# BASALTIC LAYERS EXPOSED IN LUNAR MARE CRATERS.

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**Introduction:** Lava flows were first identified on the Moon during the Apollo era. However there are few well preserved surface flows, and their morphology may not be representative of the entire stratigraphic section for the maria. The simple measure of flow thickness constrains the style of emplacement. Prior studies have estimated mare flow thickness using a variety of methods with results falling into two regimes: (1) thin flows < 20 m, and (2) thick flows >30 m. However these studies suffer from a lack of observed flows, or large range of derived thickness. Our work seeks to both increase the number of lava flows measured for thickness from exposures in fresh craters visible in high resolution (0.5-2 meters pixel scale) Lunar Reconassaince Orbiter Camera (LROC) images.

**Background:** Previous workers estimated the thickness of individual basalt flows in the mare using a variety of methods: photo-interpretation [2,3,4,5], color analyses [1,6], and chemical kinetics of Apollo samples [7]. Howard et al. [2] measured basalt flows 10-20 m in thickness (from Apollo 15 surface images) in small outcrops along the west wall of Hadley Rille. Schaber [3] measured the average thickness of the surface flows in Mare Imbrium at 30-35 m with the range of 10-63 m. Gifford and El-Baz [4] measured 19 flow scarps <20 m thick from near-terminator Lunar Orbiter and Apollo orbital photographs. Brett [7] performed chemical kinetic calculations for 14 Apollo basalts to estimate a thickness of <8 m for cooling units.

Later studies combined color relations established from Clementine UVVIS observations with existing high incidence angle photography to estimate flow thickness. Hiesinger et al. [1] estimated flow thickness by relating crater diameters on resurfaced flows to crater depths and found thickness estimates average 30-60 m. Weider et al. [6] used a similar technique to study separate flow units differentiated by color relations and found that thicknesses vary from 80-600 m. Robinson et al. [7] identified and measured layers in lunar mare pits and impact craters to be on the order of 10 m thick (actual range 2-14 m), which they interpreted to represent lava flow thicknesses.

**Methodology:** Craters are common on the lunar surface and provide our best look into the subsurface. Young craters can also preserve outcrops in their walls. Thus we searched for outcrops of layered material within young craters in the nearside mare. LROC Wide Angle Camera (WAC) and Narrow Angle Camera (NAC) images were used to identify craters exposing continuous horizontal striations that we interpret to represent basaltic flow boundaries.

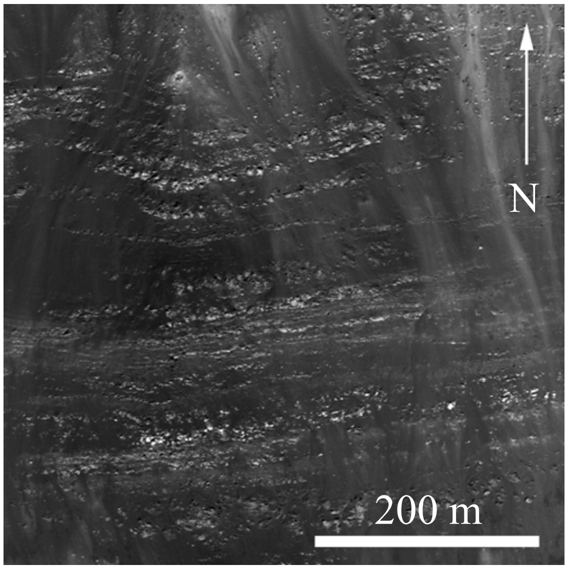

**Figure 1:** Example of a well preserved outcrop in the northern wall of Euler crater. We count a minimum of 32 horizontal striations in Euler, averaging 19 m each. Talus obscures significant portions of the crater wall. We trace the striations for 5 km horizontally across the wall and they span a ~600 m vertical section. LROC NAC M124763045LE, downslope is down [NASA/GSFC/Arizona State University].

**Results:** Horizontal striations (interpreted as outcrops; **Fig. 1**) were identified in 317 Eratosthenian and Copernican aged craters. The craters are spread randomly across the maria, but cover the major maria and expose varying numbers of layers with depth. We calculated the average layer thickness from the 50 best preserved craters.

Each striation was interpreted to be the top or bottom of the massive portion of a distinct lava flow and a pair of striations represents a flow. The average layer thickness for a crater was calculated by measuring the downslope exposure length, correcting for an assumed 30° slope, and dividing by the number of layers. There may be smaller layers (flows) buried by talus, resulting in a maximum average layer thickness: results ranged between 6-25 m with an average of 15 +/- 5 m (1 std; **Fig. 2**). A LROC NAC Digital Elevation Model (DEM) of phase III Imbrium flows near Mons Le Hire also shows thickness variations between 10-35 m.

**Models:** We interpret the striations to delimit lava flows which infilled the maria. Four models describe our interpretations of the striations. Model 1 is based on a simple lava flow (**Fig. 3**). Models 2 and 3, not pictured, are similar to Model 1 but with unknown amounts of either regolith (model 2) or ash (model 3)

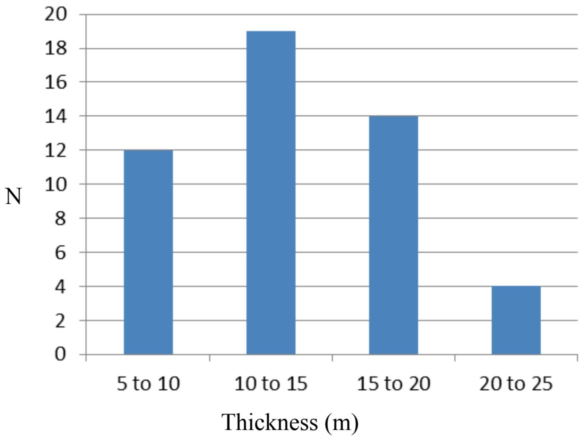

**Fig. 2.** Histogram of the maximum average layer thickness estimated from striations exposed in walls of fresh mare craters.

deposited on top of the vesiculated layer. Model 4 (**Fig. 3**) interprets flows 2x as thick as Model 1 due to a parting plane that developed as the flow cooled from the top or bottom..

**Discussion:** Model 1 is our favored model due to several observations. Key is that parting planes are not entirely common on Earth, and we have no indication of how common they are on the Moon. However, there is no way to test between model 1 and 4 from LROC images. If Model 4 is correct the number of observed flows would decrease by 2x and their thickness increase by 2x to 30 m.

We report the average layer thickness for each crater instead of the average thickness of every layer. This type of estimate could mask a bimodal distribution of layer thicknesses wherein a number of small and large layers are present in single a crater. This is an unusual case, and the standard deviation of the average layer thickness reinforces this observation. When we see large and small layers in the same crater (**Fig. 1**), the larger layers tend to be covered in more talus which might mask more layers.

The widespread geographic distribution of striations and their similar dimensions implies that similar mechanisms and processes caused the eruption and emplacement for the majority of nearside maria. Schaber [3] estimated that lava flow thickness on the Moon should be 1.7 times the thickness of terrestrial lava flows of similar length due to the lower gravity after compensating for lower viscosity of lunar basalts. Comparing the Imbrium flows to Hawaiian and Columbia River basaltic flows, Schaber [3] found the Imbrium flows are ~1.7 times the thickness of the Columbia River basalts and of similar length, so concluded that the Imbrium flows were the product of flood basalt volcanism similar to the Columbia River basalts.

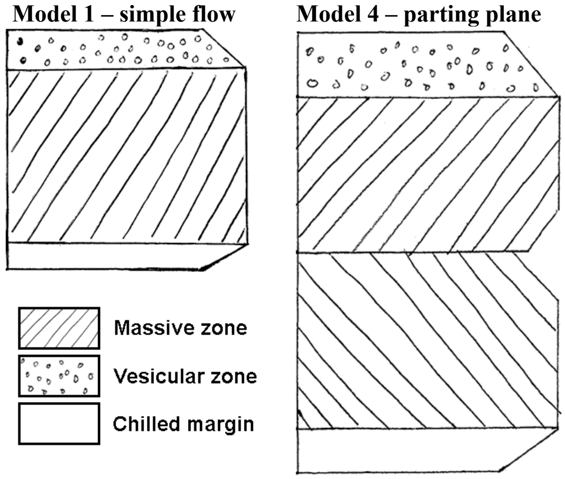

**Fig. 3:** Models of 2 interpretations of the observed striations. Model 1 shows a simple lava flow with a vesiculated top and chilled base (two striations delimit a single flow). A massive interior makes up the bulk of the flow. Erosion occurs preferentially at the base and top of the flow, creating loose debris and stair steps between separate flow lobes. Model 4 shows a flow where a central parting plane developed as a flow cools from the top down and bottom up, meeting near the center. In Model 4, erosion occurs preferentially at the parting plane as well as the flow contacts, resulting in a doubling of the thickness of the flow. Internal structures not to scale.

The Schaber result of 30-35 m thick flows implied that the maria were filled in by short, rapid eruptions of large volume [3]. However, the average layer thickness reported here is consistent with the lower thicknesses (<20 m) measured and calculated previously assuming Model 1 [2,4,5,7]. Surface flows identified in the NAC DEM of the phase III Imbrium flows have thicknesses between 10-35 m, comparable to the average layer thicknesses. However, more NAC DEMs of the Imbrium flows are necessary to confirm whether these are anomalously thin flows as they also overlap with some of the flow thickness variation originally reported [3]. Regardless, the Imbrium flows represent a younger phase of lunar volcanism, and may not be similar to the older buried flows. For now, our results are consistent with a model where the maria are filled by repetitive eruptions of thin flows of smaller volume. Further understanding of when parting planes develop in terrestrial flows may help in testing between Model 1 and 4.

**References:** [1]Hiesinger, H., et al., 2002. *GRL*, 29. [2]Howard, K.A., et al., 1972. *Proc. 3rd LSC*, 1, 1. [3]Schaber, G.G., 1973. *4th Lun. Sci. Conf.* [4]Gifford, A.W., El-Baz, F., 1981. *The Moon & the Planets*, 24, 391. [5]Brett, R, 1975. *Geochim. Cosmochim. Ac*, 39, 1135. [6]Weider, S.Z., et al., 2010. *Icarus*, 209, 323. [7]Robinson, M.S., et al., 2012. *PSS.*