SCIENTIFIC RATIONALE FOR CONSIDERATION OF CHEMICALLY ALTERED METEORITES IN A MARS SAMPLE RETURN MISSION. J. W. Ashley[1,2]. [1]School of Earth and Space Exploration, Mars Space Flight Facility, Arizona State University, Box 871404, Tempe, AZ 85287; [2]Minor Planet Research, Inc., Box 19964, Fountain Hills, AZ 85269; james.ashley@asu.edu.

Introduction: Rock materials suspected to have a meteoritic (exogenetic) origin have been identified at both Mars Exploration Rover (MER) locations [1], thus demonstrating the ready availability of such material on the martian surface. During the course of nominal mission operations, it is therefore possible (and perhaps even likely) that a roving sample-return spacecraft, or its caching predecessor, would again encounter meteoritic specimens. Providing that the ability to recognize meteorites is at least as feasible as is the case for the MERs, an opportunity for recovery would be at hand.

However, the scientific value of meteorites is traditionally focused on their relevance to the formation and evolution history of the solar system, not the planets upon which they happen to land after ejection from their parent bodies. From this standpoint, we are justified in regarding meteoritic material as a form of contamination for any Mars Sample Resturn (MSR) mission. However, the mere circumstance of meteoritic material on the surface of Mars provides an alternative way to follow the water through the effects of mineral-water interations (chemical weathering), and therefore address Mars' climatic history and habitability potential. With a successful sample return, we would have the ability to study through the alteration of materials with well-known starting mineralogies, chemistries (elemental and isotopic), and textures. Conceptually, we have an experiment equivilent to the artificial insertion of an unweathered rock of known character into the Martian surface environment, using it to probe the longer-term behavior of mineral-water interactions at ambient atmospheric pressures and temperatures. Meteorites are in effect control or "witness" [2] samples for the weathering of Mars. A great deal indeed could be learned from their study. Such an approach is particularly applicable to stony meteorites where water migration pathways exist in the form of cleavage planes, grain interstices, and fractures not normally present in iron meteorites.

Background: Meteorite weathering has been studied extensively in several Mars analog environments. Studies of mineral-water interactions have been performed to evaluate nebular and parent body processes, and the negative effects of weathering (i.e. contamination, elemental redistribution, mineralogical alteration, etc.). Unfortunately for cosmochemists, meteorites being dominantly composed of high temperature minerals weather rapidly in the terrestrial environment where pressure-temperature-concentration (*PTX*) conditions are far from the conditions of formation, and where liquid water and oxygen are abundant. However, while constituting a nuisance to the study of meteorites on Earth, low-temperature mineral-water interactions may be a significant extraterrestrial process [e.g. 3]. It has been suggested that meteoritic weathering scenarios in Antarctica may be analogous to low temperature "hydrocryogenic" alteration mechanisms on Mars, in addition to asteroid regoliths and interiors, cometary interiors, and within the surfaces of icy moons of the Jovian planetary systems [4 and 3].

Figure 1. False color MER-B Pancam image collected Sol 1049 showing cobble Ibirama, together with a portion of the Santa Catarina Cobble Field (unofficial name), located along the NNW rim of Victoria Crater, Meridiani Planum, Mars. Santa Catarina was the first member of this field of cobbles to be investigated by rover arm (Instrument Deployment Device) instruments, and is suspected of being a stony-iron meteorite [1]. Other members of this field may be meteoritic by association. Such material is highly sensitized (more so than indigenous basalts) to mineral-water interactions, and would therefore serve well to help assess the subtleties of climatic behavior through laboratory study. Image credits: NASA/JPL/Pancam.

In the process of such studies, much has been learned about mineral-water interactions in low-humidy and low-temperature environments that can be applied to the martian situation. Examples of such elemental redistribution were illustrated in 1988 by [5], where it was determined that rubidium, cobalt, iodine, and calcium may be removed from the interiors of Antarctic chondrites to be concentrated at their surfaces during the production of various evaporite minerals, thereafter to be removed completely by wind erosion. The same was found to be true for carbon [6]. The most obvious indication of Antarctic meteorite weathering is the presence of iron oxide staining [e.g. 7]. The recognized secondary products in Antarctic meteorites include hydrous and anhydrous iron oxides [7] carbonates and sulfates [8, 9, and 5], and amorphous mineraloids with smectitic compositions [4 and 10]. Indeed, [4] recognized that thin films of liquid water can exist at subzero temperatures that facilitate the elemental migration necessary for typical weathering reactions. In addition, it was empirically determined that Antarctic meteorites exposed to sunlight may have internal temperatures (at depths up to 2.0 cm in some meteorites) that rise as high as 5°C on wind-free days (even when air temperatures remain below 0°C), enabling capillary waters to promote reactions [11]. Moreover, some oxidation reactions have been found to occur in the solid state at low relative humidities [12].

Fully 88 percent of all meteorite falls contain greater or lesser amounts of reduced iron-nickel metal, which will oxidize readily in the presence of even trace amounts of water (liquid or ice, but probably not vapor in most cases). Meteoritic iron is likely to be the most sensitive material to this type of alteration on the surface of Mars. Where weathering intensities might be subtle or undetectable for indigenous rocks, they may be conspicuous in this responsive material. Many meteorites (most of which can be thought of as ultramafic rocks because of their olivine and pyroxene content) are also highly sensitive to silicate alteration. Moreover, many are unequilibrated thermodynamically, adding further to this sensitivity.

Meteoritic Materials in Martian Regolith. As discussed by [13], knowing the contribution of meteoritic materials to Martian soils and sedimentary rock origins, compositions, and weathering scenarios is important to the proper interpretation of geochemical history. [13] further point out that understanding the influx of organic material is necessary for "*constraining carbon oxidation rates in support of Martian habitability assessments.*" In addition, 1) addressing the mysteries of the titanomagnetite component of the martian dust, 2) assessment of past and present meteoritic flux rates, 3) assigning terrestrial ages to any sizable meteoritic materials for possible determination of sedimentation rates (an idea that should be explored when making sample selections), are important considerations for the study of the meteoritic component to martian regolith materials. For some of these studies, meteoritic material would be regarded as a contaminant; for others, the material is the object of study. In either case, the information is invaluable to the study of Mars conditions and processes.

Our best estimates of the extent of interaction between the Martian surface and the interplanetary medium are currently based on APXS data from both MER-A and MER-B rock and soil targets, and place the amount of contribution at 1 to 3 percent chondritic [13]. However, the authors of this study indicate that other factors could be affecting this estimate, which is based primarily on nickel abundance. Many of the uncertainties are readily avoided when samples are available for laboratory study. For example, laboratory samples of sedimentary rock and soil would allow not only the direct measurement of trace element chemistry at a higher level of accuracy, but also the probing of individual grains on the microscale.

Terrestrial Residence Time. The question of terrestrial residence time will be important for providing constraints on martian weathering behavior. Both cosmogenic stable nuclides and radionuclides are discussed by [14] for the martian situation. The authors suggest that the ^{10}Be-^{26}Al-^{21}Ne isotope system should be useful for determining exposure ages for rocks at Mars' surface up to 10^6-10^7 years b.p. If sufficient spallation/ablation and/or fragmentation had occurred during atmospheric entry (a reasonable assumption), such an age determination should be obtainable up to this maximum for a meteorite sample returned to the laboratory. Determining ages for older exposure histories may be more problematic, but could be possible within the context of contributing stratigraphic, geomorphologic, and/or geochemical factors. It should, however, be noted that a single, highly weathered meteorite would be invaluable even if terrestrial ages cannot be ascertained.

Summary: A valid approach to considering whether meteorites found on Mars would be valuable for the study of martian climatic and habitability history could be summarized with the following: 1) Meteorites are more sensitive to mineral-water interactions (chemical alteration) than most other rock types, and 2) their unaltered "starting" elemental chemistries, isotopic chemistries, mineralogies, and textures are already known. These conditions make exogenetic materials ideal witness samples for the study of surface-atmosphere interactions for any planet with an atmosphere. Thus determining the weathering intensity of the meteoritic materials for the purpose of paleoclimatic assessments, is a significant scientific objective served by a meteorite sample return mission.

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