MERIDIANI PLANUM AND GALE CRATER: HYDROLOGY AND CLIMATE OF MARS AT THE NOACHIAN-HESPERIAN BOUNDARY. J. C. Andrews-Hanna[1] A. Soto[2], and M. I. Richardson[3], [1]Colorado School of Mines, Dept of Geophysics (jcahanna@mines.edu), [2]California Inst. of Technology, [3]Ashima Research.

Introduction: Early Mars experienced a warm and wet climate, before conditions dried out considerably in the Hesperian. However, this transition from wet to hyper-arid conditions was not instantaneous, and the transition period itself left a clear imprint on the surface geomorphology in the form of widespread sedimentary deposits, including those found at Meridiani Planum. Observations by the Opportunity rover revealed the Meridiani Planum deposits to be sulfate-rich sandstones, likely formed, reworked, and diagenetically modified in a playa environment [1]. These deposits are part of a suite of erosional remnants of a formerly widespread deposit in Arabia Terra [2], and provide a record of martian climate change.

Previous work demonstrated that the Meridiani deposits formed in response to a precipitation-evaporation-driven hydrological cycle under arid conditions, with long-wavelength groundwater flow paths resulting in the upwelling and evaporation of groundwater focused within Arabia Terra [3, 4]. However, that work invoked a greatly oversimplified representation of the climate system, with a simple longitudinally symmetric low-latitude precipitation belt. We here examine the hydrology and climate of Mars together, using results of a GCM representing rainfall on an arid Mars, and the ensuing groundwater flow patterns.

Patterns of rainfall on early Mars. Although the specific conditions on early Mars that enabled warm temperatures and precipitation are unknown, there is little debate that rainfall did occur during the Noachian. Previous work predicted the distribution of rainfall on early Mars for a variety of conditions using an Earth GCM, with the martian surface topography as the bottom boundary (the Mars as Earth, or MEarth model) [5]. Though the use of Earth-like conditions to simulate rainfall in an early Mars is a simplification, it allows us to investigate the likely patterns of atmospheric circulation and rainfall that would result if Earth-like conditions did exist. This work demonstrated that in the presence of a northern ocean, widespread precipitation at rates of ~1 m/yr would be expected in a pattern approximately matching the distribution of valley networks [5], consistent with conditions for Noachian Mars.

For an Earth-like climate in the absence of an ocean, the predicted precipitation rates decrease dramatically, and the areal distribution of precipitation becomes much more restricted. A regional zone of orographically driven precipitation occurs over Tharsis. High-latitude precipitation in the cold arctic and subarctic regions is also predicted, though this would be dominantly in the form of snowfall and would not be effective in driving either surface erosion or aquifer recharge. Outside of these regions, the next largest zone of precipitation occurs at the southeastern edge of Arabia Terra, with mean rates of ~40 cm/yr. This precipitation belt is an orographic effect arising from the upslope flow as winds from the inter-tropical convergence zone travel up Arabia Terra to reach the topographic step at its southern edge. Importantly, this belt of precipitation is ideally situated to recharge the aquifers of Arabia Terra and drive a sustained flux of groundwater upwelling at Meridiani Planum. A smaller precipitation belt is predicted south of the dichotomy boundary to the east of the Isidis basin, including regions upslope from Gale crater, at rates of ~4 cm/yr.

These patterns of precipitation in an ocean-free Mars would only occur when surface and near surface water was extensively available in the tropics and mid-latitudes, either through a high groundwater table or ponding [5]. Ultimately, the available water becomes 'cold-trapped' in the polar regions. Thus, liquid water on an arid Mars would have a limited time to recharge aquifers [5]. However, these wet but ocean-free periods can recur during periods of high obliquity [7].

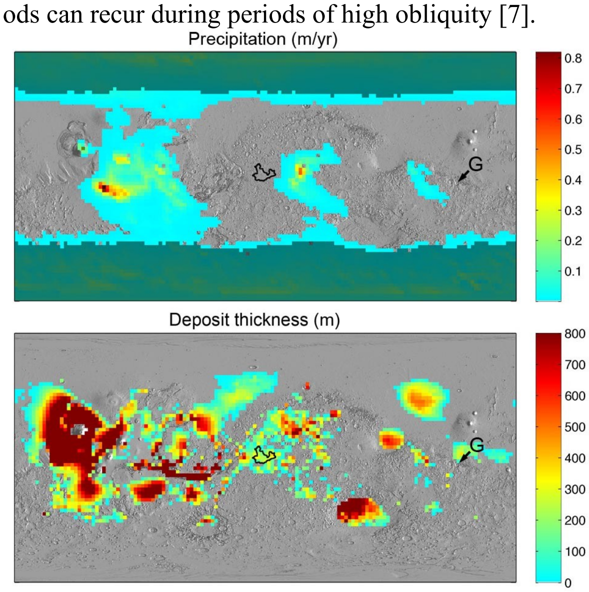

Figure 1. MEarth-predicted precipitation (top; shaded high latitude regions experience mean annual temperatures <273 K), and predicted sedimentary deposit thickness from the hydrological model (bottom). The Meridiani Etched Terrain [6] is outlined, and Gale Crater labeled 'G' for reference.

Groundwater hydrology and sedimentation. The MEarth-predicted precipitation is now used as the driver of groundwater flow in hydrological models. The GCM predicts both evaporation and precipitation rates globally. It is assumed that 10% of the precipitation is available to infiltrate the surface to recharge the deep aquifers. The remainder generates runoff and ponding or saturates the near-surface, and is subject to evaporative loss. In areas where the minimum annual temperature is <273 K, the majority of the precipitation falls in the form of snow, which is subject to sublimation. In these areas, aquifer recharge is limited to the net difference between the precipitation and evaporation rates (P-E). Precipitation in the high latitudes is neglected, as this will not generate aquifer recharge due to the persistently cold temperatures.

The precipitation-induced aquifer recharge and evaporation of groundwater at zones of upwelling drive global-scale patterns of groundwater flow. The evaporation of groundwater is assumed to result in the formation of evaporite-cemented sedimentary deposits, with a ratio between the evaporated water column height and the resulting deposit thickness of 0.02. As an approximation of the climatic control on evaporite formation, deposits in the model only form in regions where the precipitation rate is less than 1 cm/year, thereby avoiding the formation of thick evaporites in areas of more temperate climate.

Results. The first-order predictions regarding the depth to the water table and the distribution of evaporite-cemented sedimentary deposits are in agreement with the predictions of earlier models using a simpler and more widespread low latitude precipitation belt (Figure 1). The precipitation at the southeastern edge of Arabia Terra recharges aquifers driving flow down the topographic gradient towards the northern lowlands. The topographic inflection at the southern edge of Arabia Terra leads to a rise in the water table relative to the surface, driving a net upwelling flux of groundwater. Other deposits are predicted to form in the northern lowlands beyond the dichotomy boundary and in the giant impact basins.

The results of the global models were used as the boundary conditions for regional models, run at a resolution of 0.25° (~15 km) per model cell, focused on the eastern low to mid-latitudes of Mars (Figure 2). The regional model predicts widespread sedimentary deposits to form throughout Arabia Terra, reaching locally thick accumulations within impact craters, and a thickness of approximately 400 m at Meridiani Planum. The predicted deposit distribution in Arabia Terra is in agreement with the reconstructed sediment surface based on erosional remnants scattered throughout the region [2].

Further to the east, 2 km thick sedimentary deposits are predicted to form within Gale Crater, driven by the precipitation belt extending eastward from Isidis. Smaller deposits are also predicted to form in neighboring craters, as well as to the north of the dichotomy boundary in this area. Evidence for these surrounding deposits is observed both as intracrater deposits and the Aeeolis Mensa/Planum deposits in the lowlands. The models reveal that Gale Crater is uniquely situated to receive a substantial influx of groundwater, with the regional northward groundwater flow giving way to a convergence of flow at Gale. Gale is noteworthy as the deepest and freshest mid-sized crater along the dichotomy boundary, and is also ideally situated with respect to the precipitation patterns predicted by the GCM.

Conclusions. As Mars dried out towards the end of the Noachian, precipitation became limited to isolated zones over Tharsis, southeast of Arabia Terra, and east of Isidis. These precipitation belts fueled aquifer recharge, driving groundwater flow patterns that resulted in the deposition of the sulfate-rich sedimentary deposits of Meridiani Planum and Gale Crater. Thus, the formation of these deposits was a natural consequence of the increasing aridity on early Mars.

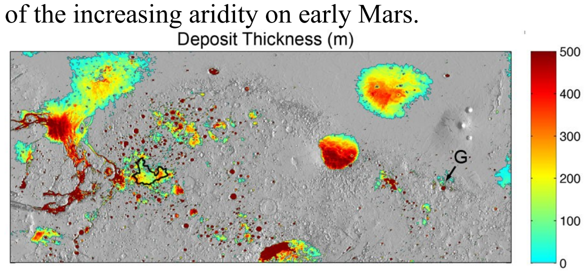

Figure 2. Regional model predictions of the predicted deposit thickness. Meridiani is outlined for reference.

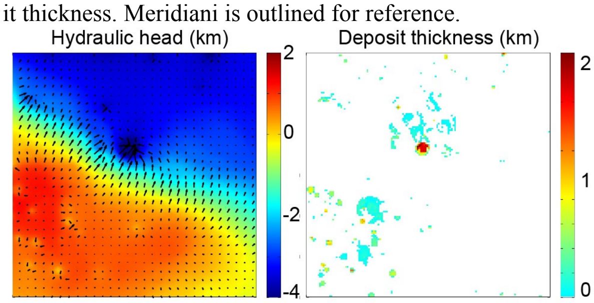

Figure 3. Snapshot of the hydraulic head and flow vectors at Gale Crater (left) showing a convergence of flow into the deep hydraulic sink at the crater, and the predicted deposit thickness (right).

References: [1] Arvidson R. E., et al. (2006) *JGR 111* E12S08, doi:10.1029/2006JE002728. [2] Zabrusky K. J. and Andrews-Hanna J. C. (2011) *LPS 42* abstract 2558. [3] Andrews-Hanna J. C. and Lewis K. W. (2011) *JGR 116* E02007, doi:10.1029/2010JE003709. [4] Andrews-Hanna J. C., et al. (2010) *JGR 115* E06002, doi:10.1029/2009JE003485. [5] Soto A., et al. (2010) *LPS 41* abstract 2397. [6] Hynek B. M. (2004) *Nature 431* 156-159. [7] Mischna, M. A et al. (2003) *JGR*, *108*, 5062, doi:10.1029/2003JE002051.