MODELING AFFECTS OF LUNAR SURFACE SLOPE, TEMPERATURE, AND MATERIAL PROPERTIES ON THE EFFICIENCY OF EROSION DURING THE FORMATION OF RIMA PRINZ. D. M. Hurwitz[1], J. W. Head[1], H. Hiesinger[2], and L. Wilson[1,3]; [1]Dept. of Geological Sciences, Brown University, Providence RI 02912, debra_hurwitz@brown.edu; [2]Institut für Planetologie, WWU Münster; [3]Lancaster Environment Centre, Lancaster University, UK

Introduction: Lunar sinuous rilles are generally considered to be channels that formed as lava of low viscosity flowed over the lunar surface in a sustained eruption. Specifics of the channel formation process are still debated, with origin theories including 1) lava flowing through and modifying pre-existing tectonic graben [e.g., 1,2], 2) lava eroding a subsurface lava tube subject to subsequent collapse [3,4], and 3) an open channel at the lunar surface [5-8]. Lava channels that formed as open channels on the surface have been interpreted as either mechanically [9] or thermally [5,7,10,11] eroded features.

The current study employs models of mechanical erosion (modeled for terrestrial fluvial channels, [12]) and thermal erosion (modeled for planetary lava channels, [5]) in an effort to distinguish between these processes in the formation of a lunar sinuous rille, specifically Rima Prinz. Four major questions are addressed with model results: 1) how gravity and slope affect both mechanical and thermal erosion rates; 2) how surface temperature affects the efficiency of thermal erosion; 3) whether mechanical or thermal erosion better describes the formation of Rima Prinz and Inner Prinz Rille; and 4) how consolidation of the substrate affects mechanical and thermal erosion rates as well as the duration of the eruption responsible for the formation of the observed channels.

Erosion of the substrate requires energetic interactions between a flowing fluid and the substrate; thus different forms of energy are incorporated into each model. Both mechanical (Eq. 1) and thermal erosion (Eq. 2) involve kinetic energy (a function of volume flux Q, i.e. fluid velocity) and potential energy (a function of gravity g and surface slope α), though mechanical erosion depends more significantly on these forms of energy than thermal erosion. Thermal erosion most significantly involves thermal energy, a form of energy that is dependent on the temperature difference between the flowing fluid and the substrate as well as the melting temperature and thermal properties of the substrate. Each energy type contributes to the erosion of the substrate, and observations and interpretations of the geologic setting of each channel are vital to infer the primary erosion regime present during the formation of a channel.

$$\left(\frac{\mathrm{d}(\mathrm{d_{chan}})}{\mathrm{d}t}\right)_{\mathrm{mech}} = K\,\rho\,g\,Q\sin\alpha \qquad \text{Eq. 1}$$

$$\left(\frac{\mathrm{d}(\mathrm{d_{chan}})}{\mathrm{d}t}\right)_{\mathrm{th-m}} = \frac{0.017\,k^{0.6}\,c^{0.4}\,\rho^{0.8}\,Q^{2/15}}{\rho_s\,[q\,\lambda + c_s\,(T_e - T_s)]}\left(\frac{2\,g\sin\alpha}{C_f}\right)^{1/3}\left(\frac{T_e}{A}\right)^{6}(T_e - T_m) \qquad \text{Eq. 2}$$

Observations of channel morphology and measurements of channel dimensions are made using Kaguya images, LROC (the Lunar Reconnaissance Orbiter Camera) images, and LOLA (Lunar Orbiter Laser Altimeter) data. These observations (Table 1), specifically regional slope, channel meander wavelength, and channel depth, are used as inputs into the models in order to constrain volume flux Q through the channel, duration of channel formation, and both mechanical and thermal erosion rates. Model results are used to address the listed four major questions.

Results: First, a generic channel is considered on Earth (g = 9.8 m s^{-2}) and on the Moon (g = 1.6 m s^{-2}), and comparisons are made between mechanical and thermal erosion rates determined for a range of slopes. Figure 1 displays the model results for these scenarios. The upper graph displays results for a channel on Earth, where high gravity facilitates a more significant role of potential and kinetic energy. Results indicate that mechanical erosion is generally more efficient on Earth for the conditions considered (basalt flowing on basalt) at all slopes considered, though mechanical and thermal erosion rates are similar at extremely low slopes. In constrast, the low gravity environment of the Moon facilitates a more significant role of thermal energy in channel formation, and thus thermal erosion is more efficient than mechanical erosion at slopes less than ~3.5^{o}. These results indicate that thermal erosion is a possible mechanism for lunar channel origin even though thermal erosion is not commonly observed during the formation of terrestrial lava channels.

Next, the significance of lunar surface temperatures on thermal erosion rates is considered. Specifically, the timing of the eruption that formed Rima Prinz, as in an eruption occurring during lunar night (120 K, Paige et al., 2010) vs. lunar day (380 K), is varied in order to determine how surface temperature affects the efficiency

Table 1: Observations

	Channel Segment	w_{chan} (m)	l_{chan} (m)	d_{chan} (m)	λ (m)	w_{lava} (m)	slope (°)
Prinz	Upper	1820	17200	190	1800	165	0.72
	Middle	990	11700	170	2100	193	0.49
	Lower	1000	31800	130	2000	184	0.36
Inner Prinz	Upper	530	14000	70	1500	138	0.59
	Middle	300	11300	20	1400	129	0.60
	Lower	320	54100	10	1000	92	0.23

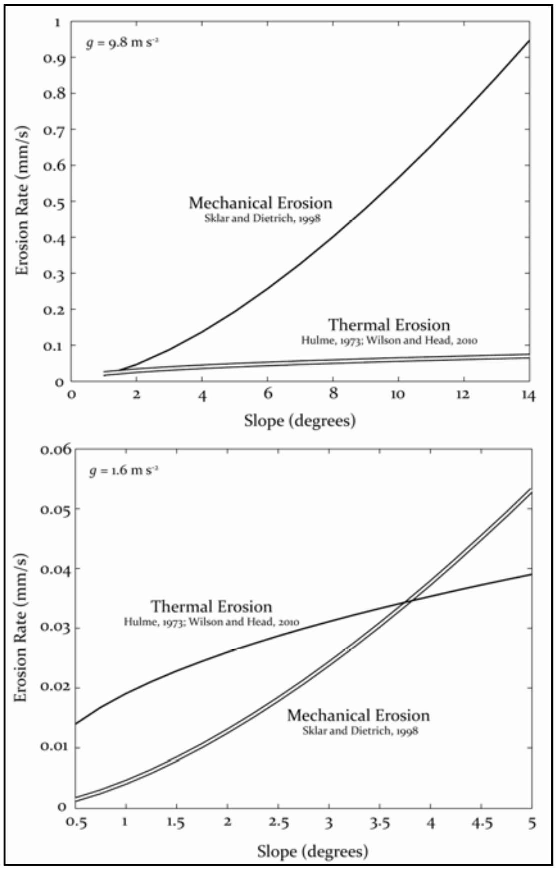

Figure 1: Erosion rate vs. slope for a given channel on Earth (above) and on the Moon (below). Mechanical erosion is generally more efficient than thermal erosion on Earth, where the high gravity facilitates a more significant role of kinetic and potential energy. In contrast, Thermal erosion is more efficient than mechanical erosion at slopes less than ~3.5° on the Moon, where the low gravity facilitates a more significant role of thermal energy in the formation of the channel.

of thermal erosion. Table 2 indicates that even though there is a slight difference in required durations between lunar night and day eruptions, the duration of channel formation expected for the formation of Rima Prinz exceeds 2-6 lunar days (30-90 Earth days), allowing the surface temperature to vary periodically from hot to cold. Therefore, an average lunar temperature is assumed in future models.

Thirdly, results shown in Tables 3 and 4 are used to determine which erosion regime was most likely present during the formation of Rima Prinz and Inner Prinz Rille. The calculated depths shown in Table 3 indicate that the model for thermal erosion more closely predicts the observed depths than mechanical erosion for Rima Prinz (slope <1°, Table 1). Results for Inner Prinz Rille are not conclusive with the measurements made, but depths of the middle and lower channel segments may not accurately indicate the depth of the initial channel, as subsequent infill from regolith formation and/or from landslides triggered by the Aristarchus impact event to the southwest may have occurred.

Finally, modeled eruption durations required for the formation of Rima Prinz in both an unconsolidated and consolidated substrate are also consistent with a thermal

Table 2: Day vs. Night Results

	Duration (Earth days)	
Channel Segment	Thermal Erosion of Substrate at Night	Thermal Erosion of Substrate during the Day
Prinz	90	77
Inner Prinz ($Q_{InnerPrinz} = Q_{Prinz}$)	42	36
Inner Prinz ($Q_{InnerPrinz} < Q_{Prinz}$)	54	46

Table 3: Calculated Depths of Erosion

		Depth (m)		
Channel Segment		Observed	Mechanical Erosion	Thermal Erosion
Prinz	Upper	190	190	190
	Middle	170	111	162
	Lower	130	86	148
Inner Prinz	Upper	70	70	70
	Middle	20	76	72
	Lower	10	41	56

erosion origin. The eruption duration for thermal erosion of an unconsolidated substrate is calculated to be 72 Earth days compared with 600 Earth days for mechanical erosion of an unconsolidated substrate. When a consolidated substrate is considered, the eruption duration is slightly increased to 100 Earth days for thermal erosion but drastically increased to nearly 30,000 Earth days for mechanical erosion. These eruption durations indicate that eruption durations for thermal erosion are more plausible than mechanical erosion, especially in the case of erosion of a consolidated surface.

Future Work: Eruption durations and erosion rates calculated for Inner Prinz Rille can be used to distinguish between two origin hypotheses for the nested rille: 1) Inner Prinz formed as the result of the same eruption as that which formed Rima Prinz, but that the flowing lava encountered a more consolidated layer that resulted in a decrease in erosion efficiency and thus a smaller channel; or 2) Inner Prinz formed as an independent eruption with a smaller eruption rate that cut the same material as Rima Prinz. Investigations of additional nested lunar rilles will increase our understanding of the formation of these enigmatic features.

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