Evidence for Water on Vesta: Comparing the Geomorphology of Debris Flows in Craters on Earth, Mars, the Moon, and Vesta

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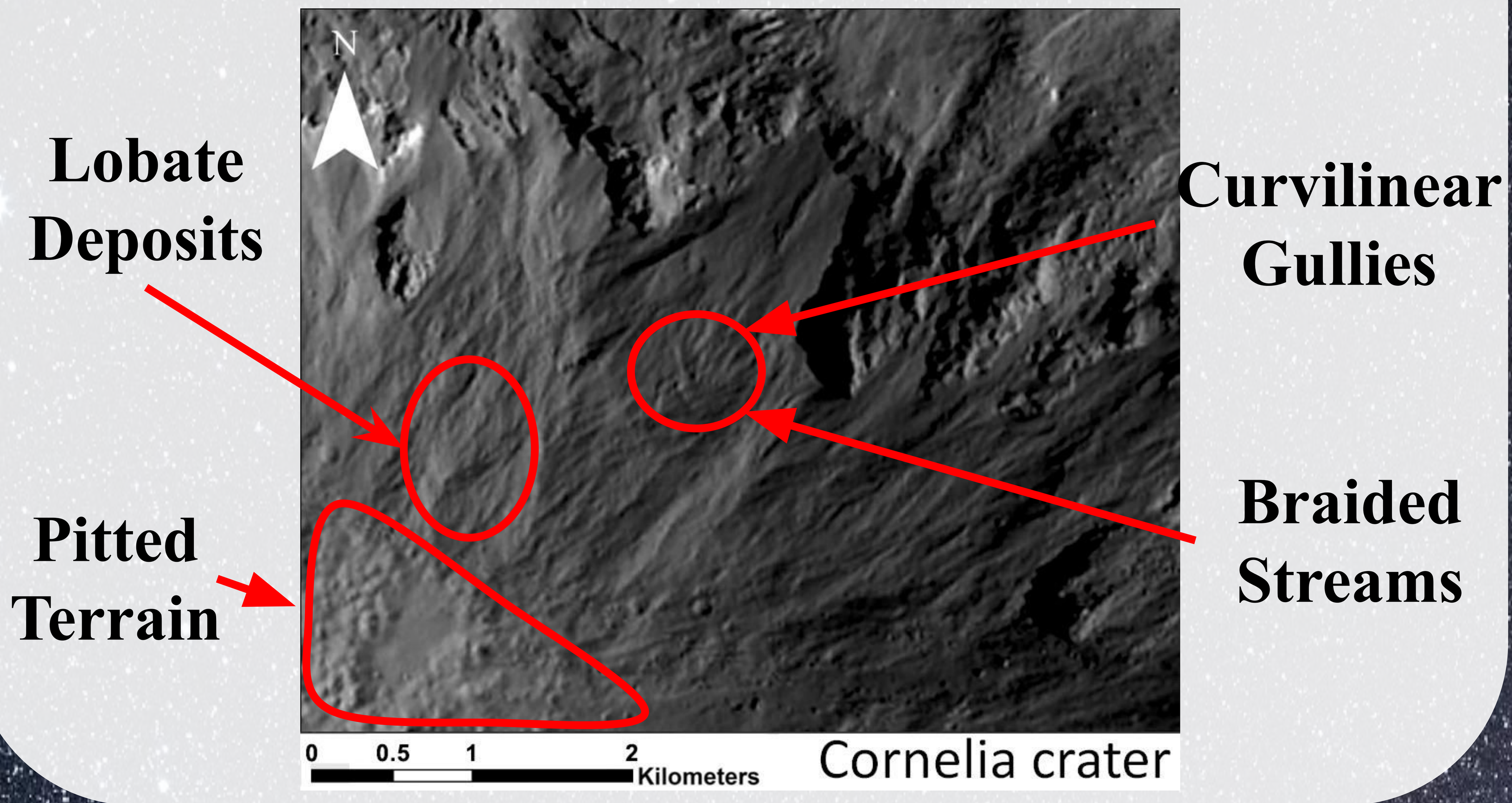
Background: Vesta was previously believed to be predominately dry, lacking volatiles, and rich with basalts. However, images from the Dawn mission revealed evidence of fluvial debris flows in multiple young Vestan craters [1]. Based on data, Vesta may have had brief flows of material mobilized by water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

Specific Question: Do Vestan debris flows exhibit morphologies consistent with debris flows found on Earth and Mars that indicate the influence of liquid?

Is There Transient Liquid on Vesta?



Methods:

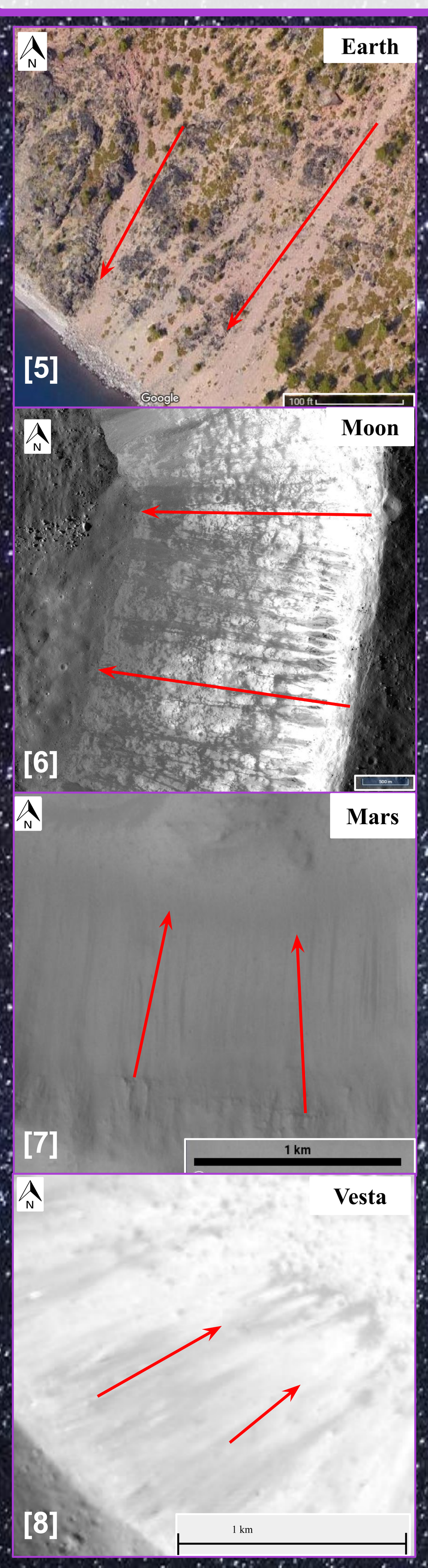
- Used image analysis tools including JMARS, Vesta Trek, Mars Trek, and LROC Quickmap.
- Found craters using the aforementioned tools, the name and location were used to find higher resolution images on [3], and [4] for Earth.
- Identified and evaluated different debris flow types in craters.
- Compared crater images to previously analyzed images to better understand the mechanism of their flow style, wet or dry.

  Wet - smoother texture, well-sorted

  Dry - rough texture, poorly-sorted

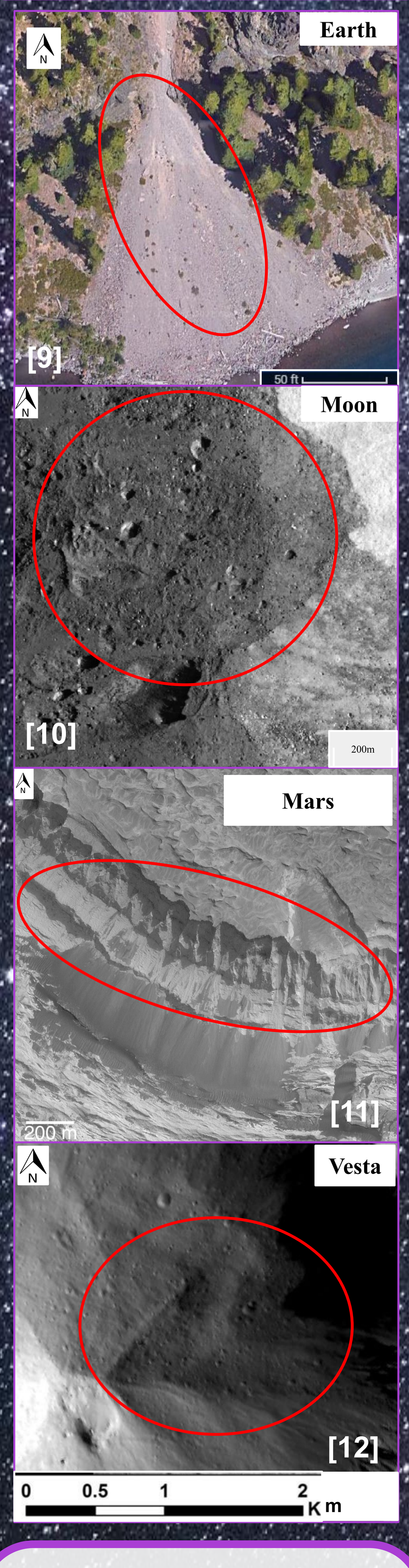
Dry Flow: Dry flows are caused by dry, rocky material moving downhill. Dry flows lacks volatiles and liquids, and appears to have a rough texture due to the mobilized unsorted materials, "poorly-sorted debris". Examples include: linear gullies, granular flows, talus slopes, and flow melts [2].

Linear Gullies



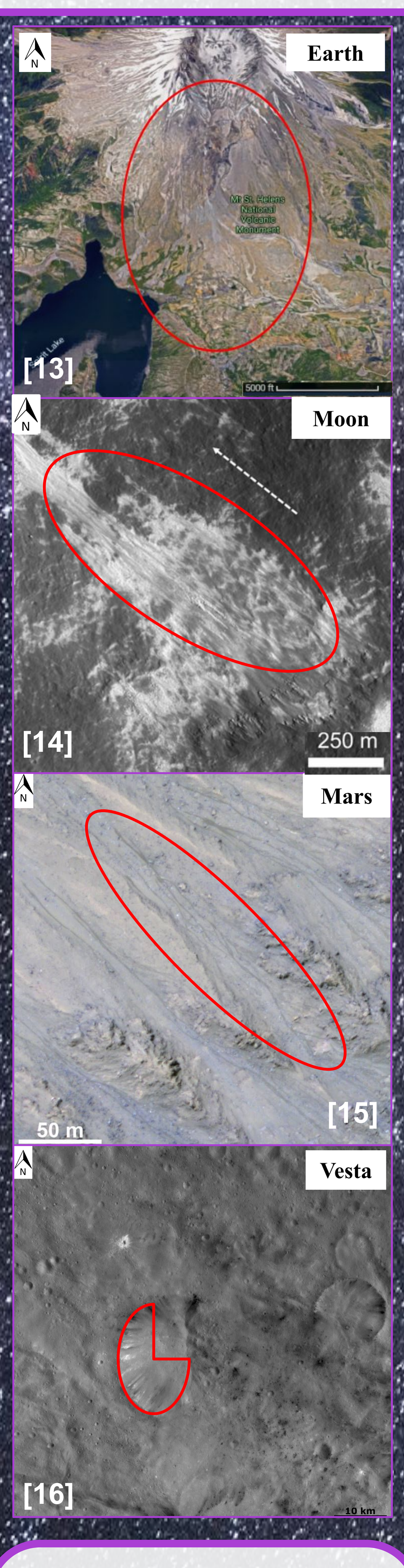
- Long, relatively uniform-width troughs formed by blocks sliding/rolling straight down the slope.
- No debris aprons.

Talus Slopes



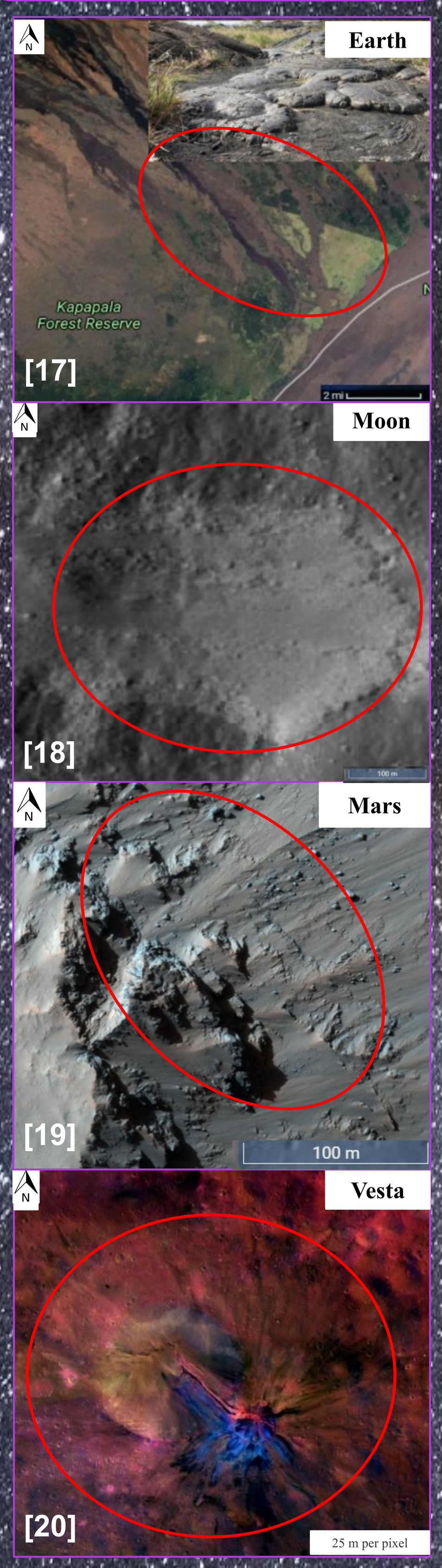
- A cone-shaped deposit formed by poorly sorted debris.
- Particles detach from a steep free surface then bounce, roll, and break.

Granular Flow



- A type of debris flow comprised of non-uniform materials.
- The end of the flow spreads forms a fan of poorly sorted debris.

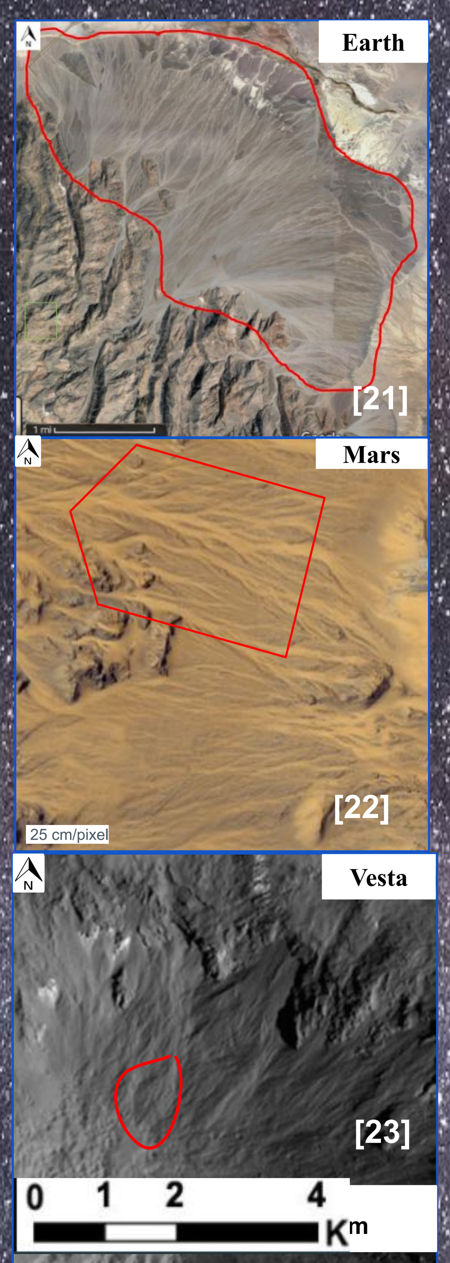
Flow Melts



- The melting of rock during an impact that solidifies to look like lava flows on Earth.
- Flows share common features such as sinuous channels and lobe shapes.

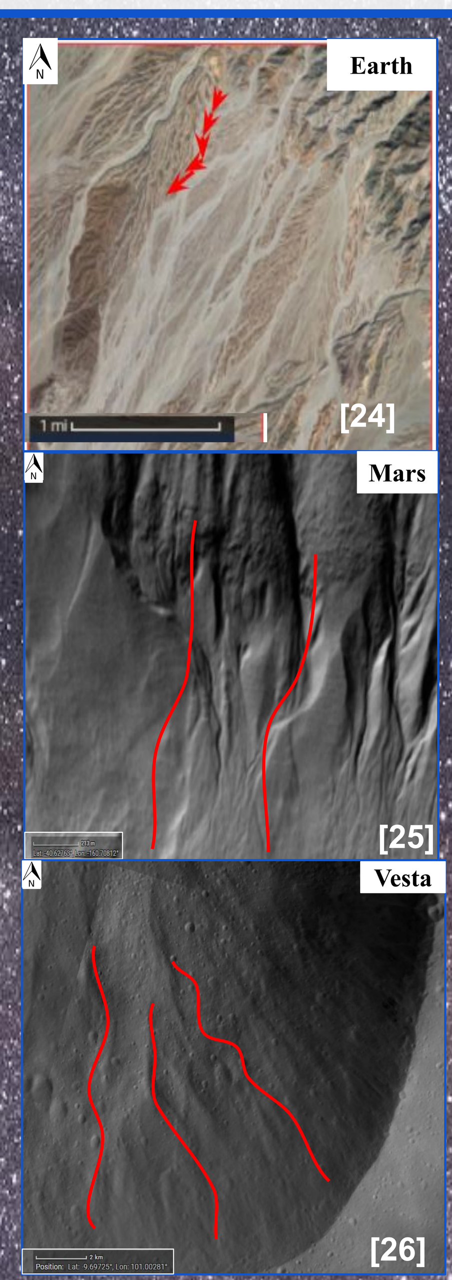
Wet Flow: Wet flows contain volatiles and liquids that influence the mass wasting processes and deposits on planetary bodies. Wet flow is smoother as a result of liquid mobilizing the materials. The debris is "well-sorted", with sediments of larger sizes found nearer the source of the flow and sediments of smaller sizes found further away. In addition, it follows a curvilinear flow pattern. Examples include: alluvial fans, curvilinear gullies, braided flows, and pitted terrain [2].

Alluvial Fans



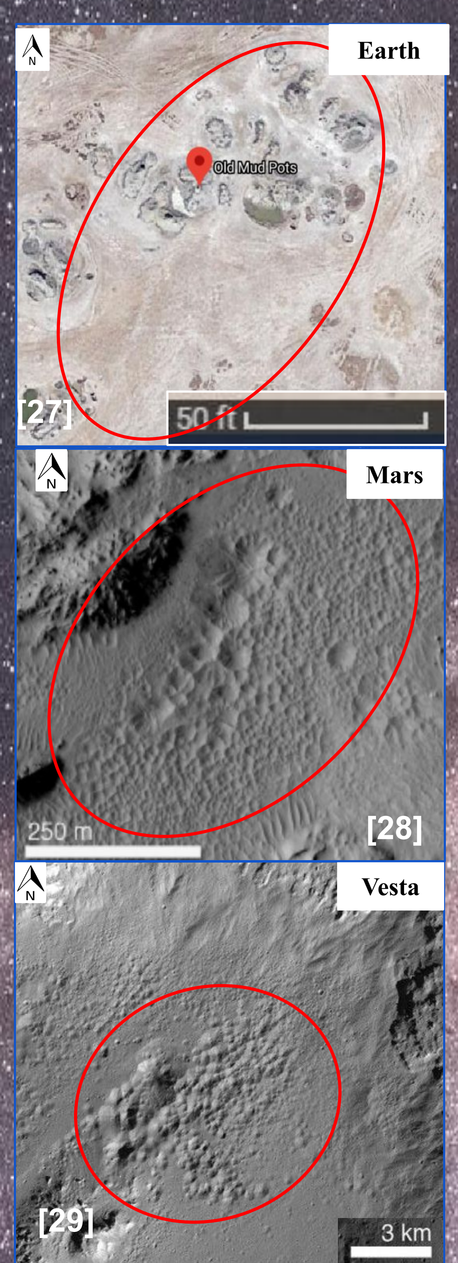
- A fan-shaped deposit of alluvium formed at the base of an incised channel.
- Characteristically display deposits of well-sorted gravel and braided streams.

Curvilinear Gullies and Braided Flows



- Characterized as interconnected, curving gullies, forming a dendritic (neuron) shape, that ends in a well-sorted, lobate deposit.

Pitted Terrain



- Volatiles evaporating to form pits that have straight edges between them, as though they formed at the exact same time.

Discussion:

- Compared dry flows to wet flows
  - Two main differences: texture and flow direction.
- Dry flows have a rough texture
  - Wet flows smoother.
- Dry flows move straight downhill
  - Wet flows are curvilinear.
- Other theories:
  - Silicate impact melt-least likely due to morphology, size, and composition

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 such as curvilinear valleys, pitted terrain, and alluvial fans. 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."

References: Publications

[1] Scully, J.E.C., et al. (2015) *Earth Planet. Sci. Lett., 411,* 151-163.
[2] Kokelaar, B.P., et al. (2017) *J. Geophy. Res.: Planets, 122, Issue 9,* 1893-1925.
[3] NASA Photojournal, https://photojournal.jpl.nasa.gov/
[4] Google Maps https://www.google.com/maps/

References: Images (Dry Flow)

[5] Google Maps; 42.97 N, 122.07 W. [6] LROC QuickMap; 2.86 N, 17.74 E. [7] JMARS; -6.039 N, 295.121 E [8] Dawn Framing Camera PIA16491; 53.25 S 68. W. [9] Google Maps; 42.97 N, 122.11 W. [10] LROC QuickMap; 0.47 N, -73.06 E. [11] Mars Global Surveyor Orbitor MOC Image PIA04881; 2.80 S, 20.5 W. [12] Dawn Framing Camera Image PIA16491; 53.25 S 68.59 W. [13] Google Maps; 46.33 N, 122.15 W. [14] Kokelaar, B.P., et al. (2017) *J. Geophy. Res.: Planets, 122, Issue 9,* 1893-1925. [15] NASA/JPL-Caltech/UA/USGS MRO HiRISE Image PIA20770; 45.9 S, 9.5 E. [17] Google Maps; 19.41 N, 155.45 W. [18] LROC QuickMap; -10.60 N, 29.18 E. [19] NASA/JPL-Caltech/UA/USGS MRO HiRISE Image PIA19123; 8.76 N, 304.80 E. [20] Dawn Framing Camera Image PIA17661; 14.26 S, 69.20 W.

References: Images (Wet Flow)

[21] Google Maps; 36.56 N, 117.04 W. [22] NASA/JPL-Caltech/UA/USGS MRO HiRISE Image PIA09391; -12.20 N, 297.60 W. [23] Dawn Framing Camera PIA16489; 9.37 S, 15.57 E. [24] Google Maps; 36.56 N, 117.04 W. [25] JMARS; 0.63N, -160.63 W. [26] VESTA TREK, 11.31 S, 100.44 W. [27] Google Maps; 33.20 N, 115.58 W. [28] NASA/JPL-Caltech/UA/USGS MRO HiRISE Image PIA16189; 23.10 N, 207.10 E. [29] NASA/JPL-Caltech/UA/USGS MRO HiRISE Image PIA16189; 11.50 S, 224.60 E.

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