FORMATION OF SINUOUS RILLES ON THE MOON AND MARS. L. P. Keszthelyi[1] [1]Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001

Introduction: Sinuous rilles are a prominent volcanic landform on the Moon, Mars, and Venus, and have been reported on Io [1-4]. However, their formation has remained uncertain despite decades of investigations. New ideas have been prompted by high-resolution images of Mars from the *MRO* spacecraft that can be tested for the Moon with data that is currently being collected by the *LRO* spacecraft.

Hypotheses for the formation of sinuous rilles fall in two basic categories: (1) high-flux erosive turbulent floods [5-7] and (2) large collapsing lava tubes [8-10]. The idea of thermal erosion by turbulent lava flows has engendered multiple quantitative models, all of which show that the process is physically viable. However, there are no (well-preserved) terrestrial analogs. In contrast, there are many well-preserved lava tubes on Earth that are in many ways analogous with sinuous rilles. However, attempts to quantitatively model lava tubes on the Moon (or Mars) are limited [e.g., 11].

New Data and Results: The cameras onboard the *MRO* and *LRO* spacecraft (HiRISE and LROC-NAC, respectively) provide unprecedented detail in orbital imagery of Mars and the Moon, respectively. >20,000 25-30 cm/pixel HiRISE images, often with 5-6 m/pixel CTX images, have been publically released. HiRISE has 3 color bands, also allowing crude spectral discrimination of materials [12]. The HiRISE experience shows that the greatest volcanologic insight is often provided by the topographic information derived from stereo imaging [13]. ~50 cm/pixel LROC-NAC images are currently being acquired and will be released in the coming months, but are not discussed here.

Turbulent Floods - Lessons from Athabasca Valles. The analysis of *MRO* data conclusively demonstrates that Athabasca Valles has been draped by a thin coating of lava [14]. Continued analysis by Jaeger et al. [15] shows that the lava flow was emplaced as a turbulent flood. The volumetric flux of lava peaked at about 10^7 m^3/s and the eruption duration is estimated to have been only a matter of weeks. This high flux eruption had the potential to erode the substrate but it did not produce features similar to sinuous rilles. Given that this is the best-preserved example of a large turbulently emplaced lava flow on Earth or Mars, it raises serious questions about forming sinuous rilles via such eruptions.

Covered Channels - Lessons from HiRISE. HiRISE has imaged the first confirmed example of a natural bridge beyond the Earth (Fig. 1) [13].

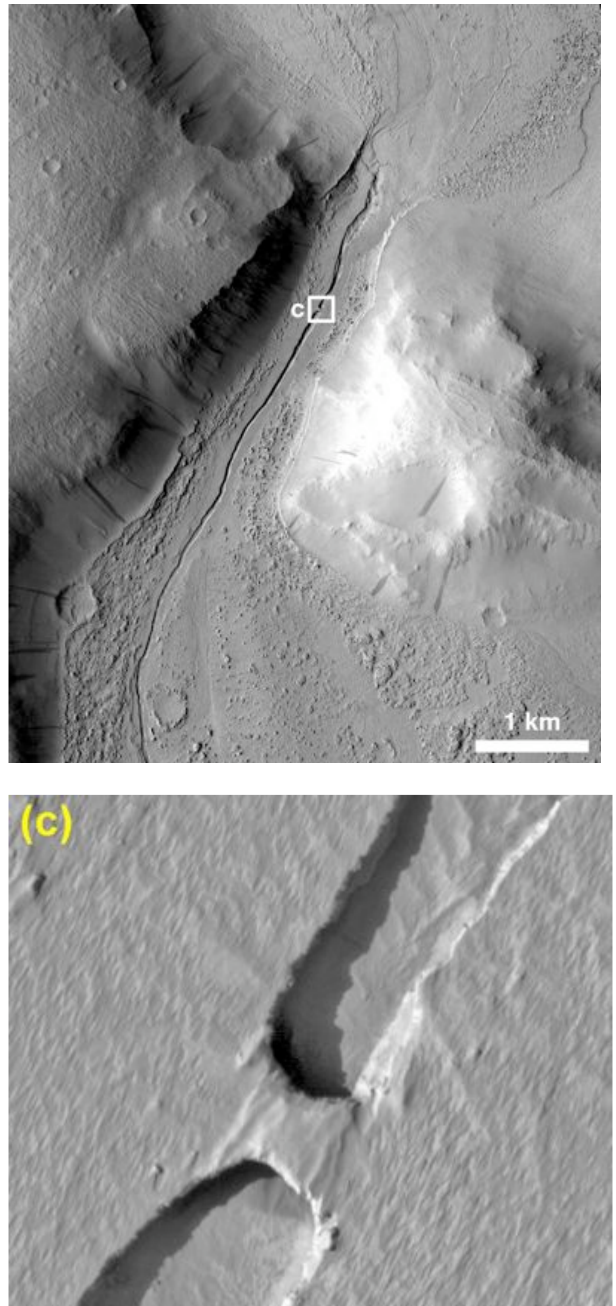

Figure 1. Portion of HiRISE image PSP_001420_2045 of the Tartarus Colles. This roofed channel utilizes a narrow passage between highland knobs, a geometry similar to some puzzling lunar sinuous rilles. Based on this Martian example, it is plausible that voluminous lava flows can pass through nar-

row (<1 km wide) constrictions. The inner channel is somewhat similar to sinuous rilles. The ~50 m wide roofed section is small compared to typical lunar sinuous rilles but is large for a roofed terrestrial channel. This supports the contention that lower gravity allows wider spans to be covered by natural bridges.

The Role of Erosion. It is noteworthy that sinuous rilles on Mars and the Moon are found in locations that may have significant pyroclastic deposits. The most rapid documented erosion by an active lava flow on Earth (~10 cm/day) was in a similar setting on Kilauea Volcano, Hawaii [16].

Figure 2. Portion of CTX image P04_002671_1792 on the southern flank of Pavonis Mons. Just south of this area is a prominent cinder cone [13], one of many indications that there are substantial pyroclastic deposits in the area. Note that the rille in the center of the figure transitions from an incised channel to a fan of lobate flow lobes. This is consistent with erosion being confined to the near vent area where the lava is hotter. The extensive control of rille orientation by regional fracture systems seen here has also been noted for the Moon.

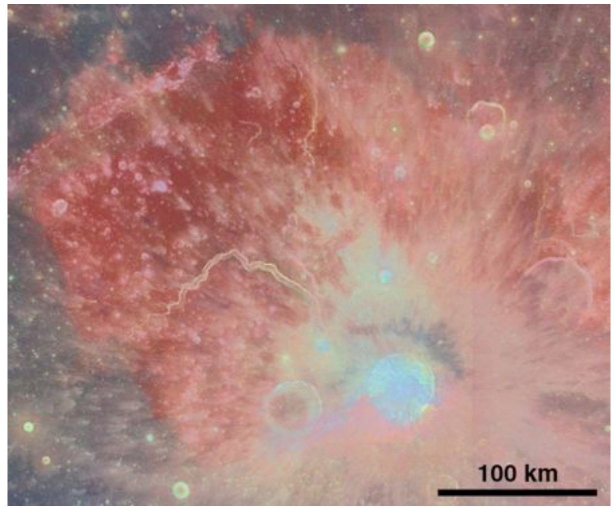

Figure 3. Portion of NASA PIA00090: Clementine Multispectral Mosaic of the Aristarchus Plateau. Pyroclastic deposits are represented in red tones in this USGS product. Note that these sinuous rilles are almost exclusively found within the red areas. While it is not necessary that the current surficial extent of the pyroclastics match the substrate tens and hundreds of meters below, this observation does suggest that a weak substrate may be important for rille incision.

Tentative Conclusions: While more data awaits analysis, it appears that sinuous rilles were probably not formed by high-flux turbulent floods of lava. Instead, sustained moderately high flux flow over mechanically weak substrates may be the key. Future work, involving more quantitative flow modeling, may reveal the importance of topographic confinement (which leads to unusually deep and fast flows) and turbulence and slope (both of which may be important in eroding through the base of the lava flow to reach the weak substrate).

References: [1] Komatsu G. and Baker V. R. (1996) Planet. Space Sci., 44, 801-815. [2] Wilson L. and Mouginis-Mark P. J. (1984) LPS XV, 926-927. [3] Carr M. H. (1974) Icarus, 22, 1-23. [4] Schenk P. M. and Williams D. A. (2004) GRL, 31, 2004GL021378. [5] Hulme G. (1973) Mod. Geol., 4, 104-117. [6] Hulme G. (1982) Geophys. Surv., 5, 245-279. [7] Williams D. A. et al. (2000) JGR, 105, 20189-20205. [8] Greeley R. (1971) Science, 172, 722-725. [9] Gornitz V. (1972) Moon, 6, 337-356. [10] Greeley R. and Spudis, P. D. (1978) LPS IX, 3333-3349. [11] Keszthelyi L. P. (1995) JGR, 100, 20411-20420. [12] McEwen A. S. et al. (2007) JGR, 112, 2005JE002605. [13] Keszthelyi L. P. et al. (2008) JGR, 113, 2007JE002968. [14] Jaeger W. L. et al. (2007) Science, 317, 1709-1711. [15] Jaeger W. L. et al. (2010) Icarus, in press. [16] Kauahikaua et al. (1998) JGR, 103, 27303-27324.