The Formation of Lunar Sinuous Rilles:
G. Hulme, *Modern Geology* **4** (1973) and D. Hurwitz et al., *JGR* (in press).

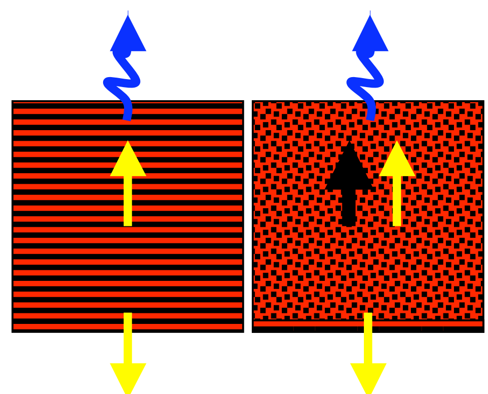
Presenter: Kat Scanlon (drop by LF 111 if you'd like a copy of Hulme, which isn't online)

Lunar sinuous rilles

- Narrow channels with parallel sides (~constant width, e.g. shift from 1.8 km to 1.0 km wide over Rima Prinz's 90 km length)
- Course determined by topography; process of meanders on gentle slopes probably the same as river meanders (lunar and Venusian lava channels follow same width / meander wavelength relationship as terrestrial rivers)

Physics of turbulent lava flow

- *Reynolds number* $Re = vL/\nu$*:* ratio of inertial to viscous forces. $Re > Re_{crit}$: turbulent flow.
- Terrestrial basalt flows are typically laminar but close to Re_{crit}.
- Re_{crit} lower for Newtonian fluids; lunar lava is less viscous, is hotter, and degasses faster, and is therefore more nearly Newtonian than $\oplus$ lava; also has > Re due to low viscosity
- In a lava channel in a laminar flow regime (left red box), heat is lost from the lava to the surrounding rock by conduction (yellow arrows) and to the above by radiation (blue). The upward radiation is balanced by conduction from deeper layers of the flow. Since radiation is a strong function of temperature, this leaves the surface temperature only higher than ambient. Heat flux must be continuous across the lower boundary, so temperature gradient must be equal in the channel and the surrounding rock, which can be shown to result in $T_{bottom} \sim 0.5*T_{center}$. Lava cools and is deposited on the bottom/sides of the channel and a thick layer forms on top.



- In turbulent flow (right red box), radiation upward is balanced by conduction and, more effectively, convection (black) from inside the channel. The surface is therefore warmer and the solid layer at the top is thin. The laminar bottom layer is thin in the turbulent case, so the bottom temperature is also closer to the average temperature in the channel, and may be high enough to erode the substrate. Lava cooling at the base is dominated by assimilation of the substrate at its T_{melt}; the lava viscosity increases, resulting in eroded depth decrease and eventually deposition.

Hulme's proposed formation mechanism

Property of sinuous rilles	How Hulme explains it
Only rarely resemble collapsed lava tubes	Are probably not collapsed lava tubes
Follow topography	Highly fluid lunar lava
Width roughly constant along rille's length	Sides of stream spread slowly, freeze quickly
Flat floors	Turbulent flow → Uniform erosion rate away from sides
Depth decreases downstream	Flow remains turbulent (still const. w) but cools

- Slumping after formation causes transition to V-shaped profile, especially in deeper areas. Slumping also increases width, so shallower parts are closer to original width.

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Rima Prinz

- In Aristarchus Plateau region with 20 vents, many other sinuous rilles
- Nested channels, smaller interpreted as sourced from a separate eruption
- Steep-rimmed source depression w/hummocky floor, cf. remnant lava lake @ Mauna Ulu
- No evidence for levees (which would imply a constructional, not erosional, origin)

Segment	l (km)	w (km)	d (km)	λ (km)	Nested rille	Slope
Upper	11 ± 3	1.8±.7	.23± .018	1.7±.7	Mirrors larger rille	0.7°±0.6°
Middle	19 ± 8	1.0±.4	.21± .045	2.4±1.6	Concealed by slump	0.5°±0.1°
Lower	57 ± 3	1.0 ±.3	.145±.028	2.0±1.2	More sinuous in places	0.4°±0.1°

Hurwitz et al. Methodology

- Modeled mechanical erosion and thermal erosion (latter with two different formulations for the heat transfer coefficient) in the upper segment of Rima Prinz to determine which process would have been faster (and therefore dominant) in forming the rille
    - Calculated eruption volume flux based on morphology and probable lava density
    - Calculated flow width based on sinuosity
    - Iterate over lava depths until calculated volume flux matches geomorphology-based volume flux
    - Models run only in upper segments to avoid complications due to substrate assimilation
    - Thermal erosion was much more efficient for lunar conditions, except during the first stages of rille formation where the substrate was likely unconsolidated regolith (low value of K)
- Used the Williams (1998) formulation for heat transfer coefficient to test effect of lava composition on erosion speed (time it would take to carve Rima Prinz)
    - Terrestrial komatiite: most efficient. 157 days to erode RP, expect 25m thick terminal deposit
    - Lunar high-Ti basalt: least efficient. 766 days to erode RP, expect 110m terminal deposit.
    - Thinness of mare that fully embays likely terminal deposit implies high-Ti basalt unlikely.

$$\left(\frac{dd}{dt}\right)_{therm} = \frac{h_T(T - T_{melt,gnd})}{E_{melt,gnd}}, \left(\frac{dd}{dt}\right)_{mech} = K\rho g Q \sin\alpha, E_{mg} = \rho_g[c_g(T_{mg} - T_g) + f_{mg}L_g]$$

$$h_{T,Hulme} = \frac{0.017k \mathrm{Re}^{4/5}\mathrm{Pr}^{2/5}}{d_{lava}} \quad h_{T,Williams} = \frac{0.027k \mathrm{Re}^{4/5}\mathrm{Pr}^{1/3}}{d_{lava}}\left(\frac{\mu_b}{\mu_g}\right)^{0.14}$$