

REGOLITH EVOLUTION ON MARS: THE PRESERVATION OF ANCIENT AQUEOUS ALTERATION PRODUCTS. G. J. Taylor¹ and S. M. Baloga², ¹HIGP, Univ. of Hawaii, Honolulu, HI 96822 (gjtaylor@higp.hawaii.edu), ²Proxemy Research, Laytonville, MD 20882 (steve@proxemy.com).

Introduction: The origin and evolution of the Martian regolith has a profound influence on the mineralogical, chemical, and physical properties of the current surface, with implications for the scientific understanding and future human and robotic exploration of Mars. The details of regolith evolution may contain the keys necessary to understand the current elemental concentrations, their regional differences, and when existing alteration products formed.

Regolith evolution involves a complex interplay of many processes. Although a host of complicating processes undoubtedly operated regionally and locally, the dominant processes at the global scale are impact cratering, aqueous weathering, volcanism, erosion, and deposition. We are launching a thorough quantitative investigation of regolith evolution and report some initial, broad-brush results here. Our initial effort focuses on the amount of aqueously-altered material in the regolith as a function of time, impact gardening, and volcanic resurfacing. (By "aqueous alteration" we mean alteration of primary rocks and formation of secondary products by chemical weathering and hydrothermal alteration, though we emphasize weathering.) The importance of aqueous alteration during impact gardening, including early in Martian history, was noted by [1,2]. We approach the computations from the perspective of global averages and the relative contributions of the dominant processes affecting the geochemical composition and dimensions of current regolith. Future work will investigate regional and local variations in the regolith forming processes that could explain the geochemical diversity now known to exist on the Mars surface.

Mean rates: There are presently gaps in information necessary to parameterize the dominant regolith processes and how they evolve. However, first-order estimates combined with plausible assumptions extrapolating from terrestrial and planetary studies leads to some provocative conclusions about the interactions between the dominant processes and the origin of the existing regolith composition.

Impact gardening. Impacts continuously churn and mix the regolith, with a rate decreasing with time. Impact fluxes were much higher before 3.8 Gy than afterwards, with different size-frequency distributions [1,2]. The ancient highlands are saturated with craters >22 km in diameter [1], suggesting thorough gardening to ~2 km depth. We take a value of 2 km for the well-mixed, oldest regolith on Mars and assume an exponential decline to 3800 My to the post-

bombardment thickness of 30 m. This results in declining impact-gardening rates with time (Fig. 1).

Volcanic resurfacing rates. Intrusive and extrusive magmatism has constructed the Martian crust. Trace element and isotopic data from Martian meteorites suggest that about half the crust was formed around 4.5 Gy [e.g., 3-5]. Thermal modeling [6] suggests that about 75% of the crust was formed by 4.0 Gy. We use a crustal production rate of 50 m/My initially (4490 My ago), declining to the rate for the Amazonian, about 1.7×10^{-3} m/My [7,8] (Fig. 1).

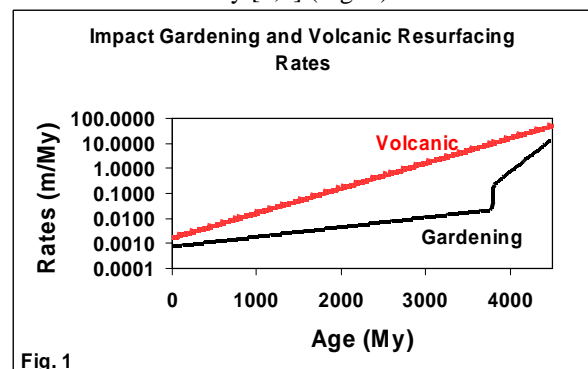


Fig. 1

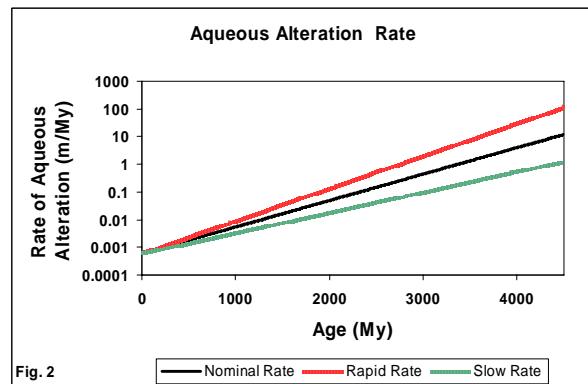
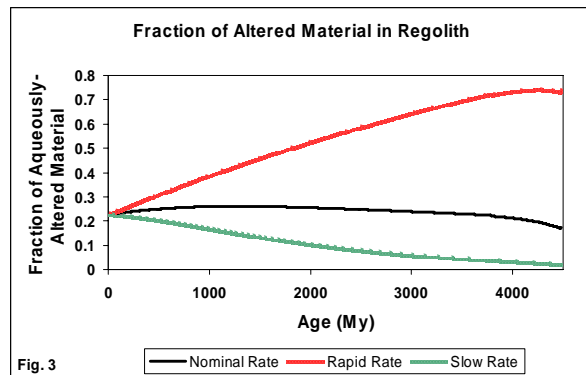


Fig. 2

Weathering rates. Chemical weathering has played an important role in the evolution of the Martian surface. The current rate of weathering appears to be very low. Kolb et al [9] estimates a rate of only 60 cm/Gy, or 0.006 m/My. We assume this rate for present-day Mars. The weathering rate early in the planet's history, when conditions are generally considered to be wetter is unknown, but can be plausibly estimated from terrestrial studies. Measurements for weathering rates on Earth vary widely, from about 1 to 100 m/My [e.g., 10-13]. Assuming that early Mars was somewhat like the Earth, we assume a nominal initial rate of 10 m/My, and consider initial rates a factor of 10 higher and lower than this value. An exponential curve fitted to the early (4490 My) and present rates is shown in

Figure 2. An exponential decline with time is also consistent with an exponential decline in magmatism, a major source of water to the surface. Weathering is complicated by many factors: Their rates in a given place decrease with time [e.g., 10] unless eroded or mixed by impacts. Impact granulation might increase rates because of changes in grain size, and volcanism provides fresh, unweathered surfaces. In spite of the simplifications, we think this approach provides a reasonable first-order assessment and identifies the areas where more detailed quantitative analysis is needed.

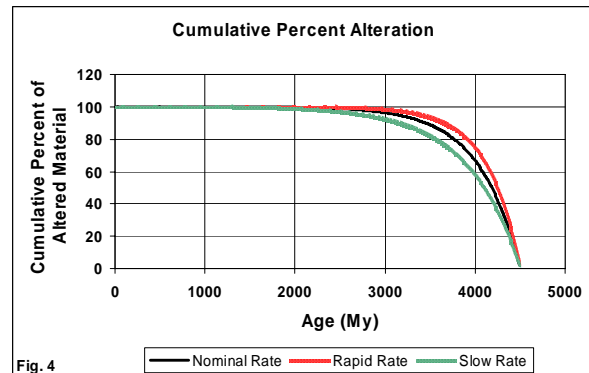
Results: We use the values in Figs. 1-2 to calculate from mass balances the fraction of aqueously-altered material in the portion of the regolith that is being gardened by impacts at a given time (Fig. 3). We assume that the regolith is uniformly mixed to the mean depth given by its rate (Fig. 1), that lava flows are mixed by impacts into the regolith, and that weathered material is completely altered. None of these assumptions are completely correct; more complex quantitative models are needed to refine and validate our initial conclusions.



For the nominal weathering rate the regolith always contains about 20% altered materials. If weathering is 10 times higher initially ("rapid rate"), which is similar to tropical conditions on Earth, the early regolith would consist of substantially more than half-altered materials. If 10 times lower ("slow rate"), ancient regolith would contain little altered material.

We calculated the total cumulative percentage of altered material produced versus time (Fig. 4). As the result of an exponentially-declining rate of aqueous alteration (Fig. 2), most of the altered material is produced early in Martian history, in spite of higher volcanic resurfacing occurring at that time. For all weathering cases, half the altered material made throughout Martian history was made by 4 Gy; for the nominal and rapid cases, over 80% of the altered material was produced by 3.8 Gy. These alteration products are mixed throughout the early, thick regolith, but much of it would be available for mixing into the regolith during the past 3.8 Gy. If only a quarter of the regolith

were available, the amount of ancient (>3.8 Gy) alteration products would equal or exceed the amount produced since then.



Geochemical implications: The preservation of ancient alteration products may be reflected in the composition of modern surface materials on Mars. If early Martian magmas were produced from non-depleted mantle sources [e.g., 14], they would be richer in trace elements than more recent magmas. Alteration products produced from them would reflect the high trace element concentrations (K, Th, REE), leading to the possibility that soils are richer in K and Th than local (younger) rocks in some areas on Mars [15]. Our results suggest that the soils may be dominated by comminuted, ancient, enriched rocks and their alteration products.

Conclusions: The weathered geochemical products in the current Mars regolith were produced primarily during the period of heavy bombardment. Moreover, the absence of plate tectonics or other mechanisms for crustal recycling suggests that early gardening and alteration products must remain near the surface. Thus the geochemical record of the early crustal evolution remains in the existing Martian regolith.

References: [1] Hartmann W. K. and Neukum G. (2001) *Space Sci. Rev.*, 96, 165-194. [2] Hartmann W.K. et al., *Icarus*, 149, 37-53. [3] Norman, M. D. (1999) *GCA.*, 34, 439-449. [4] Norman, M. D. (2002) *LPSC XXXIII*, abstract #1175. [5] Borg, L. E. (2003) *GCA*, 67, 3519-3536. [6] Hauck, S. A. and R. J. Phillips (2002) *J. Geophys. Res.*, 107, No. E7, 10.1029/2001JE0011801. [7] Tanaka, K. L. et al. (1992) Chap. 11 in *Mars*, p. 345-382. [8] Kiefer, W. S. (2003) *Meteor. Planet. Sci.*, 38, 1815-1832. [9] Kolb, C. et al. (2006) *Icarus*, 183, 10-29. [10] Steward, B. W. et al. (2001) *GCA*, 65, 1087-1099. [11] Price, J. R. and Velbel, M. A. (2004) AGU Abstracts (#H41H-03). [12] Amudson, R. (2004) Chap 5.01 in *Treatise on Geochemistry*. [13] Fletcher, R. C. et al. (2006) *EPSL*, 244, 444-457. [14] Taylor, G. J. et al. (2006) *JGR*, 111, E03S10, doi:10.1029/2005JE002645. [15] Newsom, H. et al. (2007) *JRG*, in press.