METEORITES ON MARS CAN HELP TO DECIPHER THE RED PLANET – SHOULD THEY BE CONSIDERED AS SAMPLES OF OPPORTUNITY FOR MARS SAMPLE RETURN? C. Schröder[1], J. W. Ashley[2], A. W. Tait[3], M. A. Velbel[4], P. J. Boston[5], B. L. Carrier[2], B. A. Cohen[6] and P. A. Bland[7], [1]Biological and Environmental Sciences, University of Stirling, Stirling FK9 4LA, UK, christian.schroeder@stir.ac.uk, [2]Jet Propulsion Laboratory, Pasadena, CA, United States, [3]Monash University, School of Earth, Atmosphere and Environment, Melbourne, VIC, Australia, [4]Michigan State University, East Lansing, MI, United States, [5]NASA Ames Research Center, Moffett Field, CA, United States, [6]NASA Marshall Space Flight Center, Huntsville, AL, United States, [7]Curtin University, Perth, WA, Australia.

Introduction: A growing number of meteorites have been identified on the Martian surface by the Mars Exploration Rovers (MERs) Spirit [1] and Opportunity [1-6] as well as the Mars Science Laboratory (MSL) rover Curiosity [7-10]. Following on from here we will refer to these as *Martian finds* to distinguish them from the group of SNC meteorites, which have been found on Earth but originate from Mars and are therefore often referred to as *Martian meteorites*. The Martian finds are not mere curiosities but can significantly enhance understanding of a variety of geologic and atmospheric processes on the Red Planet. Mars and Earth experience similar meteorite fluxes. Certain meteorite groups (e.g., ordinary chondrites, where encountered) can serve as standard probes inserted exogenically into the Martian environment. Their baseline composition is known with much greater precision from curated terrestrial falls than that of most Martian rocks. Any deviations in their geochemical, mineralogical, and isotopic composition (Fig. 1) resulting from the interaction with the Martian environment can therefore yield insights into the nature of those interactions. Thus, they might help to decipher the Martian rock record like a Rosetta stone. This abstract is intended to facilitate a discussion of whether or not a specific type of meteorite such as a weathered ordinary chondrite should be considered as a sample of opportunity for Mars Sample Return (MSR). Below we summarize what we have learned about Mars from the study of Martian finds already and highlight what still needs to be investigated before any meteorite could be considered for MSR.

Insights Gained from Meteorites:

Atmosphere. Meteorite accumulation rates and average size of meteorite fragments is to first order a function of the density of the atmosphere [11,12]. 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. A systematic study of certain fragment size populations could thus reveal evidence of past Martian climates [12], in particular if the upcoming NASA InSight mission can determine the current meteorite impact rate on Mars [13]. 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 [14]. Others argue, though, that under certain lower probability entry angles, Block Island could have landed even at current atmospheric densities [15].

Weathering. Iron meteorites obviously, but also many stony meteorite groups, including ordinary chondrites, contain metallic iron. This makes them extremely 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 and don't show any widespread signs of rust formation. They do, however, display patches of coating that is associated with iron oxidation [1,4,17]. This coating might have been formed during periods of burial or from ice exposure during high obliquity cycling, and is abraded when exposed [4]. Iron oxidation 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. In fact, the iron oxidation or chemical weathering rate of stony meteorites discovered by MER Oportunity 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 rock in terrestrial environments where meteorite weathering rates have been determined [19-21].

Astrobiology. The search for life on Mars requires unambiguous biosignatures. Meteorites would arrive sterile on Mars. Certain meteorite groups such as ordinary chondrites have the added benefit of narrow trace element and isotopic ranges [22], making modification by potential lifeforms easier to recognize (Fig. 1). In fact, meteorites such as ordinary chondrites make attractive habitats for terrestrial micrrorganisms in arid environments because they become hygroscopic and contain abundant metal and sulfur as energy sources [22,23]. Iron and sulfur cycling microorganisms have been found to be amoung the consortia of meteorite colonizers on Earth [23], potentially leaving signatures in the $\delta^{34}S$ record (Fig. 1).

Open Questions: Ordinary chondrites would be the most suitable targets to be considered as sample of opportunity for Mars Sample Return. They are the most common meteorite type found on Earth, and the same is expected for Mars [11]. However, though MER Opportunity identified several stony or stony iron meteorites [1,3], only one unconfirmed chondrite candidate has yet been found on Mars [24]. The majority of the Martian finds are iron meteorites. Is this a sampling bias because iron meteorites are simply easier to spot or is there another reason such as faster disintegration of chondrites in the Martian environment [9]? How can ordinary chondrites be identified by imagery and other remote sensing observations?

When looking for signatures of potential life, the Noachian period, more than 3.5 billion years ago, likely provided the most habitable conditions. While it has been shown that meteorites could potentially have survived on Mars over such timescales [11,18] it is difficult to date Martian finds in situ. When considering a weathered ordinary chondrite for sample return, would there be sufficient scientific value regardless of its terrestrial/Martian exposure age? Can it not only survive but also preserve geochemical and isotopic signatures for billions of years? Is the preservation size dependent in any way?

These are some of the open questions that should be addressed in order to assess whether meteorites such as a weathered chondrite would make viable samples of opportunity for MSR. A focused study of an ordinary chondrite candidate by either Opportunity or Curiosity, if encountered, would assist greaty with the assessment.

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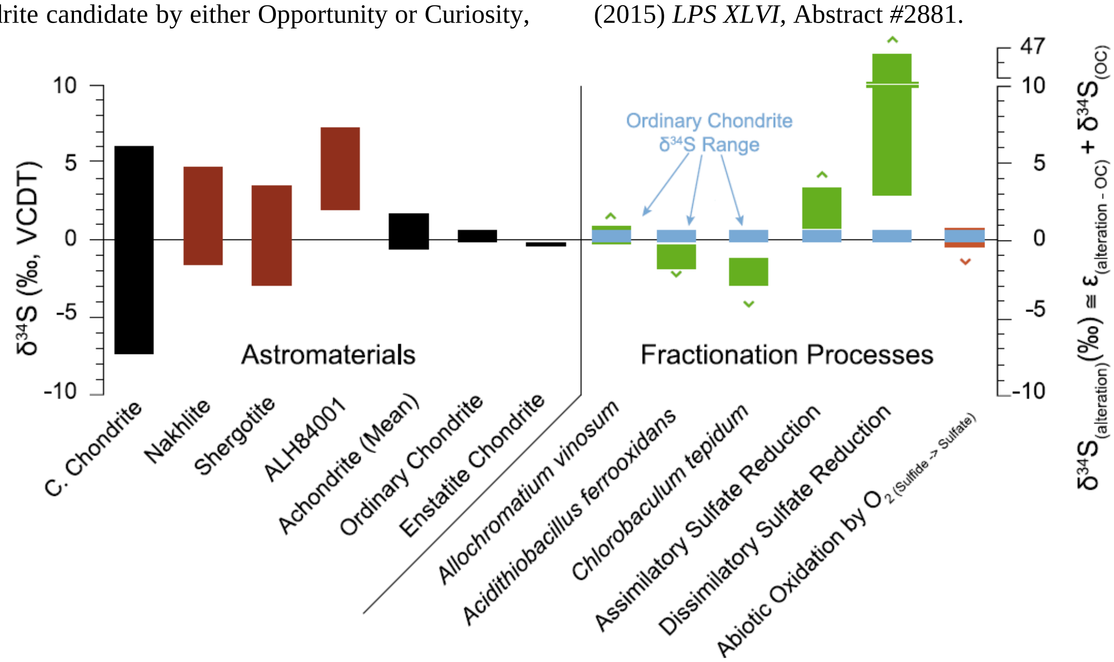

Figure 1. The left hand side shows the $\delta^{34}S$ range for different meteorite groups. Note the narrow range for ordinary chondrites and enstatite chondrites. The right hand side shows the range of S isotope fractionation as a result of sulfur-cycling processes by different microorganisms compared to the ordinary chondrite range. Figure from [22].