FLUVIAL DISCHARGE RATES OF MARTIAN GULLIES: SLOPE MEASUREMENTS FROM STEREO HIRISE IMAGES AND NUMERICAL MODELING OF SEDIMENT TRANSPORT.

R. A. Parsons[1] and F. Nimmo[1] [1]University of California, Santa Cruz, rparsons@pmc.ucsc.edu

Introduction: A stereo pair of HiRISE images of a pole-facing crater slope at 38°S, 218°E shows many fresh looking gullies. After measuring slopes using the stereo viewing geometry, we estimate the expected fluvial discharge rates using theory from Kleinhans [1] and Ikeda [2]. We also develop a numerical model of sediment transport based on theory presented in Kleinhans [1] to determine the time required to incise to the observed alcove depth. Combining the discharge estimates with the duration we estimate a total water volume needed to form these gullies. Finally, groundwater discharge has been a suggested mechanism for forming gullies on Mars [3-4]. We test whether groundwater discharge can deliver the water required by our model results.

Slope Measurements: Spacecraft viewing geometry and an observed parallax between a pair of points in two stereo images is used to calculate a change in elevation [5]. Typical errors in this slope measurement are between 0.5° to 2° over 100 m lengthscales. Topographic profiles taken along nine gullies on the pole-facing crater slope give an average alcove depth of 25 m. See Parsons et al. [6] for slope data.

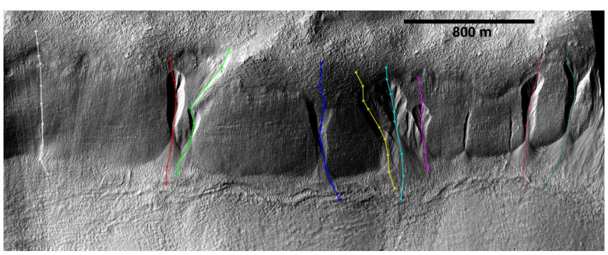

Figure 1 : Section of HiRISE PSP_002514_1420 image showing gullies incising into a pole facing crater slope. Colored lines are locations of topographic profiles measured using stereo photogrammetry.

Fluvial Discharge: Assuming liquid water is responsible for the formation of these gullies, we estimate bank-full fluvial discharge and flow velocities. In Kleinhans [1] the width-averaged fluid flow velocity is given by

$$u_K = \sqrt{8ghS/f} \tag{1}$$

where g is gravity, h is the channel depth, S is the local slope (in radians), and f is an empirical friction factor. f depends on the bed roughness and the local slope as shown in equation 13 of Kleinhans [1]. Smaller grainsizes give smaller values of u_K. We treat grainsize as a free variable. In Table 1, we calculate flow velocities for median grainsizes (D_{50}) of 0.1 mm and 10 cm for two assumed channel depths.

An alternative method of calculating flow velocity takes advantage of the wavenumber of channel meandering (k) which can be related to channel flow velocity using equation 20 from Ikeda [2]:

$$k = 2\pi/\lambda = \frac{2C_f\left(\sqrt{0.5(A+2+F^2)}-1\right)^{1/2}}{h} \tag{2}$$

where λ is the meander wavelength and A is an empirical constant equal to 2.89 for alluvial streams. The Froude number is $F = u_I(gh)^{-0.5}$ and the friction factor is $C_f = ghSu_I^{-2}$ where u_I is the fluid flow velocity. Results from these calculations are shown in Table 1 assuming the channel height:width ratio is 1:8 [7]. These velocities are comparable to the ~ 4 m s^{-1} value previously reported [7].

Table 1 :Flow velocities from Kleinhans (u_K) and Ikeda (u_I). For u_K, two different grainsizes are used.

Width (m)	8.0	2.0
Depth (m)	1.0	0.25
Slope (°)	20	20
λ(m)	30	30
$u_{K0.1mm}$ (m/s)	1.32	1.0
u_{K10cm} (m/s)	2.7	1.45
u_I (m/s)	3.6	12.1

Sediment Transport: To model the erosion and deposition of sediment on Martian slopes, we use a bed load sediment transport predictor from Meyer-Peter and Mueller [8]. In their model, the bedload sediment flux is

$$q_b = \frac{8\left(\theta' - \theta_{cr}\right)^{\frac{3}{2}}}{(Rg)^{\frac{1}{2}} D_{50}^{\frac{3}{2}}} \tag{3}$$

in m^2 s^{-1} where θ' and θ_{cr} are the nondimensional, grain-related shear stress and the non dimensional critical shear stress and $R = (\rho_s - \rho)/\rho$ [1].

In our 1D (profile) simulations, we allow the channel depth to linearly increase from zero to its final depth 20 m downslope in order to maintain numerical stability. The original profile has an initial slope of 22° shallowing to a slope of 2° based on observations of the pristine slope. We crudely address episodic mass-wasting of material into the alcove by resetting a portion of the profile equal to the angle of repose (≈ 33°) once the gully has eroded to form a vertical face 10 m high. Figure 2 shows topographic, slope, and elevation change profiles for a 1D sediment transport simulation lasting 8000 s for a channel depth of 0.25 m and D_{50}=10 mm. The red line is the initial profile, the blue line gives a profile immediately after a "mass-wasting" event, and the black lines are equally spaced in time.

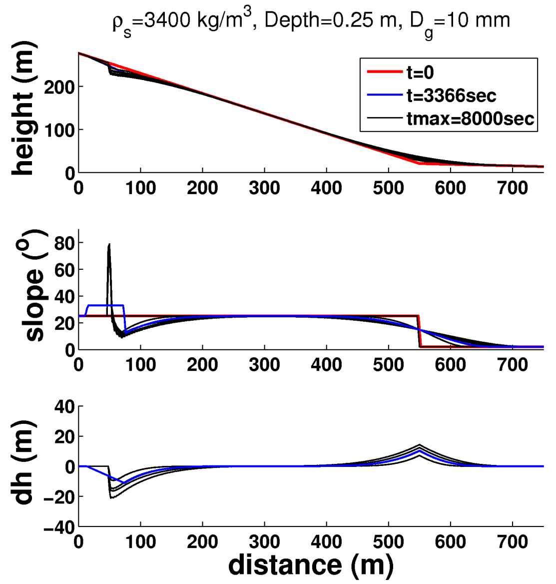

Figure 2 : Topographic, slope, and elevation change profiles for 1D sediment transport simulation lasting 8000 s for a channel depth of 0.25 m and D_{50}=10 mm.

The bottom panel of Figure 2 shows the alcove has eroded to a depth of 25 m after 8000 s - corresponding to the alcove depth we observe. The total sediment discharged is $\sim$ 3600 m^3 . A nearly identical simulation, but with a channel depth of 1 m takes 1000 s to erode to 25 m depth and discharges $\sim 14,400$ m^3 of sediment. Both simulations have a 3:4 sediment:water ratio, suggesting that flow is borderline supersaturated [1].

Testing the Groundwater Hypothesis: To determine what thickness (H) and permeability (κ) of an exposed aquifer is needed to account for this total discharge in the time required, we used the instantaneous discharge from an aquifer given in Turcotte and Schubert [9]

$$Q = \frac{H^{\frac{3}{2}}}{2}\left(\frac{\kappa\rho g\phi}{\pi\mu t}\right)^{\frac{1}{2}} \tag{4}$$

where ϕ is porosity, t is time, and the dynamic viscosity of water (μ) is 0.001 Pa s. Integrating this function over time gives the total discharge. Figure 3 plots the aquifer thickness versus permeability required to discharge the total volume indicated in the legend. Here we've assumed that the groundwater seep is 10 times wider than the channel. Using 10^{-9} m^2 as a probable upper bound for permeability [10 - 11], requires an aquifer a few 10s of m thick to generate the required flow. The minimum water table draw-down distance would range between 30-60 m given the total water discharges determined in this paper.

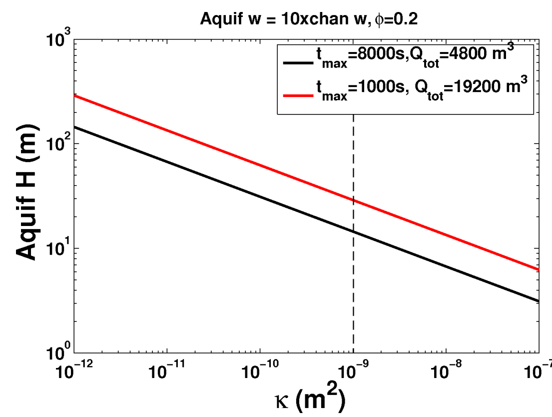

Figure 3 Aquifer thickness versus permeability given the water discharge and time constraints from two simulations.

Conclusions: Sediment transport on slopes $\sim 20°$ on Mars during a bankfull fluvial discharge event could potentially form gullies on very short timescales ($\sim$h). Water would flow with a velocity of $\sim$1.5 m s^{-1} in filled channel 1 m deep [1]. Sustained flow for 1000 s could erode unconsolidated sediment to a depth of 25 m. The volume of water discharged during this event could be delivered by a permeable (10^{-9} m^2) aquifer 10s of m thick. The minimum draw-down distance in the aquifer would be 60 m (less than the average gully spacing). After an event like the one we propose here, the aquifer would likely have to recharge over a several hundred year period.

References: [1] Kleinhans, M.G. (2005) *J. of Geophys. Res.* 110, doi:10.1029/2005JE002521. [2] Ikeda, S., Parker, G., & Sawai, K. (1981) *J. Fluid Mech.* 112, 363-377. [3] Heldmann, J.L. et al. (2007) *Icarus* 188, 324-344. [4] Mellon, M.T. & Phillips, R.J. (2001) *J. of Geophys. Res.* 106, 23165-23179. [5] Kreslavsky, M. (2007) *Workshop on Martian Gullies*, #8034. [6] Parsons, R.A., Kreslavsky, M., & Nimmo, F. (2008) *LPSC XXXIX*, Abs. 2328. [7] Howard, M. & Moore, J. (2008) *LPSC XXXIX*, Abs. 1629. [8] Meyer-Peter, E. & Mueller, R. (1948) *in Proceed. 2nd Meeting, Int. Assoc. for Hydraul. Struct. Res.*, Stockholm, 39-64. [9] Turcotte, D. & Schubert, G. (2002) *Geodynamics 2nd ed.* Cambridge Univ. Press. [10] Hanna, J.C. & Philliips, R.J. (2005) *J. of Geophys. Res.* 110, doi:10.1029/2004JE002330. [11] Manga, M. (2004) *Geophys. Res. Lett.*, 31, doi:10.1029/2003GL018958.