UNCERTAINTIES IN WATER DISCHARGE RATES AT THE ATHABASCA VALLES PALÆOCHANNEL SYSTEM, MARS.

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Introduction: The Athabasca Valles, in Cerberus Plainum, Mars, form a network of outflow channels that are among the youngest on Mars [1,2]. We interpret the origin to be the result volcano-tectonic fracturing of the cryosphere [3] which released a pressurised aquifer system at a flux rate estimated [4,5,6,7] to be in the range 1-2 x 10^6 m^3 s^{-1}. We previously used this estimate to demonstrate that the water must have been in the liquid state before eruption [8], as dyke-cryosphere thermal interactions would be insufficient to melt the required volume at the required rate.

However, our suspicion, during and following this initial study, and based on research into other channel systems on Mars [8,9], was that previously quoted uncertainty ranges were much smaller than can reliably be derived based on palaeochannel measurements when taking into account all uncertainties. The aim of this study, therefore, is to re-analyse the palaeohydrology of Athabasca Valles, in order to reassess previous water discharge estimates. The main element of this work is the inclusion of all obtainable error and uncertainty estimates.

Method: A GIS containing all relevant MOC, THEMIS and MOLA data was created within ArcMap, and organized into various data frames. Only channels with unambiguous geomorphologic indicators (unidirectional bedforms, clearly distinguishable channel margins) were digitised. In total, the dimensions of seven channel sections were measured for the purpose of the discharge estimates.

Due to the interpolated nature of the MOLA grid file the elevation measurements were performed on the spot data. The high-water and low-water marks were identified using the criteria laid out by *Baker et al.* [10], such as bank erosion, divide crossing and the elevation of the depositional zone of streamlined bedforms. The differences in elevation between the bank and the channel bed at numerous points along the channel were calculated to derive channel depths for various scenarios. Widths were measured perpendicular to inferred flow lines. Slope gradients were measured between pairs of points along the channel.

Water velocity and discharge estimates were derived using the Darcy-Weisbach equation, as described and advocated by *Wilson et al.* [8]. The data obtained from the measurements in the GIS were used to calculate the friction factor, velocity and discharge for various channel stretches and different assumptions about the nature of the channel bed. A forward uncertainty analysis on the estimation of the discharge was performed by considering the following sources of uncertainty: (1) Measurement errors on the width and depth of channels; (2) Minimum, average and maximum values of bed roughness taken from the literature; (3) Different types of channel beds (sand-bed, boulder-bed, gravel-bed and fixed-bed); (4) An assumed 10 % error in the friction coefficient calculations (a sensitivity analysis was performed to identify the most important coefficients); (5) Effects of assuming bank-full flow (different scenarios for flow depth and width).

Results: Uncertainties in the Darcy-Weisbach solution resulting from most common measurements and assumptions were analysed. Measurement errors and grain size assumptions introduced uncertainties of <33% and < a few tens%, respectively.

Bed material assumptions. The friction factor depends on the nature of the channel bed (sand, gravel, boulder or fixed) and only has a semi-physical basis [11]. We find, using terrestrial data on water flow in channels, that the bed type does not greatly affect the discharge estimates (typically <~50% error), consistent with previous studies using the Darcy-Weisbach equation for flux estimates [8]. However, water depths in martian outflow channels were much greater than common values on Earth, and it is not clear that expressions for friction factors derived from terrestrial data can be safely applied to Mars. An effort was made to obtain the standard deviations on the regression coefficients from the original sources. However, the reference papers only include the average error on the estimation of the friction factor for each of the data sets used. Many of the source databases are not published and hence it was not possible for us to reconstruct the multiple regression analysis in order to obtain an appropriate error range on the coefficients. Without such a reconstruction, further empirical work may be necessary in order to fully understand the uncertainties implicit in application of this technique to Mars.

Effect of the bank-full assumption. Due to the limited resolution of the pre-MOLA and pre-MOC data it has been difficult to obtain unambiguous palæo-height indicators for channel flow on Mars [6]. Hence, most palæo-hydraulic modelling on Mars has been performed assuming bank-full flow, i.e. the water has been thought to reach a height beyond which it would disperse over the adjacent terrain [6]. In reality, bank-full flow is unlikely, as explained by *Wilson et al.* [8]. Dismissing the possibility of post-flood erosional processes modifying the channel topography, it can be assumed that the present-day depth of the channels results from the water flow erosion of the pre-flood surface in the channel. Thus in order for the flow to remain bankfull during erosion, the water volume flux would have to increase with time. However, the pressure gradient driving water release is likely to decrease with time, leading to a *decrease* as opposed to an *increase* of the volume flux over time. Hence, it is concluded that bankfull conditions may only be achieved during a transient period of very high water flux during which the pattern of bed erosion is established [8,12]. In fact, in many cases the bank-full assumption may never be achieved if there is already a depression that is utilised by the released water, and we have found that this can significantly affect discharge rate estimates. To illustrate this, we used a conservative estimate of the actual flood height (taken here as 5% bankfull). Such a low water level is clearly subjective, but we argue that it is no more so than a bank-full assumption unless contradicted by other evidence. In all cases, we found factors of several difference when compared with the bankfull assumption; in one case (channel 2) the difference was a factor of 50.

Range of discharge estimates. Calculated discharge rates of the individual channels are given (table 1). Most of the uncertainty here is due to the range of flood heights (varying from 5% to 100%). In all but one case, discharge estimates for the Athabasca channel system vary by more than 3 orders of magnitude.

Conclusions: Our findings are that the most important sources of uncertainty are the assumption of bank-full flow and the values used for the coefficients of the equation used to calculate the friction factor for sand-beds. Discharge rate uncertainty can be almost four orders of magnitude: between 3.2×10^3 and 2.5×10^7 m^3/s for the Athabasca Valles channels. These figures could become larger if channels were found to be active in parallel, but the uncertainties are unlikely to change. However, this range is still sufficient to conclude that the erupting water must have been in a liquid state before eruption. It remains likely that subsurface flow was non-porous, and was instead through a horizontally-interconnected fracture system of indeterminate nature, that may or may not have been formed in response to the onset of activity.

Perhaps more importantly, our calculations suggest that the errors associated with water flux estimates, using either Manning or Darcy-Weisbach equations, for channels systems on Mars may need to be reassessed. With further research it may be possible to reduce the uncertainties implicit within such treatments, but it is likely that they will still be greater than the factor of a few usually quoted. A more rigorous uncertainty-based approach may be more time-consuming, but yields more reliable results that can be utilised, not only for hypothesis testing, but also for reconstructive modelling.

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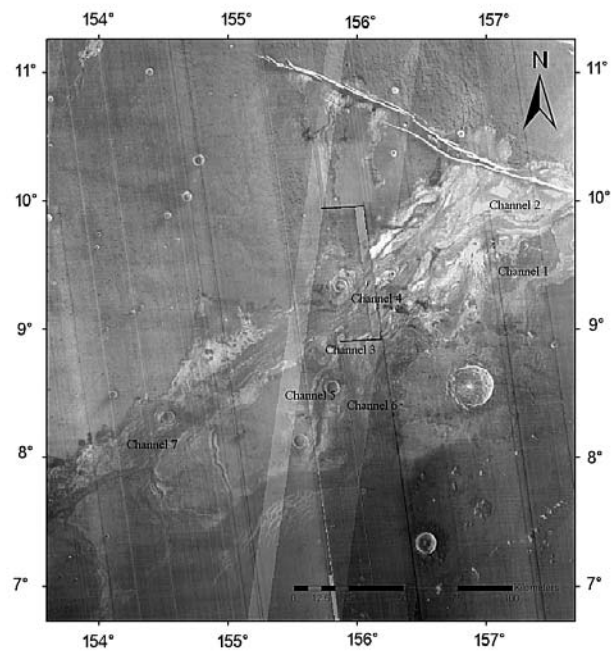

Figure 1: Locations of measured channels in Athabasca Valles.

Channel ID	Min (x 10^3 m^3/s)	Ideal (x 10^6 m^3/s).	Max (x 10^6 m^3/s)
1	6.5	1.16	16.25
2	3.2	1.68	9.61
3	9.0	0.82	8.57
4	13.7	0.72	24.53
5	6.6	0.15	11.04
6	10.7	0.35	11.74
7	8.0	2.00	9.53

Table 1: Discharge rates for 7 channel cross-sections.