CHARACTERIZATION OF THE WEATHERING PRODUCTS OF ANTARCTIC MARTIAN METEORITE ANALOG MATERIALS AND IMPLICATIONS FOR THE FORMATION OF MARTIAN SURFACE FINES. A. C. McAdam[1], L. A. Leshin[1,2] and R. P. Harvey[3] [1]Department of Geological Science, Arizona State University, Box 871404, Tempe, AZ 85287-1404, amcadam@asu.edu, [2]Center for Meteorite Studies, ASU, P.O. Box 872504, Tempe, AZ 85287-2504, [3]Department of Geological Sciences, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, OH 44106-7216.

Introduction: Understanding the role of water in the Martian near-surface environment is among the highest priorities of NASA's Mars Exploration Program. Surface fines provide the best opportunity to assess the nature of the Martian surface environment, because they are sensitive to the action of water. For example, common soils on the Earth are made up largely of chemically weathered minerals because of the abundance of liquid water. In contrast, lunar fines are produced purely by physical weathering (dominantly meteorite impact), and consist of ground igneous minerals, due to the lack of liquid water on the Moon. Mars' environment is likely somewhere between these extremes. Samples of fines from the Martian surface are not available for analysis, but their return to Earth has been proposed [1]. Through analysis of terrestrial analogs to Martian fines, insight into potential Martian surface processes can be obtained in advance of returned samples.

Weathering in Antarctica. Rocks and soils in Antarctica are exposed to some of the coldest and driest weathering environments on Earth. As a result, physical weathering processes generally dominate, although some significant chemical weathering also takes place. The main physical weathering processes that produce regolith in Antarctica are the action of water, in the form of either ice, liquid or vapor, glacial action, salt weathering, insolation and wind action. Overall, processes that depend on water are not highly effective in Antarctica, in comparison with other physical weathering processes, because of the extreme cold and aridity [2-4]. Salt weathering, or weathering and fragmenting of rock due to crystallization of salts in pores and cracks, seems to be fairly common. Solar heating of soil and rock surfaces is also known to occur. In addition, many processes of rock decay and soil formation in Antarctica are dependent on wind action, which removes and redistributes the products of many physical weathering processes. Wind also allows ice fragments, sand and dust to abrade rock surfaces and surface coatings [2].

Chemical weathering in Antarctica consists mainly of some weathering and decomposition of ferromagnesian minerals and subsequent deposition of thin iron oxide and silica coatings on more resistant grains and on rock surfaces, as well as, in some cases, clay mineral formation [2, 3, 5, 6]. The progression from amorphous iron oxides to clay minerals is highly sensitive to the availability of water [2, 5]. There are also insoluble and soluble salts found in Antarctic soils in varying amounts [2, 7].

Weathering on Mars. The mineralogy of Martian fines has not been directly measured due to limitations of in-situ instrumentation and therefore the relative proportions and nature of primary and secondary minerals is unconstrained. As a result, the relative importance and nature of physical and chemical weathering processes in the production of these fines is unknown. There are several physical weathering processes that may occur on Mars. Salt weathering could occur on Mars; high concentrations of S and Cl detected during in-situ measurements of Martian fines are consistent with this idea [8, 9]. The abrasion of rock surfaces and weathering rinds by windblown dust and ice particles likely occurs on Mars. Impact cratering is another Martian physical process. A dominance of these types of processes in Martian weathering would result in primary minerals being generally more abundant in the Martian fines than secondary ones. The main studies that support the idea that primary minerals are more abundant involve remote spectroscopic observations, sometimes in combination with in-situ chemical data [10-13], and potentially studies of certain terrestrial analogs, such as the Antarctic dust being analyzed in the current study [14, 15]. For example, recent analysis of Mars Global Surveyor Thermal Emission Spectrometer (MGS-TES) spectra of atmospheric dust indicates that it may be partially composed of plagioclase feldspar [12]. Also, after examination of corrected IRIS Mariner 9 data, [13] proposed that albite is the main dust component. Comparison with the Pathfinder elemental composition for loose soil led those authors to suggest a dust composition that involved pyroxene, olivine, plagioclase and sulfates. Very limited work has been done to date with terrestrial dust analog materials produced under cold and arid Martian analog weathering conditions [3, 16].

There are many ideas about chemical weathering on Mars. They can generally be divided into mechanisms that involve different temperature and water/rock ratios. Here, the focus will be on the chemical weathering hypotheses that are relevant to comparison with Antarctic weathering, i.e. hypotheses that involve chemical weathering under conditions of low temperature and low water/rock ratios, analogous to the current conditions on the surface of Mars. The major relevant chemical weathering mechanism is alteration by water vapor and thin liquid water films. Potential products include palagonite, partially weathered silicate minerals, nanophase ferric oxides and oxyhydroxides, clay minerals, and clay-like mineraloids [e.g. 8, 17-19]. A dominance of chemical weathering processes on Mars would result in an abundance of chemical weathering products in the Martian fines. The main studies that support an abundance of chemical weathering products are studies of in-situ chemical composition data [e.g. 17, 20, 21], studies of certain terrestrial analog materials [e.g. 18, 22-24] and remote spectroscopic data [e.g. 8, 10]. Palagonitic soils and tephras, such as JSC Mars-1, are commonly cited as visible/near-infrared (0.3 to 5 µm) spectral analogs to Martian bright regions [e.g. 21, 25] but JSC Mars-1 is thought to be "a much closer match to the reflectance spectrum than to the regolith composition of Mars" [22]. Several Martian weathering models [e.g. 8, 26, 27] support the idea that Martian fines might exhibit a "palagonite-like" composition. Clay minerals are also studied as possible Martian surface materials [e.g. 7, 19] but detection of clay minerals spectroscopically has had varied results [e.g. 8, 28]. The presence of sulfate and chloride salts is also supported by several lines of evidence [e.g. 8, 18, 20, 23].

Approach: In this study, have conducted a preliminary characterization of the <63 µm size fraction of a soil produced from weathering of the Ferrar Dolerite. The soil was collected from a bedrock plateau of the Ferrar at Lewis Cliff in the Transantarctic Mountains of Antarctica (Fig. 1). The sample site was located at high altitude (above 2000 m) in snow-free areas of Antarctica where conditions are considerably more severe than those seen in the Dry Valleys. The Ferrar consists of two pyroxenes, two feldspars, and iron and titanium oxides and shows mineralogical similarities to the basaltic Martian meteorites [14]. Outcrops and hand specimens of the Ferrar are exposed to some of the driest and coldest weathering environments on Earth and show characteristic desert weathering features observed in images of Mars, such as ventifacts, desert varnish, and cavernous weathering [14, 16]. JSC-Mars 1, a Hawaiian palagonitic tephra and a commonly used terrestrial analog to Martian surface materials, was produced in a very different environment than the analog under investigation in this study [22].

In order to apply the results of this study to Mars, several reasonable assumptions are necessary. The first is that the Antarctic Ferrar Dolerite is an adequate analog to Martian materials, as represented by the Martian meteorites [14]. The second is that the cold and arid Antarctic environment is an analog to recent environments on the surface of Mars [14]. Given this framework, an analogy can be drawn between processes that produced the Antarctic dust and Martian surface weathering processes. In the absence of samples or in-situ mineralogical measurements of Martian fines, the results of detailed analyses of these Antarctic fines with equipment available in terrestrial laboratories can be used to make inferences about the extent of Martian surface weathering and the nature of Martian weathering environments (chemical vs. physical weathering, low vs. high water/rock ratios, etc.).

Figure 1. A typical outcrop of the Ferrar Dolerite in the Transantarctic Mountains [from 14].

Very limited work has been done on the soils produced from the weathering of the Ferrar Dolerite in Antarctica. In [2] and [3], several soil profiles of soil derived from the Ferrar are described and some analyses of samples from different depths in the profiles are discussed. The authors determined the particle size distribution and chemical composition of samples of several different soil horizons within one of their soil profiles, and studied the clay fraction of some of these samples with x-ray diffraction (XRD) and electron microscopy. The clay fractions (the <2 um size fraction) of soil horizons above 7 cm depth were not analyzed because the soil horizons closer to the surface did not have enough of the clay fraction to perform their analyses. This study is intended to be a detailed addition to these previous analyses that will focus on characterizing the mineralogy and spectral properties of the fine fraction of the surface soil from the perspective of investigating the properties of a Mars dust analog. Detailed studies of the Antarctic dust will allow several questions to be addressed, such as: What is the relative significance of physical and chemical weathering products in the dust? What is the nature of the chemical and physical weathering products? What are the IR spectral properties of the dust and how do they compare with IR spectra of Martian dust? Some preliminary progress on addressing these questions has been made and the results are discussed below.

Methods and Preliminary Results: Preliminary work has involved study of the mineralogy and spectral properties of the <63 µm size fraction of both the Antarctic soil and JSC Mars-1 with a JEOL JSM-IC 845 scanning electron microscope equipped with an IXRF energy dispersive spectroscopy system (SEM) and with a Nicolet Nexus 670 infrared (IR) spectrometer (spectral range ~5-45 µm) (Fig. 2, 3 & 4). Details of spectrometer setup and calibration are given in [29]. The preliminary studies allow several initial conclusions to be drawn. Based on estimates from SEM studies, the Antarctic dust appears to be enriched in primary minerals (~77% primary minerals) compared to the JSC Mars-1 dust (~19% primary minerals). This suggests that significant non-chemically weathered minerals may be present in the Martian dust. The IR spectra (~5-45 µm) of the <63 µm size fraction of the Antarctic and JSC Mars-1 dust show qualitative differences from each other, with the Antarctic dust showing more spectral contrast (Fig. 4). Also, the Antarctic dust IR spectra show qualitative similarities with Martian dust spectra recovered from Mars Global Surveyor Thermal Emission Spectrometer (MGS-TES) spectra, while the JSC Mars-1 dust IR spectra do not. It is important to note, however, that further spectral studies of a smaller size fraction (e.g. <20 µm) are needed to make more conclusive comparisons with TES dust spectra. Mineral types obtained by deconvolution of Antarctic dust IR spectra are similar to those estimated from SEM studies [30].

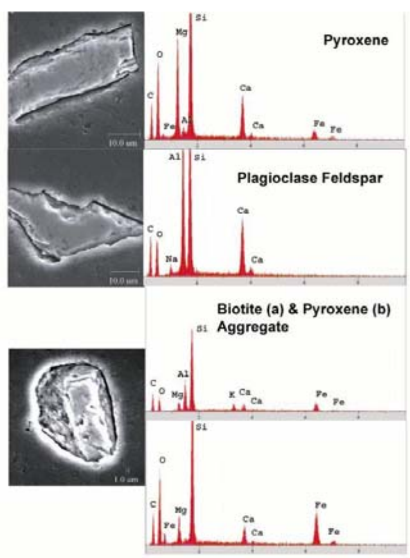

Figure 2. Examples of Antarctic dust particles observed with SEM and corresponding EDS spectra. All spectra have the same vertical scale.

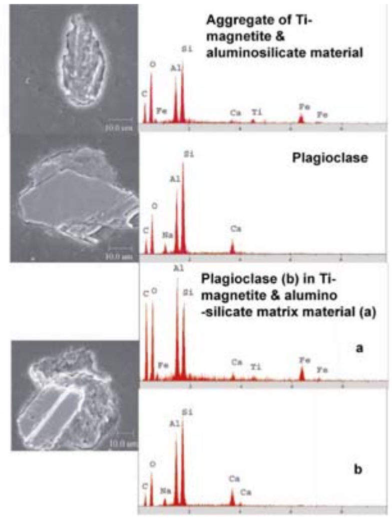

Figure 3. Examples of JSC Mars-1 particles observed with SEM and corresponding EDS spectra. All spectra have the same vertical scale.

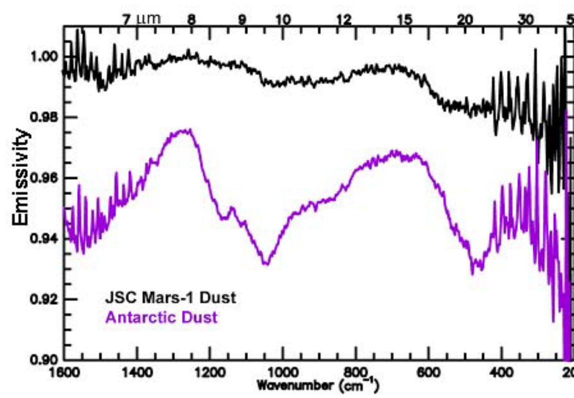

Figure 4. IR spectra of <63 µm Antarctic and JSC Mars-1 dust. Each spectra is an average of 270 scans and the spectra are offset by 0.05 for clarity. The measured radiance spectra were converted to emissivity as outlined in [29].

Future Work: Future work will fully characterize the mineralogy and spectral properties of a smaller <20 µm size fraction of the Antarctic dust, which is closer to the average size of Martian atmospheric dust. Initial studies of the mineralogy, mineral abundances, and IR spectral properties of the dust will be carried out with SEM, electron microprobe (EMP), XRD and IR spectroscopy. More detailed study of the dust mineralogy will be performed with transmission electron microscopy (TEM). As the characterization of the dust continues, the results will indicate the nature of the Antarctic weathering that produced the dust, allowing inferences to be drawn about Martian surface weathering.

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