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Aram Chaos outflow channel: water volume and time scale

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Abstract

The evaluation of the water volume and the formative time scale needed to carve the outflow channels represents a fundamental process for the validation of their evolutive models. We calculate these attributes for the Aram channels and we compared the results with the volume of liquid water that was produced in a single chaotization event of the Aram Chaos. The analysis suggests that a single rapid and catastrophic event is sufficient to carve the channel and the volume of flood is compatible with the volume of liquid water release in a single chaotization event of the Aram Chaos.

1. Introduction

Outflow channels represent one of the most important indications of liquid water occurrence on Mars. Attributes such as grooves, terraces, teardrop island, streamlined lands and the high width-to-depth ratios suggest a clear erosive origin of the channels. The indication of Hesperian chaotic terrains as the source of the outflow channels [1] has led a common general scenario: water is discharged from the subsurface and results in catastrophic outflows. However this model seems to be not in agreement with the morphological observations indicating few but huge water flood events needed to carve the channels. Within this scenario it is clear as the amount and timing of the water release are fundamental parameters for the validation of the evolutive models of the outflow channels.

We chose to evaluate the flow volume and the formative time scale needed to carve the Aram Chaos channel (Fig. 1). The latter is clearly identifiable as the outflow channel of the Aram Chaos, a near-circular confined basin of 280 km of diameter [2]. For the Aram Chaos channel we estimate the amount and timing of the water flow and we compare the results with the volume of liquid water that was produced in a single chaotization event by taking the subsidence as the measure of the water escaped [3]

2. Outflow water volume and time scale determination

In this section we describe the method for deriving flow volume and formative time scale from the morphology of the Aram Chaos channel (Figs. 1 and 2). Sources of uncertainty are discussed in combination with a likely course of events in the excavation of the channel.

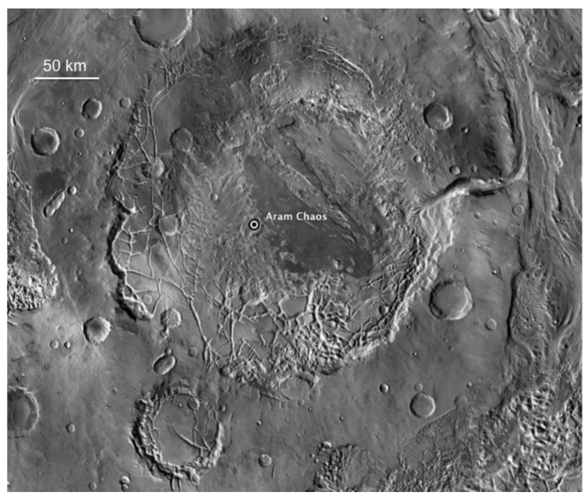

Figure 1: View of Aram Chaos (THEMIS IR day image, 2°N, 21°W; credit GoogleMars) showing the typical fractured and tilted chaos blocks, and associated outflow channels (thick arrow). The difference in elevation between the fractured chaotic terrain and the surrounding highlands is about 2000 m in this particular case.

2.1. Principle of formative time scale and flow volume calculation

The principle of the calculation of formative time scale is that a flow needs a certain time to remove or deposit a known volume of sediment [1]. The integrated flow flux during that formative time period is the independent estimate of water volume to be compared to the volume of water released during the chaotization process as estimated from the geological reconstruction of Aram.

We estimate the volume of sediment eroded from the valley from cross-sections and the length of the valley. The simplest approximation is to use the average width and depth and length of the valley to calculate a triangular volume, resulting in $5.4{\cdot}10^2$ km^3 sediment removed. The more detailed estimates are based on the calculation of cross-section surface area averaged over several HRSC profiles and multiply that with the length of the valley (Figs. 2 and 3). This yields a valley volume of $3.7{\cdot}10^2$ km^3.

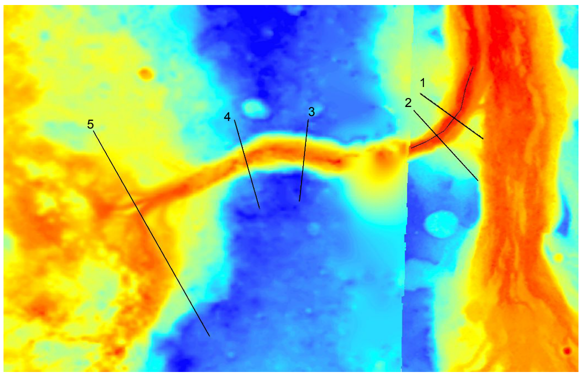

Figure 2: Locations of the cross-sections (in two HRSC datasets from orbit 401 and 923).

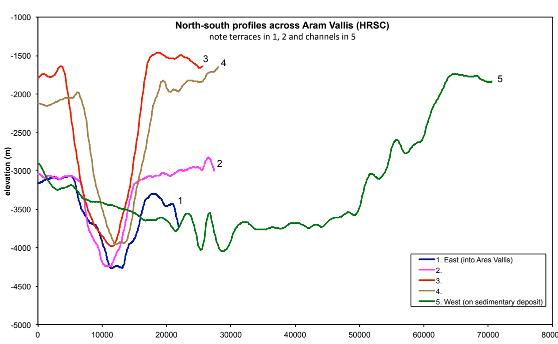

Figure 3: North-south profiles across Aram Vallis (HRSC): note terraces in 1, 2 and channels in 5.

The flow flux from the Aram Chaos crater was likely (nearly) clear water, so that the sediment transport capacity of the flow is entirely used up on the erosion of the Aram Chaos channel. This clear water scour is basically the inverse of the deposition of crater lake deltas from a sediment-laden flow that enters a crater lake [3], [4]. The sudden transition from sediment transport to zero transport in the delta case and vice versa in the Aram Chaos channel case allows us to calculate the time scale T_s of formation directly from the volume of displaced sediment V and the sediment transport rate Q_s (corrected for porosity) as $T_s = V/Q_s$ [3]. The sediment transport rate is calculated from the flow flux through the channel.

Flow flux is calculated by the following steps. First, width, flow depth and gradient of the channel are estimated. Width and cross-sectional valley shape is estimated from HRSC topography. Flow depth is estimated from terrace heights in the eastern part of the valley and in the western sedimentary deposit. The valley gradient is the most uncertain parameter (discussed below). Then hydraulic roughness is calculated [3], from which the flow velocity [3] and flow discharge [3] follow. The water depth inferred from terraces is within the expected range based on the resulting width-depth ratio of the flow (20 for terrestrial gravel bed rivers) and results in reasonable Froude numbers and sediment mobilities (expressed as non-dimensional Shields number) as in large terrestrial rivers [3].

Sediment flux is calculated with two methods: one assuming a bed load dominated event (with mostly rolling and saltating particles – limited energy) and one assuming a suspended load dominated event (with suspended particles – more energy). Classical sediment transport capacity predictors are employed corrected for gravity [3], and sediment properties as estimated in [3] are used. The ratio of suspended and bed load transport is much larger than unity, so that the system is suspended load dominated and the appropriate predictor is used [3]. The time scale for channel formation then becomes of the order of tens of days with an order of magnitude uncertainty range [3].

To estimate the total water volume V_w that must have come out of the Aram Chaos crater to form the observed Aram Chaos channel, the formative time scale T_s for channel excavation can be multiplied with the flow flux Q so that $V_w = T_s Q$ [3]. This yields a water volume estimate of $3.8{\cdot}10^4$ km^3 , which is not significantly different from the independent estimate of the volume from crater geology ($3{\cdot}10^4$ to $12{\cdot}10^4$ km^3, assuming a simple cylindrical shape of the crater. The uncertainty in the calculation of the water volume results from uncertainty in the magnitude of subsidence (between 1 and 2 km, with local variations). As a best estimate of the water volume released assuming a single event we therefore use $9{\cdot}10^4$ km^3 [2]

A sensitivity analysis was done for the parameters that are the least well-known, in particular water depth (Fig. 4). The resulting time scales for the water flow and for the sediment removal are plotted against the used water depth. Since it is the water flow that removes the sediment, the time scales must be equal. The figure 4 shows that they are equal within a water depth range of about 250–400 m and a formative time scale of a few tens of days, taking into account all conservative estimates of uncertainties. This water depth is in agreement with observed terrace heights in the valley (Fig. 3), which are indicative of water depth. The order of magnitude uncertainty in time scale for sediment removal T_s is due to the uncertainty of water surface gradient, which has here been estimated from the final bed surface gradient (ignoring later debris flow deposits) and the maximum likely slope from the crater rim surface just outside the channel. Neither is likely to be representative for the entire period, so we chose a gradient magnitude in between for the best guess scenario.

2.2. Description of outflow process

The formative time scale and the volume of water involved in carving the channel were calculated as if the fluxes were constant during the event. It is likely that the fluxes were not constant in reality but the likely process of channel formation as described below can be approached with constant fluxes for our purpose. The processes as described below are informed by geomorphology literature and preliminary scale experiments by Kleinhans and co-workers of a similar kind as in [4].

Initially, the first flow over the rim between Aram Chaos and Ares Vallis would have found initially topographical low areas. Most initial erosion would have taken place at the downstream end, where the flow descended steeply into Ares Vallis. The backward steps might have had some antidunes in the initial stages as in the [4] experiment where the flow debouched into the empty crater basin initially. The channel would have been narrower where it cut deeper into the plateau. This means that the abandoned flow terraces on the north-eastern rim of Aram Chaos channel are remnants of the very first flow, and their depth below the surrounding plateau (320 m) is a reasonable estimate of channel depth. On the upstream rim there would not have been much erosion as the flow essentially initially went uphill. That is, converged strongly as the bed surface gradient was uphill whereas the water surface gradient must have been downhill. With most of the erosion at the downstream end, the initial channel would have had a concave-upward long profile from the crater across the crater rim into Ares Vallis, which it still has to some extent.

During the outflow event the channel would have deepened, while the lake water level incrementally dropped as it emptied through the channel. The width of that channel is not necessarily equal to the width of the present valley, as the valley would have widened through slab failure and mass wasting while the channel undercut the valley sidewalls. A recent granular debris flow in the middle of the present channel indicates that failure of the side walls would immediately collapse the material into non-cohesive granular sediment. This debris flow formed as a dry granular flow since only this rheology allows for a debris flow that goes slope-upward on the opposite valley wall. The non-cohesivity of the material confirms the validity of our calculations with transport capacity predictors.

In waning flow the sediment transport capacity would have dropped dramatically, so that the channel floor excavation no longer kept up with the lake water level lowering. This would have ended the outflow event. This may have been rather abrupt or more gradual depending on the hypsometry of the crater basin immediately after the catastrophic melting event.

3. Conclusions

The flow volume needed to carve the Aram channel ($3.8{\cdot}10^4$ km^3) is quite similar to the volume of water that was produced in a single chaotization event of the Aram Chaos ($9{\cdot}10^4$ km^3) [2]. This analysis confirms that a single, rapid (tens of days) and catastrophic event is sufficient to carve the channel rather than many small groundwater events active for a relative long time.

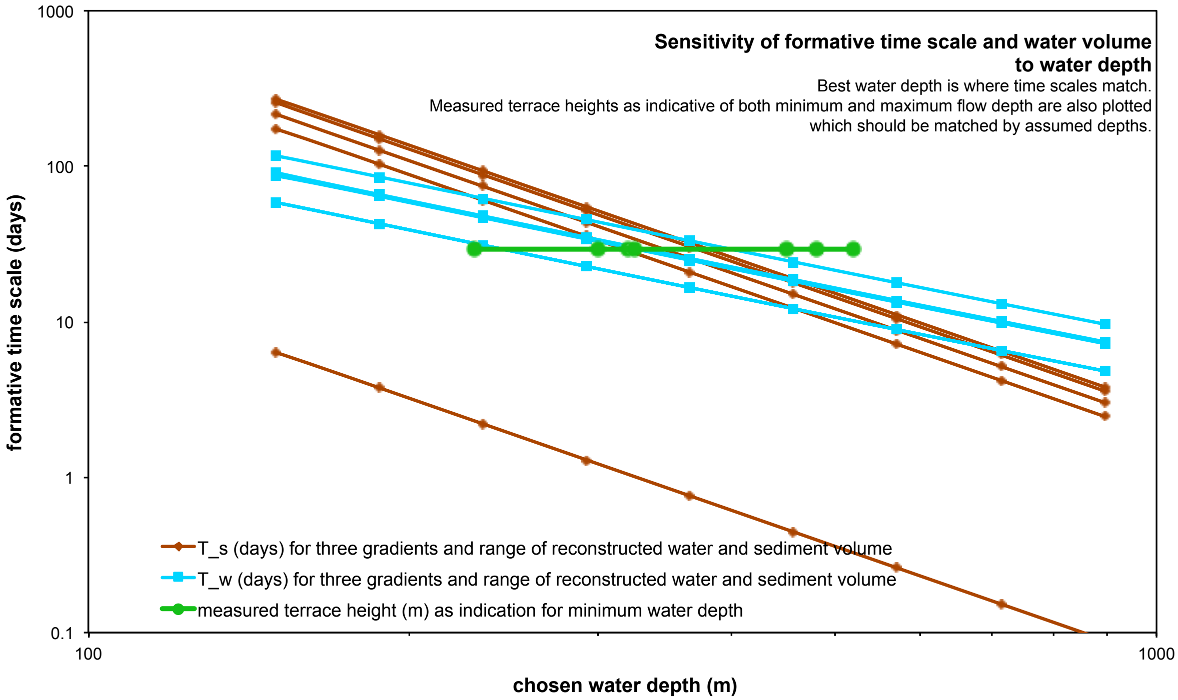

Figure 4: Sensitivity of formative time scale and water volume to water depth in the channel. The formative time scale for sediment (T_s) is calculated by dividing the volume of Aram channel to the predicted sediment transport rate. Ts is plotted versus the most uncertain parameter: water depth. Five lines are plotted for different combinations of gradient and estimated water volume. The formative time scale derived from the calculated flow discharge and measured volume of water (T_w) in Aram Chaos is drawn for the same calculations. When T_w=T_s, the measured amount of water is exactly sufficient to erode the measured amount of sediment based on predicted flow and sediment transport rates. The range of depths for which this is the case matches the range of observed terrace depths and gives the likely time scale of tens of days.

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