

INVESTIGATION OF WEATHERING PRODUCTS OF MARTIAN METEORITE ANALOG MATERIALS AND IMPLICATIONS FOR THE FORMATION OF MARTIAN SURFACE FINES. A. C. McAdam¹, L. A. Leshin^{1,2}, T. G. Sharp¹, R. P. Harvey³, and E. J. Hoffman⁴ ¹Dept. of Geological Sciences, Arizona State University, Box 871404, Tempe, AZ 85287-1404, amcadam@asu.edu, ²Center for Meteorite Studies, ASU, P.O. Box 872504, Tempe, AZ 85287-2504, ³Dept. of Geological Sciences, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, OH 44106-7216, ⁴Physics Dept., Morgan State University, Baltimore, MD, 21251.

Introduction: Terrestrial analogs to martian surface materials can be used to gain insight into potential martian weathering processes and the role of water in the near-surface environment. We are investigating the mineralogy and chemical properties of fine size fractions of a soil weathered from the Ferrar Dolerite. The soil was collected near Lewis Cliff in the Transantarctic Mountains. The Ferrar exhibits mineralogical similarities to martian basaltic lithologies, as represented by the shergottites [1]. Production of fines from this protolith in the cold, arid Antarctic makes the fines a promising Mars analog material. Also, these materials were altered in a colder, drier environment than other well-studied Mars analogs, such as Hawaiian palagonitic tephra (e.g. JSC Mars-1) [2]. Our detailed studies of Ferrar fines are focused on addressing several questions. What is the relative significance of inherited, primary phases and chemical weathering products? What are the spatial, structural, and chemical relationships between minerals? What is the nature of any chemical weathering products? Have such products “ripened” into well crystalline phases or are they poorly crystalline? Progress to date on addressing these questions is discussed below.

Background: Martian soil fines are likely produced by processes such as physical weathering (wind-blown dust and ice abrasion, salt riving), chemical weathering, volcanism, and impact. Chemical weathering mechanisms can be divided into low or high water/rock categories. High water/rock mechanisms can produce well formed clays and low water/rock mechanisms tend to produce more poorly crystalline secondary phases. Also, temperature and pH can affect weathering reactions and rates. Two of the most cited low water/rock mechanisms are alteration by thin water films and water vapor (low T, variable pH) and alteration by “acid fog” (low T, low pH). The first mechanism should produce slightly weathered silicates, poorly developed clay mineraloids, and nano-phase ferric oxides and oxyhydroxides (np-ox) [e.g., 3, 4]. The second mechanism should produce moderately weathered silicates, clays, clay mineraloids, np-ox, and chloride and sulfate salts [e.g., 5].

There is debate about the significance of chemical vs. physical weathering in the production of martian soils and dust. Detailed mineralogy would help but is not known. There are, however, constraints from a

variety of datasets. For example, TES spectra have indicated ~2-5% carbonates [6] and significant plagioclase in the dust [7, 8], though the plagioclase features can also be interpreted as zeolites [9]. Plagioclase implies significant primary minerals, while zeolites imply significant secondary products. Fe oxides and oxyhydroxides have been widely hypothesized [e.g., 10, 11]. Additional likely components are S and Cl salts, [e.g., 9], palagonite [e.g., 2, 10] and possibly clays [e.g., 12].

Results: We have analyzed the <20 µm size fraction of the Ferrar soil, a size fraction close to the average size of martian dust [13]. These fines have been studied with SEM/EDS, IR spectroscopy, XRD, TEM, and Mössbauer spectroscopy. XRD-derived semi-quantitative mineral abundances in the Antarctic fines are given in Table 1.

Table 1.

Minerals Identified with XRD	Estimated Mineral Abundances (%)
Gypsum	34 ±5
Plagioclase Feldspar	19 ±5
Bassanite (2CaSO ₄ ·H ₂ O)	15 ±5
Clay minerals (Smectite, chlorite, illite)	~15 ±5-10
Diopside ^a	(~7%)
Stilbite ^a	(~5%)
Augite ^a	(~3%)
Quartz ^a	(~2%)

^a Numbers in parentheses are below the ~10% “detection limit” of the XRD quantification procedure used (see text).

Clay mineral identification involved analyzing XRD spectra of oriented clay mounts. Minerals in the <20 µm fraction were identified by peaks in a random powder spectrum. A combination of Rietveld refinement and whole pattern fitting was used on XRD spectra to obtain mineral abundances (see [14] for more detail). Due to the well known difficulty in obtaining quantitative mineral abundances from XRD spectra of complex mixtures and to limited sample amount, error in abundances is ~±5% for values >10%. Below 10%, phases are present but abundances are more uncertain.

The thermal IR spectrum of the Antarctic fines shows low spectral contrast due to particle size effects. Qualitative evaluation of the spectrum revealed silicate, bound water and sulfate features.

Mössbauer spectra indicate the Antarctic fines’ Fe³⁺/Fe_{total} is lower (0.8) than JSC Mars-1’s (0.94),

indicating less Fe oxidation in the Antarctic fines. Both are more oxidized than average values obtained for undisturbed soils by the MER rovers at Meridiani Planum (0.3) and Gusev Crater (0.32) [15, 16].

Initial TEM work has revealed that many particles are clays or clay mineraloids, which exhibit a range of crystallinity and stacking disorder, or aggregates of these (Fig. 1). While occasional particles are well crystalline clays or amorphous secondary products, most clay-like particles exhibit short-range order, and thus are of intermediate crystallinity. Also, gypsum, primary minerals and particles in which secondary minerals are associated with primary minerals are present.

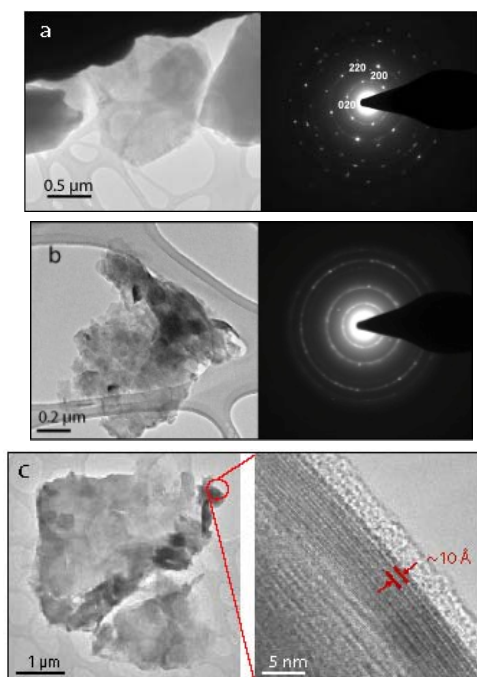


Figure 1. Electron micrographs and diffraction patterns of a) a crystalline clay ($\text{K}_{0.7}\text{Na}_{0.3}\text{Ca}_{0.2}\text{Al}_2\text{Mg}_{0.2}\text{Fe}_{0.8}\text{Si}_3\text{O}_{10}(\text{OH})_2$, assuming a dioctahedral structure and all Fe is Fe^{3+}), and b) a poorly crystalline clay particle. c) Clay particle or aggregate and high resolution image of clay layers.

Discussion: A significant amount of the Antarctic fines, ~70%, comprises secondary phases. This indicates that even in the coldest, driest environment on Earth, there is enough water and energy to weather a significant fraction of the minerals. Antarctic surfaces have the longest terrestrial exposure ages, several Ma in some cases [e.g., 17]. Long exposure may compensate for slow weathering reaction rates due to extreme cold and aridity. This is important to consider for Mars. Although Mars is much colder and drier, its surface has averaged much longer exposure ages. Also, some particles could be exogenic dust from continental sources. This can be investigated by comparing soil REE patterns to parent rock REE patterns [18].

Weathering by sulfate aerosols may have been significant in producing the abundant sulfate salts in the fines (~50%). Antarctic soils often have high salt contents, but their source in some cases is still debated (in situ formation, sea salt, and atmospheric sources are all possibilities) [e.g., 19, 20, 21]. Oxygen isotope studies of sulfates from the Antarctic Dry Valleys have revealed a $\Delta^{17}\text{O}$ anomaly, up to +3.4‰, which suggests the sulfate is not just from sea salt ($\Delta^{17}\text{O} = 0$) but also from atmospheric oxidation of gaseous sulfur compounds (e.g. biogenic dimethylsulfide from the ocean) [19]. The anomaly implies that atmospheric sulfur aerosols interact with rocks and soils in Antarctica, similar to the acid fog model for martian weathering [e.g., 5]. Also, several clay-like aggregate particles examined contain sulfur. Fe oxides and clays in soils can absorb sulfate anions [e.g., 22, 23]. The significance of acid fog weathering in producing the Antarctic fines' sulfates is still at issue. It can be addressed by measuring the $\Delta^{17}\text{O}$ of the sulfates, as done by [19].

TEM studies have revealed that many particles are clays or clay mineraloids with varying crystallinity and stacking disorder. Also, particles containing primary and secondary minerals are present. Chemical and structural relationships between reactants and products are still being studied and will be addressed by microtoming particles to examine interfaces more easily.

Conclusions: The fact that many particles are clay particles of varying crystallinity and layer orientation, or aggregates of these, implies that the cold, dry Antarctic environment does not abate significant chemical weathering, but it is consistent with limited water availability. The characteristics of the fines' mineral assemblage support the hypothesis that chemical weathering products were produced by interaction of acidic aerosols with soils and rocks. Additional alteration by thin water films and water vapor can not be ruled out, however.

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