METEORITE FINDS ON MARS – A NEW TOOL TO STUDY ATMOSPHERE AND SURFACE PROCESSES.

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Introduction: Mars provides the necessary conditions for exogenic rock (meteorite) accumulation and preservation, and finding meteorites on Mars has been predicted [1]. The Mars Exploration Rovers (MER), Spirit and Opportunity, are the first to find and characterize such meteorites [2-4]. Among those meteorites is the IAB iron complex meteorite Meridiani Planum a.k.a. Heat Shield Rock [2,4] (Fig. 1), the first meteorite on Mars that was officially recognized in the MetSoc meteorite database. Heat Shield Rock was the first in a suite of several irons of similar composition found across the Meridiani Plains during Opportunity's extended traverses. Besides iron meteorites, Opportunity also identified several stony meteorites (Fig. 2) with a composition approaching HED achondrites or potentially the silicate fraction of mesosiderite stony irons [2,3], and one putative (based on weathering pattern) but unconfirmed chondritic candidate [5]. The Mars Science Laboratory (MSL) rover Curiosity has since found additional meteorites, most of them irons [6] but also identified more chondrite candidates [7]. The current tally of confirmed and candidate meteorite finds on Mars stands at 45, ~80% of which are irons. Future missions such as the NASA Mars 2020 and the ESA ExoMars rovers will add to this tally further. Importantly, these meteorites provide new tools to study atmosphere and surface processes on the Red Planet. Here we review insights gained about Mars from their study.

Atmospheric Density: Meteorite accumulation rates and average size of meteorite fragments is to first order a function of the density of the atmosphere [1,8]. Mars' atmosphere must have been denser in the past to allow for liquid water on the surface, and its density varies in response to obliquity changes. For example, the large size of the iron meteorite Block Island has been used to argue that this meteorite must have fallen at a time when the atmosphere was at least an order of magnitude denser, possibly even during the Noachian period [9]. Others argue, however, that under shallower, lower-probability entry angles, Block Island could have landed at current atmospheric densities [10]. The iron meteorite Lebanon discovered by MSL is even larger and more massive than Block Island though [11], and makes the presence of a denser atmosphere during its fall more likely. A systematic study of certain fragment size populations could thus reveal evidence of past Martian climates [12]. The NASA InSight mission may help provide information on hypervelocity arrival of meteoritic materials in the smaller diameter range [13].

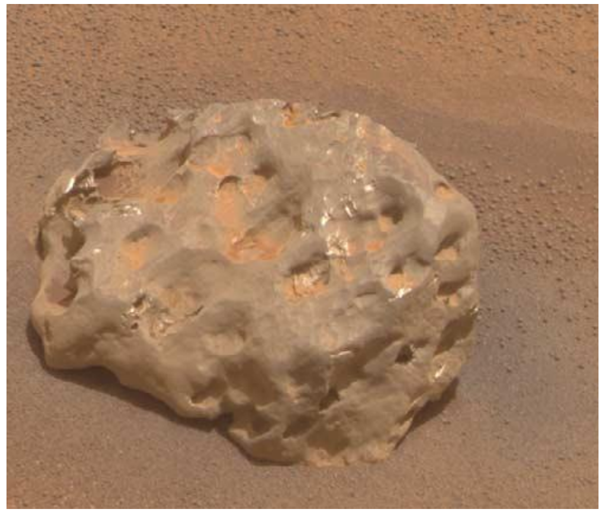

Fig. 1. The iron meteorite Meridiani Planum displays a highly reflective surface and measures ~31 cm across. Approximate true color Pancam image acquired on sol 346.

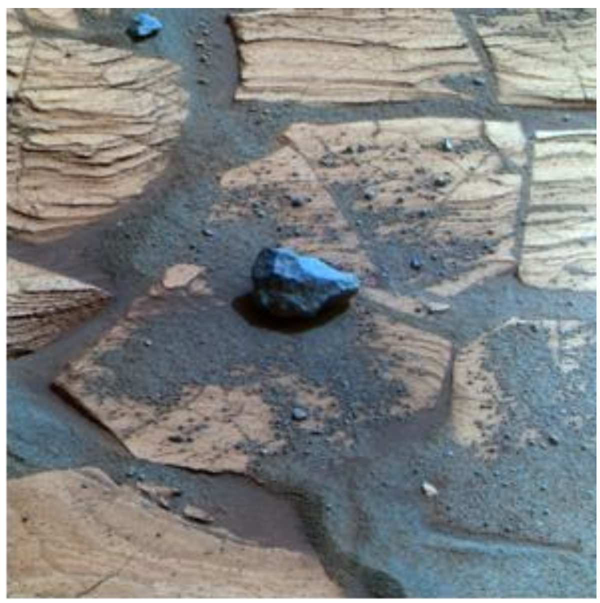

Fig. 2. Santorini is one of the stony meteorites discovered with Mars Exploration Rover Opportunity and measures ~8 cm in its longest dimension. Pancam false color image acquired on sol 1713.

Transport Processes: The Curiosity rover during its ascent of Mount Sharp in Gale crater has identified a cluster of iron meteorites on Vera Rubin Ridge [14,15]. These turned out to be chemically distinct and therefore do not represent paired fragments of a larger impactor but independent falls. This alone is a significant finding for meteorites located close to each other, and suggests either some kind of transport process which led to their accumulation on Vera Rubin Ridge [14,15], or simply speaks to high preferential preservation bias for irons over time in this locale. It may also be trying to tell us something about the flux of meteorite falls in Mars space.

Atmosphere-Surface Interactions (Weathering): Iron meteorites obviously, but also many stony meteorite groups (including ordinary chondrites), contain metallic iron. This makes them sensitive tracers of any presence of water [16]. All of the iron meteorites discovered on Mars so far have been identified in the visible and mid-infrared by the metallic glint or reflections of sky spectra and don't show any widespread signs of rust formation (Fig. 1). Some of them do, however, display patches of coating that is associated with iron oxidation [2-4,17]. This coating might have been formed from water exposure during periods of burial or from ice exposure during high obliquity cycling, and is abraded when exposed [4]. Iron oxide production is thus slower than wind abrasion, betraying the extremely arid conditions on current Mars, and both of these processes are orders of magnitude slower than the equivalent processes on Earth. Ample evidence of acidic corrosion, in addition to oxide production, is also found within the Meridiani iron suite, and remains to be fully understood in its implications for the chemical weathering history of this landing site [4]. Stony meteorites weather differently. Higher porosity allows water to penetrate deeper between mineral grain boundaries and they tend to weather from the inside out. The iron oxidation or chemical weathering rate of stony meteorites discovered by MER Opportunity has been determined to be 1-4 orders of magnitude slower than the Antarctic weathering rate of similar materials [18]. This can be translated into weathering rates for other rock types by studying such rocks in other environments where meteorite weathering rates have been determined [19-21].

In addition to mineral-water interactions, the uniquely malleable iron-nickel materials in these rocks have proven useful for exploring the effects of physical weathering. Examples of flutings, oriented scallops, enlargement of hollows, anomalous sculpting features, and cavernous excavations are attributed in part to wind-blown sand (likely in concert with acidic corrosion) [e.g., 4]. These and other features are currently being explored using terrestrial analogues and recently generated digital data products [22].

Conclusions: Meteorite finds on Mars provide new tools to study its atmosphere and surface processes. Future missions can rely on coming across more meteorites. Significant geochemical, isotopic, and even microbial arguments outside the scope of this abstract strongly suggest that a formal discussion is warranted to weigh the pros and cons for considering a well-chosen chondritic (not metallic) meteorite sample or its weathered debris for Mars Sample Return [23-26].

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