

TECTONIC PRESSURIZATION OF AQUIFERS IN THE FORMATION OF MANGALA AND ATHABASCA VALLES ON MARS. J. C. Hanna and R. J. Phillips. Dept. of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, St. Louis, MO 63130 USA (jhanna@levee.wustl.edu)

Introduction: A distinct class of martian outflow channels, including Mangala and Athabasca Valles (Figure 1), originate within extensional tectonic features [1,2]. Here we demonstrate that the stress change in the crust associated with the tectonism would result in a significant near-instantaneous pressurization of the aquifer contained therein, if such an aquifer existed at the time, resulting in the floods that carved the observed channels.

The extensional tectonics of Mars is dominated by giant radiating swarms of fissures and grabens, including Memnonia Fossae and Cerberus Rupes at the sources of Mangala and Athabasca Valles, respectively. The driving stress responsible for the tectonism is likely due to the flexure induced by the loading of the crust at the Tharsis and Elysium rises [3]. In addition, there is evidence that these tectonic features may be underlain by dikes at depth [4,5], in which case the driving stresses would be a combination of the flexural/membrane stresses and the dike magma pressure.

Regardless of the exact form of the tectonism and the source of the driving stress, the sense of the stress change surrounding the tectonic feature is the same. For simple faulting, the release of the extensional stress results in an effective compression of the crust surrounding the fault. For dike-induced tectonism, the growth of the dike is accommodated by compression of the surrounding crust. In either case, the resultant

compressive stress change surrounding the fault and/or dike is accommodated largely through a decrease in the volume of the pore space and fractures. Since the timescales of both faulting and dike swarm propagation are much less than typical hydraulic diffusion times, the tectonism will lead to a pressurization of the water within the pore spaces of the crust. For the cold-climate conditions currently prevailing on Mars, a thick cryosphere prevents pressurized aquifers from draining directly to the surface. However, the tectonic event not only pressurizes the aquifer, but also provides a conduit by which flow can reach the surface, resulting in a high-discharge, large volume flood of water. This process has been demonstrated to result in increased spring and river discharges following terrestrial normal faulting earthquakes [6], and is likely important in the formation of martian tectonic outflows as well.

Model: The aquifer pressurization can be quantified by modeling the stress change surrounding the fault or dike due to the tectonism, taking into account the fraction of the stress change that is borne by the water within the pore space. The regional distribution of the stress drop is calculated using a boundary element model modified from *Crouch and Starfield* [7]. The elastic response of the crust to the tectonic event depends upon the dimensions of the fault or dike, and the displacement or change in stress. For Mangala Valles, the graben depth implies a total extension of approximately 1 km, likely occurring in a

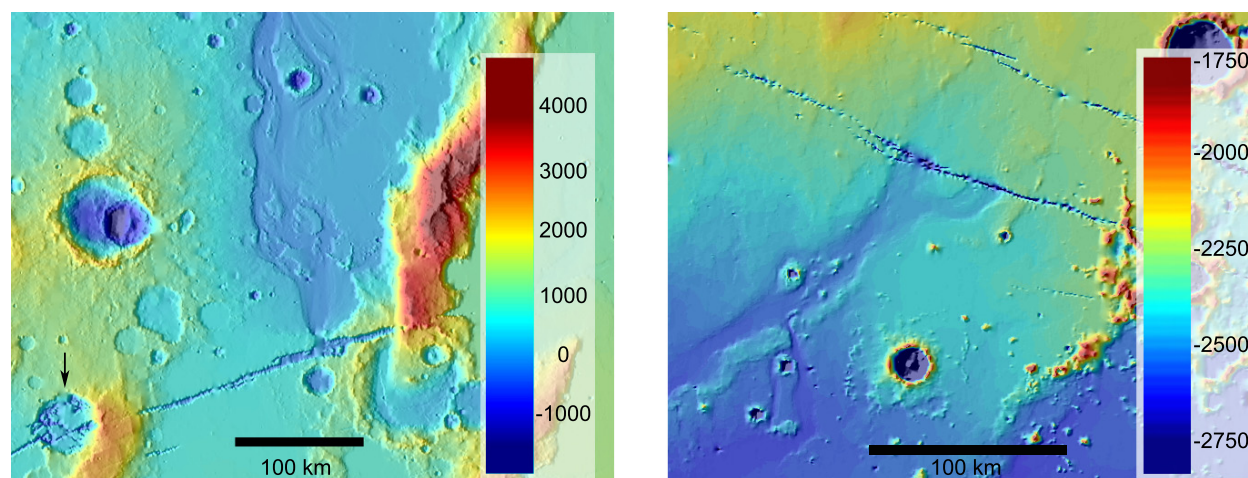


Figure 1. MOLA topographic shaded relief maps of the source regions of Mangala Valles (left) and Athabasca Valles (right) (elevation in m). Chaos region within crater along the Mangala Valles source graben indicated by arrow. Images centered on -17.1°N , -149.3°E (left) and 9.4°N , 157.4°E (right).

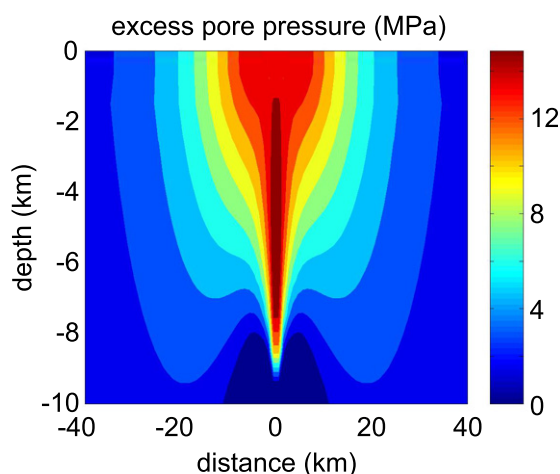


Figure 2. Pore pressure increase resulting from a tectonic feature with a maximum normal displacement of 100 m, extending to a depth of 10 km.

series of smaller events.

Once the tectonic pressurization of the aquifer has been modeled, the hydrologic response is found using a finite-difference model to simulate the resulting flow within the aquifer and the discharge to the surface. The tectonic event will likely increase the permeability of the surrounding aquifer substantially [8], through both the creation of new fractures and the opening up of existing ones. Thus, we approximate the surrounding aquifer as having a uniform and relatively high permeability of $5 \times 10^{-11} \text{ m}^2$. The compressibility must be chosen so as to be compatible with the Young's modulus used in the tectonic modeling. We assume that the fault presents essentially no resistance to flow, and thus the aquifer can drain directly to the surface along it. Upon reaching the surface graben or fissure, the flow will be channeled along-strike until it reaches the lowest point in the bounding walls, where it will flow out onto the surface and down slope, thus carving the observed channel.

Results: We here consider only the simplest case of normal displacement on a vertical tectonic feature, representing the opening of a fissure or dike extending to the surface. More complicated tectonism involving grabens and/or dikes at depth result in a similar magnitude of pressurization, though with a slightly different distribution. The aquifer pore pressures resulting from a tectonic feature with a height of 10 km and a maximum normal displacement of 100 m is shown in Figure 2. For the above geometry, a discharge of approximately $3 \times 10^5 \text{ m}^3 \text{ s}^{-1}$ after 1 hour and a total flow volume of 90 km^3 are observed. Considering a wider range of parameter space yields discharges between 10^5 and $10^6 \text{ m}^3 \text{ s}^{-1}$ and total flow volumes of 10^2 's to 10^3 's of km^3 . The actual discharge

within the channel would be dependent upon the rate of drainage from the graben or fissure.

These results represent the hydrologic response to a single tectonic event, however, and so the total flow volume over the entire history would be much greater. The integrated extension across the area of the tectonic feature provides an approximate upper limit on the total flood volume, though in practice roughly half this amount is more likely. For Mangala Valles, this would imply a rough upper limit of several thousand km^3 , depending on the subsurface geometry of the tectonism, which is approaching the estimated flood volume [1]. The amount of extension at the source of Athabasca Valles has yet to be estimated, and so no limits can be placed on the tectonically generated floods there. Flow from adjacent portions of the dike or fault and the possibility of additional pressurization mechanisms would increase these values further.

Conclusions and Discussion: These results demonstrate that the floods responsible for carving Mangala and Athabasca Valles could have been produced solely in response to the tectonic deformation at the source regions. Previous studies assumed that the faults played a passive role in the flooding, by simply providing a conduit to the surface for an aquifer pressurized by another means, such as the presence of a distant perched aquifer [1,2]. The occurrence of chaotic terrain within a crater along the source graben of Mangala Valles (Figure 1) provides geologic evidence of super-lithostatic pore pressures localized at the graben, as would be predicted by a tectonic pressurization mechanism. This mechanism has the added advantage in that it does not require any coincidental external contributing factors, but relies only on the observed tectonism.

In addition to explaining the floods at Athabasca and Mangala Valles, this mechanism has broader significance for the tectonic and hydrologic history of Mars. It is a viable means of bringing water to the surface even under today's cold-climate conditions, and thus has important astrobiological implications. Furthermore, tectonic pressurization likely played an important role in the formation of Valles Marineris and the nearby circum-Chryse outflow channels, the largest tectonic and fluvial features in the Solar System.

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