MANGALA VALLES, MARS: INVESTIGATIONS OF THE SOURCE OF FLOOD WATER AND EARLY STAGES OF FLOODING.

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Introduction: Mangala Valles, a ~900 km long north-south trending outflow channel located southwest of the Tharsis rise, extends northward from one of the Memnonia Fossae graben across the southern highlands, terminating at the dichotomy boundary. Previous Viking-based analyses suggest that the water that carved the channel was expelled from the graben, possibly during two distinct flood events, one in the Late Hesperian and one in the Latest Hesperian/Early Amazonian [1]. The mechanism by which the water was transported to the graben, and ultimately to the surface remained ambiguous, although two general scenarios were proposed: melting of near surface ground ice via nearby Tharsis lava flows [2], and tapping of a near surface aquifer via faulting associated with the graben [1]. Here we use MOLA altimetric data and MOC and THEMIS images to reexamine Mangala Valles and the surrounding region. Further, we develop a new model for the production and transport of the floodwater.

Mangala Valles head region: Mangala Valles is flanked to the east by a north-south trending Noachian-aged scarp [3,4], and to the west by high-standing cratered terrain (Figure 1). The channel heads at a ~5.5 km wide and ~10 km long canyon in the northern wall of one of the Memnonia Fossae graben (arrow in Figure 1), which trends N72E, and extends for several thousand kilometers. In the region near the channel, between the east and west flanking high topography, the graben extends for ~220 km, and consists of several en-echelon components. The canyon occurs immediately north of two overlapping sections of the graben. The terrain south of the graben is smooth, with a northwest regional slope of less than a degree, and appears to be composed of Tharsis-related flood lavas [2], although it has also been mapped as a smooth plateau unit of Late Noachian/Early Hesperian age. Also directly south of the canyon is a 25 km wide impact crater (A in Figure 1), the ejecta of which is transected by the graben. To the east of this crater is an 80 km wide crater (B in Figure 1), intersected to the north via the north-south trending scarp that flanks Mangala to the east. Previous mapping suggested flooding of this crater due to overflow of the graben [3].

Our analysis of the topography of the graben with MOLA data shows that the graben s northern wall is generally several tens of meters lower than the southern wall. As such, as the graben flooded, water would have spilled out to the north without significant drainage into crater B. Further, there would have been little to no drainage to the south, accounting for the lack of water-related features south of the graben. As water over-topped the graben it would have preferentially utilized the areas of lowest elevation for drainage. Our examination of the graben s northern rim reveals three narrow (~3 km wide) north-south trending conduits of lower elevation than the surrounding terrain located within the ejecta of crater A. Additionally, the area occupied by the canyon would certainly have been utilized for drainage, and the size and extent of the canyon argues that most of the drainage out of the graben occurred through that pathway. How quickly did water coalesce into the area of the canyon? To address this issue we can compare the morphology of the ejecta from crater A north and south of the graben. The southern ejecta should not have encountered any of the flood water pouring out of the graben, whereas if significant volumes of water spilled out from the graben elsewhere than from the canyon, the northern ejecta would be expected to show significantly different morphology than the southern ejecta. THEMIS visible image V04762003 covers the area of the canyon, as well as portions of the northern and southern ejecta from crater A. Examination of the image reveals no significant variation in morphology between the two regions of the ejecta, suggesting that little spill-over occurred as the graben filled with water. Rather, it appears that as the graben filled, spill-over to the north quickly coalesced into the region now occupied by the canyon. From the time of coalescence into the canyon onward, all the water responsible for erosion of the remainder of Mangala Valles apparently passed through the canyon.

Assessment of previous models for origin of source water: While the graben at the head of Mangala has largely been accepted as the pathway to the surface for the water that carved the channel, the actual source of the water is debated. *Zimbelman et al.* [2] suggested melting of near-surface ground ice due to emplacement of lava flows in southern Tharsis led to the production of large volumes of meltwater. This water would have traveled down slope towards the head region of Mangala, and would have found a conduit to the surface where the source graben intersects a potential north-south trending thrust fault that parallels the western margin of the north-south trending scarp east of Mangala. Complications with this hypothesis include generation of sufficient volumes of meltwater necessary to erode the channel, and retention of that water near the surface of the planet for prolonged periods to account for interpreted high fluxes.

Alternatively, *Tanaka and Chapman* [1] proposed a model whereby the production of liquid water is less difficult. In their model a liquid water aquifer at depth is overlain by a frozen zone of crust that seals the aquifer and keeps the water under hydrostatic head. Fracturing of the crust associated with graben formation would have tapped the aquifer, providing a pathway for water to the surface. [1] cite several problems with this scenario, including the initial production of water for the aquifer and transport of water along the fault zone.

In general the conditions for the *Tanaka and Chapman* [1] scenario are analogous to the *Clifford* [5] model of a liquid water hydrosphere overlain by an impermeable cryosphere. Invoking the *Clifford* [5] model, the aquifer at depth proposed by *Tanaka and Chapman* [1] would be part of a globally interconnected groundwater system, recharged in the south polar region due to basal melting of the polar cap. Alternatively, the close proximity of Tharsis provides additional means for recharge of a subsurface aquifer.

Recently, *Head et al.* [6] developed a model for Cerberus Fossae/Athabasca Valles for flow of water through a subsurface aquifer under hydrostatic head, and up a fracture (formed in association with dike emplacement) that taps that aquifer. Here we apply an updated and improved version of that model to Mangala Valles.

A new model for origin of source water: While graben may result from tensional stress in the crust due solely to tectonic processes, they may also result from propagation of dikes in the crust that stall near the surface. As discussed by

Head et al. [6], such dike related graben provide an attractive mechanism for cracking a cryospheric cap, tapping an aquifer, and providing a pathway for groundwater to the surface. *Wilson and Head* [7] suggest than many of the Tharsis-radial graben systems result from the propagation of dikes near the surface of the planet and penetration to shallow depths. Of particular interest here are the Memnonia Fossae, specifically the source graben for Mangala, which is among those graben considered by *Wilson and Head* [7] to be a good candidate for a dike-related graben.

In our model [Ghatan et al., 2004], the emplacement of the dike responsible for the source graben created a pathway for drainage to the surface of water from a confined subsurface aquifer. To model the flow of water through the aquifer and up the fracture we relied upon conservation of mass (flux of water through the aquifer equals flux up the fracture) and force balance among those forces driving flow through the system and those resisting flow. The results are two equations, one describing the flux of water through the aquifer and one describing the flux up the fracture. While we make reasonable estimates of several system parameters, including aquifer depth, elevation and permeability [9], too many unknowns exist between these two equations in order to solve the system. We rely upon a third equation, which describes the fracture width in terms of the pressure necessary at the base of the fracture in order to keep it open. Using the three equations we solve the system numerically, and obtain the fracture width and the discharge of water to the surface along the length of the active fracture. The length of the active fracture is unknown, but must be less than the length of the graben in the vicinity of Mangala (~220 km), and is likely greater than the length of the graben near the canyon (~5.5 km). We use these lengths as endmembers for the active length to determine the range of possible discharges from the fracture, yielding results of 2.75 x 10^5 m^3 / s, and 1.11 x 10^7 m^3 / s, respectively. Probably, the true length of the active fracture is between this range, yielding an intermediate discharge.

Using the results from our model, we can determine the range of time it would take to fill the graben, leading to the first spill-over to the north. We determine the volume of the graben to be 460 km^3, so for an active fracture of 5.5 km the graben would first spill-over after 465 hours, and for an active fracture of 220 km the graben would spill-over after 11.5 hours.

Of significant importance in the evolution of the flooding is that the total volume of water necessary to carve Mangala (10-20 x 10^3 km^3) far exceeds the volume of water that can be stored in the graben. This implies that the flooding was not simply a result of drainage and down-cutting of a lake, but was an active and ongoing process continuously supplied by water. This is consistent with tapping a confined aquifer at depth, and transport of water to the surface along a fracture.

Discussion and Conclusions: Cracking of the cryosphere in the vicinity of Mangala Valles via a dike provides a reasonable mechanism to account for the pathway of the floodwater to the surface. Such a fracture would tap a confined aquifer, charged either through a globally continuous hydrosphere, or locally via Tharsis, releasing the groundwater to the surface. After a maximum of 465 hours the graben at the head of Mangala would have filled with water, resulting in the first spill-over to the north. Relatively quickly the flooding coalesced into the region occupied by the canyon, after which point all the water that carved Mangala passed through the canyon.

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Figure 1. MOC wide angle mosaic of Mangala head region, overlain with MOLA color topography. Arrow indicates canyon.