EPSC Abstracts
Vol. 8, EPSC2013-858-1, 2013
European Planetary Science Congress 2013

Aqueous Minerals on Early Mars from CRISM, OMEGA, THEMIS and TES

B.L. Ehlmann (1,2), C. Edwards (1), L. Pan (1)
(1) California Institute of Technology, USA, (2) Jet Propulsion Laboratory, USA (ehlmann@caltech.edu)

Abstract

High spatial resolution spectroscopy from Mars orbit has enabled combined analysis of mineralogy plus morphology and has provided a new means of understanding environmental conditions on early Mars and tracing environmental change through time. Here we review the principal findings concerning the mineralogy and spatial distribution of alteration phases, with particular emphasis on differences between the southern highlands and newly discovered hydrated silicate-bearing geologic units in the northern lowlands.

1. Introduction

The association of alteration mineral phases with particular, distinctive geologic units began with the Thermal Emission Spectrometer (TES) discovery of coarse, gray hematite in layered sediments at Meridiani Planum, which resulted from chemical reactions with liquid water [1,2]. Mapping of the Observatoire pour la Minéralo-gie, l'Eau, les Glaces, et l'Activité (OMEGA) discovered new hydrous mineral classes including phyllosilicates [3,4] and sulfates [5-6]. Analysis of stratigraphy and time-ordering of phases showed fundamental transitions in Mars' history from comparatively water-rich and near-neutral conditions in which phyllosilicates formed to a water-limited, acidic epoch where sulfate formation dominated to mostly anhydrous, oxidative weathering conditions dominant at present [7].

Subsequent investigations by the Compact Recon-naissance Imaging Spectrometer for Mars (CRISM) [8] revealed an even greater diversity of phyllosilicate [9], sulfate, carbonate [10] and silica [11] phases (Figure 1). Continued TES analysis also revealed chlorides in association with topographic lows [12]. The mineral diversity discovered is organizable by distinctive mineral assemblages exposed in craters [13], stratigraphies of units of multiple compositions [13-19], and basins/ watersheds with mineralogically distinctive sediments [19-24]. Indeed, the organized nature of the mineralogic diversity permitted the identification and time-ordering of nearly a dozen distinctive aqueous environments from early Mars [19].

2. Spatial/Temporal Distribution

2.1 The Southern Highlands

Eight key observations include (i) the prevalence of phyllosilicates in Noachian terrains and their absence most later terrains [7], (ii) the prevalence of sulfates (and silica) in terrains from the late Noachian to late Amazonian [19], (iii) the relative rarity of carbonates, at least as compared to the detections of sulfates and chlorides [10]; (iv) that most clay mineral-bearing formations are not accompanied by salts [25]; (v) the common presence of some hydrothermal minerals, e.g. prehnite, and hydrothermal mineral assemblages in craters [13, 26, 27], (vi) minerals indicating distinctive conditions: reducing-alkaline (e.g. serpentine; [28]), reducing-acidic (e.g. alunite; [30]), and oxidizing-acidic (e.g. jarosite; [11]) in discrete locations; (vii) the common stratigraphy of Al-phyllosilicates above Fe/Mg phyllosilicates [13, 26, 30, 31], (viii) the fact the iron-magnesium smectites and chlorites are found globally where Noachian terrains are exposed, while other phases are more restricted to discrete geographical areas [26].

2.2 The Northern Lowlands

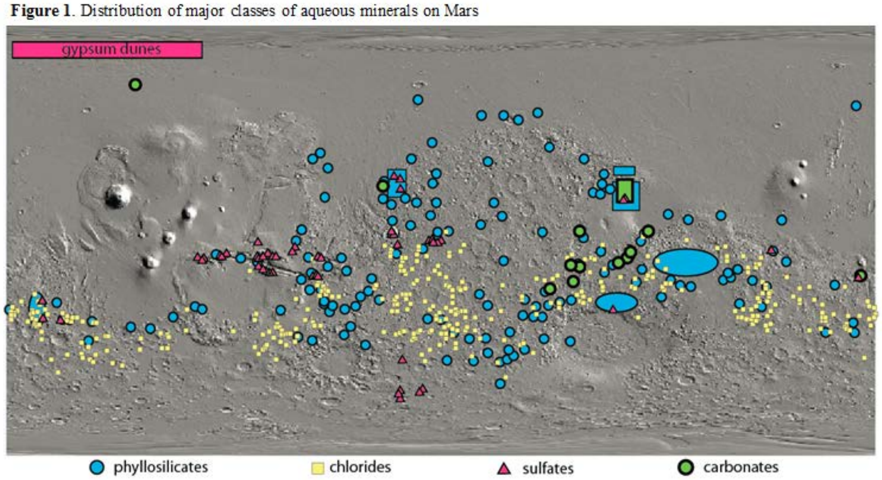
In contrast to the basaltic character of much of the southern highlands, there is widespread evidence of thin coatings on basalt [e.g. 32, 37] or basaltic glass [38] throughout the northern lowlands. Exposures of phyllosilicates in large craters [27] and olivine in several small craters [32], suggest a stratigraphy of buried Hesperian lavas and altered Noachian crust.

We recently reported [33] the discovery of Fe/Mg phyllosilicates and hydrated silica associated with terrains in Acidalia that possess knobs and cones thought to result from late volcanism [34, 35]. The Fe/Mg phyllosilicates are spatially associated with the knobs, consistent with remnants of eroded Noachian crust; however, hydrated silica is restricted to more recent Hesperian or later units mantling the knobs. This work along with a recent similar detection by [36] in Utopia, points to Hesperian or later locally intense processes of alteration. Using a combination of CRISM parameter maps and TES indices related to the presence of hydrated silicates [39], we have found additional locales with discrete exposures of hydrated silicates, located in knobby terrains and near the outflow channels. Interestingly, in spite of careful investigation, it remains the case that carbonates [26] and chlorides [40] have not yet been discovered in the northern lowlands in deposits visible from orbit.

6. Summary and Conclusions

Vigorous debate and research continues as to the significance of particular mineral phases and geologic formations as indicators of Mars' past environmental conditions. Al-clay over Fe/Mg clay stratigraphies appear similar to terrestrial weathering profiles, albeit at a much larger scale. Within Noachian-aged stratgraiphic units in the southern highlands and newly discovered Noachian-aged knobs within the northern lowlands, Fe/Mg phyllosilicates predominate, supporting hypotheses of an early, global clay-forming process that was largely complete by the beginning of the Hesperian [7, 9, 26]. Fe/Mg smectites, chlorites, and their accompaniment by higher temperature phases suggests subsurface low-grade hydrothermal processes [26]. In contrast, as surface and groundwaters were available locally during the Hesperian, salts and silica minerals precipitated in basins and topographic lows with the composition of the alteration mineral determined by local water chemistry. A key effort for the future will be determining the process(es) that resulted in episodic availability of waters of these different chemistries.

Figure 1. Distribution of major classes of aqueous minerals on Mars



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