METEORITES ON MARS: IMPLICATIONS FOR SAMPLE-RETURN STRATEGY B. J. Thomson[1], N. T. Bridges[1], and M. C. McCanta[2], [1]Jet Propulsion Laboratory, California Institute of Technology, [2]California Institute of Technology. (bthomson @ jpl.nasa.gov)

Introduction: The recent discovery of at least 3 iron-nickel meteorites on the surface of Mars [*e.g.,* 1-3] highlights the importance of exogenic material in planetary surface evolution. Because iron meteorites represent but a small fraction (~5%) of the total population of terrestrial meteoritic debris, the question arises as to the whereabouts of the reminder of the meteorite population, *i.e.*, the chondrites, achondrites, and stony-irons (which are about 86%, 8%, and 1%, respectively, of the terrestrial non-cometary bolide population [4]). The high Ni content of Martian soil [5] indicates an average of 1-3% contamination from meteoritic debris (confirming previous estimates [*e.g.*, 6]). Here we estimate the meteorite population that may be archived on the Martian surface and discuss potential recognition criteria. Retrieving exogenic material (meteorites) from the Martian surface is unlikely to be a principal aim of the proposed sample return program. Therefore, a coherent sampling strategy must be employed to determine the origin of potential samples prior to their acquisition.

Terrestrial meteorites inform us of a fundamental disparity in the type abundance of meteorites recognized on the ground (finds) as opposed to the rarer events where meteoritic debris is actually observed to fall from the sky (falls). In the former category, the percentage of iron meteorites vastly exceeds their observed abundance in the latter [4]. This over-representation of irons in finds is due to a combination of ease of recognition, preferential preservation, and greater resistance to fragmentation in passage through the Earth's atmosphere and surface impact processes. Observations of asteroid populations [*e.g.*, 7] and the relatively unbiased Antarctic micrometeorite collections [8] have confirmed the view that the type abundance of falls more accurately reflects the type distribution of meteorite parent bodies than do the finds.

Martian finds: The twin Mars Exploration Rovers (MER) have been continuously operating in excess of 4 Earth years. Through Sol 1170, the total distance traversed by Spirit and Opportunity is 6.2 km and 10.3 km, respectively. Assuming that each rover can nominally collect remotely sensed data on targets within an effective radius ~15 m, the cumulative area explored is about 0.5 km^2, representing less than 7×10^{-9} of the Martian surface. Yet even in this limited area, at least 3 distinct rocks have been recognized whose characteristics are consistent with iron meteorites (dubbed "Heat Shield", "Zhong Shan", and "Allan Hills"). Initially recognized by their unique spectral properties, these bodies have bland visible, near-infrared, and thermal infrared spectra that lack absorption features due to mafic minerals or other silicates, sulfates, or carbonates [9, 10]. Surfaces textures are generally pitted, and overall rock shapes tend to be sub-rounded to rounded (Fig. 1). APXS (Alpha Particle X-ray Spectrometer) measurements of the rock Heat Shield indicate a Ni abundance of ~7% [11], and Mössbauer analyses indicate that ~94% of its Fe is in the form of the iron-nickel mineral kamacite [12], both of which are consistent with the interpretation of Heat Shield as an iron meteorite. Interestingly, the extremely low ferric iron content (Fe^{3+}/Fe_{Total} <0.06) suggests minimal surface weathering [12]. Since native Fe is not a common igneous or volcanic product, its presence on a planetary surface is a likely indicator of an exogenic process (*i.e.*, impact delivery).

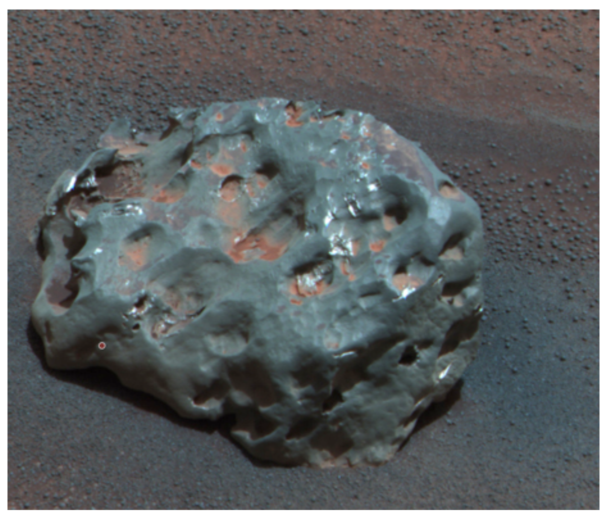

Figure 1. Pancam mosaic of "Heat Shield" rock, an iron-nickel meteorite at the Opportunity site (Sol 346).

An even rarer find at the Opportunity site is the pebble "Barberton," which may be a mesosiderite [3, 5, 12], a stony-iron meteorite. Stony-irons comprise ≤1% of terrestrial falls [4].

Atmospheric passage: The presence of an atmosphere both helps and hinders the survival of incoming meteorites. Thermal stresses due to the friction of passing atmospheric gasses heat up and ablate the outer surface layers of a bolide, and induced mechanical stresses can fracture and fragment incoming material. But atmospheric processes also serve to decelerate incoming projectiles, thus allowing them to reach the surface at terminal velocity rather than at cosmic velocity (>2 km/s).

Using the relative percentage of iron meteorites known from falls on the Earth as a guide, the percentage of iron bolides at the top of Earth's atmosphere is about 5% [4]. Although the total flux of incoming bolides at Mars is greater than the flux at the Earth by about a factor of about 2 (due to Mars' closer proximity to the asteroid belt) [13], one can assume that the same relative proportions of irons to stones is applicable to the top of the Martian atmosphere. So for every incoming iron bolide, this suggests ~19 incoming stony bolides. The survival rate of incoming projectiles through the thin Martian atmosphere has been estimated for vertical (θ=90°) [14], inclined (θ=45°) [15], and vertical to oblique (θ=0-90°) [16] entry trajectories. The results from these studies indicate that upwards of 10% of the incoming meteorites may make it to the surface (either intact or in a fragmented state). The survival rates for irons and stones are different and model-dependant [*e.g.*, 14-16] – irons are more susceptible to ablation due to their higher thermal conductivities, while they are also more likely to resist fragmentation and survive a high-velocity collision with the surface without shattering. For simplicity, assuming the same survival rate for irons and stones, the discovery of 3 iron meteorites on the Martian surface suggests 30 incoming iron bolides and 570 incoming stony bolides. Therefore, on the order of 60 stony meteorites should be present in the area thus far examined by the rovers.

Implications and potential recognition criteria: Recognizing this predicted suite of stony meteorites hidden among normal (endogenic) rocks on the Martian surface will be a challenging task. Fortunately, several characteristics of stony meteorites may facilitate their recognition. A universal trait of terrestrial meteorites is a fusion crust—a low albedo, charred outer layer—resulting from frictional heating during atmospheric passage. The ability to abrade the outer surface layer of a rock with the RAT (Rock Abrasion Tool) would facilitate recognition of a fusion crust. Abraded or broken surfaces of ordinary chondrites might reveal the presence of chondrules (but only in low petrologic grade meteorites). Fusion crusts would also have spectral signatures corresponding to silicate glass. Atmospheric passage also shapes the outer surface layers of meteorites in the form of regymplytic surface textures. Finally, if potential meteorites were analyzed with the APXS, ChemMin, or ChemCam instrument suites, they would exhibit distinctive chemical signatures. For example, a rock with a high elemental carbon abundance would be a strong carbonaceous chondrite candidate.

Importance for proposed sample return: Low erosion rates on Mars imply that fallen meteorites will be long-lived surface components. Accidentally returning a meteorite sample from Mars would hamper efforts to calibrate the relative Martian chronology, and would contribute no information about endogenic processes. Alternatively, meteorites or impactites might be interesting targets to sample due to their potential to archive paleo-atmospheres [17] or due to their potential to provide additional insight to the period of heavy impact bombardment in the inner Solar System. In either case, there is a clear need to develop sample protocols that would allow us to distinguish potential meteorites before surface samples are acquired.

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