**EARLY MARS HYDROLOGY: VALLEY NETWORKS AND EVAPORITES.** Jeffrey C. Andrews-Hanna[1], Maria T. Zuber[1], and Roger J. Phillips[2], [1]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139-4307, jhanna@mit.edu. [2]Planetary Science Directorate, Southwest Research Institute, Boulder, CO 80302.

Introduction: There is now abundant and compelling evidence for warmer and wetter conditions on early Mars, as revealed by geomorphology, remote sensing, spectral, and *in situ* surface observations. The challenge now is to integrate these diverse observations into a coherent understanding of the early climatic and hydrologic evolution of the planet. This study investigates the early history of water on Mars using a model of the global-scale groundwater hydrology [1]. In this model, groundwater flow is driven by a combination of the surface topography and a precipitation-evaporation driven hydrological cycle under arid conditions. Water is assumed to evaporate upon reaching the surface, with the globally-integrated evaporation flux redistributed as low-latitude precipitation in a cosine distribution between ±45° latitude. Earlier work focused on the formation of evaporites in Meridiani Planum [1], and the transition from phyllosilicate to sulfate deposition [2]. We here extend this work by considering the global distribution of valley networks, and by using high-resolution models to explicitly model the growth of evaporites both globally and in the Meridiani region.

Noachian Hydrology: The distribution of valley networks provides a key constraint on the early hydrology of Mars. The valley networks are distributed asymmetrically about the equator, following an approximate great-circle, dipping southwards beneath Tharsis and northwards above Hellas (Figure 1), leading to earlier suggestions of true-polar wander [3]. This distribution agrees qualitatively with the long-wavelength variations in the depth to the water table predicted by the hydrological models. Groundwater evaporation in the deep Hellas basin draws down the surrounding water table. Its location at mid-southern latitudes places it on the edge of the precipitation belt in the models, leading to a dramatic drawdown of the water table throughout the high southern latitudes expanding outwards from Hellas. The opposite situation occurs at Tharsis, with the high topography leading to perched aquifers draining down the rise into the surrounding highlands. The net effect is that the water table is close to the surface in a skewed belt dipping southwards below Tharsis and northwards above Hellas. The first-order agreement between this belt of near-surface groundwater and the distribution of valley networks suggests that groundwater exerts a significant control over valley network formation. Where the water table lies deep below the surface, infiltration of precipitation would be favored over runoff and channels would not intersect the water
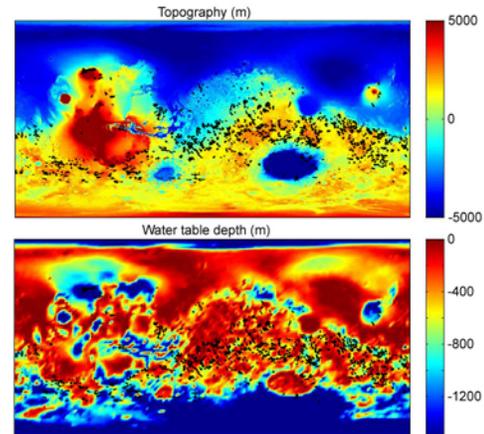
Figure 1. Distribution of valley networks [4] superimposed over MOLA topography (top) as well as the predicted depth to the water table from the hydrological models (bottom).

table, thereby inhibiting the development of mature fluvial systems [5]. The valley network distribution is thus consistent with precipitation that is distributed symmetrically about the current equator, and does not require true polar wander.

Late Noachian hydrological transition: Evidence suggests a hydrological shift in the Late Noachian, including a decrease in erosion rates [6], a shift from runoff- to sapping-dominated valley networks [5], and a geochemical transition from phyllosilicate to sulfate deposition [7]. We have suggested that this transition could have been brought about by a shift from a "wet" to "arid" hydrological regime [2], in response to a net loss of water due to impact and solar wind stripping of the atmosphere [8], or increased storage as ice or hydrates. A dramatic decrease in the rate of water cycling would result, leading to a decrease in precipitation and erosion rates, an end of phyllosilicate formation, and the focusing of groundwater upwelling at the locations of observed sulfate deposits [2].

Late Noachian-Early Hesperian hydrology: Widespread evaporitic sulfate deposits have ben identified in Meridiani Planum and the surrounding Arabia Terra region, with localized occurrences also found in the canyons and chaos regions at the sources of the outflow channels. The location of these evaporite deposits coincides with regions of predicted groundwater upwelling and evaporation from the hydrological models [1]. In this scenario, the unique topography of the Arabia Terra region drove groundwater upwelling and evaporation north of the break in slope separating Arabia Terra from the southern highlands.

In improved higher resolution models, groundwater upwelling is focused within isolated craters whose floors reached the water table (Figure 2a). However, focused groundwater evaporation within these craters would have led to thick deposits of evaporites and cemented aeolian materials, filling in the local topographic lows. Indeed, there is evidence that many craters on Mars were once filled with sediments and later exhumed [9]. New models include active sedimentary deposition in regions of groundwater upwelling, leading to a dynamical coupling of the topography and hydrology. As the system evolves, individual craters intersecting the water table in the highlands fill with sediments, terminating the groundwater flux. In contrast, evaporite formation in Meridiani evolves from being limited to isolated craters, to being broadly distributed over Meridiani and much of the Arabia Terra region (Figure 2b,c).

To better resolve the hydrological environment at Meridiani, we embed a high-resolution local model within the results of the global simulations (as done by [10] for the outflow channels). Deposits of evaporites several hundred meters thick form in Meridiani over ~100 Myr (Figure 2d,e). Evaporite deposits are also predicted in the nearby outflow channels, but these depressions likely did not exist in their current form at the time the Meridiani evaporites were forming.

Climatic forcing: In addition to a long-term net loss of water, the climate of Mars was driven by astronomical forcing on periods ranging from 120 Kyr obliquity cycles, to chaotic shifts in mean obliquity on timescales of 10's to 100's of Myr [11]. This forcing would change the amount of water in storage within the polar caps and cryosphere, and thus the volume of water available to the hydrologic system. The obliquity cycles operate on a shorter timescale than the hydrologic response time over typical flow path lengths, and have little impact on the global-scale hydrology. In contrast, the aquifers respond in near equilibrium with hydrologic forcing on periods of several hundred Myr. However, chaotic shifts in mean obliquity predicted on timescales of ~10's of Myr [11] lead to a disequilibrium hydrologic response. In wet phases associated with this forcing, the low latitude water table rises towards the surface, leading to alternating periods of valley network and evaporite activity (Figure 3).

Synthesis: The emerging picture is a Mars in which groundwater processes have exerted a dominant control over the history of water. Groundwater flow likely played a key role in determining the distributions of both the Noachian valley networks and the later evaporite deposits. We suggest that the long-wavelength groundwater flow was modulated by both a long-term net loss of water as well as periodic and chaotic fluctuations due to orbital forcing.
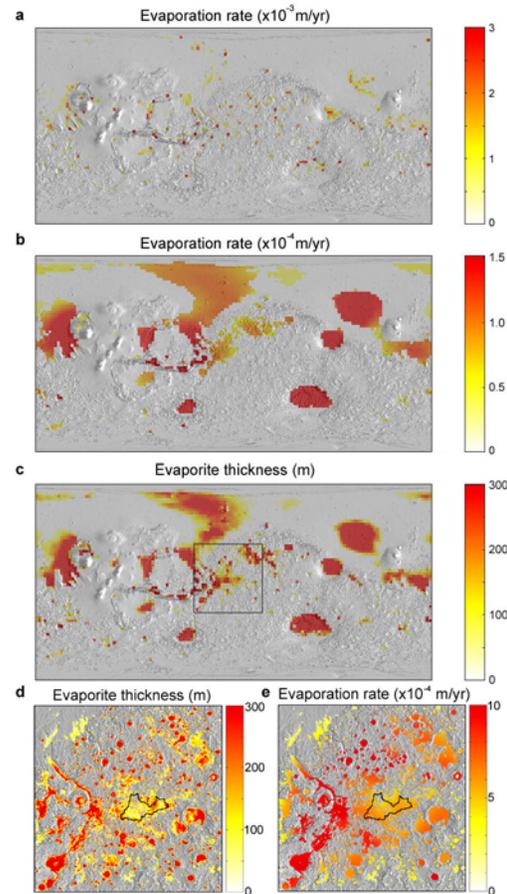
Figure 2. Predicted evaporation from hydrological models assuming present-day topography (**a**). The deposit thickness and evaporation rate after 100 Myr of evaporite deposition is shown in **b** and **c**. The results of high-resolution local hydrological models of Meridiani are shown in **d** and **e**.
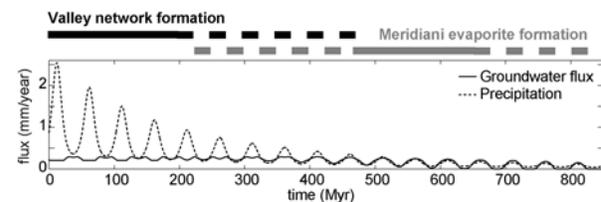
Figure 3. Predicted precipitation and evaporation rates at Meridiani for a simulation incorporating a secular loss of a global equivalent depth (GED) of 60 m of water and a periodic forcing of a GED of 30 m of water.

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