INFLATED PAHOEHOE AT RIMA HADLEY. L. Keszthelyi[1], [1]U.S. Geological Survey, Astrogeology Team, 2255 N. Gemini Dr., Flagstaff, AZ 86001 (*laz@usgs.gov*).

Introduction: The origin of sinuous rilles on the Moon remains enigmatic. While originally considered to have been carved by flowing water [1-3], the Apollo missions showed the rilles to be volcanic. However, it is still unclear if they are predominantly constructional or erosional and whether the lava was transported through stable lava tubes or partially roofed lava channels. This uncertainty is frustrating, given that the Apollo 15 mission included astronauts entering part of Hadley Rille and returning samples from its walls. Does this point to the futility of humans conducting physical volcanology studies on the Moon? Or is this a stark demonstration of the immaturity of our understanding of lava flows in the early 1970s?

Reinterpretation of Apollo-Era Observations: At least two layers of rock were observed in the far wall of Rima Hadley by the Apollo 15 astronauts (Fig. 1a), but it is not clear that these are exposures of multiple lava flows as originally hypothesized. The observations are also consistent with a single lava flow that thickened via injection of liquid lava underneath of continuous stable crust (i.e., inflated pahoehoe). An outcrop sketch from the Apollo 15 Preliminary Science Report [4] (Fig. 1b) is remarkably similar to the field sketches of the central parts of inflated pahoehoe lava flows (Fig. 1c). The upper layer could be simply the transition from regolith/soil to more competent rock and the lower layer could be the transition from the vesicular flow top to the dense interior of a lava flow.

The inflated pahoehoe hypothesis is supported by the rock containing horizontal vesicle sheets (HVSs) that the Apollo 15 astronauts photographed but did not collect (Fig. 2). HVSs form during the post-emplacement freezing of an inflated lava flow [5]. The late stage melts become enriched in incompatible and volatile elements and thus become more vesicular and less dense. This differentiated residuum then rises as buoyant columns that are sometimes preserved as vesicle cylinders [6]. This material then spreads out along the base of the solidified upper crust. HVSs cannot form while there is significant lateral motion of the lava because the buoyant diapirs are mixed back into the flow. HVSs have only been reported in lava lakes and inflated pahoehoe lava flows. Since the rille is unequivocal evidence that the lava was a flow and not a lake, it can be concluded with a high degree of confidence that this in an inflated pahoehoe lava flow.

This hypothesis helps explain some other previously confusing observations. The astronauts reported climbing over a shallow ridge as they approached the rille's edge [4]. This was taken as evidence of levees along a lava channel. However, tumuli and pressure ridges can form over lava tubes, producing a local topographic high. In fact, a line of tumuli was used to identify the location of a lava tube in the Carrizozo Flow Field in New Mexico [8].

Perhaps the most puzzling observation at Hadley Rille was that the plains to the east of the rille are a few tens of meters higher than the west side. This elevation difference did not fit the lava tube or lava channel models of the time. However, such topographic variations are expected on an inflated flow. The higher plains to the east could be a large inflation plateau. There is no requirement that the lava tube feeding the plateau run through its center.

Overall, the Apollo-era observations are consistent with Hadley Rille being a drained (and collapsed) lava tube that formed within a thick inflated pahoehoe flow. The great thickness of the flow (possibly greater than 400 m) is outside our terrestrial experience. However, given the lower gravity on the Moon, it seems plausible that the flow thickness could be correspondingly larger. The thickness could be less if the lava tube eroded its substrate mechanically, as is observed to happen in Hawaii [9].

In conclusion, future human exploration of lunar volcanic terrains should yield much more insight than the Apollo missions, simply because we have learned so much more about lava flows in the >30 years that have passed.

References: [1] Urey H. C. (1967) *Nature, 216*, 1094-1095. [2] Peale S. J. et al. (1968) *Nature, 220*, 1222-1225. [3] Lingenfleter R. E. et al. (1968) *Science, 161*, 266-279. [4] Apollo 15 Preliminary Science Report (1972) *NASA SP-289*. [5] Self S. et al. (1998) *Annu. Rev. Earth Planet. Sci., 26*, 81-110. [6] Goff F. (1996) *JVGR, 71*, 167-185. [7] *http://history.nasa.gov/alsj/a15/a15.rille.html*. [8] Keszthelyi L. and Pieri D. C. (1993) *JVGR, 59*, 59-75. [9] Kauahikaua J. P. (1998) *JGR, 103*, 27303-27323.

Figure 1 (next page). Rima Hadley wall. (a) Digitized version of Apollo 15 photograph AS15-89-12115 showing layering in the wall of Hadley Rille. (b) Inset on the left is an outcrop sketch map of the wall of Hadley Rill (Figure 5-37 from [4]). (c) Inset on the right is an idealized cross-section through an inflated pahoehoe flow in the Columbia River Basalt Group from [4]. The Apollo 15 sketch is an extremely good fit to the transition between the vesicular upper crust and the dense core, a region marked by abundant vesicle sheets.

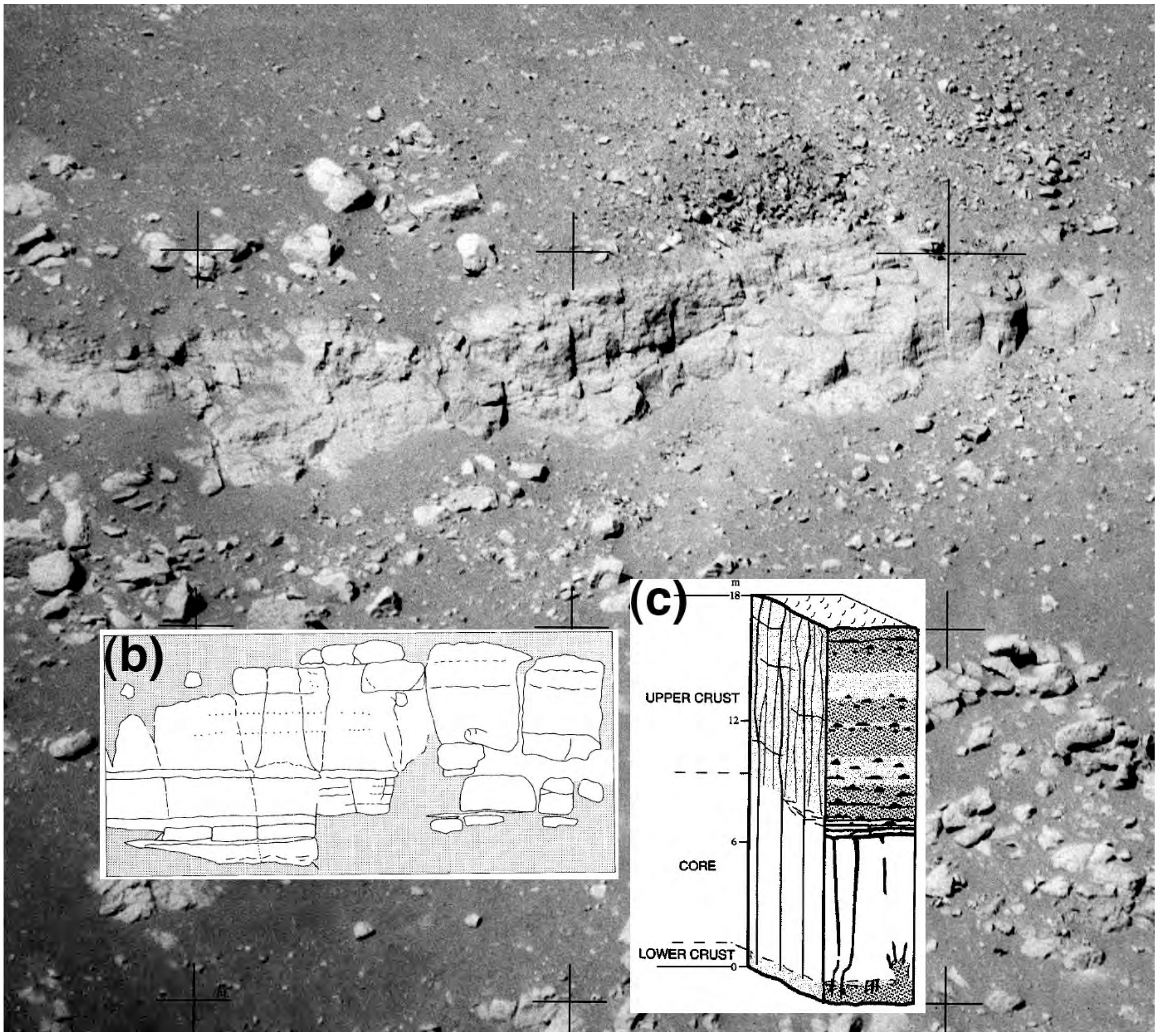

Figure 2. Rock containing a horizontal vesicle sheet. Digitized version of Apollo 15 photographs AS15-82-11130 and AS15-82-11131. Horizontal vesicle sheets are characteristic of inflated pahoehoe lava flows [4].