If we already have samples from Mars, why do we need sample return missions? The importance of martian meteorites and the value of Mars Sample Return. C.K. Shearer[1], L.E. Borg[2], A. Treiman[3] and P. King[1]. [1]Institute of Meteoritics, University of NM, Albuquerque, NM 87131 (cshearer@unm.edu) [2]Institute of Geophys. and Planetary Phys, Lawrence Livermore National Laboratory, Livermore, CA, 94550; [3]Lunar and Planetary Institute, Houston, TX 77058.

Introduction: Approximately 40 unpaired meteorites are acknowledged as samples derived from Mars. The total mass of these samples exceeds 84 kg. All of them have an igneous origin and formed by the crystallization of basaltic magmas on or near the martian surface. With such a large mass in hand, why is it critical to return an additional 0.5 to 1.0 kg of material from Mars? Here we focus upon: (1) what has been learned from martian meteorites; (2) questions suggested by, but not answered by, the meteorites; and (3) what questions, crucial to the exploration and understanding of Mars, cannot be answered by the martian meteorites and therefore require sample return.

Knowledge from the martian meteorites: Within this abstract format it is not our goal to present all of the fundamental insights derived from martian meteorites. Instead, we list several important findings from martian meteorite studies.

Mars is active!: The relatively young ages of many martian meteorites indicate that Mars was a dynamic planet in the recent past, capable of igneous processes, specifically melting of the martian mantle [1-4]. The young ages further indicate that igenous processes are probably active on Mars today.

Mars differentiated early: Radiogenic isotope studies of martian meteorites show that Mars differentiated rather quickly (within ~25 Ma of solar system formation) and that the products of this early differentiation did not remix for most of its history [3-7]. This early differentiation is consistent with the presence of a magma ocean, comparable to that inferred for the Moon [3-8].

Mars is complex: Some chemical features of the martian basalts (e.g., K/La, Fe/Mn, O isotopes) link them to a common parent body. The array of shergottite compositions implies that they were derived by mixing of two distinct sources produced during the early stages of martian differentiation [3-8]. The superchondritic Ca/Al of many of the martian basalts suggests that they may have been derived from (magma ocean) cumulates that experienced the removal of garnet prior to their formation [8]. Estimates of the crystallization conditions of martian basalts implies that the martian mantle may be under a range of f_{O2} conditions from IW+1 to more oxidizing conditions [7,9,10].

Mars has "groundwater": Most of the martian meteorites contain complex assemblages of water-deposited minerals, and many of these clearly formed on Mars [i.e. 11,12]. The water-deposited minerals include: smectite; Fe-O-H phases; Fe-Mg-Ca carbonates; Ca, Mg, and K-Fe sulfates; Na & K chlorides; Ca & Mg-Fe phosphates; and amorphous material. Ages of these assemblages range from ~ 3.9 – 0.1 Ga, proving that Mars had "groundwater" through most of its history [13]. S isotope data ($\delta^{34}S$ and ^{33}S depletions) and large ^{17}O excesses imply that this water came from (or interacted strongly with) the Mars' atmosphere [14-17]. Alteration phases in the martian meteorites provided a first glimpse of phases that could be stable at or near the martian surface.

Composition & evolution of the martian atmosphere and hydrosphere: Noble gases, N_2, and CO_2 trapped in impact-produced glass not only confirmed that these meteorites were from Mars, but provided constraints on the composition and dynamics of the martian atmosphere [i.e. 12,18,19]. The $\delta^{13}C$ data from martain meteorites provide insights into the martian carbon cycle [20]. The D/H in apatite relative to atmospheric D/H has been used to suggest early H_2O escape from a wetter Mars [21].

Questions posed by martian meteorites:

How abundant are H and C in the martian basalts and mantle? The martian basalts contain only parts per million of indigenous magmatic H and C. Were their parent magmas (and thus mantle) so poor in H and C, or were these (and other) volatile elements lost on eruption or after crystallization?

Is martian magmatism essentially basaltic in composition? All martian meteorites are derived from basaltic magmas. Does this imply that all martian magmatism is a product of mantle melting followed by crystallization under fairly anhydrous conditions? Alternatively, does Mars produce all sorts of igneous rocks, and the martian meteorites are only a limited sample?

What is the composition of the martian crust? The Moon illustrates an example of a planetary crust which is essentially a product of basaltic magmatism. Based on the martian meteorites, is such a model for the composition and evolution of the crust valid for Mars or does the martian crust exhibit a greater range of compositional diversity (e.g. andesites)?

How did Mars' geochemical reservoirs remain isolated? Martian meteorites are derived from several distinct sources that have remained isolated for ~4.5

Ga. If these sources are in the mantle, how could they remain isolated in the face of convection and plumes? On the other hand, if these sources represent the mantle and crust, how is the crust produced?

Do low-T phases in martian meteorites preserve evidence of alteration processes on Mars? Do some salt minerals in martian meteorites result from terrestrial contamination? Have microbeam analyses of stable isotopes in hydrous minerals been affected by terrestrial contamination?

Is there evidence for martian biology in the martian meteorites? A claim that martian meteorites contain signs of ancient martian life has been vigorously debated, and mostly rejected [i.e. 22,10]. It is not clear, what markers martian biota might have left in rocks destined to be meteorites, and whether those markers could be preserved.

The value of Mars Sample Return:

The martian meteorites present a biased view of Mars: Orbital and surface missions have revealed that Mars' surface is far more diverse than was imagined only a decade ago. This indicates that Mars has a plethora of distinct environments, each of which is characterized by different samples types, with different potential scientific returns. For example, the meteorite collection does not contain samples representative of clays identified from orbit [23] or Br- or Si-rich samples identified by rovers [24]. Most of the lithologies encountered by orbital and surface missions on the martian surface are not in the meteorite collection because they are extremely fragile and do not survive the impact process that would launch them into space. These fragile samples record processes on the surface or in the shallow martian crust that reflect the activity of water. These lithologies potential represent abodes which were hospitable to life.

Geologic context: Although the data derived from martian meteorites paints a general picture of martian planetary evolution and development, it would be significantly more valuable if the data could be placed within a geologic context. Although dates reflecting crystallization or alteration can be tied to a specific sample or groups of samples, they cannot be related to the evolution and alteration of a particular martian terrain or placed within the context of planetary scale events. For example, geologic context is required in order to determine cratering rates and develop accurate crater density chronology. Thus, returned samples that are placed within a geologic context (local-, regional-, and planetary-scale) will provide a means of dating events on the martian surface, as well as constraining the regional extent of mineralogical and geochemical features, thereby more precisely establishing the overall history of Mars.

Ground truth: Sample return should not be viewed as a terminal mission in the exploration of Mars. Ground truth offered by sample return provides insights into the reinterpretation of data gathered by previous orbital and surface missions. Orbital and surface observations allow sample data to be placed in a planetary-scale context. "New Views of the Moon" [25] illustrates the scientific dynamics among orbital, surface, and sample observations in better understanding a planetary body. Further, ground truth enables the implementation of much more complex orbital and surface missions in the future.

Follow the Waters: Both orbital and surface missions have demonstrated that water has a central role in shaping the martian surface and perhaps the evolution of the martian crust. However, the history of water on Mars and its evolving role in shaping the martian crust have not been extracted from these observations. These previous missions have identified numerous lithologies that upon sampling will provide insights into fluid characteristics, sources of fluids, interactions with environments of biologic activity, and history-duration of fluid activity. Samples returned from Mars will potentially preserve more of the fragile secondary alteration phases used to track aqueous processes. Importantly, returned samples may be analyzed with a greater variety of analytical techniques than possible on the surface of Mars by rovers or remotely with orbiters.

Search for life: The initial "groundbreaking" sample return mission will probably not return samples that directly answer the question of whether or not life flourished on Mars. Because life and the history of life is inextricably connected with the physical factors of its environment, the study of Mars as a possible home for life is more likely the prudent scientific investigation for an initial sample return mission.

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