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# LUNAR HADLEY RILLE: CONSIDERATIONS OF ITS ORIGIN

by Ronald Greeley

Ames Research Center
Moffett Field, Calif. 94035

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ABSTRACT

Geomorphology, topographic configuration, comparisons with terrestrial analogs and considerations of the chemical and physical characteristics of mare lavas indicate the Hadley Rille is a lava channel. Some of the structure was roofed to form a lava tube, parts of which have subsequently collapsed.

Hadley Rille, in a valley of the Apennine Mts. east of Mare Imbrium, has been selected as the Apollo 15 landing site (1). Considerations of its origin are essential to geologic interpretation of the site. The rille is about 135 km long and averages 900 m in width x 370 m in depth. The northern section (Fig. 1) is 25 km long, shallower than the main rille, and may not be genetically related to it. Rima Fresnel II, a probable graben, intersects the northern section. An increase in elevation at the northern end may reflect post-rille formation adjustments of the mare, as indicated by lineaments interpreted as step faults. Hadley Rille is in a class of sinuous rilles which characteristically: 1) appear to originate in irregularly shaped craters or depressions, 2) trend generally downslope, 3) have discontinuous channels and cut-off branches, 4) are fairly uniform in width, or occasionally taper toward the terminus, 5) are restricted to mare surfaces and appear to be controlled by highland or pre-mare topography, and 6) form topographic highs along the rille axis. These characteristics, with considerations of mare composition and recently derived elevation determinations of the area (2), enable speculation on the origin of Hadley Rille and similar lunar structures.

Several diverse modes of origin have been proposed for lunar sinuous rilles, including erosion by ash (3) or water (4,5), surface collapse resulting from intrusive stoping (6), fluidization of regolith by outgassing through fractures (7), or that the rilles are lava channels, collapsed lava tubes, or both (8,9). Most investigators agree that fluid flow is involved; controversy arises as to type of fluid - ash, water, gases, or lava. Each mode has one or two strong points in its favor for a particular rille and it is probable that each class of sinuous rille may have a unique origin. The characteristics of the Hadley Rille, however, most closely resemble those of a lava channel and partly collapsed lava tube.

Recent investigations of prehistoric basalt flows (10) and observations of active flows (11) provide qualitative and quantitative data on the geomorphology of lava tubes and channels. Tubes and channels are morphologically similar and, because channels often form well defined crusts of solidified lava, it is often difficult to separate channels from tubes in active flows. For convenience, tubes may be defined as having freestanding roofs after drainage of molten lava, while channels result from open (non-crusted) flow, or from crustal collapse during lava drainage. Depending upon gradient and other parameters, a single structure may have both roofed and unroofed segments, giving the appearance from the air of a discontinuous channel similar to Hadley Rille (Fig. 1, A). Lava tubes and channels form commonly in fluid varieties of basalt. Experimental studies of lunar basaltic lavas (12) show that the lavas were very fluid, permitting the formation of tubes, and that the thermal conductivity was quite low, permitting long lava flows and hence long lava tubes. It is, therefore, reasonable to expect lava tubes/channels on mare surfaces and that under prolonged meteoroid bombardment many tube roofs would collapse, leaving sinuous trenches.

Lava tubes/channels often originate in vent-craters or depressions associated with regional tectonic features, such as faults, fissures, or fracture systems concentric to calderas. Hadley Rille, similarly, is on the mare-highland boundary marked by fault systems concentric to the Imbrium basin (13). The apparent source of the rille is a cleft-shaped structure (Fig. 1, B) probably of internal, rather than impact, origin. Lingenfelter, et al. (4), proposed sinuous rille formation from erosion by water which originated from subsurface reservoirs tapped by meteoroid impact. Because impact is required for the initial stage, this process is not likely to explain the origin of Hadley Rille. In addition to the lack of initiating impact there are several other objections to erosion of the rille by water. Estimated volume of the rille is $2.8 \times 10^{10}$ $m^3$. Although this material should form a significant alluvial fan or outwash plain, there is no indication of sedimentary structures at the terminus. If the material were spread over the surface at the end of the rille and thinned to feather edges, the unit would have no well-defined boundaries and would be younger than the eroded mare surface. Crater counting, a technique to determine relative ages of lunar surfaces (14), however, shows no difference in age for the surface at the terminus compared to the surface along the rille. Second, there is no indication of tributaries to have carried water from the "watershed" to the rille. Third, the rille narrows "downstream," rather than widens as is normal for rivers. Fourth, the rille is discontinuous (Fig. 1, A), a situation not possible for fluvial channels, but quite common in lava tubes/channels (Fig. 2).

Most proposals of water erosion require relatively short times for water erosion to occur, which in turn requires an easily eroded regolith extending several hundred m deep (at least, equal to rille depths). Evidence does not support these conditions. Apollo results show the lunar soil is composed of poorly sorted material containing rocks 10 cm and more in diameter, not the fine, homogeneous sand required by Lingenfelter, et al. (4). In addition, the regolith is so compacted (a few centimeters below the surface) that Apollo 11 astronauts were able to drive the coring device only about 15 cm (15), in contrast to the contention that the soil is loosely bonded to depths of tens of m. It has been shown (16) that the average mare regolith thickness ranges from about 3.3 to 16 m, much less than the several hundred m required by water erosion of short duration.

Hadley Rille is situated on the crest of a topographic high (Fig. 3, B). It is unlikely that any erosive agent, whether ash or water, could have cut a channel along the top of a ridge. It is more plausible for the ridge and channel to have formed simultaneously through a constructional process. Lava tubes/channels are the primary structures permitting fluid basalt flows to advance from the vented magma chamber. Distributary tubes, formed radially from the main structure, and overflow of lava from open channels deposit lava parallel to the structure, forming broad ridges (Fig. 3, A) very similar to Hadley Rille. Similar relationships have been noted for rilles in the Marius Hills (17). Structures C and D (Fig. 1) may be remnants of overflow channels or collapsed distributary tubes from Hadley Rille.

Fluidization of lunar regolith by outgassing through fractures may also produce depressions with lateral levees, shown experimentally by Schumm (7). Unlike the large, broad ridges of lava tubes/channels and the Hadley Rille, fluidization channel levees are small compared to channel width (Fig. 3, C). Outgassing through fractures should result in structures reflecting the trend of the fractur Although many terrestrial fractures are arcuate, no single fracture is as sinuous as the Hadley Rille. Fractures are relatively independent of topography, yet the Hadley Rille is restricted to the mare between highland blocks. Basaltic lava flows are almost completely controlled by pre-flow topography and tube/channels represent the axis of most rapid flow. Thus, tube/channels often meander from one side of the confining valley to the other, occasionally eroding parts of the valley wall.

Considerations of topography, photographic interpretation, comparison with terrestial analogs (10,11) and extrapolation from experimental studies (12) permit a tentative proposal for the origin of Hadley Rille. Following the formation of Imbrium basin, basaltic lava was emitted through faults and fissures at the base of the Apennine Mts. and poured into the basin. Although many of the fissure vents probably have no surface expression (similar to terrestrial fissure vents) detectable on Orbiter photographs, the elongate cleft at the head of Hadley Rille is interpreted to be a volcanic vent situated on or near a fissure. Typical of basalt flows on earth, the very fluid lunar lavas flowed from the vent into the basin through a lava channel that in some places became roofed to form a tube. Although terrestrial tubes/channels are not as long or as wide as Hadley Rille, considerations of the lunar environment (9) and laboratory analysis of viscosity and thermal conductivity for mare lavas (12) indicate that weathered lunar lava tubes/channels could easily be as large as Hadley Rille.

Controlled by pre-flow topography, the lava filled low regions and the tube/channel was relatively free to meander within the flow. Where slope was low, the velocity of the flow decreased, permitting the formation of a thick, stable crust over the channel. The discontinuous channel, irregular width and depth, and coalesced elongate craters making up the rille at "A" (Fig. 1) are remnants of a lava tube possibly formed in conjunction with low velocities where the flow passed through the highland blocks into the basin. Multiple surges of lava from the vent, or possibly multiple eruptions over a long period of time, resulted in overflow of lava from the main channel through distributary channels and tubes (Fig. 1, C, D) to build a topographic high along the rille axis.

Meteoroid bombardment collapsed nearly all roof sections and caused slumping of the rille rim (slump blocks 80 m wide x several hundred m long, (Fig. 1, A, E), thus widening the rille. The lava flow has been impact-fragmented to a relatively shallow depth (similar to other mare surfaces) indicated by the boulder ledge which crops out in several places along the rille very near the rim. Roof collapse, channel crust material, lateral slumping, and impact generated debris has partly filled in the rille with blocks (visible at the surface) 30 m in diameter and smaller, resting at an angle of repose of about 28°, similar to that measured for basalt blocks over collapsed terrestrial lava tubes.

While the above now appears to be a satisfactory account of the origin of Hadley Rille, geologic observations, returned samples from the Rille region, improved photographs and topographic maps from the Apollo 15 mission will undoubtedly enable refinement of this interpretation.

Ronald Greeley

Space Science Division

Ames Research Center, NASA

Moffett Field, Calif. 94035

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REFERENCES AND NOTES (Continued)

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# FIGURE CAPTIONS

Fig. 1. Hadley Rille; numbered lines refer to cross sections of Fig. 3; sun is about 19° above eastern horizon. Base photomosaic prepared by U.S. Army TOPOCOM from Lunar Orbiter V frames M-104 through M-107.

Fig. 2. Lava channel, partly roofed to form a tube at "A," originating from the Southwest Rift Zone ("B") of Mauna Loa, Hawaii.

Fig. 3. Cross sections of (A) Modoc Lava Tube, Lava Beds Nat. Mon., Calif.; (B) Hadley Rille (prepared from U.S. Army TOPOCOM elevation determinations); and (C) fluidization channel [estimated from photographs of Schumm (7)]. Vertical exaggeration X3.5.

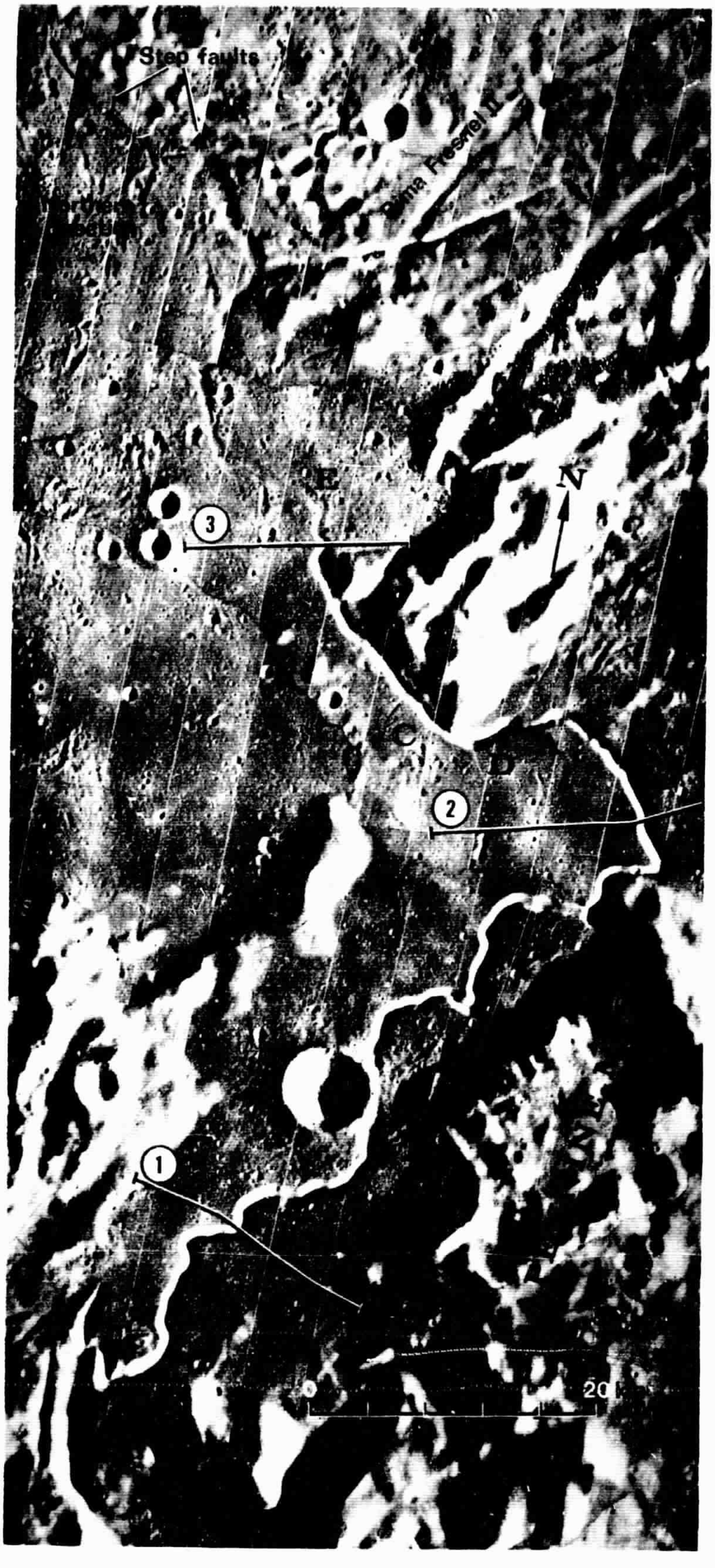
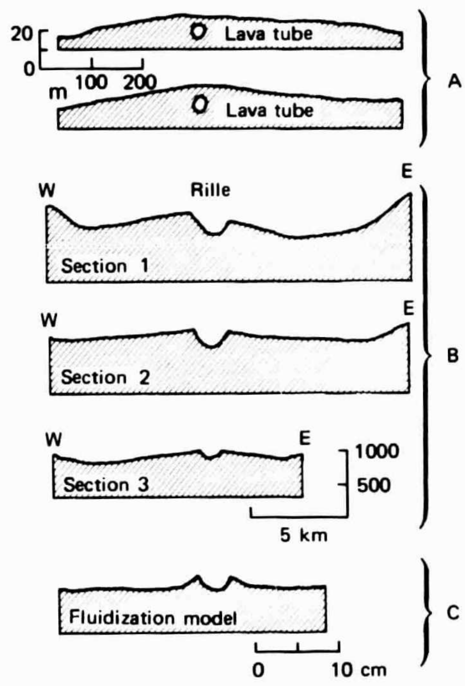



Figure 1.


Figure 2.



20
0
m
100
200
Lava tube
Lava tube
A
W
Rille
E
Section 1
W
E
Section 2
W
E
Section 3
1000
500
5 km
B
Fluidization model
0
10 cm
C


Figure 3.