CONSIDERATION OF STREAM POWER AND THE OUTFLOW CHANNELS OF MARS.

Neil M. Coleman and Christopher Coughenour, University of Pittsburgh at Johnstown (Dept. of Energy & Earth Resources, Johnstown, PA 15904; ncoleman@pitt.edu, coughenour@pitt.edu).

Introduction: The remarkable outflow channels and valley networks of Mars reveal lengthy episodes of hydrologic activity during Noachian and Hesperian time. Some outflow channels are tens of km wide and thousands of meters deep. The factors that controlled the size of these channels include the duration, volume, and number of repetitive flood events. Another controlling factor is the nature of the eroded geologic materials. For example, surface regolith would have been easily incised by floodwaters. But as Mars' meteorites and spectroscopic data from surfaces and canyon walls indicate, deeper units likely consist of flood basalts that had overrun much of the planet's surface.

The speeds and depths of floodwaters in the outflow channels determined the erosive power exerted on channel floors, and the size range of transported materials. The greatest erosive power was exerted in places where huge cataracts formed and migrated far upstream, like the spectacular examples in Kasei Valles (Fig. 1) [1]. The cataracts confirm that water was the erosive agent.

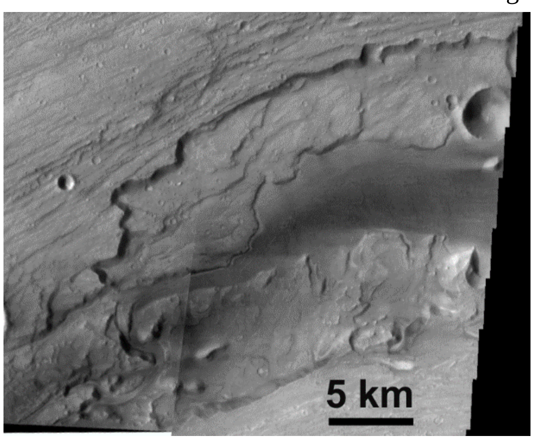

Fig. 1. Large "horseshoe-shaped" cataract complex in Kasei Valles. Crater at upper right is at 25°14' N, 61°4' W. Themis images V18412016 and V02611007 [2].

Energy considerations: Stream power is the rate of potential energy loss over a unit length of stream. By the work-energy theorem it is a measure of available energy of the stream to perform work, namely, changing the kinetic energy of the flow, moving sediment, and frictional heating [3]. Stream power is given as:

$$\Omega = \rho g Q S \quad (1)$$

where Ω is stream power, ρ is water density (1000 kg m^{-3}), g is surface gravity (3.7 m s^{-2}), S is the channel energy slope, and Q is flow discharge (m^3 s^{-1}). Dividing Ω by channel flow width yields "unit stream power", $\boldsymbol{\omega}$ (W m^{-2}), which is the stream power per unit streambed area. The lower gravity on Mars is fully considered in equation 1. Note that a large suspended load in floodwaters would increase $\boldsymbol{\rho}$, adding to the erosive power.

Floods from the Breach of Crater Lakes: It is difficult to know how deep were the flows in the Martian outflow channels. This previously led some investigators to estimate upper limits on discharges by assuming that the channels we see today once flowed bank full. However, revised insights about flow depths come from analysis of floods that issued through breaches in the sides of crater lakes. Those paleofloods provide unique opportunities to study likely envelopes of flood depths, erosion rates, and stream power [4]. Plausible hydrographs have also been developed. For such floods the time varying discharges were controlled by the initial depth of water in the crater lake and the inception and growth rate of the breach opening. Few flood scenarios have greater potential to deeply fill a channel. Yet, even here, calculations show that the channels, *once fully formed*, never flowed bank full [4]. This differs from the incipient channels eroded by initial scabland flooding.

Tana Vallis. Tana Vallis (Fig. 2) was created by a flood from a crater lake that overtopped and breached Galilaei Crater [4]. The channel as seen today never experienced bank-full flow or even flow at three-fourths of its maximum depth, because the implied discharges would have exceeded peak flows through the breach.

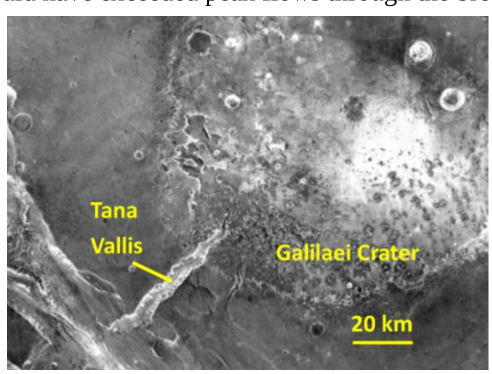

Fig. 2. Night-time infrared image of Galilaei Crater and the outflow channel Tana Vallis at its southwest rim. Sub-frame of Themis mosaic image [5].

Hydraulic erosion of basalts. Fig. 3 represents erosive power with respect to depth for a segment of Tana Vallis [4]. We compare this plot to the conclusion of

O'Connor [6], who reported that the peak values of ω for the larger of the terrestrial Missoula paleofloods exceeded 2.5 $\times 10^5$ Wm^{-2} and that erosion of basalt layers mostly occurred in channel reaches where ω exceeded 20,000 W m^{-2}. Benito [7] described thresholds of critical unit stream power to begin eroding various Missoula landforms. He estimated 2000 W m^{-2} for basin-and-butte scabland topography and 4500 W m^{-2} for deep inner-channel incision. As inferred from Fig. 3, mean flow depths of <50 m in the Tana Vallis channel would have sufficed to deeply erode jointed basaltic bedrock. Tana flows likely attained significantly greater depths.

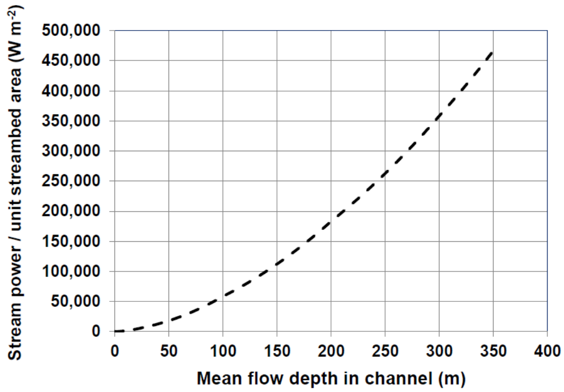

Fig. 3. Stream power curve for a part of Tana Vallis during flood from breach of Galilaei Crater (after [4]).

Eroded fraction. The volume of water contained in former crater lakes can be compared to the volume removed from channels to obtain an estimate of the eroded fraction. The volume of the channel of Tana Vallis is only 1.4% of the Galilaei Crater drainable volume of 1.11×10^{13} m^3. However, Tana Vallis could have been carved by just a fraction of that water volume. If the channel fully formed in 5 days, the lake surface elevation would have fallen ~400 m, which relates to a cumulative discharge of $\sim5\times10^{12}$ m^3. Therefore through 5 days of flow, each cubic meter of water would have stripped away and transported 0.03 m^3 of geologic materials to form Tana Vallis. Less than half of the lake volume would have sufficed to form the vallis.

Formation of the Large Outflow Channels: Most of the large channels on Mars had distinct and plausible source areas capable of delivering enormous volumes of water, including repetitive flows. For example, Ares Vallis had a major source from overflows that topped the northern rim of the Argyre basin. Tiu and Simud Valles were readily sourced from breached paleolakes in the ancestral Valles Marineris canyons. Likewise, the floods that carved Maja Valles issued from Juventae Chasma. However, one of the largest channel systems is enigmatic in that the ancient source areas are unclear.

The Kasei Paradox? The enormous channels of Kasei Valles present a fascinating dilemma – what were the sources of the floodwaters that carved these channels kilometers deep and tens of km wide? The Kasei channels begin on the eastern flank of the Tharsis plateau. Multiple episodes of flooding are confirmed by many cross-cutting erosional features in the channels, and by the long distances that huge cataracts [1] migrated upstream. One episodic source of water may have been large-scale genesis of liquid water caused by rapid melt of large ice fields by Tharsis flood basalts. Echus Chasma is also a likely source area, especially if its present-day volume had been reduced by extensive flood basalts after the aqueous flooding episodes.

Simple calculations confirm that the Kasei channels were eroded by extreme flood volumes. To illustrate, we calculate the eroded volume for one segment of Kasei, outlined in Fig. 4. If the eroded fraction was 10% (volume of eroded solids per cubic m of water), then at least 6×10^{13} m^3 of water was needed to erode just this small segment of the southern channel of Kasei Valles. That is 2.6 times the entire volume of the Great Lakes.

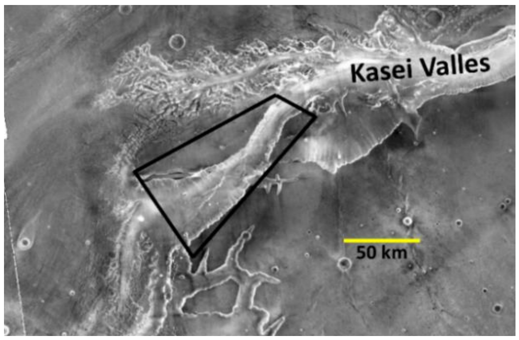

Fig. 4. Segment of Kasei Vallis where eroded volume is estimated at >6000 km^3). Base image credit [5].

Conclusions: The enormous outflow channels on Mars demonstrate extraordinary erosive power. Despite the lower surface gravity (38% of Earth) which reduced the effective stream power and erosion, the speed and depth of the floods overpowered all obstacles, incising channels kilometers deep and tens of km wide.

References: [1] Coleman N. (2010) LPSC 41, Abs. # 1174, Kasei cataracts, https://www.lpi.usra.edu/meetings/lpsc2010/pdf/1174.pdf. [2] Christensen et al., THEMIS public releases, http://themis-data.asu.edu/. [3] Bagnold R. A. (1966) An approach to the sediment transport problem…*USGS PP* 422-I. [4] Coleman N. (2015) Hydrographs of a Martian flood….*Geomorphology* 236 [5] JMars, THEMIS day IR mosaics, https://www.mars.asu.edu/data/thm_dir/. [6] O'Connor, J. (1993) GSA Spec. Pap. 274 (83 pp). [7] Benito, G. (1997) Earth Surface Proc. & Landforms 22, 457–472.