EVIDENCE FOR WATER ON VESTA: COMPARING THE GEOMORPHOLOGY OF DEBRIS FLOWS IN CRATERS ON EARTH, MARS, THE MOON, AND VESTA. Dylan Daneman, Cheng "Steven" Huang, Audrey Mills, John Shaughnessy, Zyris Zacha, Holly Bensel (Mentor), Dr. Ryan Watkins (Advisor), St. Mary's School, 816 Black Oak Drive, Medford, Oregon, 97504

Background Work and Motivation: The protoplanet Vesta was previously believed to be predominately dry, lacking volatiles, and rich with basalts. However, using images from the Dawn mission, [1] described evidence of fluvial debris flows in multiple young Vestan craters. Based on data from Dawn, Vesta may have had brief flows of material mobilized by water on its surface.

Specific Question and Relationship: The focus of this study is the result of work done by Dr. Scully in her 2015 paper, which presented the idea that Vesta had wet debris flows similar to those formed on Earth and Mars. Specifically, we wanted to address if Vestan debris flows exhibit morphologies consistent with debris flows found on Earth and Mars that indicate the influence of a liquid.

General Topic: Debris flows occur on all of the inner solar system bodies, and are a geologic phenomenon in which rocky material flows downhill under the force of gravity. In accordance with an article written by Kokelaar [2], debris flows are divided into two categories: wet and dry. Wet flows contain volatiles and liquids that influence the mass wasting processes and deposits on planetary bodies, such as gullies on Mars. Volatiles and liquids are absent from dry flows, with the example of granular flows on the Moon. Dry flows are a type of mass wasting that results in dry, rocky material moving downhill. The focus of this research is the comparison of granular flows, rock falls, talus slopes, linear gullies, and flow melts. By definition in this project, wet flows involve liquid. The flow styles encountered in this study are alluvial fans, curvilinear gullies, pitted terrain, and braided streams.

Methods: The purpose of our research was to study debris flow geomorphologies on Earth, Mars, the Moon, and Vesta. On Earth, these features have been studied extensively and the mechanisms that form them are well-understood. The understanding of debris flows on Earth can be applied to other solar system bodies such as the Moon, Mars, and Vesta. Using image analysis tools including JMARS, Vesta Trek, Mars Trek, and Lunar Reconnaissance Orbiter Camera Quickmap, we identified and evaluated different debris flow types in craters. After analysis, we compared these images to better understand the mechanism of their flow style, wet or dry. Once a crater was found using the aforementioned tools, the name and location were used to find higher resolution images on NASA's Photojournal [3] and Google Maps [4] for Earth.

Results: From our observations and comparisons of images from the Moon, Mars, Earth, and Vesta, we found that all four of these bodies share many similar styles of mass wasting. When we observed dry flows compared to wet flows, we noticed two main differences: texture and flow direction. Dry flows appear to have a rough texture due to unsorted material. Wet flows appear smoother as a result of liquid mobilizing the materials. Dry flows also tend to move straight downhill whereas wet flows are curvilinear. Figure 1 shows examples of similar linear gullies on Earth, the Moon, Mars, and Vesta. Of particular interest, our analyses revealed that Vesta does have curvilinear valleys, pitted terrain, and alluvial fans; all of which point to the presence of a liquid that is at least transient in nature.

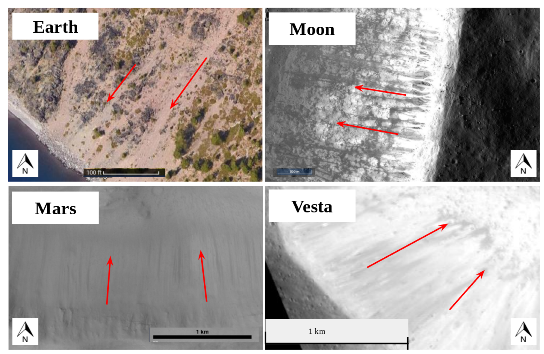

Figure 1: Examples of similar linear gullies appearing on Earth, the Moon, Mars, and Vesta

Conclusions: Based on our study of debris flow geomorphologies on Earth, Mars, the Moon, and Vesta, there is clear evidence that several Vestan craters contain debris flows formed in combination with a liquid. Our research supports Dr. Scully's [1] contention that there is "evidence that transient water flowed on the surface, in a debris-flow-like process, and left distinctive geomorphologic features."

[1] Scully, J.E.C., et al. (2015) *Earth and Planetary Science Letters, Volume 411,* pages 151-163 [2] Kokelaar, B.P., et al. (2017*) Journal of Geophysical Research: Planets, Volume 122, Issue 9,* pages 1893-1925 [3] NASA Photojournal, https://photojournal.jpl.nasa.gov/ [4] Google Maps https://www.google.com/maps/