HARNESSING WATER AND RESOURCES FROM CLAY MINERALS ON MARS AND PLANETARY BODIES.

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Introduction: Clay minerals provide a source of water, metals and cations that can be harvested to provide resources for human exploration on Mars, asteroids and other planetary bodies. Planning how to access these resources from clays could be a vital component of future human exploration. Mark Whatney (*The Martian*) missed an opportunity to extract resources from the clays and other minerals on the surface of Mars. We need to prepare for this opportunity through experiments on clays and other minerals that represent potential resources for human missions.

Clay Minerals in our Solar System: Phyllosilicates are common aqueous alteration products on Earth, and are also present in thousands of locations on Mars and in a few meteorites, asteroids and comets. Clay minerals are readily detected from orbit or remote sensing by the distinctive OH and H_2O bands in near-infrared (NIR) spectroscopy [e.g. 1]. Clay minerals have been detected on the asteroid Ceres [2,3] and in some chondrites and Martian meteorites [4-6]. Nontronite clay was also detected at comet Tempel-1 using mid-IR spectra [7].

Clay Minerals on Mars: The martian surface is covered with clay mineral exposures wherever the ancient rocks are visible [e.g. 8-10]. Fig. 1 illustrates how these clays may have formed on early Mars when liquid water was present on the surface. The Mawrth Vallis region exhibits clay-bearing rocks that likely formed in such aqueous environments (Fig. 2). These phyllosilicates were buried over time and are exposed on the surface where the caprock is eroded. Clay minerals may have also formed in subsurface environments in some locations such as Nili Fossae [11].

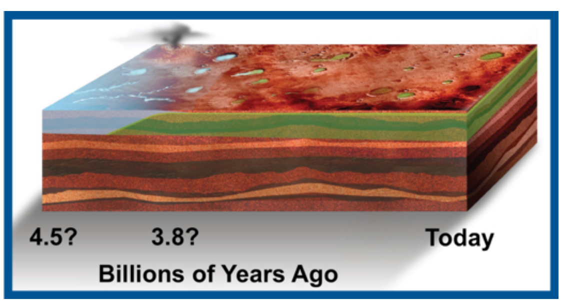

Fig. 1 Diagram of clay formation on Mars. Phyllosilicate formation was likely a pervasive process in aqueous environments on early Mars (<~4 Gyr). Subsequently, much of the phyllosilicate-bearing unit was covered and the water disappeared. Thus, phyllosilicates may be even more wide-spread just below the surface on Mars [12].

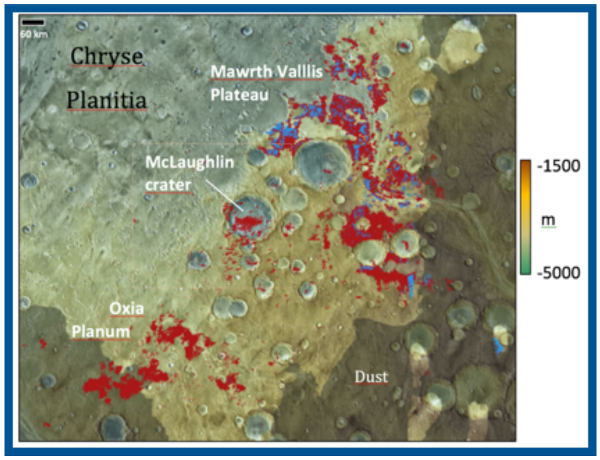

Fig. 2 Regional clay-rich outcrops across Chryse Planitia. Fe/Mg phyllosilicates are mapped in red over MOLA terrain and include nontronite, saponite, chlorite and serpentine. Al/Si-rich alteration products are shown in blue, and are comprised of kaolins, smectites, opal and allophane [1].

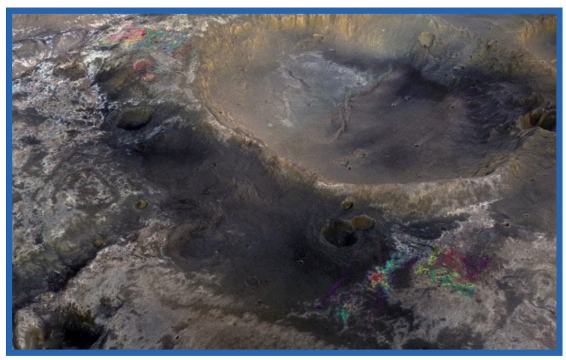

Fig. 3 View of light-toned phyllosilicate-rich material at Mawrth Vallis. This HRSC stereo mosaic shows the abundance of clay-bearing light-toned terrain exposed on the surface. CRISM parameters are overlain to indicate variations in the clay minerals and hydrated phases present [13].

Phyllosilicates on Mars are frequently observed in light-toned, layered outcrops, such as those in the Chryse Planitia region (Figs. 3-4). Typically Fe/Mg-smectite clays are present as a thick unit lower in the clay stratigraphy, while sulfates and Al/Si-rich materials are often present in upper units [e.g. 10, 12]. This stratigraphy is especially well documented in the Mawrth Vallis region. Poorly crystalline aluminosilicates (e.g. allophane, imogolite) exist at the top of the clay stratigraphy here (Fig. 4) [14] and are abundant surface components at Gale crater as well [e.g. 15].

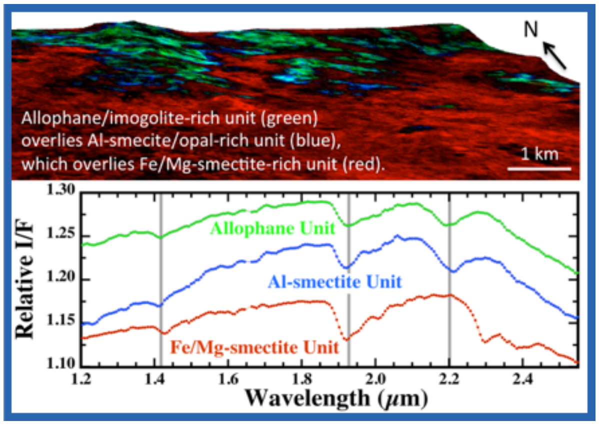

Fig. 4 Variations in clay units at Mawrth Vallis. This 3D view of CRISM image FRT0000AA7D displays the allophane/imogolite unit above the crystalline clay-bearing units with 5X vertical enhancement [14]. The spectra illustrate shifts in the bands for the allophane/imogolite-rich unit (1, green), the montmorillonite/hydrated silica unit (2, blue) and the Fe/Mg-smectite unit (3, red). Grey lines mark bands near 1.41, 1.92-1.93, and 2.19-2.20 µm.

Resources Available from Clay Minerals: Phyllosilicates are composed of sheets of FeO/OH, MgO/OH, or AlO/OH in octahedral configurations connected to sheets of connected SiO_4 tetrahedra (Figs. 5-6). Smectite clays have a layer of H_2O molecules bound to Na or Ca sandwiched in between the metal-bearing sheets and adsorbed H_2O on all surfaces. This adsorbed water is typically released ~100-150 °C and the bound water can be harvested by heating to ~300 °C [e.g. 16]. Retrieving water from poorly crystalline aluminosilicates is even easier because of the reduced structural integrity and high surface area [e.g. 17].

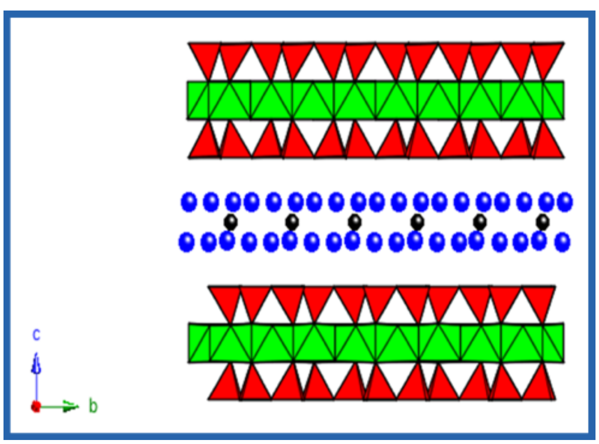

Fig. 5 Mineral structure of smectite clays. This diagram illustrates the water molecules (blue) and Na/Ca cations (black) in the interlayer region (blue), metal cations in the octahedral layer (red), and Si in the tetrahedral layer (green) [18].

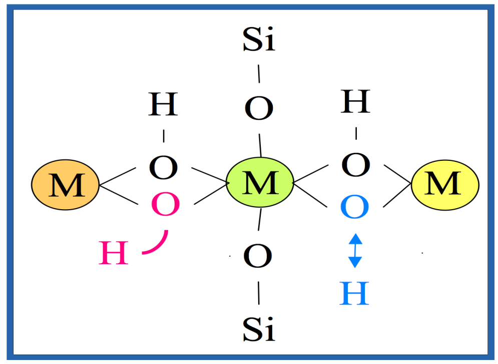

Fig. 6 OH bonds in phyllosilicate structures. This diagram illustrates the bonding configuration of the octahedral layer [from 18]. The OH stretching (blue) and bending (pink) motions have vibrational energies that depend on the type of metal cations (M) occupying the octahedral sites in the mineral structure.

What is Needed Now: Preparation for future human missions should include plans for harvesting resources from the surface rocks. Hydrated clay minerals and the associated poorly crystalline aluminosilicates are abundant at the surface and near surface on Mars. We need to document their global presence more precisely with future NIR imaging spectrometers (at least 1.2-2.6 µm) and characterize clays and associated hydrated phases at the landing site with VNIR spectroscopy (~0.4-4 µm). Lab experiments are also needed to determine optimal procedures for extracting water, cations and metals from clays and related minerals.

References: [**1**] Bishop, Michalski & Carter (2017) Remote Detection of Clay Minerals. In: *Infrared and Raman Spectroscopy of the Cationic Clay Minerals*. Kloprogge et al., Eds. (Elsevier). [**2**] King et al. (1992) *Science 255,* 1551-1553. [**3**] De Sanctis et al. (2015) *Nature 528,* 241-244. [**4**] Zolensky & McSween (1988) Aqueous alteration. In *Meteorites and the Early Solar System*. Kerridge & Matthews, Eds. (Univ. Arizona Press) 114-143. [**5**] Morlok et al. (2006) *GCA 70,* 5371-5394. [**6**] Gooding et al. (1991) *Meteoritics 26,* 135-143. [**7**] Lisse et al. (2006) *Science 313,* 635-640. [**8**] Poulet et al. (2005) *Nature, 438,* 623-627. [**9**] Murchie et al. (2009) *JGR 114,* doi:10.1029/2009JE003342. [**10**] Carter et al. (2015) *Icarus 248,* 373-382. [**11**] Ehlmann et al. (2011) Subsurface water and clay mineral formation during the early history of Mars. *Nature 479,* 53-60. [**12**] Bishop et al. (2013) PSS, 86, 130-149. [**13**] Bishop et al. (2016) LPSC 47, Abs. #1332. [**14**] Bishop & Rampe (2016) *EPSL 448,* 42-48. [**15**] Vaniman et al. (2014) *Science 343,* doi: 10.1126/science.1243480. [**16**] Bishop et al. (1994) *Clays Clay Miner. 42,* 702-716. [**17**] Parfitt (2009) *Clay Miner. 44,* 135-155. [**18**] Bishop et al. (2008) *Clay Miner. 43,* 35-54.