GROUNDWATER DEPTH, CRYOSPHERE THICKNESS, AND CRUSTAL HEAT FLUX IN THE EPOCH OF RAVI VALLIS, MARS.

Neil M. Coleman[1] and Cynthia L. Dinwiddie[2], [1]U.S. NRC, Washington, DC, (nmc@nrc.gov), [2]CNWRA at Southwest Research Institute®, San Antonio, TX (cdinwiddie@swri.edu)

Introduction: Ravi Vallis is an outflow channel that emerged from Aromatum Chaos, a region of collapsed ground in Xanthe Terra, Mars. The megaflood that carved Ravi Vallis incised the crust >700 m. We propose that this erosion penetrated the cryosphere and triggered the genesis of secondary chaos zones in the deepest parts of Ravi Vallis (Figure 1). Iamuna* and Oxia* Chaotes (IAU provisional names) represent a class of chaotes that can form solely in response to fluvial incision. We estimate the cryosphere thickness and depth to groundwater as the sum of the incision depth and the thickness of rock beneath the channel floor that could be disrupted by artesian pressure [*Coleman*, 2005]. Figure 2 shows a MOLA profile across the deepest channel of Ravi Vallis. At this location, fluvial erosion incised ~730 m into the upper crust and created an inner channel more than 200 m deep. Iamuna Chaos formed just downstream of the profile in Figure 2. The inner channel leads directly into the deepest part of the chaos, which we interpret as the point of initial groundwater outbreak.

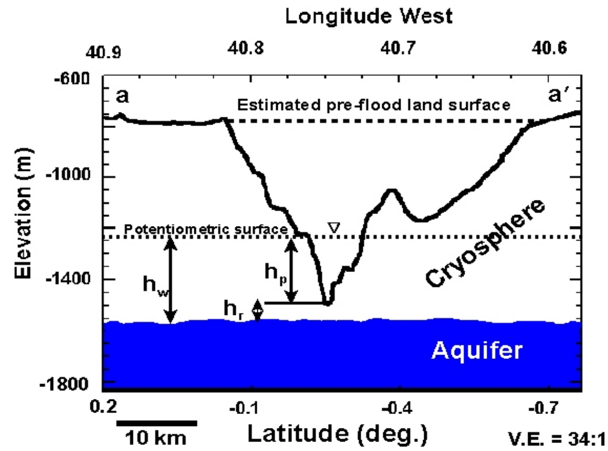

Fig. 2. *GRIDVIEW* [2004] plot of MOLA elevations along profile a-a', located just west of Iamuna* Chaos. The deepest part of the channel is an inner channel with a floor elevation of -1507 m. Elevation of the pre-flood land surface is estimated using the northern channel margin, which stands at -780 m. Total channel depth is >700 m. Spatial relations of the "h" variables used in equations 1 and 2 are illustrated.

Discussion: The hypothesized mechanism for chaos initiation and groundwater release is illustrated in Figure 3. Prior to the flooding, groundwater in Xanthe Terra was confined beneath a thick layer of permafrost, with a potentiometric surface that was higher than the land surface. Eventually, at the present-day location of Aromatum Chaos, the cryo-confining layer was disrupted by a tectonic, geothermal, or impact event. Groundwater erupted onto the surface, flowed torrentially downslope, and rapidly eroded the land surface to the E-NE. Flow would have readily maintained itself because re-freezing of the cryosphere would have been inhibited by the initial high discharge rate, relatively warm groundwater temperatures, the high heat capacity of water, and physical erosion of the aquifer and confining layer. A lake would have filled Aromatum Chaos during the flooding, with the lake level controlled by the overflow elevation (-1230 m) of the channel floor to the east.

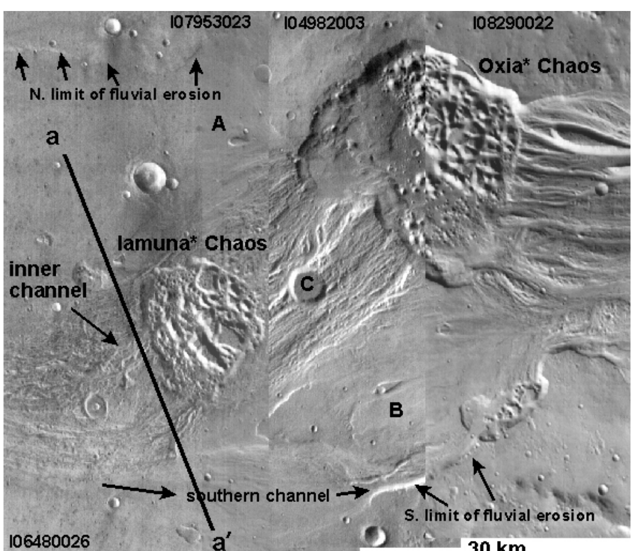

Figure 1. Secondary chaos zones in the deepest channel of Ravi Vallis. Flow direction was from left to right. Streamlined islands (A, B, & C) and erosional scarps reveal that initial flooding carved a scabland >60 km wide. Island "C" is located at MOLA 0.17°S, 40.34°W. Mosaic of 4 THEMIS images.

The critical condition for groundwater breakout occurred as the flood discharge waned and the inner channel attained its maximum depth. As long as water flowed in the channel, overpressure from below would have been partly offset by the floodwater depth. As the floodwaters receded, the overpressure would have increased until it overcame the overburden load and rock strength and broke through the channel floor, initiating a new groundwater discharge area. With pressures being relieved downstream at Iamuna Chaos, flow from Aromatum Chaos would have slowed and stopped. Flow from Iamuna further incised the northern branch of Ravi Vallis and spawned another secondary outbreak at the site of Oxia Chaos.

The former cryosphere and groundwater depth at Iamuna Chaos can be estimated over a relatively narrow range. The minimum depth is the estimated depth of channel incision (i.e., ~730 m) relative to the pre-flood surface. The maximum depth is estimated by analyzing the pressure differences that existed at the channel floor. The channel floor would have ruptured from below if the

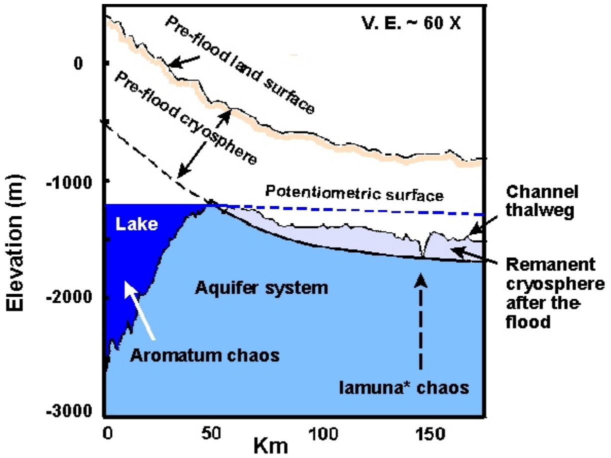

Figure 3. Cross section of the upper crust at the time of the Ravi Vallis flood, illustrating both pre-flood and post-flood conditions. The top line represents MOLA elevations for the N. bank of Ravi Vallis at places where the slope changes dramatically, marking the vertical and lateral limit of fluvial erosion. The thalweg represents the path of lowest elevation along the channel floor. Elevations were obtained using *GRIDVIEW* [2004] and data file 30s_0_300e_330e.grd [*GSFC*, 2004].

confined hydraulic pressure exceeded the overburden pressure of the residual confining layer. Given that pressure equals the product of average fluid (or rock) density, gravitational acceleration, and height of the fluid (or rock) column, the condition for groundwater breakout occurs when $\rho_r g h_r \leq \rho_w g h_w$ [equation 1] where ρ_r is the average rock density beneath the channel floor, g is the acceleration of gravity on Mars (3.7 m s^{-2}), h_r is the thickness of the confining layer between the channel floor and the top of the aquifer, ρ_w is the groundwater density, and h_w is the potentiometric head above the top of the aquifer. Note that h_w is the sum of h_r and h_p (height of potentiometric surface above the channel floor - see Fig. 2). We simplify equation 1 and introduce h_p to obtain Equation 2, where $h_r \leq (\rho_w \cdot h_p) / (\rho_r - \rho_w)$ [*Coleman*, 2005].

The critical thickness for the rock layer beneath the channel was analyzed using a bulk density ρ_r that represents basalt (>2500 kg m^{-3}), a groundwater density ρ_w that represents a strong brine (~1200 kg m^{-3}), and h_p ~ 276 m. These values yield an upper limit for the layer thickness that could be ruptured by overpressure. We solve for h_r using equation 2 to find that, beneath the channel floor, strata ≤255 m thick would have been ruptured by the maximum confined hydraulic pressure of 2.4×10^6 N m^{-2} [2.4 MPa or 23 atm]. Adding 255 m to the incision depth (~730 m) yields a maximum groundwater depth and cryosphere thickness of ~985 m. Our initial analysis of Oxia Chaos yields similar results.

Near Iamuna Chaos the cryosphere thickness and groundwater depth was 700 to 1000 meters at the equator, indicating a cold, long-term climate trend. The cryosphere thickness can be used to constrain crustal heat flow. We apply the steady-state equation for 1-D conduction [see *Clifford*, 1993] using parameters that should yield a minimum value for the heat flux. We used a column-averaged thermal conductivity (k) for the upper crust of ≥1.0 W m^{-1} K^{-1} [lower limit of *Clifford*, 1993], a mean annual surface temperature [MAT] ≤220 K, a cryosphere thickness of ≤1 km, and a melting isotherm [T_{mp}] of ≥252 K to represent a dense groundwater brine at the base of the cryosphere. We obtain a *minimum* crustal heat flux of ~32 mW m^{-2} at the time of the Ravi Vallis flood. This estimate would increase significantly using other parameter values. For example, new geochemical evidence from Meridiani [*Squyres et al.*, 2004] suggests that sulfate salts might have dominated the hydrosphere of Mars. A strong brine of $MgSO_4$ has a freezing point depression of only 3 to 4 K. Therefore, in the above calculation, increasing T_{mp} to ~270 K would yield a crustal heat flux of ~50 mW m^{-2}. Mixed salt solutions would somewhat lower the calculated heat flux.

If correct, our evidence for a thick cryosphere would place limits on the former pervasiveness of exotic groundwater brines with T_{mp} ~210 K [lower limit of *Clifford*, 1993]. Such brines would not freeze unless the prevailing MAT at the equator was less than ~210 K.

Conclusions: The fluvial incision and groundwater breakout model described here can fully account for the inception of Iamuna and Oxia Chaotes. A locally elevated geothermal flux was not required. In the epoch of Ravi Vallis, the groundwater depth and cryosphere thickness was 700 to 1000 m at the equator in the vicinity of Iamuna Chaos. We estimate a minimum crustal heat flux of 30 to 50 mW m^{-2}.

References: Clifford, S., *JGR*, 98, 10973-11016, 1993; Coleman, N., *submitted to JGR*, 2005; Squyres, S. et al., *Science*, 306, 1709-1714, 2004. To obtain GRIDVIEW [2004] and MOLA data grids [GSFC, 2004], visit http://core2.gsfc.nasa.gov/.

Disclaimer: Prepared in part by an employee of the NRC on his own time apart from regular duties. NRC has neither approved nor disapproved the technical content of this abstract.