Mars - It's What's Inside That Counts: Laura L. Griffith and Raymond E. Arvidson, McDonnell Center for the Space Sciences, Department of Earth and Planetary Sciences, Washington University, St. Louis, MO 63130.

Spectral reflectance and emittance data covering the surface of Mars suggest a planet with basaltic bedrock covered with ferric-rich weathering products and only a few percent of carbonate material. This view of the surface may be biased by photo-oxidation and other weathering effects and thus may not be representative of the textural or mineralogical character of the crust. Hydrothermal alteration of the upper few kilometers of the crust may be widespread and may have occurred globally, even when surface temperatures were below the triple point of water. The main driving forces for the hydrothermal system would have been shallow intrusive and extrusive magmatic events. Extensive hydrothermal activity would have altered the properties of the upper crust and created subsurface reservoirs of volatile species, including carbonates. Physical and chemical modeling of hydrothermal systems on Mars provide predictions as to the nature and locations of altered crustal sections and suggestions as to where to make observations to test the hypothesis.

What is typically seen of Mars with imaging cameras, infrared instruments, radar, and even the Viking Lander *in situ* analyses necessarily involves aeolian sediment, local debris, and whatever bedrock is exposed. From various spectra (ISM [1], Mariner 9, IRIS [2], and ground-based [3]) the presence of ferric oxide or oxyhydroxide coverings or coatings on basalt is inferred. Ground-based spectra have also been used to deduce the presence of scapolites [4] and predict an upper limit of 10 -15% of sulfates and carbonates in the airborne dust [5]. It has been estimated that 10 - 20 bars of CO_2 should have been outgassed by Mars; this amount of CO_2 is about equivalent to 225 - 450 m of calcium carbonate [6]. This CO_2 is in the polar caps, adsorbed onto the regolith, and in the atmosphere, but these reservoirs do not account for all the CO_2.

Kasting [7] has suggested that the martian surface temperature did not surpass the water triple point (i.e. 273 K) because CO_2 condensation in the upper atmosphere lowered the thermal gradient. In the absence of greenhouse gases other than CO_2 (e.g. SO_2), this result implies that rainfall and runoff were negligible. It has further been suggested that regional hydrothermal activity, instead of rainfall and runoff, was responsible for the runoff channels in at least the Hecates Tholus and Alba Patera regions [8]. Global hydrothermal alteration has also been sited for the "uniform" depth (~ 1 - 2 km) of erosion found at many scarp faces [9]. We propose that there has been extensive global hydrothermal activity on Mars that has affected the physical and chemical properties of the upper crust, even though rainfall and runoff did not necessarily occur on a global basis. Indeed, hydrothermal activity is a natural process accompanying intrusive and extrusive volcanism, both of which have occurred on Mars [10].

On Earth it is known that many hydrothermal circulation systems effect and alter their host rocks down to at least 2 km [11]. In most of these hydrothermal systems, calcite and/or aragonite and other carbonates are deposited along subterranean flow channels. Deposition occurs regardless of whether the hydrothermal water comes into contact with carbonate bearing rocks; in other words, the carbonate source constituents can be basalt or other volcanic rocks [11]. Greater than 15 wt% of altered volcanic rock may end up as carbonate [12]. Also, carbonaceous chondrite parent body alteration models have been run where the entire planetesimal is altered (up to ~ 35 km) [13]. These models, which start with a pseudo-basaltic composition (mostly olivine and pyroxene) and end up agreeing with meteorite mineralogies, also produce carbonates in a variety of Eh-pH and temperature regimes: Eh: -0.5 - -7.5 V, pH: 7 - >12, T: 1° - 150°C [14]. Volatiles other than carbon can also be sequestered in alteration phases [11]. If SNC's are assumed to be of martian origin, then fracturing and veining actually has occurred on Mars, since SNC's exhibit calcite and sulfate veins [15].

In our conceptual model three related heat sources are considered as forcing mechanisms: extrusive volcanism, intrusive magmatic emplacement, and an overall higher thermal gradient earlier in geologic time [16]. A frozen surface is assumed as a boundary condition. Thus, it is possible that carbonate and other volatile deposition have occurred in relatively large subterranean veins and not lakes, sequestering the carbonates along with other volatiles mostly below the surface. Frozen boundary conditions are also used in meteorite parent body circulation models [13], suggesting circulation patterns would be similar between the two models on regional scales. With a fixed amount of available fluid and the decreased porosity with depth (due to overburden pressure), the circulating systems would only be able to alter the crust to depths of several kilometers. Competing factors of available fluid, pressure, and porosity will be fairly uniform over the planet; therefore, planet-wide, a common base level of alteration would develop. This base level would explain the roughly uniform erosion depth observed in the fretted terrains [17]. In addition, variations in topography and magmatism will lead to regional-scale circulation systems and changes in physical and chemical propertiesof the crust. Consider a system in which aqueous fluids are in circulation away from an intrusion. Circulation patterns will be governed by the topography and local thermal characteristics. Fluids initially undersaturated with respect to carbonates might become saturated at a temperature ~150°C when the pH is ~7 and the Eh is ~-0.4 V. At lower temperatures, ~25°C, (further from the heat source) a wider range of pH is allowable for carbonate saturation, ~7.5 - ~9.5, along with Eh values between -0.5 and -0.75 V [14].

We are currently pursuing coupled physical and chemical modeling of hydrothermal systems on Mars, using 2D ground water flow and the EQ3/6 algorithm [18] to compute ionic concentrations and saturation states. The intent is to predict the nature and locations of hydrothermal products under a variety of topographic and heat source geometries and magnitudes. The predictions will also serve to focus attention on key areas on Mars to observe with the Gamma Ray Spectrometer and Thermal Emission Spectra, assuming a reflight of Mars Observer or another orbiter or orbiters. For example, the walls and interior layered deposits of Valles Marineris are prime candidates for exploring this hypothesis. These areas offer several advantages over of areas of the planet: a) they are in an area where volcanism has been extensive, b) the canyon walls expose crustal sections, c) the interior layered deposits have various properties, including texture, topography, and coloration, which might be explainable by hydrothermal alteration, and d) the fretted terrain in the eastern end of the canyon shows features suggestive of fluvial activity.

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