A COMPLEX HISTORY OF MARTIAN SURFACE MINERALOGY AND AQUEOUS PROCESSES.

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Introduction: The initial interpretation of recent global spectral datasets has led to relatively simple hypotheses regarding the igneous and climate history of Mars [e.g. *1-2*]. However, a more complete examination and inclusion of multiple datasets by a number of researchers indicates that Martian history and the processes that have formed surface compositions may be considerably more complex.

The Martian Global Mineralogical and Aqueous History Hypothesis: The initial hypothesis put forward by *Bibring et al.* [*2*] divided martian history into three eras based on three types of "surface alteration products". These eras were based largely on Mars Express OMEGA results and inferences regarding their relationship with more general geological properties of the planet. Some of these inferences warrant further examination and verification in order to be used as a basis for a global history and timescale.

Age of phyllosilicates. Phyllosilicates appear to be concentrated in older Noachian terrains. However, most of the exposures are small and have been exhumed, making it impossible to directly date either the formation or exposure ages of the surfaces to constrain the period of aqueous alteration. In addition, as pointed out by [*2*], it is not clear if phyllosilicate formation was necessarily a surface process and it is not clear how directly their formation is tied to the martian near-surface conditions. The periods and mode of phyllosilicate formation remain poorly constrained.

Age of martian sulfates. The presence of sulfates has been used to infer a, "change in the global aqueous chemistry of Mars" [*2*]. This does not consider that multiple aqueous environments could be present on the planet at the same time. For example, rather than representing time periods, phyllosilicates may generally represent subsurface aqueous activity and sulfates may represent the near-surface environment. As with the phyllosilicates, the age of sulfates remains poorly constrained, based largely on the inference that the formation of Tharsis and Hesperian volcanic activity would have provided a source of the sulfur [*2*].

Alteration late in martian history. Light amounts of alteration in the presence of liquid water often result in the production of amorphous silica phases and oxides and commonly do not leave clear hydration features in near-infrared spectra [*3*]. These signatures are prevalent across much of the planet. The lack of a hydration feature (even when present in other terrains) cannot be used to infer that small amounts of liquid water were not a significant factor in alteration of martian surfaces during the Amazonian. In addition, there is no evidence that this process has not occurred continuously throughout martian history.

Incorporation of Additional Spectral Datasets Into the Global History Hypothesis: Results from a number of spacecraft instrument investigations have revealed a complex pattern of surface mineralogy that does not readily fit into a simple 3 mineral types = 3 eras timescale.

MER results. One of the major results from the Mars Exploration Rovers has been the remarkable complexity of compositions and their geological relationships in the Columbia Hills within Gusev Crater. In addition to a variety of igneous compositions, concentrations of a variety of aqueous compositions have been identified within a small area with both rovers, including sulfates, oxides, and amorphous silica [e.g. *4-8*]. There is no clear indication that the formation of the various compositions is separated by considerable amounts of time. Close collaboration between the MER and OMEGA investigations [*9*] has not addressed how the Columbia Hills results can be placed in the global history hypothesis. Certainly, local results at Gusev cannot be extrapolated globally, but they may be expected to fit within the proposed global framework.

TES/THEMIS results. Thermal infrared spectral datasets have sensitivities that are complimentary to those of visible and near infrared spectral datasets. TES and THEMIS data have provided estimates of the bulk composition of coarse particulate surfaces, including plagioclase and silica-rich phases, both of which are common on Mars. These results have led investigators to propose that both Surface Types 1 and 2 [*1*] have been substantially altered from their original igneous compositions [*10-11*]. This alteration has occurred, but is not restricted to, late in Mars' history and most likely involves the presence of liquid water. Small amounts of carbonates have also been proposed to be present in the ubiquitous dust and also likely involves small amounts of liquid water [*12*]. These results do not support gas/solid reactions as the sole or primary alteration process in the Amazonian and the processes involved in recent alteration on Mars may be substantially different than those proposed by [*2*].

Hematite has been identified in Ophir and Candor Chasmas, Aureum, Iani, and Aram Chaos, and Merdiani Planum [e.g. *13-14*]. These exposures, while limited in both areal and stratigraphic extent, are found within a large region of equatorial Mars and may have formed during times from the Noachian through the late-Hesperian [*14*]. The possible periodic nature of the formation of hematite is a response to changing environmental conditions throughout this time period.

TES and THEMIS have also identified other compositions that add to the picture of martian aqueous history. Surfaces composed of ~70 areal % silica-rich components have been identified in western Hellas Basin [*11*]. These surfaces postdate the Noachian period and may be similar in nature to the high-silica deposits identified in the Columbia Hills. Amorphous silica appears in a variety of concentrations and occurs on surfaces of a variety of ages at Gusev Crater, Meridiani Planum, and Hellas Basin [*8,11,15*]. These materials appear to be important in discerning the aqueous history of Mars.

Spectrally unique materials have been associated with polygonally fractured, light-toned surfaces throughout the equatorial highlands regions [*16*]. Although a positive spectral identification remains elusive, these surfaces display morphological and spectral properties similar to halides. This adds another compositional class that is likely associated with the aqueous history of Mars and does not fit within the existing proposed historical framework.

GRS results. The Gamma Ray Spectrometer suite of instruments has identified a number of elemental compositional geographic trends, including substantial hydrogen-rich deposits in low latitude regions [e.g. *17*], but without any obvious corresponding spectral mineralogical identification. Based on the relative instability of near-surface ice in these regions, it is likely that these deposits represent some sort of hydrated mineralogy [e.g. *18*]. These deposits represent by far the dominant known source of hydrated compositions on the planet and are also likely to have a substantial role in the mineralogical and aqueous history of Mars.

Conclusions: The mineralogical and aqueous history hypothesis put forward by Bibring et al. [*2*] has some basis in the patterns observed in the spectral and other datasets. Mars likely had an environment that was more conducive to the formation of phyllosilicates in the past and the recent cold and dry climate will not produce highly altered surface compositions.

However, the extent of surface versus subsurface mineralogical genesis remains largely unknown as is the corresponding link with the climate at the time of formation. The ages of the surfaces of various mineralogies remain poorly constrained and, as shown in Gusev crater, compositions that would have formed in a number of aqueous environments appear within meters of each other with an apparently complicated geological history. The formation of sulfates do not necessarily have a direct link to Tharsis and Hesperian volcanism and the timing of sulfate formation remains largely unconstrained. Finally, there is evidence that oxidized surfaces have been subjected to aqueous alteration and their formation cannot be constrained to more recent Martian history and gas/solid reactions.

The proposed framework for the mineralogical and aqueous history of Mars also does not address a number of significant global compositional trends. The results from these additional datasets do not necessarily contradict the global history hypothesis, but give an indication that the picture is likely to be considerably more complex. MER, TES/THEMIS, GRS and other investigations contribute a considerable amount of additional information towards our understanding of the global mineralogical and aqueous history of Mars. In addition, the Columbia Hills have shown how variable surface compositions can be in a limited area and how completely these compositions have gone undetected in the orbital datasets. These observations appear to make significant additions and corrections to the global history hypothesis necessary.

The MGS, Odyssey, Mars Express, MER, and MRO missions have all helped revolutionize our understanding of Mars. The inclusion of results from all of these missions in a self-consistent manner is crucial to assembling an accurate picture of the complex mineralogical and aqueous history of Mars.

References: [1] Bandfield, J.L. et al. (2000) *Science*, *287*, 1626-1630. [2] Bibring, J-.P. et al. (2006) *Science*, *312*, doi:10.1126/science.1122659. Minitti, M.E. et al. (2007) *JGR*, *112*, doi:10.1029/2005JE002560. [4] McSween H.Y. et al. (2006) *JGR*, *111*, doi:10.1029/2006JE002698. [5] Ming, DW. et al. (2006) *JGR*, *111*, doi:10.1029/2005JE002560. [6] Ruff, S.W. et al. (2006) *JGR*, *112*, doi:10.1029/2006JE2747. [7] Clark, B.C. et al. (2006) *JGR*, *111*, doi:10.1029/2006JE002756. [8] Ruff, S.W. et al. (2007) *EOS*, *88*, Abstract P23A-1097. [9] Bibring, J-.P. et al. (2006) *Science*, *301*, doi: 10.1126/science.1088054. [10] Wyatt, M.B. and McSween, H.Y. (2002*) Nature, 417,* 263-266. [11] Bandfield, J.L. and Rogers, A.D. (2007*) EOS, 88,* Abstract P23A-1094. [12] Bandfield, J.L. et al. (2003*) Science, 301,* doi:10.1126/science.1088054. [13] Christensen, P.R. et al. (2001) *JGR*, *106*, doi:10.1029/2000JE001415. [14] Glotch, T.D. and Rogers, A.D. (2007) *JGR*, *112*, doi:10.1029/2006JE002863. [15] Glotch, T.D. et al. (2006) *JGR*, *111*, doi:10.1029/2006JE002863. [16] Osterloo, M.M. et al. (2007) *EOS*, *88*, Abstract P13D-1563. [17] Feldman, W.C. et al. (2004) *JGR*, *109*, doi:10.1029/2003JE002160. [18] Feldman, W.C. et al. (2004) *GRL*, *31*, doi:10.1029/2004GL020181.