WHAT METEORITES ON MARS TELL US ABOUT THE MARTIAN ENVIRONMENT AND THE CASE FOR RETURNING ONE. A. W. Tait[1*], C. Schröder[1], J. W. Ashley[2], M. A. Velbel[3], P. A. Bland[4]. [1]Biological and Environmental Sciences, University of Stirling, Stirling FK9 4LA, UK (alastair.tait@stir.ac.uk), [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, [3]Department of Earth and Environmental Sciences, Michigan State University, East Lansing, MI, USA, [4]Department of Applied Geology, Curtin University, Perth, WA, Australia.

Introduction: The discovery of meteorites on Mars [1-4] opens up the possibility for investigation of materials with known starting composition (major and trace elements, isotopes, mineralogy, texture, etc.) exposed to the Martian environment. Known pre-weathering compositions allow for a more definitive subtraction from alteration histories compared to Martian rocks (for which protolith compositions and baselines are still being established [5]). The consequence of studying the alterations of these known materials could allow for a better signal when determining paleo-reconstructions [3,6], and potentially putative biological signatures [7]. Nearly 40 meteorites have been discovered on Mars. Most are irons, with some achondrites or stony-irons, and at least one putative chondrite [1-4,8]. Under current conditions, meteorites can have long residence times on Mars of $>10^9$ years that span much of the planets history [6,9]. Thus meteorites are the ultimate 'witness plate' to climatic changes on Mars, acting as a kind of 'Rosetta stone' for deciphering Martian climate history. Here we explore some common paleo-reconstruction techniques that could be applied to a returned meteorite (preferably an ordinary chondrite, due to its polymineralic composition, and drilling constraints), and potential astrobiological considerations. Lastly, we will discuss the criteria for selecting a meteorite suitable for return within the limits placed on the upcoming Mars2020 mission.

Palaeoclimatology: *Atmospheric Change*. For any given meteorite type, the maximum mass at the Martian surface is a function of atmospheric density, entry angle, and bolide velocity [10]. By surveying the number of meteorites within a certain mass range on a given surface, past atmospheric density can be constrained [10,11]. Fusion crust development (or preservation) on Mars is unknown at this time; if such a sample is found, that would illuminate further properties of the Martian atmosphere. Fusion crust iron compositions can change based on the fO_2 in the troposphere. Photochemical O_2 on Mars could change these mineral redox states and react with the metals to record upper atmospheric oxygen. Allowing for paleo $\Delta'^{17}O$ measurements on Mars, and ground truth for modelers.

Surface water history. Meteorites contain abundant redox-sensitive elements such as iron and sulfur that make good tracers for water-rock interaction. Magnetically ordered iron-oxide alteration products are more prevalent in humid environments, and arid iron-oxides are dominated by paramagnetic iron, giving a good indication as to the climate. This mineralogy-based approach has been used in situ on Martian finds to determine that iron-meteorites on Mars had interacted with water/ice in the past [3,12,13]. Using the alteration mineralogy can indicate not only the presence of water (possibly occurring as thin films), or water-vapour, but also the pH of that water. For example, the sulfate mineral Jarosite forms at low pH values, and has been found within meteorites on Earth [7,14]. A similar discovery on Mars could shed light on the habitability of water at the Martian surface. Furthermore, many of the primary meteorite minerals are prone to hydrolysis, with hydrated alteration minerals containing structural water (e.g. gypsum $[CaSO_4 \cdot 2H_2O]$)[15]. These minerals are only stable within a narrow range of relative humidity and temperature. The presence of these minerals could become diagnostic of environmental water cycling, and humidity oasis in the near-surface environment.

Paleo Temperature. Meteorites on Mars would record alterations starting at the time they land, providing a chronology of surface alteration histories. Carbonate alteration products vary depending on temperature, with Ca-carbonates dominant in hot-deserts but mostly absent in colder climates such as in Antarctica [16]. If carbonates form within Martian meteorites they would record $\delta^{13}C$ and $\delta^{18}O$, the latter of which can be used to determine the temperature of formation [17], the former may also be isotopically lighter than modern Martian atmospheric CO_2, providing a snapshot of atmospheric loss. Carbonates are not the only minerals that could be used for paleoclimate reconstruction; triple oxygen and hydrogen isotopes within structural water of gypsum (and potentially hydrated smectites) could be used to reconstruct the humidity [18]. This technique is important to evaluate microhabitats as many organisms near the water activity limit for life on Earth use hygroscopic minerals to regulate humidity [19,20].

Residency and surface age. Currently, surface ages on Mars are restricted to crater counting and cosmogenic dating of surface exposure using Curiosity instruments. Returning samples from Mars will open up the use of more powerful radiometric dating techniques to give absolute ages of in situ rocks. However, by using cosmogenic dating of meteorites (e.g., ^{10}Be, ^{36}Cl) the age of alteration in the meteorite could be constrained [21], which would give a data point to help calibrate atmospheric models.

Astrobiology: There are three areas of astrobiology that can yield evidence of life: 1) Organic-biosignatures, 2) Fossil-preservation, and 3) Isotope-biosignatures. Each path has its limitations. Organics have been discovered on Mars but in low quantity due to UV degradation and oxidative perchlorates; and are indistinguishable from meteoritic organics [22]. Of note, 1-3 wt% of the Martian soil is believed to be of meteoritic origin [23], so exogenic organic contamination is expected. Fossils are not a good indicator of life in themselves and require further quantitative information [24]. Lastly, recognition of isotope biosignatures in indigenous rocks will be limited by a lack of understanding of starting compositions. On Mars, $\delta^{34}S$ values span -47‰ ± 14‰ to +28‰ ± 7‰ at Gale Crater alone [25], significantly large to hide a putative dissimilatory, sulfate-reduction biosignature.

Habitat potential of chondrites. Much work has been conducted on endolithic habitats on Earth, of which the environment within the meteorite overlaps considerably. Tait et al. [7] found the main differences over crustal rocks to be: 1) Increased electron donors, through sulfides, FeNi alloys, and organics, 2) Reduced chemistry leads to faster production of hygroscopic minerals that help trap water and entomb microbes, 3) Dark fusion crust leads to increased albedo and temperature versus surrounding rocks, and 4) Elevated and bioavailable CHNOPS elements. These traits make meteorites a viable past habitat for putative microbes on Mars.

Isotopic biosignatures. Iron and sulfur isotopes for chondritic meteorites fall within narrow ranges exhibition < 0.5‰ variation [26,27]; making deviations from these starting reservoirs more pronounced. Iron meteorites were fed to *A. ferrooxidans* and generated a heavy redox precipitate of $\delta^{56}Fe$ = 0.38‰ ± 0.03 [28]. Similarly, experimental studies using *A. ferrooxidans* generated sulfur isotope fractions in Chelyabinsk of $\Delta^{34}S_{SO4-FeS}$ = 2.0‰ ± 1.7‰ [29]. That same study also recorded positive enrichments in environmental meteorite sulfates from the Nullarbor plain of $\Delta^{34}S_{SO4-FeS}$ = 2.0 ‰ ± 1.7 ‰, indicating biological mediation. If found on Mars such fractionations could be indicative of biological alteration and separated from abiotic signatures.

Meteorite organics. Carbonaceous meteorites contain a varied and documented inventory of organics [30], however how they contribute to Martian organics is not known at this time. Most recently aromatic hydrocarbons were found on Mars and look similar to meteorite pyrolysis products leading to ambiguity as to their origin [22]. This finding is similar to that of SNC meteorites [31]. Returning a carbonaceous chondrite could inform how meteorite organics degrade within the Martian environment.

Mars 2020 Consideration: The Mars 2020 rover will sample about thirty ~15g cores of material. A single 15g core of unaltered chondrite would contain: S 309 mg, Fe 4280mg, P 37mg, Ni 213mg, Ca 194mg, and Mg 2188mg. When altered in the Martian environment, these elements would react with volatiles to create new minerals. Their isotopic ratio would fractionate due to equilibrium with the atmosphere or kinetic effects. The Mars 2020 landing site, Jezero Crater, has surface exposures well within the potential age limits for meteorites. Meteorites as samples of opportunity would require an active decision to be made. However, micrometeorites are likely to be included within regolith samples, as were chondrite fragments in returned Apollo samples [32]. Consideration should be made for such "samples of accident" as well as "samples of opportunity".

Chondritic meteorites provide the most scientifically diverse samples on Mars that could provide the baseline for Martian environmental geochemistry, paleoclimatic reconstruction, atmospheric science, and astrobiology. Not to mention that they would providing value to other returned samples by quantifying the Amazonian weathering overprint across several mineral phases.

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