An Overview of Classes of Martian Phyllosilicate Deposits from Orbital Remote Sensing. S. Murchie[1], J. Mustard[2], B. Ehlmann[2], R. Milliken[3], J. Bishop[4], F. Seelos[1], and the CRISM Team. [1]Applied Physics Lab., Laurel, MD (scott.murchie@jhuapl.edu); [2]Brown U., Providence, RI; [3]JPL, Pasadena, CA; [4]NASA/Ames and SETI Institute, Mountain View, CA.

Summary: The occurrence, types, and geologic settings of aqueous minerals have been investigated by the Mars-orbital spectral mapping instruments TES, THEMIS, OMEGA, and CRISM using an increasingly expanded wavelength range and higher spatial resolution. Each has complemented previous investigations by re-imaging sites having spectral evidence for aqueous minerals, except using broader wavelength coverage and/or higher resolution. MRO's contribution is centered on the 20 m/pixel spatial resolution offered by CRISM, and 30 cm/pixel resolution of HiRISE images that typically are coordinated with CRISM observations. In conjunction with earlier data, these new measurements indicate at least five different classes of deposits containing phyllosilicates and related hydrated silica, each with a distinct combination of spectral signatures and morphological features. These deposits may represent depositional environments recording different phases of the history of water on Mars, and their future investigation promises significant new insights in Mars' hydrologic evolution.

Layered Phyllosilicates. The phyllosilicates detected by OMEGA at Nili Fossae and Mawrth Vallis [1], when observed at high spatial resolution, are resolved into layers having stratified compositions [2]. At Mawrth Vallis (Fig. 1) an erosion-resistant deposit typically overlies hydrated silica and Al-rich clays including kaolinite and montmorillonite, which in turn overly Fe/Mg-rich clays [3]. The layering is consistent over hundred of kilometers inplying regional processes, and remnants extend over a region 700x900 km suggesting a formerly more extensive deposit [4]. Stratigraphically it is younger than Mawrth Vallis indicating a lesser age than previously thought [5]. Comparable layered structure is observed in phyllosilicates occuring in eastern Nili Fossae, where Fe/Mg-rich clays are more predominant. There are only kilometer-scale, local occurrences of overlying Al-rich clay [6]. Proposed origins for the layered phyllosilicates include alteration of volcanic ash, subaerial weathering of basaltic regolith, subaqueous sedimentation of sorted, transported clays [7], and hydrothermal deposition [3].

Massive Noachian Phyllosilicates: These occur in ejecta, walls, and central peaks of several- to several-tens-of-kilometer diameter craters in the highland plateau (Fig. 2), in massifs of eroded highlands, and in the walls of Valles Marineris [2]. A variety of phyllosilicate mineral groups is indicated by their spectral signatures, with chlorite and saponite dominating in contrast to the smectite and kaolinite that dominate layered phollosilicates. Regional differences are observed in the relative abundance of these phases between Argyre, Tyrrhena Terra and western Nili Fossae, suggesting the occurrence of mineralogic "provinces" [8,9]. In general the mineralogy suggests a low level of alteration, but a few locations exhibiting kaolinite and muscovite may indicate locally higher temperatures or a more active hydrology to flush Fe and Mg from the rock (assuming basaltic parent rock). Based on CRISM global mapping at reduced (200 m/pixel) spatial resolution, we estimate that there are 5000-10,000 exposures exceeding 1 km in size, that occur throughout the Noachian highlands where tens-of-kilometers diameter craters and escarpments provide "windows" relatively free of eolian sediment through Hesperian and upper Noachian plains, to about 3-6 km depth. However larger basins such as Argyre that penetrate deeper expose massifs of relatively unaltered mafic and ultramafic rocks [10]. These observations suggest that massive phyllosilicates occupy a globally extensive layer of uncertain continuity, emplaced at the surface or shallow depths in the early Noachian period.

Phyllosilicate-containing Intracrater Fans. MRO observations of highland intra-crater fans [e.g. 11] have revealed that parts of several fans exhibit enhanced content of phyllosilicate (Fig. 3), most evident in Holden [12], Eberswalde [13], Terby [14], and Jezero [15]. Jezero is a type example because spectral contrast in the drainage basin provides a tracer for fluvial transport of sediment. The phyllosilicate is concentrated in lower, horizontally bedded parts of the fans whose morphology suggest a fine-grained texture and deposition in a lacustrine environment. These lower beds are overlain by coarser deposits interpreted as alluvial fans. Spectrally, the phyllosilicate is consistent with outcrops of massive or layered phyllosilicate in the drainage basin, suggesting that it was fluvially transported to a deltaic environment with minimal alteration [15].

Glowing Terrain. "Glowing terrain" was identified in THEMIS data based on thermal infrared properties indicating a significant content of minerals having an emissivity <<1.0. The geologically most reasonable candidate is chloride in excess of 25% mass fraction, consistent with the deposits' location typically in closed basins [16]. HiRISE images (Fig. 4) show distinct color properties, fine layering, and intense polygonal fracturing. CRISM data reveal a disinctive near-infrared signature characterized by a weak 3-µm H_2O absorption and a red spectral slope, properties consistent with intermixture of a high-albedo anyhydrous component such as chloride. In addition this signature is sometimes located near the center of an irregular bulls-eye, surrounded by phyllosilicates that extend from flat areas containing the glowing terrain into surrounding highlands (Fig. 5).

Hydrated Silica Deposits. CRISM data have revealed the widespread occurrence of hydrated silica in light-toned layered deposits on the Hesperian-aged plains surrounding Valles Marineris (Fig. 6) [17]. The light-toned deposits are eroded in some places into yardangs, and in others display inverted channels suggesting eolian erosion of fluvial deposits. Discrete layers have a broad, shallow 2.2-µm absorption distinct from that in phyllosilicates, but matching hydrated silica. The shape and center of the band, and strengths and positions of accompanying bands at 1.4 and 1.9 µm, indicate a variety of forms including altered glass, opal, and chalcedony. Other layers exhibit absorptions due to Fe sulfates. The relationship of the hydrated silica to high-Si deposits found by MER/Spirit [18] is unknown.

Discussion. The diversity and widespread occurrence of phyllosilicate and related phases suggests depositional environments that extend from the early Noachian (massive phyllosilicates) through early Hesperian (layered phyllosilicates and hydrated silica) periods. Key questions to develop a more compete understanding of formation of these materials include: (a) What were the genetic mechanisms of layered phyllosilicates, and how were they related to those of hydrated silica? (b) What are the spatial extent, lateral continuity, and mineralogic distributions of massive phyllosilicates? (c) Are the massive phyllosilicates equivalent to layered phyllosilicates that subsequently were buried and further altered into different phases, or did they form by distinct mechanisms such as hydrothermal alteration driven by radiogenic or impact heat? (d) What is the relationship of phyllosilicate-containing fans and glowing terrain with associated phyllosilicates? Do they represent a continuum of lacustrine environments with different proportions of evaporite and clastic sediments, or were they formed by distinct processes? As the MRO mission continues, the targeting strategy for new observations is incorporating the discoveries outlined above, to test these hypotheses with newly acquired data.

References: [1] F. Poulet et al., Nature, 438, 623, 2005. [2] J. Mustard et al., Nature, 454 , 305-309, 2008. [3] J. Bishop et al., Science, 321, 830-834, 2008. [4] E. Noe Dobrea et al., LPSC 39, 1077, 2008. [5] J. Wray et al., Geophys. Res. Lett., 10.1029/2008GL034385, 2008. [6] B. Ehlmann et al., 7th Mars Conf., 3270, 2007. [7] D. Loizeau et al., J. Geophys. Res., 112, doi:10.1029/2006JE002877, 2007. [8] B. Ehlmann et al. LPSC 39, 2326, 2008. [8] J. Mustard et al., this volume. [9] M. Malin and K. Edgett, Science, 290, 227, 2001. [10] D. Buczkowski et al., LPSC 39, 1030, 2008. [11] M. Malin and K. Edgett, Science, 302, 1931, 2003. [12] J. Grant et al., 7th Mars Conf., 3229, 2007. [13] R. Milliken et al., 7th Mars Conf., 3282, 2007. [14] M. Golombek et al., LPSC 39, 2181, 2008. [15] B. Ehlmann et al., Nature Geosciences, 1, 355-358, 2008. [16] M. Osterloo et al., 7th Mars Conf., 3269, 2007. [17] R. Milliken et al., Geology, in press, 2008. [18] S. Squyres et al., Science, 320, 1063-1067, 2008.

Fig. 1. HiRISE image of Noachian layered clays (type location, Mawrth Vallis). The light-colored materials are clay-bearing.

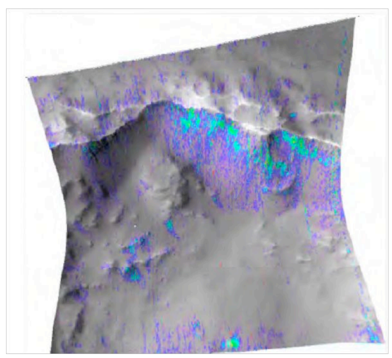

Fig. 2. CRISM image of massive phyllosilicate (in blue) excavated and exposed in a crater wall (type location, Tyrrehena Terra).

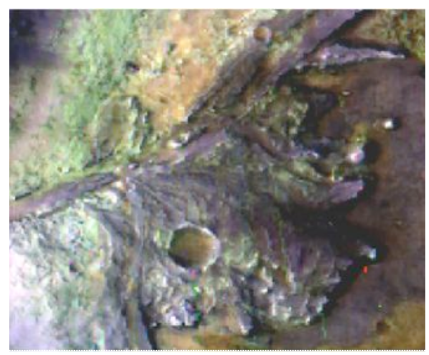

Fig. 3. CRISM IR false color image of intra-crater fan. Green material in the base of the fan is phyllosilicate-bearing (type location, Jezero crater).

Fig. 4. HiRISE image of the polygonally fractured surface of glowing terrain. Thermal IR properties are consistent with a high chloride content (type location, Terra Sirenum).

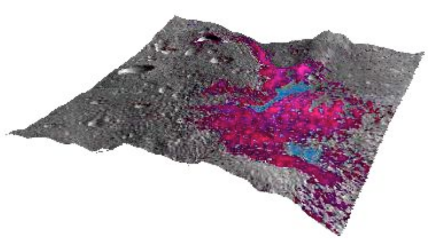

Fig. 5. CRISM spectral map of glowing terrain draped over MOLA topography with 5x vertical exaggeration. Blue areas are glowing terrain, and red areas contain Fe-Mg phyllosilicates.

Fig. 6. CRISM IR false color image of thin, light-toned layered deposits on the plateau around Valles Marineris. Discrete layers (having a bluish color) contain hydrated silica and jarosite (type location, Sinai Planum).