EVOLUTION OF MARTIAN D/H DURING THE HESPERIAN AND AMAZONIAN. Michael H. Carr¹ and James W. Head². ¹U.S. Geological Survey, Menlo Park, CA 94025 USA (carr@usgs.gov), ²Department of Earth, Environmental and Planetary Sciences, Brown University, Providence RI 02912 USA (james_head@brown.edu).

Introduction: We recently estimated the current inventory of near-surface water and how that inventory changed with time as a result of outgassing, losses to space and to the ground and additions as a consequence of eruption of groundwater to form outflow channels [1]. More recently Curiosity’s SAM experiment has determined that the D/H ratio in smectites from mudstones from the floor of Gale crater is 3.0 SMOW [2]. Estimates of the age of the mudstones range from 3.0 to 3.8 billion years [2, 3]. The D/H ratio in the current martian atmosphere is approximately 5.2 times SMOW [4]. From this Mahaffy et al. concluded that Mars had already lost a significant fraction of its near-surface water inventory to space by the time the Gale mudstones were deposited. Here we examine what the D/H ratio of the mudstones might imply for the water inventories during the Hesperian and Amazonian, after the mudstones were deposited.

Water inventories during the Hesperian and Amazonian. In our earlier paper [1] we estimated that 34 m GEL (global equivalent layer) of water was within 80 m of the surface, most (22 m) being in the polar layered deposits. The inventory does not include water fixed in minerals near the surface. The inventory has evolved over time as a result of losses to space and to the ground and as a result of water outgassed from the mantle by volcanic activity. We estimate that during the Amazonian 3 m was outgassed and 31 m was lost to space and chemically fixed in the ground so that 62 m of unbound water was near the surface at the end of the Hesperian. During the Hesperian 5 m was outgassed and 7 m was lost to space and chemically fixed, thereby leaving 64 m to be derived by other events in the Hesperian or carried over from the Noachian. These estimates incorporate significant uncertainties. For example, we estimated outgassing rates from the volcanic areas depicted on the recently published geologic map of Mars [5], which are significantly smaller than previously published areas [6]. We also assumed that the losses of water from the upper atmosphere were controlled by oxygen losses [7,8]. Measurement of the D/H provides a means of testing some of these assumptions.

Evolution of D/H. A simple model was constructed to trace the D/H from its present value of 5.2 SMOW backwards into the Hesperian under the following assumptions. Outgassed water was derived from the Tanaka et al. [5] areas by assuming the units are 1 km thick and released 1 wt.% water with D/H equal to SMOW on eruption. The volcanic volumes so derived were approximated by the function $V=0.39e^{1.19t}$ where $V$ is in $10^6$ years and $t$ is in billion years. Losses to space were assumed to be constant throughout the Hesperian and Amazonian and to have a D/H fractionation factor of 0.32 [9]. Chemically fixed water was assumed to have the D/H that prevailed at the time it was fixed. It was also assumed that formation of the outflow channels did not change the D/H, which implies that the water that formed the channels was part of the exchangeable inventory. (This assumption only affects values calculated for the early Hesperian). The D/H for the inventory was calculated in 100 m.y. increments back from the present to the beginning of the Hesperian. With these assumptions and the values for losses and gains given in [1] the model predicts that the D/H was 2.4 SMOW 3 billion years ago at the end of the Hesperian and 2.1 SMOW 3.7 billion years ago at the beginning of the Hesperian. The calculated values are close but somewhat lower than the measured value which implies that the model is predicting more fractionation from Early Hesperian to the present than actually has occurred. Nevertheless, the calculated and measured values are comparable which gives our model of the evolution of the near-surface water inventories some plausibility.

Less post Noachian fractionation could result from a larger inventory than assumed, less loss to space and more volcanic outgassing. Raising the present-day inventory to 50 m GEL, keeping the other factors constant increases the D/H at the end of the Hesperian to 3 SMOW, the measured value. Halving the losses to space, and keeping the other factors constant also increases the D/H at the end of the Hesperian to 3 SMOW. The effect of changes in outgassing rates by a factor of two are negligible. Thus a combination of small adjustments in the present inventory and loss rates would bring the model predictions and measurements into agreement.

Conclusion. The recently determined D/H ratio in 3 - 3.8 m.y. old mudstones in Gale Crater [2] provides a means of testing the plausibility of a recently published model for the changing inventories of near-surface water on Mars [1]. The D/H values predicted by the model are comparable to the measured values, thereby giving support to the model. The model predicts only modest near-surface inventories (34-64 m) of unbound water during the Amazonian and Hesperian, inventories that fall far short of those needed for ocean size bodies of water.