METALLIC IRON IN METEORITES AS A SENSITIVE TRACER OF SURFACE-VOLATILE INTERACTIONS ON MARS – A PROGRESS REPORT.
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Introduction: Meteorites on Mars (martian finds) are more than curiosities. They may provide a means to gauge the past and recent extent of water exposure across the martian latitudes.

The many roles of water in solid, liquid, and vapor phases pose a set of outstanding questions relating to the geologic history and habitability of Mars. Because we are looking for evidence of trace amounts of water in many cases, a sensitive water indicator is desirable. Reduced (metallic) and ferrous iron in meteorites provides such an indicator because it will oxidize readily in the presence of liquid water, water vapor, and possibly even water ice [e.g. 1]. Weathering effects may thus be recorded by oxidation/hydration states and secondary mineralogy on rock surfaces and interiors [2].

Background: Iron-nickel metal is found in some 88 percent of meteorite falls on Earth [3]. The percent fraction is likely to be similar (if not identical) in near-Mars space [4]. The meteoritic flux on Mars could be relatively high as well. Studies indicate that meteoritic nickel contributions to martian soil may be as high as 3% [5]. Because of their high relative reactivities, a martian find might exhibit subtle signs of alteration where a martian basalt would not, depending on the extent of exposure. Martian finds therefore represent the most sensitive indicators of water exposure available on the martian surface.

A hypothetical global distribution map showing locations and weathering intensity of meteorites on Mars would help constrain models of ice extent during periods of high martian obliquity, and possibly address more long-term paleoclimatic trends as well. Both Mars Exploration Rover (MER) vehicles are located in near-equatorial latitudes, where water exposure under current obliquity cycles is anticipated to be negligible [6]. A single "rusty" meteorite with measurable oxyhydroxides at either location would therefore be evidence of either 1) more drastic paleoclimatic trends than previously modeled, or 2) widespread surface water at some time in the history of the planet. Such a finding would be significant irrespective of meteorite residence time. A *lack* of oxyhydroxides in meteorites is also insightful, but questions of residence time become more important in such cases. The difference between irons and stony meteorites becomes significant here because alteration products may still exist within stony meteorite interiors while they may be readily abraded by wind erosion from the surfaces of irons.

This work encompasses three phases, including 1) identifying reduced iron-bearing meteorites on Mars; 2) assessing their weathering intensity; and 3) conducting laboratory-based meteorite studies to assess weathering in terrestrial desert environments, and to refine the techniques used in steps 1 and 2. This abstract reports progress on studies 1 and 3, conducted in parallel, which address the detection of meteorites on Mars using the MER science instruments.

Meteorite spectral library: Vibrational spectroscopy using the Miniature Thermal Emission Spectrometer (Mini-TES) on the rovers is ideal for recognizing meteorites at a distance. Therefore, a comprehensive library of thermal emission spectra for meteorites of all relevant types and in various stages of weathering is being prepared. The library may also be useful for independent assessment of weathering intensity (Table 1).

Meteorites in Thermal Emission Spectra Database

Meteorite ID	Class	Surface type
Allende	CV3 carbonaceous chondrite	cut; unweathered
ALH77233	H4 ordinary chondrite	interior; weathering category C
Juancheng	H5 ordinary chondrite	fusion crust; unweathered
Carichic	H5 ordinary chondrite	cut; highly weathered
LEW85322	H6 ordinary chondrite	interior; weathering category C
ALH84082	H6 ordinary chondrite	interior; weathering category C
ALH84082	H6 ordinary chondrite	fusion crust; weathering category C
LEW86015	H6 ordinary chondrite	interior; weathering category C
Bruderheim	L6 ordinary chondrite	cut; unweathered
Long Island	L6 ordinary chondrite	cut; moderately weathered
Abee	EH4 enstatite chondrite	interior; unweathered
Dhofar 007	eucrite	cut; unweathered
Kapoeta	howardite	cut; unweathered
Estherville	A3/4 mesosiderite	fusion crust; unweathered
Clover Springs	A2 mesosiderite	cut; moderately weathered
Brahin	pallasite	cut; no obvious alteration
Canyon Diablo	IAB coarse octahedrite	exterior; oxide coating
Canyon Diablo	IAB coarse octahedrite	sandblasted; blackbody radiance
Canyon Diablo	IAB coarse octahedrite	sandblasted; garnet-rich radiance

Table 1. Meteorites for which emissivity spectra have been measured using the Mars Space Flight Facility Nexus 670 FTIR interferometric spectrometer.

Figure 1 shows the diversity of spectral features among different meteorite types and surfaces in the thermal infrared (TIR). These differences are essential to rock identification using remote sensing techniques.

Iron-nickel meteorites: On Sol 339, the MER-B (Opportunity) Mini-TES instrument measured anomalously low thermal emissivity for a 31-cm diameter rock (originally designated Heat Shield [HS] Rock) indicating a highly reflective material. The Mini-TES spectra for HS Rock (recently renamed Meridiani Planum (MP) [8]) contain features unlike any previously observed rock on Mars, but similar to the martian sky. It is well understood that metals are strongly reflective at all infrared wavelengths and have the capacity to reflect the spectral features of the sky. The MP Mini-TES spectra were therefore consistent with those for an iron-nickel meteorite. This was later confirmed by IDD work [e.g. 7], and the rock is now classified as a IAB-complex iron-nickel meteorite [8]. Since Sol 339, at least four additional Mars rocks are suspected meteorites. These include Zhong Shan and Allan Hills in Gusev Crater (Figure 2) and two at Meridiani Planum. The Meridiani rocks include the stony-iron Barberton [9], and one cobble suspect at the time of writing named Santa Catarina near the Bay of Toil on the rim of Victoria Crater.

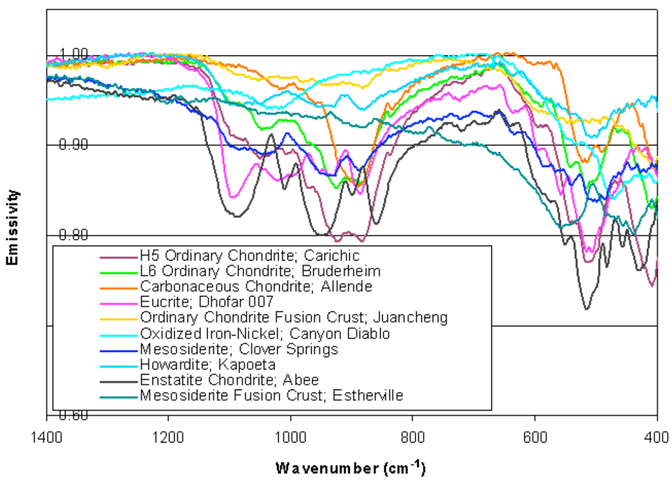

Figure 1. Thermal emission spectra of various meteorite types and surfaces.

All Mini-TES results for iron meteorites must be 'calibrated' to the environmental effects that have apparently altered the meteorite's emissivity from its purely compositional values. This is being done in a controlled laboratory setting. The full parameterization will determine the effects of possible blackbody cavities, dust coatings, and oxides in the Mini-TES spectra. The character and contribution of these variables is required before the full meaning of these spectra can be quantitatively determined.

Methods: A 10,195 g sample of the IAB coarse octahedrite meteorite Canyon Diablo was obtained though the Center for Meteorite Studies at ASU. The sample was selected for its size, oxide coatings, deep cavities, and smooth obverse surface, characteristics that are comparable to those of MP. Following spectral characterization of the oxide-coated surfaces, the meteorite was sandblasted using a 100-170 mesh size glass bead blasting medium to remove portions of the coating down to bare metal. To simulate the spectral effects of downwelling radiance akin to the martian atmosphere, a layer of 50 grit garnet sandpaper was applied to the interior sides and roof of the spectrometer sample chamber. Spectra were collected with and without the sandpaper in place and ratioed to reveal a low-spectral contrast garnet component. The martian sky has a much higher spectral contrast as evident in the Mini-TES spectra for Zhong Shan, Allan Hills, and MP.

Results: Our initial iron meteorite study results demonstrate that an unoxidized Fe-Ni meteorite displays low emissivity and reflects the spectral features of the environment in which it is measured. However, future studies will utilize a quartz-based control to enhance the spectral contrast of the downwelling radiance. Additional work will include the application of Mars-analog dust coatings to the bare metal Canyon Diablo surface to evaluate the effects of dust on MP's spectral emissivity in the martian environment.

Summary: *In-situ* meteorite studies on the martian surface with respect to secondary oxidation products could yield valuable insights into the past and present roles of liquid water and water vapor at the MER landing sites. The Mini-TES instrument is demonstrating the utility of remote sensing in the search for meteorites on other worlds. At the time of writing, Opportunity is located within a cobble field near the Bay of Toil, Victoria Crater, where the possible meteoritic origin of the Santa Catarina cobble is being explored. Mini-TES is being used in conjunction with the meteorite spectra library to assist in these determinations. The fact that two apparent iron meteorites were found at Low Ridge in Gusev Crater is significant. Though likely to be paired individuals (from the same fall), their presence, together will MP and Barberton, strongly suggests that meteorites are indeed common on the surface of Mars, and that future vigilance using Mini-TES to select targets is warranted.

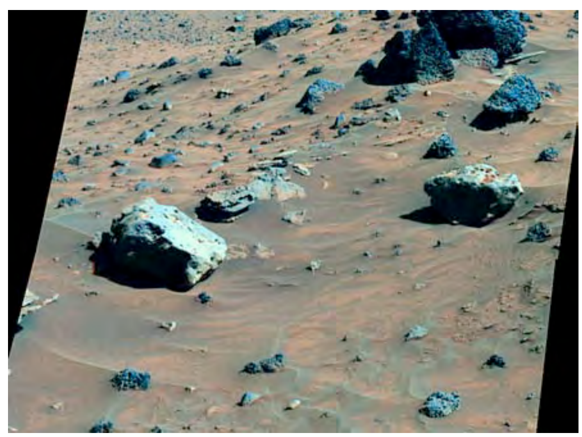

Figure 2. False color image featuring Zhong Shan (left) and Allan Hills (right), two suspected iron-nickel meteorites recognized by Mini-TES at Low Ridge, Gusev Crater.

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