**A NEW MODEL OF THE HYDROLOGIC PROPERTIES OF THE MARTIAN CRUST AND IMPLICATIONS FOR THE FORMATION OF VALLEY NETWORKS AND OUTFLOW CHANNELS.** J. C. Hanna and R. J. Phillips, Department of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University (Campus Box 1169, One Brookings Drive, St. Louis, MO 63130, jhanna@levee.wustl.edu)

**Introduction:** There is abundant geomorphic evidence for the importance of groundwater in the Martian hydrologic cycle. It appears likely that the valley networks formed as a result of groundwater sapping [1], and it is clear that the outflow channels are the manifestation of large-scale eruptions of groundwater to the surface [2]. Thus, our understanding of the formation of these features is only as good as our understanding of the hydrologic properties of the Martian crust. Clifford [3] modeled the Martian crust based upon interpretations of the lunar seismic data and general comparisons to terrestrial aquifers. MacKinnon and Tanaka [4] modeled the Martian curst as a layer of regolith overlying a fractured basement. The present model builds upon this groundwork to construct a more general and widely applicable model of the hydrologic properties of the Martian crust, based on the decomposition of the aquifer into its component parts and the detailed modeling of each component. Given the varying proportions of competent rock and breccia or sediments, as well as the fracture frequency, the porosity, hydraulic conductivity, and compressibility of an aquifer can then be calculated as functions of the depth and pore pressure. The individual aspects of this model are easily adjustable to match the inferred geologic environment of different areas and times in the planet's history, as well as any combination of depth and pore pressure.

**Model.** *Ancient highlands crust.* The Noachian aged highlands crust is assumed to be dominated by the effects of impacts. A simplified model of the crust beneath an impact crater includes a brecciated region and a fracture zone. Gravity studies of terrestrial and lunar impact craters suggest that the breccia lens beneath a crater of diameter *D* extends to a depth of *D*/3 [5]. A deep drill core into a terrestrial impact crater has revealed that the brecciated region for this crater is actually composed of large blocks of bedrock separated by zones of breccia, with a ratio of rock to breccia of 3:1 [6]. The fracture frequency within the fractured zone can be estimated based on fracture counts in a drill core into the upper portions of a terrestrial impact crater [7]. This simple crater model was applied to the Martian surface using the crater distribution in Noachian terrains to calculate the porosity, hydraulic conductivity, and compressibility of the top 10 km of crust (see Figure 1). It is assumed that with the essential saturation of craters in the southern highlands, the effects of the impacts overlap, creating a homogenous and isotropic distribution of fractures and breccia.

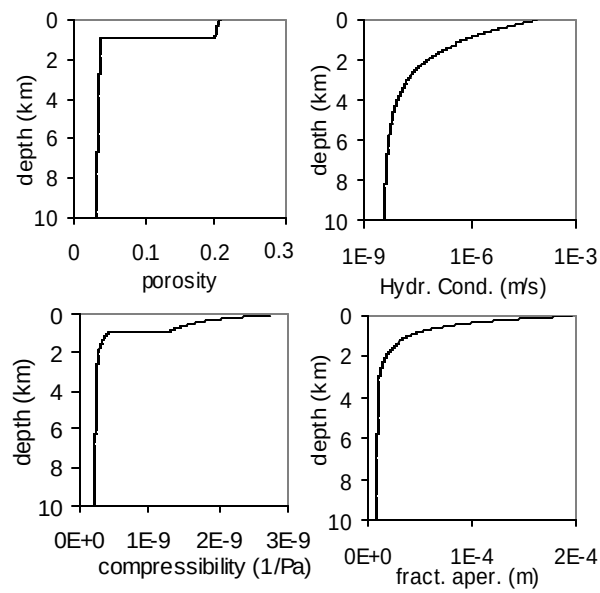


**Figure 1.** Sample aquifer model for the top 10 km of crust in the southern highlands.

In this model, the porosity of the ancient Martian crust is determined primarily by the porosities of the breccia and the bulk rock, as fractures add relatively little to the total pore space except under conditions of extremely high pore pressure or low confining pressure. The estimates of porosity and compressibility of the breccia fraction is based on samples of lunar and terrestrial impact breccias and terrestrial fault breccias [4,8,9]. The hydraulic conductivity, on the other hand, is determined almost exclusively by the fracture frequency and aperture, as breccias typically have low to negligible hydraulic conductivities [10]. A novel approach of calculating fracture apertures has been devised, in which the fractures are modeled as following a non-linear elastic behavior. This approach was found to agree well with both data on fracture apertures [11,12] and hydraulic conductivity data from the deep terrestrial crust [13].

The ancient highlands crust, modeled above, is assumed to be overlain by a 1 km thick regolith [4]. At some relatively shallow depth, this regolith is probably lithified into a coherent breccia which is susceptible to impact fracturing just as the bedrock is [10]. Thus, the

fracture network is inferred to permeate both the bedrock and the overlying and intermixed breccias. At some depth, the fractures and pore space in the aquifer will be closed off by pressure solution. However, this process is poorly constrained even for well-studied terrestrial environments [14].

*Basalt aquifers.* The crust in the Tharsis region, and other volcanic provinces on Mars, is modeled after the Snake River Plains basalts [15]. These thick basalt sequences are composed of alternating layers of massive basalt and highly fractured and porous interflow zones, occasionally interbedded with sediment layers. The fracture density of the interflow zones is estimated based upon the measured hydraulic conductivities and the modeled fracture apertures. On Mars, it is likely that these basalt flows are interbedded with breccia layers.

**Applications.** Numerical models utilizing a finite difference scheme have been generated to examine the response of both basaltic and ancient highlands aquifers to different scenarios involving periodic fluctuations in the thickness of the cryosphere. Temporal changes in the thickness of the cryosphere, due to both obliquity oscillations and long-term changes in the climate, have the potential to create significant pore pressures in the underlying aquifer [16]. This process has been modeled for both confined and partially confined aquifers with a variety of geometries corresponding to variations in topography and water table height. Partially confined aquifers are those that are locally confined from above by the cryosphere, but are laterally continuous with regions of the aquifer that are fully unconfined. Terrestrial studies have demonstrated that over large spatial scales and long time scales, there is a high degree of aquifer interconnectivity, and the concept of a “closed aquifer” rarely applies [3].

Preliminary results indicate that obliquity oscillations may have been effective in generating flow to the surface under certain aquifer geometries, with possible implications for the formation of the valley networks. It is thought that pore pressures in excess of the lithostatic pressure are necessary to generate the outflow channels [2]. Models of the effects of a sudden cooling of the climate indicate that it is difficult to generate such pressures by this scenario. As the pressure in the aquifer rises, the aperture of the fractures increases accordingly, thus increasing the hydraulic conductivity and allowing the pressure to diffuse away laterally towards the unconfined portion of the aquifer.

**Conclusions:** There are several important aspects of this model. First, it allows a full characterization of the aquifer properties based upon parameters such as fracture frequency and breccia fraction, which can be estimated based upon a combination of terrestrial and planetary studies. These properties can be modeled to represent specific geologic environments expected to exist at a particular location and time in Martian history. Second, it includes a detailed representation of the elastic properties of the aquifer, which are particularly important if the development of substantial overpressures is to be considered. Thus, it allows for actual modeling of the hydrologic processes thought to occur on the planet, rather than relying on analogies to oversimplified scenarios with simple analytical solutions. Third, the new model of fracture aperture provides a more accurate estimation of hydraulic conductivity than previous models allowed. Fourth, it is a fully dynamic model in which all of the properties change both with depth and with pore pressure. Finally, it allows for a great deal of flexibility to accommodate new data on the relevant parameters.

Preliminary modeling results have already indicated the potential power that this approach has in understanding the Martian hydrological system. Further efforts will continue to focus on the interaction of aquifers with changes in the cryosphere depth, as well as on hydrothermal processes, polar cap basal melting [3], and global scale circulation.

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