

ANTARCTIC MARS ANALOGS AND INTERPRETATION OF MARTIAN ALTERATION SIGNATURES. A. C. McAdam¹, T. G. Sharp², L. A. Leshin³, R. P. Harvey⁴, E. J. Hoffman⁵, ¹Atmospheric Experiments Laboratory, Code 699, Goddard Space Flight Center, Greenbelt, MD 20771, Amy.McAdam-1@nasa.gov, ²School of Earth and Space Exploration, Arizona State University, Box 871404, Tempe, AZ 85287-1404, ³Goddard Space Flight Center, Greenbelt, MD 20771, ⁴Dept. of Geological Sciences, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, OH 44106-7216, ⁵Physics Dept., Morgan State University, Baltimore, MD 21251.

Introduction: Understanding the nature of the martian surface environment, and the implications for past and present alteration conditions, is among the highest priorities of NASA's Mars Exploration Program. The role of fluids on Mars has important implications for martian climatic history, surface weathering processes and the possibility of past or present life. Investigations of surface materials, especially soil fines, provide the best opportunity to assess the nature of the martian surface environment, because they are sensitive to interaction with aqueous solutions. Surface material characteristics, and any implications for formation processes, can be investigated using several approaches. Here, we studied the mineralogy and chemistry of two soils (Stations A and B) derived from the Ferrar dolerite and a sample of the dolerite (diabase) parent rock as analogs to martian materials.

Results and Discussion: Many soil studies focused on the < 20 μm (referred to as "soil fines") and < 2 μm (clay) fractions. Our goal was to interrogate the samples with several analytical techniques, as might be done with actual martian samples. Overall, semi-quantitative analysis of XRD patterns from random powder mounts of soil fines and crushed dolerite showed that silicate mineral abundances, including clay mineral and zeolite abundances, were similar (Fig. 1).

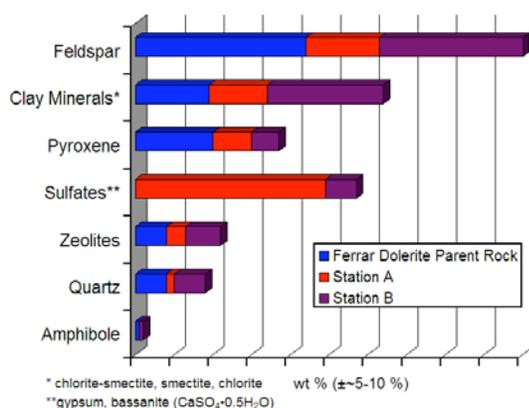


Figure 1. Semi-quantitative mineral abundances from powder XRD data.

This suggested that most soil secondary products formed originally in the rock. XRD patterns from glycolated, oriented mounts of the rock and soil clays in-

dicated that the clay types, dominated by interlayered chlorite-smectite, di- and tri-octahedral smectites, and chlorite, were similar. Near-infrared (NIR) data were consistent with this, though the shift in the $\sim 2.3 \mu\text{m}$ band in the rock to near $2.2 \mu\text{m}$ in the soil suggests the soil smectite clays are less Fe/Mg-rich than those in the rock (Fig. 2). The clay types are consistent with, though not exclusive to, high temperature (T) rock alteration. Differences in smectite chemistry may reflect some low T alteration of rock clays after breakup into the soil.

Several other lines of evidence were also consistent with high T rock alteration. While the outer rock edge is slightly more orange than the interior in hand sample, overall secondary phases and pyroxene dissolution features occur throughout the rock thin section. These features did not seem confined to the rock exterior or to fractures or obvious avenues of water into the rock. Also some pyroxenes appear to have amphibole rims that may be the result of urulization, a replacement of pyroxene by amphibole during deuteric alteration [1]. Commonly, the rock clays occurred in "clumps" and appeared to replace glassy mesostasis.

Though silicate mineralogy was very similar, some mineralogy differences between soil fines and rock were observed. The major difference was that the soils contained significant Ca-sulfates, especially the Station A fines ($\sim 50\%$ Ca-sulfates). These salts commonly occurred as cements or grain coatings. Oxygen isotope studies indicated that some sulfates resulted from the interaction of sulfate aerosols with Antarctic materials, though strontium isotope studies indicated the materials were not dominantly dolerite, but instead likely other rocks in the Lewis Cliff area.

Small differences in clay mineral abundances were also observed, indicating some pedogenic clay formation. Mössbauer spectroscopy indicated more Fe^{3+} in iron oxides (rather than silicates) in the soils as compared to the parent rock [2], suggesting some low T Fe oxidation in the soil.

The fine scale properties of soil and rock clay sized particles were observed with transmission electron microscopy (TEM). Phyllosilicate-like materials exhibited a range of crystallinity, from amorphous material to very well-ordered crystals. The most common particles in both cases, however, were aggregates of

smectite or chlorite-smectite crystals with a “fluffy” morphology (Fig. 3). Even at a very fine scale, rock and soil clay particles were similar, further supporting the idea of most clays being inherited from the rock.

Summary: The dominant process that produced the soils from the Ferrar Dolerite in Antarctica was physical weathering of deuterically or hydrothermally altered parent rock, even though there are significant clays and minor zeolites in the soil. Overprinting by lesser low T alteration in the soil also occurred, resulting in more iron oxides/oxyhydroxides, significant soil sulfates, and minor additional clays/clay-like materials.

Implications for Mars: Clays on Mars, such as those detected recently at several sites through NIR spectroscopy of the surface [e.g., 3-7], could have formed through high T processes. Some regions on Mars may have similar clay or clay-like mineral abundances to those formed under high T conditions in our analog setting (15 to 30 ±5-10 wt%) [e.g., 7,8]. The clay types (smectites, chlorites) in the analog samples are also similar to those observed or expected in martian materials [e.g., 6,7,9,10]. In addition, several specific clay detections could have formed at high T. For example, Fe-rich smectites observed in association with dikes and volcanic landforms in Nili Fossae could be a result of subsurface high T processes [e.g., 5]. In the case of layered, likely sedimentary, deposits such as those in Mawrth Valles [4], some clays could have formed originally during high T alteration related to impact or volcanic processes and then later been physically weathered out of those rocks, transported and deposited to form sedimentary units.

Formation of analog clays from glassy mesostasis is similar in a general sense to the process of palagonitization, but here well-crystalline clays were formed due to the high T conditions. Interestingly, however, some glass particles were observed in the Antarctic soils. Relatively well-crystalline clays and residual basaltic glass could occur together in materials on Mars which have experienced both high T and low T alteration.

The production of significant iron oxides at low T suggests that martian iron oxides could be formed at low T, even if most clays are not. Martian soil salts may have a complex origin, similar to the Antarctic case. The partially aerosol-derived salts form coatings and cements in the soils; this supports the idea of martian aerosol-derived sulfate coatings and cements.

High T processes, physical rock breakdown and lesser low T alteration could produce materials in which unexpected primary and secondary minerals (e.g., pyroxene or olivine and significant well-crystalline clays) occur together. For example, olivine

occurs mixed with clay minerals in some units in Nili Fossae [e.g., 5].

Finally, having a sample of the parent rock of martian sediments may be crucial to understanding the source of any secondary products and the nature of the alteration processes that have occurred at a given site.

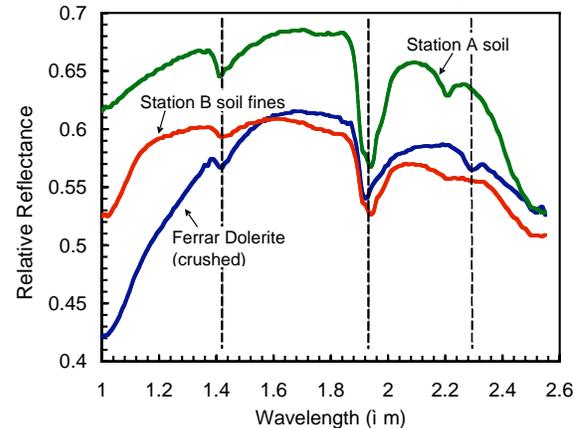


Figure 2. NIR spectra of rock and soil samples. Note: Clay mineral, pyroxene, and gypsum/bassanite bands are present. Marked bands are the ~1.4, ~1.9, and ~2.3 μm bands that may be expected from an Fe/Mg-smectite.

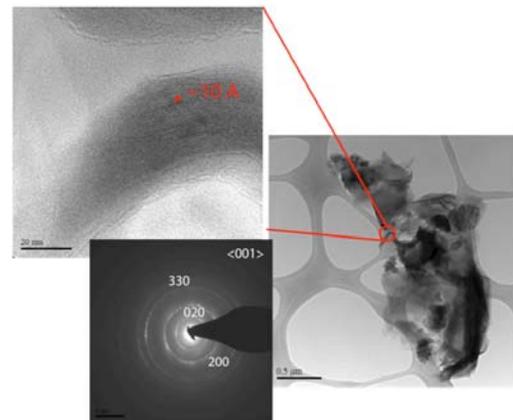


Figure 3. Right: Bright-field image of rock clay aggregate particle. Upper: High-resolution bright-field image of clay fringes. Lower: Diffraction pattern from the particle; the indexed rings are consistent with a smectite mineral.

References: [1] Shelley D. (1993), *Ign. & Met. Rocks*, 445 pp., Chapman and Hall. [2] McAdam, A. C. et al. (2008) *MAPS*, 43, A94. [3] Poulet F. et al. (2005) *Nature*, 438, 623. [4] Loizeau D. et al. (2007) *JGR*, 112, doi:10.1029/2006JE002877. [5] Mangold, N. et al. (2007) *JGR*, 112, doi:10.1029/2006JE002823. [6] Mustard J. F. et al. (2008) *Nature*, 318, 305. [7] Poulet F. et al. (2008) *A&A*, 487, L41. [8] Michalski J. R. (2006) *JGR*, 111, doi:10.1029/2005JE002438. [9] Bridges J. C. (2001) *Space Sci Rev.*, 96, 365. [10] Clark B. C. (2007) *JGR*, 112, doi:10.1029/2006JE002756.