There are a number of different possible interpretations for the formation mechanism of the vestan gullies, which are discussed below.

Interpretation A: flow of impact melt. Flow of impact melt is considered the least likely formation mechanism for either type of gully due to the low volumes of impact melt observed and predicted based on calculations [e.g. 16]; the spectral characteristics of the gullies being inconsistent with impact melt; and the paucity of impact melt morphologies associated with the gullies (although melt may be incorporated within some of the pitted terrain regions).

Interpretation B: dry flow. The morphology of the linear gullies is analogous to lunar gullies and it is likely that they formed by flow of dry granular material. However, since the morphologies of the linear and curvilinear gullies are dissimilar, the principle of morphology indicating flow conditions suggests that some flow condition(s) that formed the linear gullies must be different from the flow condition(s) that formed the curvilinear gullies. In searching for the different flow condition(s), it is found that both types of gullies: i) form on the same ranges of slopes; ii) have similar amounts of material available for flow; and iii) have similar compositions. Also, thermal inertia data [17] indicates that the curvilinear gullies are not formed by flow of relatively finer grained material. Thus, it seems likely that linear gullies are formed by flow of dry granular material, but no varying flow condition can be found to explain how flow of dry granular material could also form the morphologically dissimilar curvilinear gullies.

Interpretation C: dry flow and transient flow of liquid water.

Since no varying flow condition(s) can be found to explain the flow of dry granular material forming the curvilinear gullies, it is proposed that dry granular flow formed the linear gullies but that flow of transient liquid water was involved in the erosion of the curvilinear gullies. Observations that support this proposal are the morphologies of the curvilinear gullies, their formation of complex networks, their similarity to the Martian surficial gullies and their association with pitted terrain.

Proposed formation mechanism of curvilinear gullies: Water will be stable in the gaseous state at vestan surface conditions and could be trapped and survive for billions of years in ice form as shallow as a few meters in the regolith [18]. It is proposed that the water is sourced in sub-surface ice-bearing deposits (Fig. a). The sub-surface distribution of these deposits may be represented by the two clusters of craters containing curvilinear gullies.

The preferred source of the sub-surface ice-bearing deposits is accretionary rather than later deposition by water-rich bodies, because it would be difficult to retain and bury exogenous ice on the surface of Vesta before it changed phase to a gas and was lost to space. Even though water and other volatiles originally present in the bodies that completely melted, such as Vesta, are usually assumed to be completely lost [19], quartz veins in a eucrite meteorite have been dated to be older than 4.4 Ga [3], which suggests that at least some water was present early on in Vesta's history.

Sub-surface ice-bearing deposits can be tapped by small-medium impacts that excavate material and sufficiently increase the temperatures and pressures so that part/ all of the ice-bearing deposit melts (Fig. b). Once water leaves the ice-bearing deposit and reaches the crater wall it begins to evaporate. However, not all will instantaneously evaporate. Only the top layer will be exposed and evaporating at any one time, which hinders the evaporation of lower levels (Fig. c). This process is enhanced because low surface temperatures also cause the water surface to partially freeze. Thus, water can transiently flow under a temporary protective evaporating and/ or freezing barrier before it finally all evaporates and is lost. Observations support this scenario because no curvilinear gullies are found on escarpments outside of impact craters. Experiments are underway at vestan surface temperatures and pressures to demonstrate this transient flow process. After the transient flow, loss, through evaporation, of the water on the crater floors may contribute to pitted terrain formation (Fig. d).

Conclusions: We propose that curvilinear gullies are morphological evidence for localized water on Vesta, which is in keeping with recent meteorite and remote sensing evidence.

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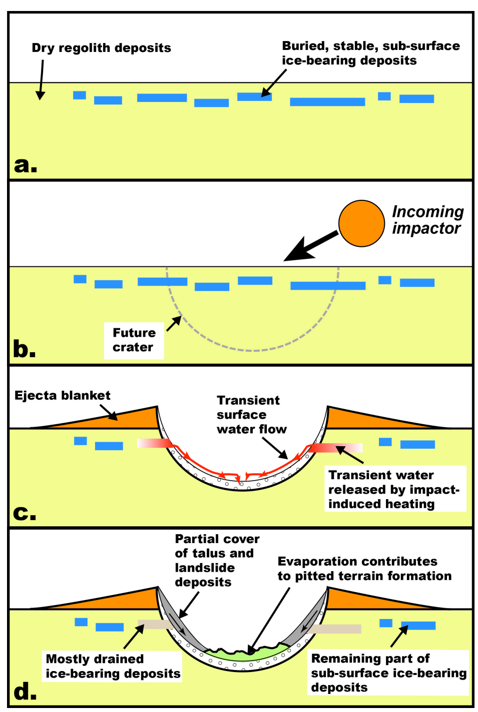

Figures a-d. Schematic illustration of proposed formation mechanism of curvilinear gullies.