Aram Chaos outflow channel: water volume and time scale

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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 (Baker, 2001) 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.

Geological outline

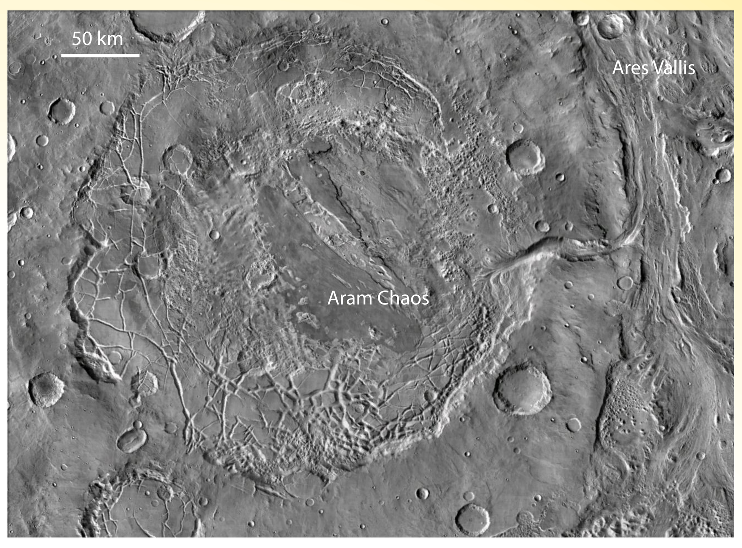

Fig. 1 - Aram Chaos image (THEMIS IR day). Credits: Google Earth

Aram Chaos is situated in a circular region with a diameter of 280 km centered in 2.5º N and 338.5º E suggesting that it is developed in a large, most likely early Noachian, impact crater (Glotch & Christensen, 2005). It is connected to the Ares Vallis by a 15 km wide and 2.5 km deep outflow channel, the Aram Valley. There are no indications about the the time of formation of the original impact crater, but for a crater of that size it is likely that the impact took place in the Noachian (>3.7 Ga, Zegers et al., 2010)

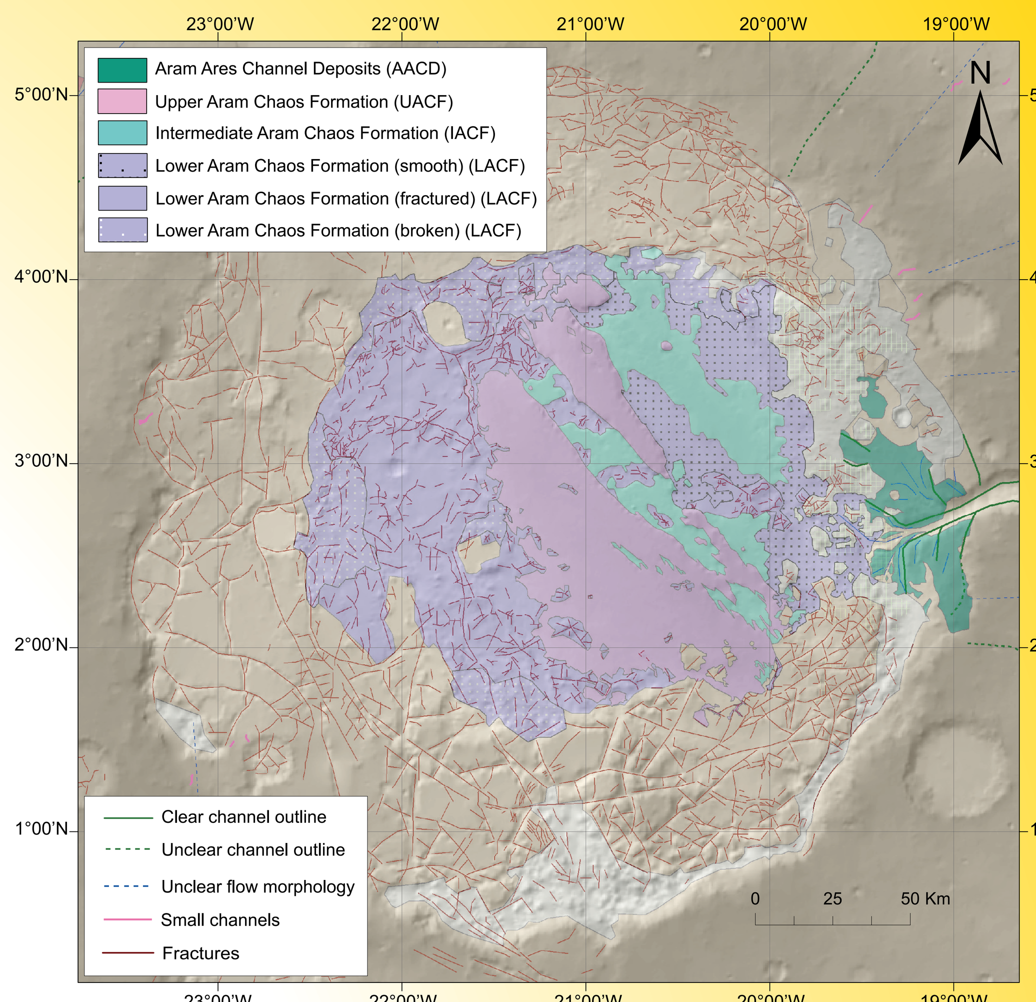

Fig. 2 - Geological map of Aram Chaos (Oosthoek et al., 2007)

Glotch & Christensen (2005) divide the Aram chaotic terrain into three, possibly lateral units. The largest unit, the Fractured Plains unit, almost completely surrounds the crater rim. It consists of up to tens of kilometers sized slumped blocks forming a curvilinear fracture pattern. The second unit, the Knobby Terrain unit, occurs in the central part of Aram Chaos and at some locations surrounds the crater rim. It consists of km scale irregular blocks (knobs). The High Thermal Inertia Chaotic Terrain unit occurs in the central part of Aram Chaos and underlies outcrops of layered material. These layered units (500 m thick) are composed by mono- and polyhydrated minerals such as sulfates and ferric-oxides. The geological mapping (Oosthoek et al., 2007) shows fractures in the Highland Unit, locally covered by the distinct depositional fractured Lower Aram Chaos Formation. The fractured Aram unit is itself also fractured.

Aram Valley morphology

The Aram Valley is a deep (2.5 km) V-shaped valley (Fig. 3a, b) with a low width/depth ratio (6-8) which connect the Aram Chaos to the Ares Vallis. The inlet of the valley along Aram Chaos boundary is characterised by a high number of relative small and deep channels and radial grooved terrains overlying the fractured and knobby units (Fig 3b, d). The distal part of the inlet stands at higher elevation with respect to Aram Valley floor (Fig. 3c). This complex structure is interpretable as a **fan-shaped erosive remnant** from flow converging into the channel.

The valley slope, obtainable removing from the profile (Fig. 3c) two landslides which occur along the northern rim of the Aram Valley, **is quite constant with a gentle gradient** (0.004) toward the Ares Vallis. In the valley cross-section 1 and 2 (Fig. 3b), **some abandoned flow terraces** are observable on the north-eastern part of Aram channel and their depth below the surrounding plateau (from 230 to 520 m) **is a reasonable estimate of channel depth.**

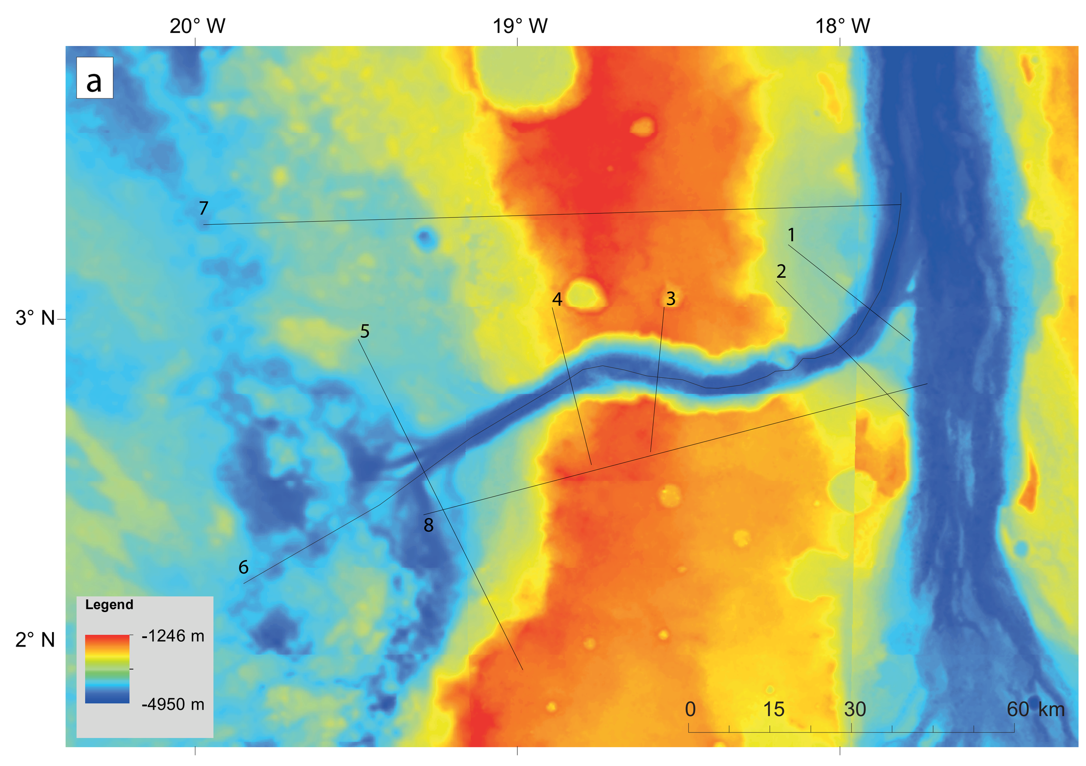

Fig. 3a - DTM image of Aram Valley (HRSC)

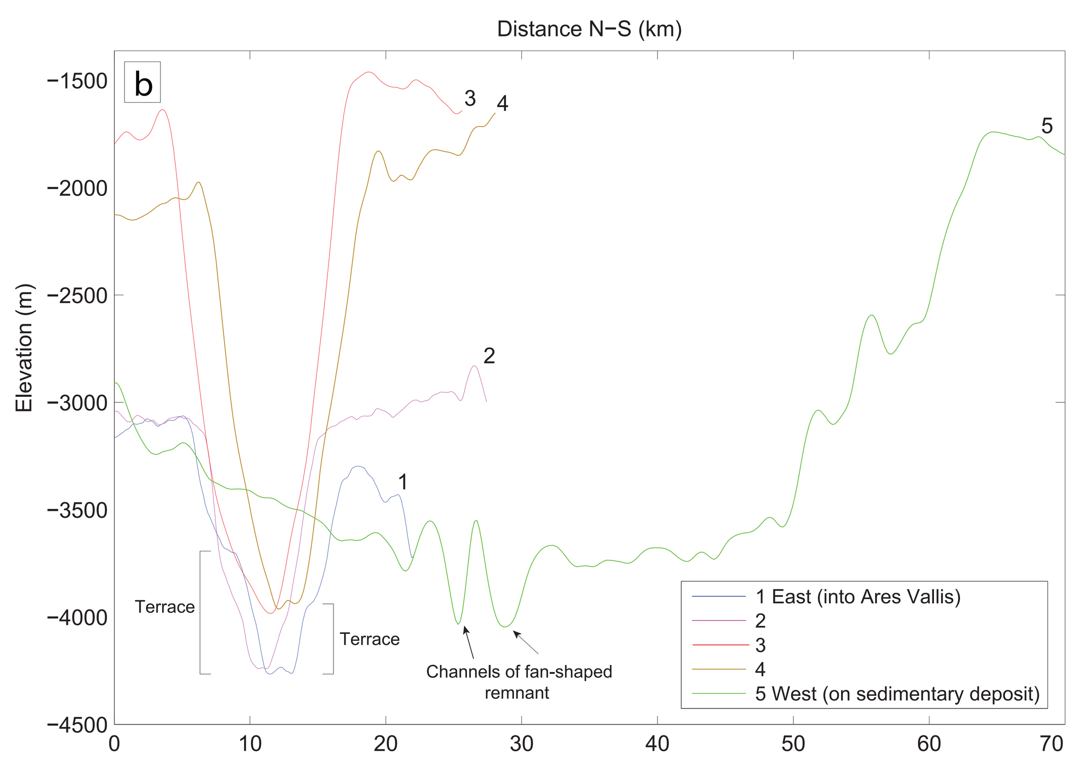

Fig. 3b - N-S cross-sections across Aram Valley

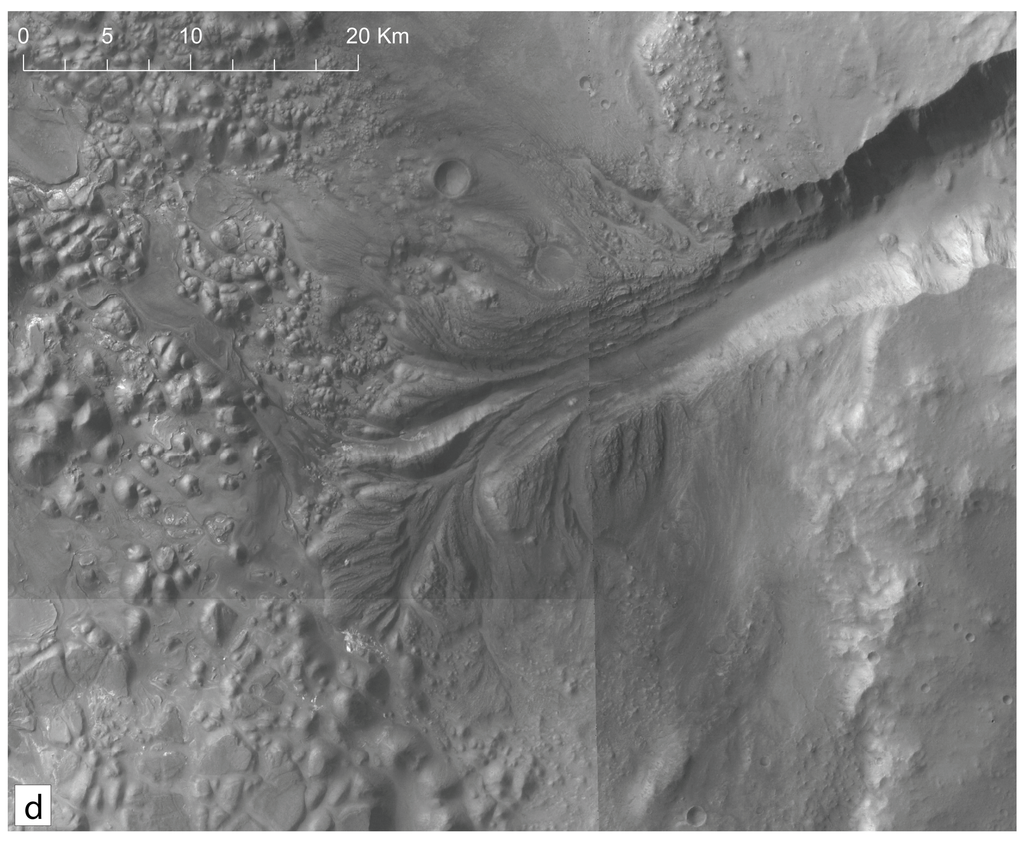

Fig. 3d - HRSC image of fan-shaped erosive remnant located at the inlet of Aram Valley

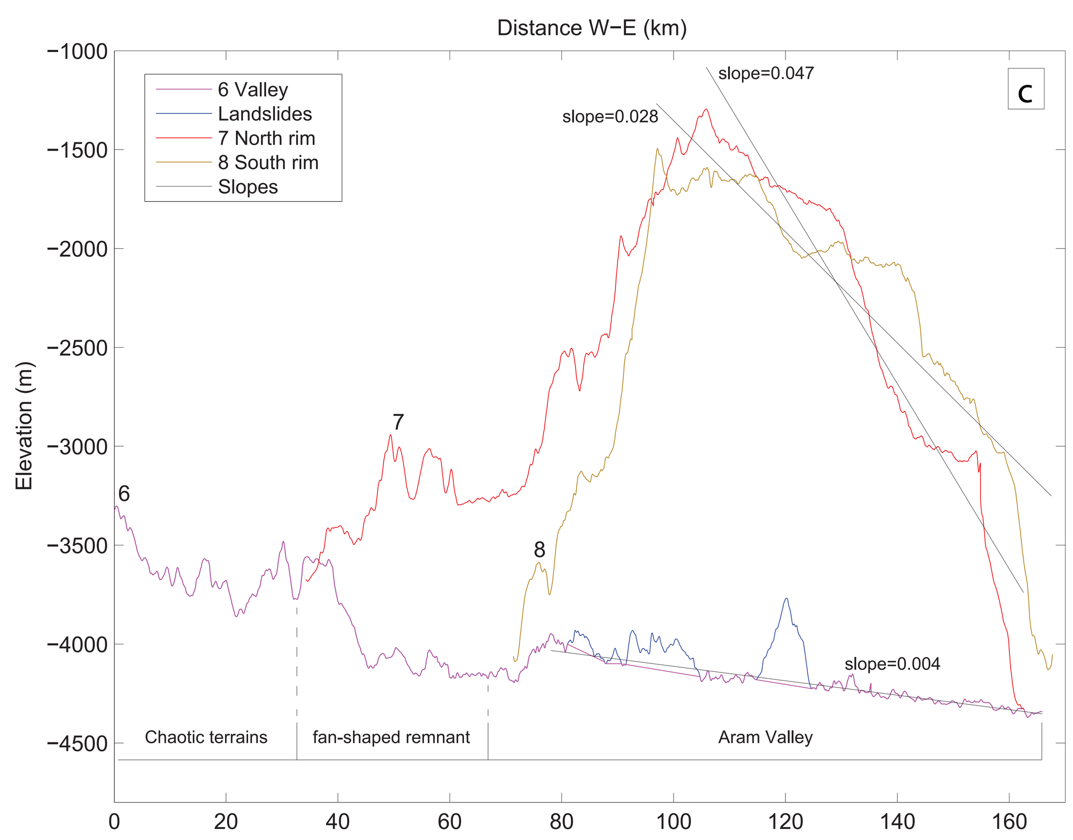

Fig. 3c - N-S cross-sections across Aram Valley

The topography of Ares Vallis (Fig. 4) shows an abrupt increase in slope at the confluence with Ares Valley as well as and an increase of width. These observations clearly support the interpretation of Warner et al., (2009) suggesting that the water outflow from the Aram Valley was synchronous with final erosive event of Ares Vallis.

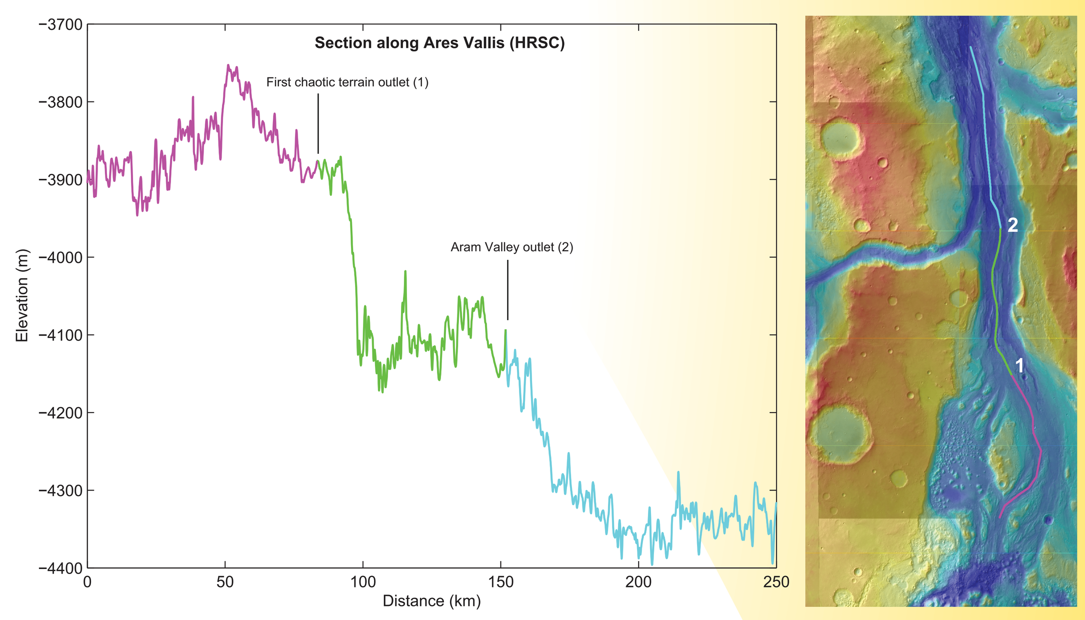

Fig. 4 - N-S cross-sections along Ares Vallis

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 (Kleinhans, 2005).

1) We estimate the **volume of sediment eroded** from the valley from cross-sections and the length of the valley. The 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 (Table 1).

2) **Flow flux (Table 1) is calculated using flow depth and gradient of the channel.** Then hydraulic roughness is calculated, from which the flow velocity and flow discharge 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 (Kleinhans, 2005).

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). The ratio of suspended and bed load transport is much larger than unity, so that the system is suspended load dominated.

The time scale for channel formation then becomes of the order of tens of days (Table 1)

4) To estimate the total **water volume that must have come out of the Aram Chaos crater** to form the observed Aram Chaos channel, the formative time scale for channel excavation can be multiplied with the flow flux . This yields a **water volume estimate of $9.3e^4$ km^3** , which is not significantly different from the independent estimate of the volume from crater geology ($9.3e^4$ km^3, Zegers et al., 2010), assuming a simple cylindrical shape of the crater.

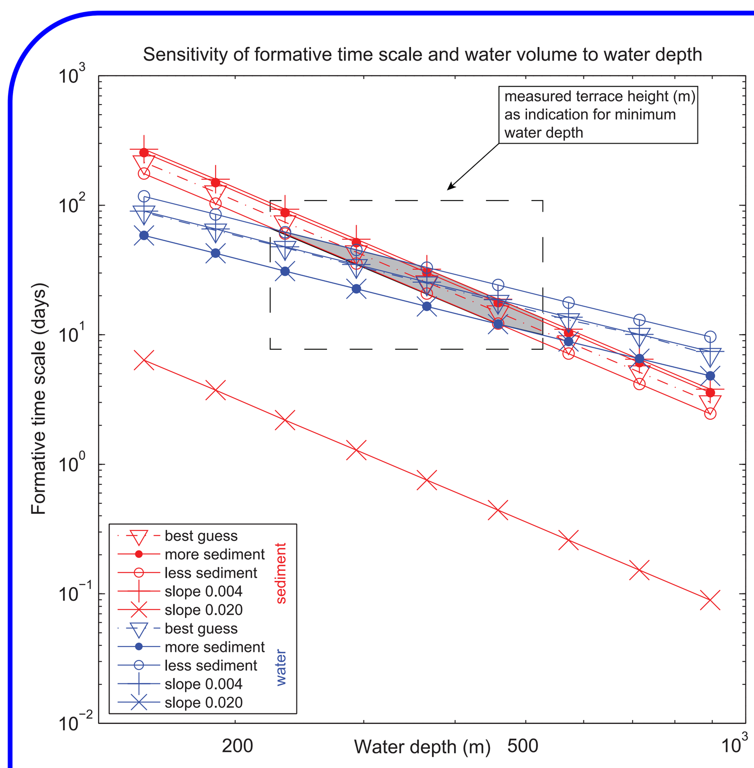

Fig. 4- Sensitivity analysis of formative time scale and water volume to water depth in the channel.

A sensitivity analysis was done for the parameters that are the least well-known, in particular **water depth.** 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.

Input Values	Gravity, g	m3/s	3.74
	Channel width, W	m	8000
	Channel depth, h	m	375
	Slope of upstream channel	m/m	0.0045
	Median Grain Size (D50)	m	0.1
Discharge calculations	Hydraulic radius, Rh	m	342.9
	width/depth ratio (line 5/4)	-	21.3
	Friction factor, f, eq.13 Kleinhans	-	0.2
	Effective Manning coefficient (Mars, not used here)	-	0.2
	Velocity, u	m/s	14.9
	Froude Number, Fr	-	0.4
	Reynolds Number, Re	-	3182800354
	Discharge, Qw	m3/s	4.46E+07
Bedload transport	Grain friction factor, f	-	0.02
	Grain Shear Stress	Pa	4.53E+02
	Shields Parameter (grain-related)	-	0.48
	Volumetric transport rate Qs	km3/day	0.21
	water/sediment ratio	-	1.88E+04
	total/bedload ratio (if >10 then use total load calculations)	-	92.2
Total load transport	Total Shear stress	Pa	6.31E+03
	Shields Parameter (total)	-	6.7
	Volumetric transport rate Qs	km3/day	18.9
	water/sediment ratio	-	2.04E+02
Erosion/sedimentation	Eroded sediment valley volume (+/- 9E+1)	km3	455.2
Time-scale of Formation	**Valley volume / total sediment flux**	**days**	**24.1**
Predicted volume of flood	**formation time scale * flux (compare to 41)**	**km3**	**9.27E+04**

Table 1 - Input parameters and resuls for flow volume and time scale determinaton

Conclusion

The flow volume needed to carve the Aram channel (**$9.3e^4$ km^3**) is quite similar to the volume of water that was produced in a single chaotization event of the Aram Chaos (**$9e^4$ km^3**). 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.

References

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