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Phyllosilicate-bearing Rocks at Mawrth Vallis, Mars, and Implications for Habitable Environments and Biomarkers

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Abstract

Phyllosilicates observed in the Mawrth Vallis region of Mars by OMEGA and CRISM indicate a wide range of past aqueous activity [1,2,3]. Here we discuss the phyllosilicate stratigraphy observed at Mawrth Vallis, possible formation scenarios, and the plausibility of habitable environments. We also present the potential for prebiotic chemistry and biosignatures in thick clay-rich environments similar to those observed here. This region also contains multiple safe landing site options for future missions.

1. Introduction

Phyllosilicate minerals have been identified on Mars in OMEGA and CRISM images using spectral absorptions at 1.38-1.42, 1.91-1.93, 2.16-2.33 and 2.39-2.41 µm [2,3,4]. Analyses of Mawrth Vallis spectra revealed large exposures of Fe/Mg-smectite as the deepest phyllosilicate unit within the ancient cratered terrain. This exists as a thick, pervasive unit that was subsequently covered by material rich in Al-phyllosilicates and hydrated silica.

2. Phyllosilicates at Mawrth Vallis

Fe/Mg-smectite (nontronite) is observed in outcrops of the ancient cratered terrain and is overlain by rocks rich in hydrated silica, montmorillonite, and kaolinite [3,5]. A Fe^{2+} phase is present at the transition from Fe/Mg-smectite to Al/Si-rich material. The stratigraphy of Fe/Mg-smectite overlain by a ferrous phase, hydrated silica and then Al-phyllosilicates implies a complex aqueous history. This stratigraphy is shown in Figure 1 with example spectra shown in Figure 2. As the clay profiles are similar across a 10^6 km wide expanse [6], common aqueous processes likely occurred throughout the greater Mawrth Vallis region to produce this expansive clay profile.

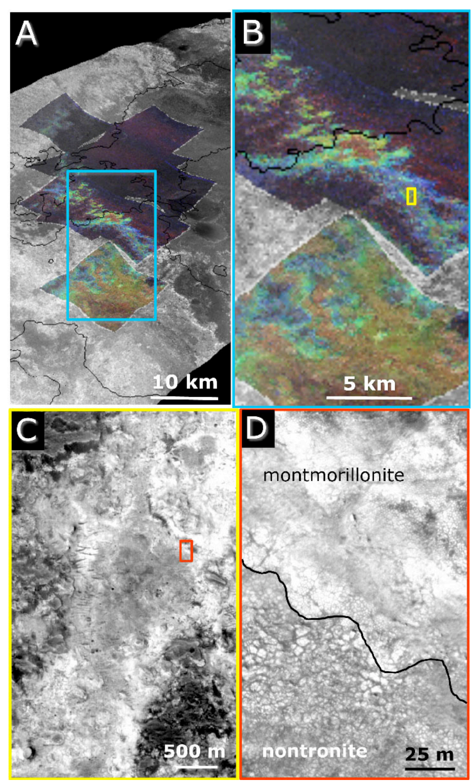

Figure 1: A)+B) CRISM phyllosilicate map [R=nontronite, G=Fe^{2+} phase, B=Al-clay/silica] overlain on CTX, C) CTX image +D) HiRISE image showing rock textures of nontronite-rich and montmorillonite-rich units.

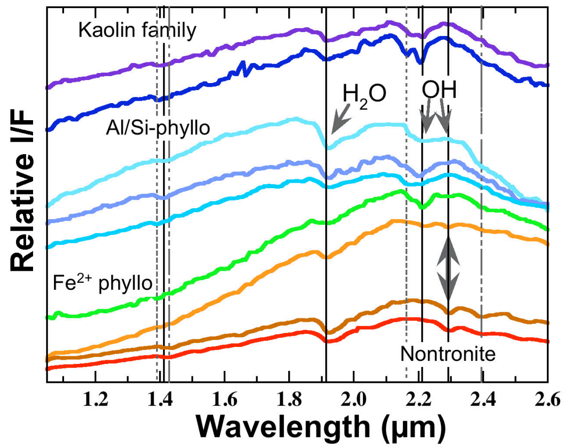

Figure 2: CRISM ratioed I/F spectra from Mawrth Vallis including outcrops dominated by nontronite (bottom), a Fe^{2+} phase (clays?), hydrated silica, montmorillonite, and kaolinite (top). Spectra are approximately color-coded to Figure 1 A+B.

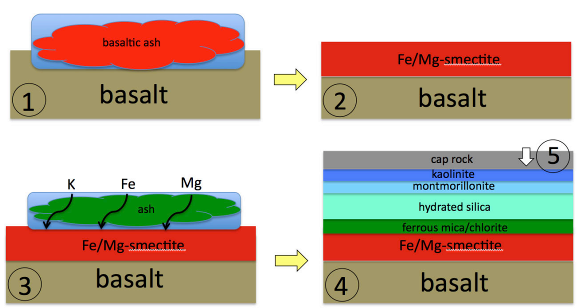

Figure 3: Diagram of possible formation processes for phyllosilicate outcrops at Mawrth Vallis. (1) basaltic ash is altered in an aqueous environment to form Fe/Mg- smectite (2) that is then covered by subsequent water and ash (3), where elements such as Fe, Mg and K are leached out of the ash to crystallize Al-phyllosilicates and hydrated silica on top and Fe/Mg-bearing mica or chlorite below (4), where the leached elements are trapped at the upper boundary of the Fe/Mg-smectite unit. Finally, a cap rock is deposited on the surface (5).

Large-scale aqueous events were required to form the massive clay outcrops detected at Mawrth Vallis. A diagram of a possible scenario is shown in Figure 3. Nontronite is likely to have formed under reducing, low-O_2 conditions where the Fe^{2+} oxidized *in situ* to Fe^{3+} in the Fe/Mg-smectite unit [7]. The presence of a ferrous phase (Fe^{2+}) on top of the nontronite (Fe^{3+}) is further evidence for anoxic conditions, active chemistry and changing redox conditions. This Fe^{2+} phase could be an Fe^{2+} clay such as mica or chlorite, or it could be another mineral such as a carbonate, sulfate or olivine. As this phase is mixed with the nontronite below and montmorillonite above, it is likely another clay mineral. The upper unit (Fe^{2+} material, hydrated silica, montmorillonite and kaolinite) likely formed together in one complex chemical system, perhaps including hydrothermal processes or acid-leaching.

3. Pre-biotic chemistry in clays

Early phyllosilicate-bearing rocks on Mars may have provided an optimal reaction setting for pre-biotic chemistry and possibly for the development of life. Phyllosilicates can catalyze chemical reactions due to their surface acidity and by bringing together molecules on their surfaces [8]. Metal ions in a clay matrix may also have played a crucial role in the origin and early evolution of life by reacting with amino acids and nucleotides [9].

4. Biosignatures

Preservation of biosignatures is favored in rapid burial conditions in fine-grained clay-rich systems and long-term preservation is most successful in phyllosilicate- and silica-bearing host rocks that are resistant to weathering and provide an impermeable barrier for biosignatures [10]. This suggests that if microbes did once inhabit the early environment at Mawrth Vallis, biosignatures could be retained in the phyllosilicate and hydrated silica deposits there.

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