DISCOVERY OF DIVERSE MARTIAN AQUEOUS DEPOSITS FROM ORBITAL REMOTE SENSING.
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Summary: Over the past decade the occurrence, types, and geologic settings of aqueous minerals have been investigated by Mars-orbital spectral mapping instruments using an increasingly expanded wavelength range and higher spatial resolution (TES, THEMIS, OMEGA, and CRISM). Each has complemented previous investigations by re-imaging sites having spectral evidence for aqueous minerals, except using broader wavelength coverage and/or higher resolution. Each has also found previously unrecognized evidence for new aqueous minerals. HiRISE has provided sub-meter resolution images of the mineral occurrences and revealed their physical geology in unprecedented detail. There is clear evidence for at least eight types of deposits each with a distinct combination of mineral and structural features. These diverse deposits likely represent multiple depositional environments recording different phases of the history of water on Mars, and their *in situ* investigation promises significant new insights.

Layered Phyllosilicates. The phyllosilicates detected by OMEGA at Nili Fossae and Mawrth Vallis [1], when observed at high resolution, have discrete, commonly polygonally fractured layers with a stratified composition [2]. At Mawrth Vallis (Fig. 1) an erosion-resistant deposit typically overlies a sequence of Al-rich clays, probably montmorillonite, on top of Fe/Mg-rich clays. Eroded remnants extend over a region 700x900 km in size, suggesting a formerly more extensive deposit [3]. In Nili Fossae, Fe/Mg-rich clays dominate a diverse suite of alteration products [4]. Possible origins include alteration of volcanic ash or impact ejecta, subaerial weathering of basaltic regolith, or aqueous sedimentation of transported clays [5].

Deep Noachian Phyllosilicates: These occur in ejecta, walls, and central peaks of several-kilometer and larger 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 are indicated by their spectral signatures, with chlorite and saponite common, especially in highland craters. In Nili Fossae some localities exhibit zeolite, muscovite, or hydrated silica, and there is evidence for mineral "provinces" [6]. In general the mineralogy suggests a low level of alteration, but locations with the latter phases may have experienced higher temperatures or a more active hydrology. Based on CRISM global mapping, the current estimate is that there are 5000-10,000 exposures exceeding 1 km in extent.

Phyllosilicate-containing Intracrater Fans. MRO observations of highland intra-crater fans [e.g. 7,8] have revealed that typically the lower portions of the fans exhibit parallel bedding and an enhanced content of phyllosilicate (Fig. 3). Spectrally, the phyllosilicate is consistent with outcrops of deep or layered phyllosilicate in the drainage basins, and may have originated in the uplands rather than having formed *in situ* in the fans. MRO results are consistent with sorting of fines and deposition in a lacustrine environment [9, 10].

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 salt in excess of 25% mass fraction, consistent with the deposits' location typically in closed basins, sometimes at the terminus of inflowing channels [11]. CRISM has not yet detected non-chloride salts in the glowing terrain, but HiRISE images (Fig. 4) show distinct color properties, fine layering, and intense polygonal fracturing.

Meridiani-type Layered Deposits. These layered, etched, gray hematite- and sulfate-bearing deposits were investigated *in situ* by MER/Opportunity [12,13]. A wide variety of MRO data shows that compositional and sedimentary features characteristic of the landing site also typify etched terrain extending over 300,000 km^2. The material has near-horizontal parallel beds having different erodibilities, with layers that are not deformed by extensive faulting or folding (Fig. 5). Discrete beds have enhanced signatures of mono- and polyhydrated sulfates [13,14] and hematite [12,13].

Valles-Type Layered Deposits. High-resolution MRO data show that Valles Marineris interior layered deposits (ILDs) have features that distinguish them from Meridiani-type layered deposits, despite also containing sulfates and hematite. In western Candor Chasma the deposits are extensively folded and faulted (Fig. 6) [15]. Narrow color bands forming low ridges are interpreted as mineralization by fluid flow along fractures [16]. Spectral signatures of sulfate are much more pervasive than in Meridiani, and sulfate mineralogy is interlayered on a tens-of-meters scale with evidence for kieserite, polyhydrated Fe- or Mg-sulfates, and gypsum. Some of the layers appear well-indurated, whereas others - typically with a strong monhydrated sulfate signature - are friable and erode into yardangs and dune-forming material [17,18].

Hydrated Silica Deposits. A major discovery by MRO is the widespread occurrence of hydrated silica in light-toned layered deposits on the Hesperian-aged plains surrounding Valles Marineris (Fig. 7) [19]. The light-toned deposits in some places are eroded 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 [20] is unknown.

North Polar Gypsum Deposits. High-resolution MRO observations (Fig. 8) of the Amazonian gypsum deposit in the north polar erg [21] surprisingly suggest that gypsum is concentrated in dunes, especially at the crests [22]. Morphology of the erg (friable, sandy dark material interlayered with light, polygonally fractured resistant layers) strongly resembles the basal unit [23], except reworked by wind. MRO's observations of the erg have not yet revealed a gypsum source region.

References: [1] F. Poulet et al., Nature, 438, 623, 2005. [2] J. Mustard et al., submitted to Nature, 2008. [3] E. Noe Dobrea et al., LPSC 39, 1077, 2008. [4] B. Ehlmann et al., 7th Mars Conf., 3270, 2007. [5] D. Loizeau et al., J. Geophys. Res., 112, doi:10.1029/2006JE002877, 2007. [6] B. Ehlmann et al. LPSC 39, 2326, 2008. [7] M. Malin and K. Edgett, Science, 290, 227, 2001. [8] M. Malin and K. Edgett, Science, 302, 1931, 2003. [9] J. Grant et al., 7th Mars Conf., 3229, 2007. [10] B. Ehlmann et al., submitted to Nature Geosciences, 2008. [11] M. Osterloo et al., 7th Mars Conf., 3269, 2007. [12] S. Squyres et al., Science, 306, 1698, 2004. [13] R. Arvidson et al. J. Geophys. Res., 111, doi:10.1029/2006JE002728, 2006. [14] S. Wiseman et al., 7th Mars Conf., 3111, 2007. [15] C. Okubo et al., in prep., 2008. [16] C. Okubo et al., Science, 315, 983, 2007. [17] S. Murchie et al., 7th Mars Conf., 3238, 2007. [18] L. Roach et al., 7th Mars Conf., 3223, 2007. [19] R. Milliken et al., LPSC 39, 2025, 2008. [20] S. Squyres et al., submitted to Science, 2008. [21] Y. Langevin et al., Science, 307, 1584, 2005. [22] L. Roach et al., LPSC 38, 1970, 2007. [23] K. Herkenhoff et al., Science, 317, 1711, 2007.

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

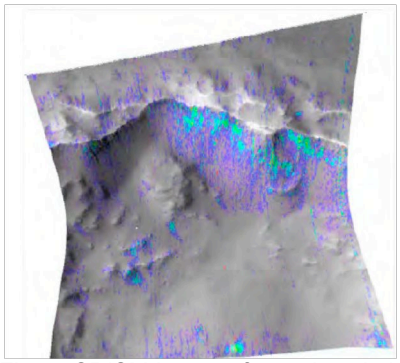

Fig. 2. CRISM image of massive phyllosilicate (in blue) excavated and exposed in a crater wall (type location, Tyrrhena Terra).

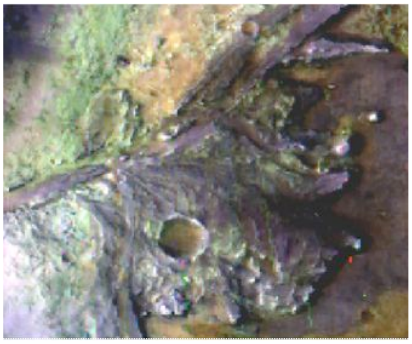

Fig. 3. CRISM IR false color image of an intra-crater fan. Green material in the base of the fan is phyllosilicate-bearing (type location, Jezero crater).

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. HiRISE image of sulfate- and gray hematite-bearing, horizontally layered, largely undeformed deposits (type location, Terra Meridiani).

Fig. 6. HiRISE image of sulfate- and gray hematite-bearing layered, faulted, folded deposits in Valles Marineris (type location, Candor Chasma). Oblique projection using digital topography.

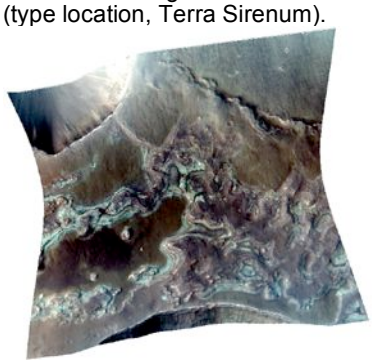

Fig. 7 (left). CRISM IR false color image of thin, light-toned layered deposits on the plateau around Valles Marineris. Discrete layers contain hydrated silica and jarosite (type location, Sinai Planum).

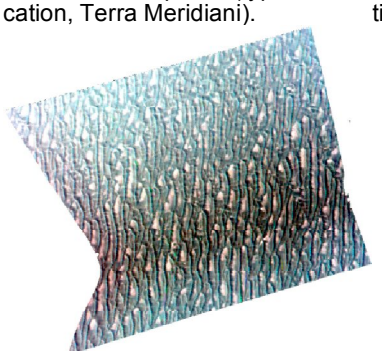

Fig. 8 (right). CRISM IR false color image of gypsum-rich dunes in the north polar erg (type location, Olympia Undae).