CLAY-BEARING ROCKS IN THE MAWRTH VALLIS REGION, MARS. J. R. Michalski[1], J.-P. Bibring[1], F. Poulet[1], R. Fergason[2], N. Mangold[3], D. Loizeau[3], E. Noe Dobrea[4], J. L. Bishop[5], [1]Institut d'Astrophysique Spatiale, Université Paris-Sud, 91405 Orsay, France. [2]School of Earth and Space Exploration, Arizona State University. [3]Laboratoire IDES-Orsay, Université Paris-Sud, [4]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove, Pasadena, CA, 91109. [5]The SETI Institute, Mountain View, CA 94043.

Introduction: Clay minerals have long been studied in Martian meteorites [1-2], but recent discoveries of vast exposures of phyllosilicates on Mars [3-4] opens a new window into the aqueous history of Mars. Undoubtedly these deposits will be high priority targets for future exploration, including a possible sample return effort. The phyllosilicates, which can accurately be described as clay minerals, occur in geomorphically and mineralogically diverse terrains, suggesting multiple formation mechanisms and various geologic contexts.

In this paper, we describe the mineralogy and geologic context of the largest exposure of clay minerals on Mars: those in the Mawrth Vallis region. We describe the rationale for interpreting these deposits as clay-bearing and report a multi-instrument remote sensing perspective on these deposits. We present the current understanding of how these deposits fit into the global geologic history of Mars, their implications for past habitability, and their value as possible sample return targets.

Mineralogy: The evidence for phyllosilicates on Mars rests on the observation of multiple, correlated spectral absorptions in near infared (λ = 1-3 μm) reflectance spectra of certain terrains: 1) a strong 1.9 μm hydration feature attributed to mineralogic H_2O, 2) weaker absorptions in the 2.2-2.35 μm range attributed to octahedral metal-OH absorptions in clay minerals, and 3) a weaker band sometimes observed near 1.4 μm also attributed to octahedral O-H. The occurrence of the these features together in the same pixel argues for either a single, expandable TOT clay mineral or a combination of TO clay and another hydrated phase (*e.g.* zeolites). However, the overall spectral shape of these altered terrains that is extracted by spectral ratios compares favorably with the spectral shape of specific clay minerals. The spectral features are confirmed by multiple observations with the OMEGA instrument onboard Mars Express [3-4] and later observations by the CRISM instrument aboard Mars Reconnaissance Orbiter [5].

In the Mawrth Vallis region, the precise placement of the near infrared metal-OH bands and overall spectral shapes suggest the presence of montmorillonite, nontronite, kaolinite, and hydrous silica (similar to opal-A) [6-7]. Nontronite is the most common based on spectral mapping, and the most abundant, based on spectral modeling. Model results suggest 20-65% contribution from clay minerals in the surface spectra, along with other alteration minerals such as minor silica and ferrihydrite [8]. The spectral models also require a significant component of spectrally neutral material – possibly plagioclase feldspar.

Thermal infrared (λ = 6-30 μm) spectra do not, however, show evidence for abundant clay minerals in this location [9]. The disagreement between the two datasets with regard to clay mineral detection could be due to a combination of factors: 1) low actual abundances of clays, which are below the detection limit of the TES instrument given its larger spatial footprint or 2) rough surface textures that favor multiple scattering and improve near-infrared detectability, but decrease thermal infared detectability. Thermal infrared spectra of the altered surfaces are dominated by spectral features of feldspars and amorphous silica. A simple comparison of the spectral shapes of the clay-bearing units and adjacent, dark, basaltic terrains shows that the two are spectrally different and the clay-bearing surfaces are higher in silica content. Comparison of the placement of the major Si-O absorption feature to terrestrial trends [9] suggests the clay-bearing rocks are >60% SiO_2 (wt. %) compared to ~50% SiO_2 for the basaltic surfaces.

Geologic context: The geologic context of clay minerals at each site are interpereted from visible imaging and thermophysical data. In the Mawrth Vallis region, clays are associated with a thick section of ancient, eroded bedrock [10-11]. Detailed geomorphic and stratigraphic [12] studies reveal a complex stratigraphic section with 100s to 1000s of individual layers. The geomophic diversity (*i.e.* resistance to weathering, surface textures and landforms) among these units suggests a range of lithologies. Some of the clay-bearing layers correspond to resistant, butte-forming units. Others appear unable to form significant topography and contain large cracks/fissures probably related to negative volume change and dessication (Figure 1). No single idea of lithologic context is likely to capture the diversity of the Mawrth Vallis region. However, the environment must have been dynamic in space and/or time to allow for the thick accumulation of such diverse rocks. Because the clays are tied to layering, present over a large area, present throughout a thick section of rocks, interbedded with relatively clay-rich and clay-poor units, and present along with plagioclase and silica, it seems the most likely geologic context is sedimentary and/or pyroclastic. In either case, geomorphic relationships show that the clay-bearing rocks were deeply eroded early in Mars history and the clays were already in place at this point.

Implications: The close association of the clay mineralogy to ancient, eroded, layered rocks of probable sedimentary origin [10-11] suggests that these deposits could provide a window into the aqueous sedimentary processes in the earliest history of the Solar System. The neutral pH conditions implied by the preponderance of smectite clays could be compatible with the formation of pre-biotic chemistry on Mars as it is understood on Earth [13]. Combined geomorphic and spectroscopic studies provide constraints on the lithologic context of the clays, but questions remain about the lithology of the clay-bearing units.

Lithologic classification is a function of both the mineralogy and texture of a rock and to understand the lithology of these clay-bearing rocks, we must acquire more information. Based on all available data, the altered rocks in the Mawrth Vallis region have a bulk mineralogy of feldspar + Fe-smectite + silica + ferrihydrite ± montmorillonite ± kaolinite, but how these minerals are distributed at the sub-pixel level is not known. Are the minerals partitioned among different layers? Do the clay minerals occur as cements around grains of feldspars and other phases? Are the clays clastic and if so, what is their provenance? Is the silica in these rocks present as primary volcanic glass or secondary cement and vein fill? What accessory phases have escaped detection? Are carbonates present in these rocks and if so, do they hold a clue to the early atmospheric composition and pressure on Mars?

Conclusions: Clay-bearing deposits on Mars are likely to be visited by upcoming landed missions such as the Mars Science Laboratory and/or ExoMars landers. Results from these missions will solidify our understanding of the geologic context of certain clay deposits. Pending the outcome of these missions, it may make sense to collect clay-bearing rocks during a sample return mission because these deposits almost certainly contain a range of particles of distal sources along with authigenic secondary minerals. Through detailed analysis of these deposits, it may be possible to date a range of processes on Mars, search for isotopic signatures of an ancient martian hydrosphere and atmosphere, and search for chemical clues of early organic processes.

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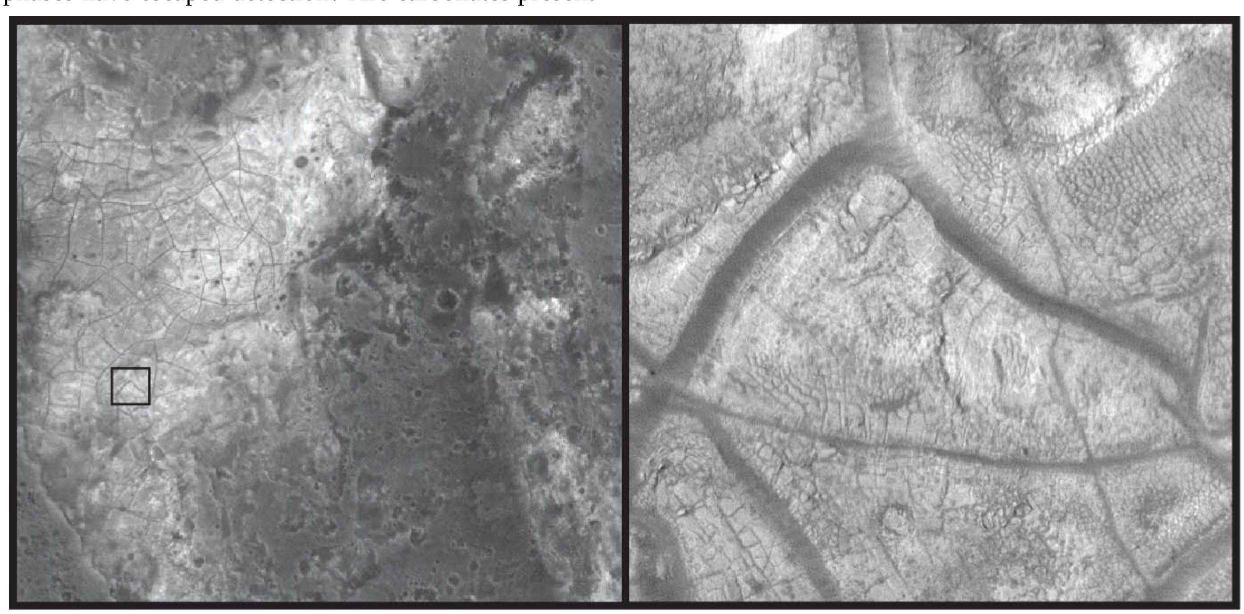

Figure 1: MOC image M1800673 (at left) showing the “polygons” sub-unit of the light-toned, clay-bearing unit in the Mawrth Vallis region. OMEGA detects nontronite and ferrihydrite in this deposit [7].The MOC image is 3 km across. The inset shows the location of HiRISE image PSP_001454_2030 (at right), which reveals the morphology of two scales of fractures present in this unit. The question remains open as to whether the cracks are related to desiccation of smectites in this rocks.