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Meteorites as Environmental Witness Plates for Mars Sample Return Consideration

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1. Introduction

Returning samples from Mars is a mutual science goal for NASA and ESA administrations. The discussion of what samples to target and bring back is well underway [1]. 'Samples of Opportunity" (SOO) are serendipitously discovered targets that contain scientific-value, that otherwise would not be searched for due to their aleatory distribution. Meteorites found on Mars, in particular ordinary chondrites (OCs), are one such SOO. Over 24 iron and stony-iron meteorites have been identified on the Martian surface by the Mars Exploration Rovers (MERs) [2-5] and the Mars Science Laboratory (MSL) rover Curiosity [6-9] (Figure 1). These Martian finds are different from the SNC meteorites that are fragments of Martian crust found on Earth, and often referred to as Martian meteorites. If available to laboratory study, the Martian finds can significantly enhance understanding of geologic, geochemical, atmospheric, and potentially biological processes on the Red Planet because meteorite baseline compositions are known with much higher precision from curated terrestrial falls than that of Martian rocks. Therefore any deviations in meteorite geochemical, mineralogical, and isotopic composition, while resident on Mars, would be the sole result of alteration by the Martian environment. Therefore, an OC might act like a 'Rosetta stone', helping to decipher Martian surface history. The ability to record environmental weathering and potential biosignatures against a known baseline should make stony-meteorites primary SOO in the upcoming Mars2020 stage of the sample return endeavour.

2. Insights Gained from Meteorites

2.1 Atmospheric Evolution

Meteorite accumulation rates and the average size of meteorite fragments is to first order a function of the density of the atmosphere [10, 11]. For example, the martian iron-meteorite Block Island has been used to argue that the atmosphere was at least an order of magnitude denser when it fell [12], although, others argue this could be a recent fall under current conditions with a shallow entry angle [13].

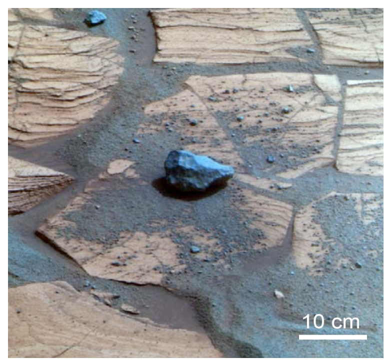

Figure 1: (Sol 1713) "Santorini " is a stony-iron meteorite discovered at Meridiani Planum by MER Opportunity.

2.2 Weathering Environment

Metallic phases in meteorites make them extremely sensitive tracers to the presence of water [14]. None of the iron meteorites discovered on Mars so far show widespread signs of rust. They do, however, display patches of coating that is associated with iron oxidation [2,5,15]. This coating may have formed during periods of burial or ice exposure during high obliquity cycling [5]. Iron oxidation rates of stony-meteorites discovered by MER Opportunity are determined to be 1-4 orders of magnitude slower than the Antarctic weathering rate of similar materials [16]. Meteorites on Earth are found to contain Fe-(oxy)hydroxides, sulfates, carbonates, salts, and smectites. These alterations reflect both different stages of weathering [17], and environmental conditions [18]. By investigating the mineralogy of these alteration products of weathered meteorites on Mars, it would be possible to reconstruct paleo-environments. Such alteration could also provide a regional alteration baseline, providing value for other returned samples.

2.3 Putative Biosignatures

The search for life on Mars requires unambiguous biosignatures. The compositions of Ordinary Chondrites (OC) are well known, making the detection of modifications by putative organisms easier to recognise [18]. In fact, ordinary chondrites make attractive habitats for terrestrial microorganisms in arid environments because they become hygroscopic and contain abundant metal, sulfur and even organics as energy sources [18]. Meteorites recovered from the Nullarbor Plain, Australia, were found to contain various cryptoendolithic and chasmoendolithic communities of bacteria and archaea [18]. 16S rRNA gene analysis of meteorites from the Nullarbor Plain showed microbial colonisation by a variety of microorganisms including some iron- and sulfur-metabolising genera such as *Geobacter sp* and *Desulfovibrio sp* [19], potentially leaving $\delta^{34}S$ signatures in the secondary weathering products [18]. Many microbial communities exacerbate weathering and form biofilms on mineral surfaces, where they can also become entombed by secondary minerals and preserved [19].

3. Open Questions and Conclusions

Ordinary chondrites would be the most suitable targets to be considered among the list of exogenic samples of opportunity for MSR. They are the most common meteorite type found on Earth, and the same is expected for Mars [10]. So far, however, the observed Martian finds are dominated by iron and stony-iron meteorites [2-4] (Figure 1), with only one candidate OC. Is this an observational sampling bias, or is there another environmental reason [8]? Indeed, how can OCs be identified by imagery and other remote sensing observations [e.g., 14]?

When considering a weathered ordinary chondrite for sample return, is there sufficient scientific value independent of exposure age? Given the potential upper limit of Noachian resident ages [12,16], can OCs not only survive but also preserve geochemical and isotopic signatures for billions of years?

These are some of the questions that need to be addressed to assess the viability of OCs as samples of opportunity for MSR. A focused study of an ordinary chondrite candidate by either Opportunity or Curiosity, if encountered, would assist greatly with the assessment. Additional studies of samples from warm and cold deserts could enhance our understanding in advance of such encounters on Mars.

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