THE FORMATION OF AROMATUM CHAOS AND THE WATER DISCHARGE RATE AT RAVI VALLIS. Harald J. Leask, Lionel Wilson and Karl. L. Mitchell. Planetary Science Research Group, Environmental Science Dept., Lancaster University, Lancaster LA1 4YQ, UK. (h.leask@lancaster.ac.uk; l.wilson@lancaster.ac.uk)

Summary: The Aromatum Chaos depression-Ravi Vallis outflow channel system is sufficiently simple that water flow rate and volume estimates can be made that throw light on processes operating to form the Aromatum and Ravi features. Typical discharge rates through Ravi Vallis are estimated at 3 x 10^6 m^3 s^{-1}. By assuming a high sediment load in the water we find a minimum duration of ~2 months. Too much water flowed in the channel to be explained by cryosphere melting alone, and drainage of a local aquifer system delineated by intrusions is clearly implicated.

Aromatum Chaos: The main Aromatum Chaos depression is a truncated triangle ~92 km long and an average of 30 km wide (Fig. 1). Its interior consists mainly of a mass of blocky-chaotic terrain, with blocks generally becoming progressively smaller towards its Eastern end. Some larger blocks at the Western end show some evidence of rotational slumping and also appear to be less eroded, having flat tops showing a rather angular connection between the flat top and the walls. The edges of Aromatum Chaos show strong evidence of local structural control and so, in an attempt to look for similar control of the interior, we examined all MOLA profiles crossing the interior, and found 30 profiles which collectively crossed the tops of 20 blocks. From these we measured the absolute heights (relative to Mars datum) of the tops of the blocks and their depths below the rim of the depression. The tops of blocks lie between 1,008 m and 2,361 m below the rim and show no systematic correlation with depth below rim or height above floor, suggesting piecemeal collapse rather than a structural control on their subsidence.

We also integrated the topographic profiles to find the volume of material missing from the depression, and extrapolated a smooth curve through the local minima of the profiles to find an approximation to the shape of the depression disregarding the blocks on the floor. The depression is an asymmetric bowl-shape with a maximum depth of 3.45 km below the rim level. It shallows more slowly to the NE, where it connects with Ravi Vallis (Fig. 1), than to the SW. The missing volume is ~4,100 km^3 and the mean depth is ~1.49 km.

It seems very unlikely that the volume of the depression represents compaction after removal of cryosphere ice: If the geothermal gradient on Mars is ~15 K km^{-1} and the annual average mean surface temperature near the equator is 210 K, this implies that the cryosphere thickness is ~[(273-210) K] / [15 K km^{-1}] = ~4 km, and if the cryosphere ice content is ~10% [1], the thickness of ice which can be removed is only ~400 m. Even if one added the vertical extent of complete compaction in an underlying aquifer of depth, say, 5 km and maximum pore space ~5% [1], the added vertical change would only be ~250 m. The shape of Aromatum, especially the presence of straight segments of the margin on the south side (Fig. 1), strongly suggests that the formation of the depression is related to the intrusion of one or more dikes and the emplacement of a sill [2]. We therefore explore the possibility that the intrusions breached the cryosphere as well as melting ice within it, and that some crustal material has been carried away by water seeping into the depression from an underlying aquifer system and overflowing into Ravi Vallis.

Ravi Vallis Channels: The floor of Aromatum Chaos rises to about 1 km below the rim at its Eastern end as it connects into Ravi Vallis. This opening is the narrowest part of Aromatum Chaos and forms the highest part of the floors of either the Chaos or the Vallis. There are multiple indicators of water flow in Ravi Vallis, especially teardrop shaped islands and longitudinal floor grooving. There are also two small areas of chaotic terrain, Iamuna Chaos and Oxia Chaos, on the floor of the Vallis. Although there are indications that water overflowed the width of the main channel for a while early in its formation, the presence of typically 6 deeply eroded and sometimes braided sub-channels, each 50-100 m deep, within the main channel, suggests that the water was rarely more than 100 m deep in Ravi Vallis despite its typical ~700 m depth. A total volume of about 2000 km^3 has been eroded to form the channel.

For a wide range of possible water depths from 50 m to bank-full, we used the average regional slope of the channel floor (0.0026) to calculate the water flow speed in each sub-channel seen in each of 7 MOLA profiles. The Darcy-Weisbach bed friction coefficients (rather than the Manning coefficients, about which there are uncertainties that we shall discuss elsewhere) were used for a range of channel roughnesses. Since the water depth is much greater than the roughness scale there is little spread in water speed values for a given water depth. Multiplying the speed by the depth and average channel width for that depth we obtain a water flux. These were summed for each MOLA profile and the values averaged. For bank-full flow the flux would have been ~2.6 x 10^7 m^3 s^{-1} but for water depths in the 50-100 m range, which we consider much more likely, the flux would have been 2.3-4.6 x 10^6 m^3 s^{-1}, with formal errors of ~30%. We adopt 3 x 10^6 m^3 s^{-1} as a best estimate.

Flood duration and total water volume: There is no unambiguous way of estimating the duration of the water flow in Ravi Vallis and hence the total water volume released. However, a lower limit can be estimated by assuming that all of the missing crustal volume not attributable to cryosphere ice removal was carried away as sediment at the maximum possible water loading, of order 40% [3, 4]. If ice formed 10% of the cryosphere [1], the missing rock volume is [0.9 x (4100 + 2000) =] 5490 km^3. If this represented 40% of the flood volume, then the remaining water volume was [(60/40) x 5490 =] 8235 km^3. This water volume would have consisted of the ~610 km^3 derived from melted cryosphere ice and an additional [8235 - 610 =] 7625 km^3 derived from the underlying aquifer system.

Using our best (~50-100 m water depth) estimate of typical flood discharge, 3 x 10^6 m^3 s^{-1}, and allowing for the fact that only 60% of this is water, i.e. ~1.8 x 10^6 m^3 s^{-1}, the implied duration of flow is [(7625 x 10^9 m^3) / (1.8 x 10^6 m^3 s^{-1})] = ~4.2 x 10^6 s, i.e. ~49 days. Of course, if the flood were not capable of transporting as much as 40% by volume solid debris, the durations would be increased and the aquifer water volume estimate would also increase. For example at 20% load the aquifer water volume would have to be 21350 km^3, the water flux 2.4 x 10^6 m^3 s^{-1}, and the duration 103 days.

Assuming aquifer porosities of ~5% and vertical extents of ~5 km, the surface areas of the aquifer systems needed to contain water volumes of 7625 and 21350 km^3 are 30500 and 85400 km^2, respectively. The surface of the region immediately to the West of Aromatum Chaos shows clear evidence of fracturing, pitting and collapse, and extrapolation of the regional topography implies that it was originally at a higher elevation than the rim of Aromatum Chaos. The surface area affected is ~37000 km^2, which would therefore correspond to the area of drained aquifer needed to supply the Ravi flood if the sediment load had been about 30%. It is very tempting to conclude that the scenario proposed here, of volcanic intrusions disrupting the cryosphere and allowing drainage of a section of part of the regional aquifer system confined by dikes acting as aquicludes, is the explanation for the Aromatum-Ravi system.

References: [1] Hanna, J.C. and Phillips, R.J. (2003) *LPS XXXIV*, abstract #2027. [2] Head, J.W. & Wilson, L. (2002) pp. 27-57 in *Geol. Soc. Lond. Spec. Publ. 202*. [3] Komar, P.D. (1980) *Icarus, 42,* 317-329. [4] Carr, M.H. (1987) *Nature*, *326*, 30-35.

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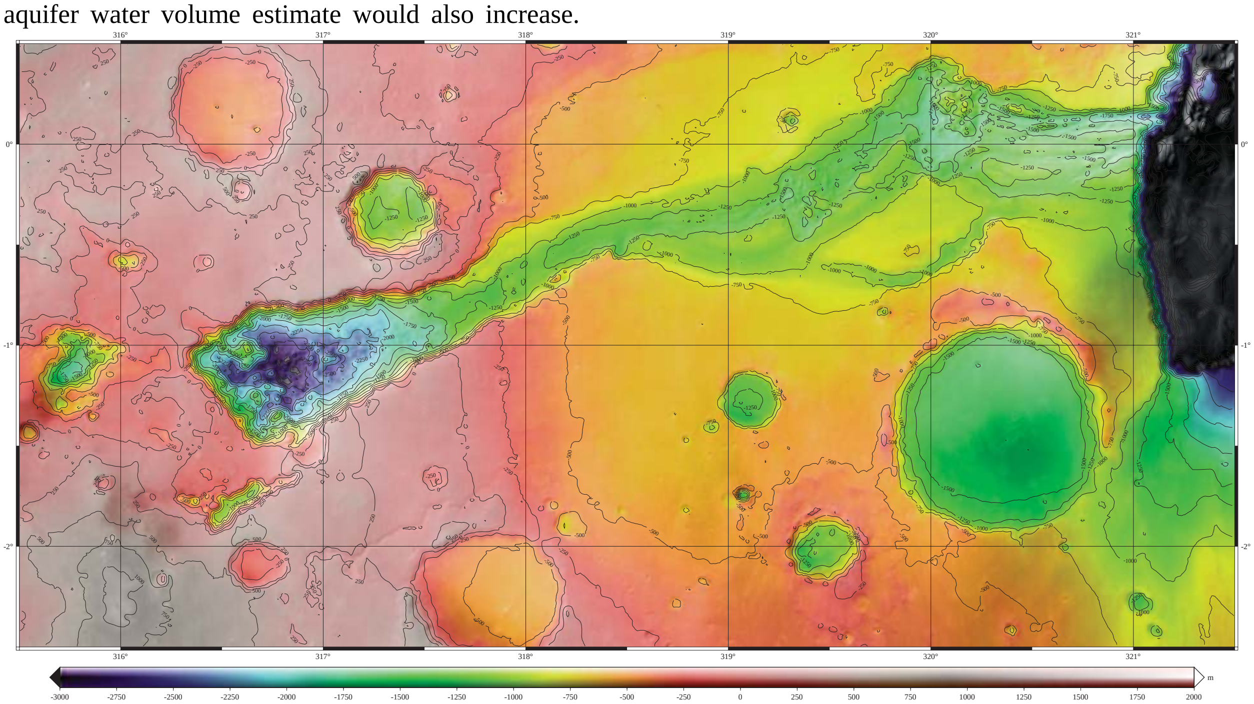

Fig. 1: Overview map of Aromatum Chaos and Ravi Vallis, using the MOLA MEGDR 128 ppd gridded dataset and the MOC global mosaic, converted to planetocentric projection by Trent Hare, USGS Flagstaff.