DECIPHERING OUTBURST FLOOD DISCHARGES FROM THE MORPHOLOGY OF HESPERIAN CANYONS.

Mathieu G.A. Lapotre[1], Michael P. Lamb[1], Rebecca M. Williams[2]. [1]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA, USA. [2]Planetary Science Institute, Tucson, AZ, USA.

Introduction: On Earth and Mars, some amphitheater-headed canyons with steep walls and roughly constant widths were carved by outburst floods (Figure 1) [1-4]. On Earth, these canyons are generally found in columnar basalts, as near-vertical cooling joints favor the formation of steep walls [5]. As water spills over an escarpment, the rock columns at the rim are subjected to large shear stresses, and are prone to toppling.

On Earth, several paleohydraulic tools can be used to infer the discharge of past floods, such as using a Shields stress criterion for incipient motion of the bedload, or assuming bankful conditions. Nevertheless, these methods respectively provide lower and upper bounds on the flow discharges, and the bankful assumptions likely largely overestimates the discharge for eroding canyons. Moreover, grain sizes are not readily available on the surface of Mars. Consequently, there is a need for a new, more robust, paleohydraulic method.

Because canyons are eroded in concert with floods, we test the hypothesis that the morphology of canyons is an indicator of the hydraulics of the floods that carved them, and in particular that their width is set by the flood discharge.

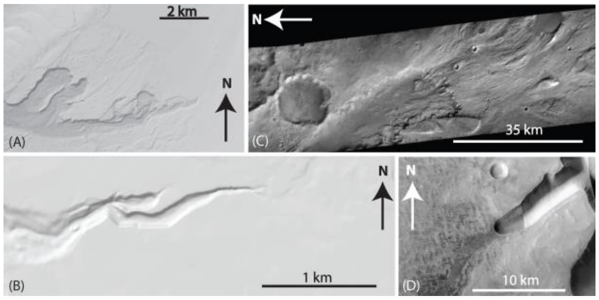

Figure 1: Shaded relief maps derived from ASTER at (A) Dry Falls, WA and (B) Malad Gorge, ID. (C) HiRISE image (P08_004171_1883_XI_08N024W) of a canyon near Ares Vallis. (D) CTX mosaic (JPL, NASA) of a canyon near Echus Chasma, the source region of the Kasei Valles outflow channel system.

Methods: We model the flooding of canyon escarpments of various geometries under various flow conditions using ANUGA, a 2D depth-averaged scheme of the shallow water equations [6]. This hydraulic model allows for fully turbulent flows and Froude number transitions. We analyze the effect of five non-dimensional parameters on the shear stress and discharge distributions: the Froude number of the flood upstream of the canyon, the ratio of the canyon width to the width of the flood, the ratio of the canyon length to the half- width of the flood, the ratio of a the backwater length to the half-width of the flood, and the bed slope upstream of the canyon. We map the distribution of the shear stresses and discharges around the rim of canyons (Figure 2). Assuming that the canyons erode through toppling, we cast the shear stress distributions in terms of canyon evolution, by comparing the shear stresses at the canyon head and walls to the critical shear stress for erosion.

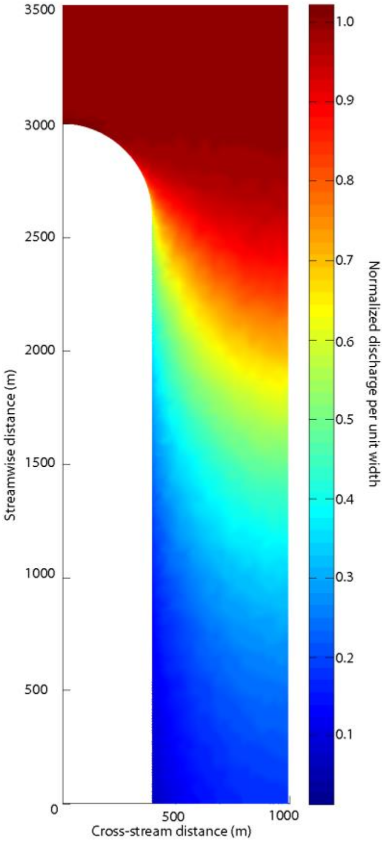

Figure 2: Simulation example in map view. Only half of a canyon is modeled because the system is axisymmetric. Water enters the domain through the top boundary, and overspills in the canyon. Colored is the modeled flow discharge upstream of the canyon rim, normalized by the inflow discharge.

Results: The Froude number of the flood has the greatest effect on the distribution of shear stresses and discharges around the canyon rim – higher Froude numbers lead to less convergence of the flow towards the canyon, and thus to lower shear stresses (and discharges) on the sides of the canyon. The canyon to flood-width ratio and the backwater length to flood half-width ratio have minor effects on the distribution of shear stresses and discharges around the head, while the canyon length to flood width ratio affects the shear stresses and discharges along the walls and the toe of the canyon. The bed slope, independently of all the other parameters, does not affect the distribution of shear stresses and discharges.

Implications: Based on these results, we derive a phase diagram for canyon evolution under the assumption that erosion is driven by toppling and is detachment limited. This phase diagram provides us with bounds on the discharge of a flood that is in equilibrium with a canyon of a certain width. Larger floods result in wider canyons because of erosion of the walls, and smaller floods produce narrower canyons because of focused erosion at the canyon head. The reconstructed flood discharge is a strong function of the assumed Froude number, which can be constrained from measurements of land surface slope.

We apply this novel method to Dry Falls, WA, and compare the obtained discharges to independent minimum estimates based on a Shields stress criterion for incipient motion of the bedload. We show that these results are in good agreement. We also compare our estimates to the discharge calculated by filling the canyons up to the brim, and show that these are are much larger by up to several orders of magnitude. Finally, we apply this novel method to reconstruct the discharges of floods on Mars. Figure 3 shows the predicted flood discharge necessary to carve a canyon of constant width as a function of vertical joint spacing at Echus Chasma (Figure 1D).

References:

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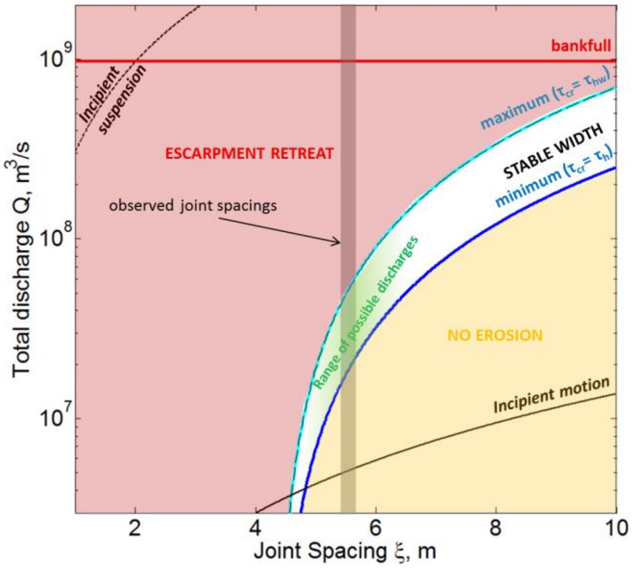

Figure 3: Inverted paleoflood discharge as a function of vertical joint spacing. Joint spacings of 5-6 meters were observed in the area from HiRISE, thus requiring discharge of 1-5x10^7 m^3/s to maintain a constant canyon width.