STRATEGIES FOR INVESTIGATING EARLY MARS USING RETURNED SAMPLES. Returned Sample Science Board (B. L. Carrier[1], D. W. Beaty[1], H. Y. McSween[2], A. D. Czaja[3], Y. S. Goreva[1], E. M. Hausrath[4], C. D. K. Herd[5], M. Humayun[6], F. M. McCubbin[7], S. M. McLennan[8], L. M. Pratt[9], M. A. Sephton[10], A. Steele[11], B. P. Weiss[12] [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [2]University of Tennessee, Knoxville, TN, [3]University of Cincinnati, Cincinnati, OH, [4]Universitiy of Nevada, Las Vegas, NV, [5]University of Alberta, Edmonton, Canada, [6]Florida State University, Tallahassee, FL, [7]NASA Johnson Space Center, Houston, TX, [8]Stony Brook University, Stony Brook, NY, [9]Indiana University, Bloomington, IN, [10]Imperial College, London, U.K., [11]Carnegie Institution, Washington, DC, [12]Massachusetts Institute of Technology, Cambridge, MA)

Introduction: The 2011 *Visions & Voyages* Planeary Science Decadal Survey identified making significant progress toward the return of samples from Mars as the highest priority goal for flagship missions in next decade[1]. Numerous scientific objectives have been identified that could be advanced through the potential return and analysis of martian rock, regolith, and atmospheric samples [2,3]. The analysis of returned martian samples would be particularly valuable in increasing our understanding of Early Mars.

There are many outstanding gaps in our knowledge about Early Mars in areas such as potential astrobiology, geochronology, planetary evolution (including the age, context, and processes of accretion, differentiation, magmatic, and magnetic history), the history of water at the martian surface, and the origin and evolution of the martian atmosphere. Here we will discuss scientific objectives that could be significantly advanced by Mars sample return.

Early Mars Scientific Objectives: There are several broad categories of study related to early Mars that could significantly benefit from the return and analysis of martian samples. For the purposes of this discussion, we have identified four such categories:

1. Astrobiology/signs of ancient life:

The question of whether life arose on Mars billions of years ago and for how long it persisted (or may still persist) has long been a driving factor in Mars exploration. Our current understanding of Mars and its history suggest that the planet was habitable for at least part of its history and parts of it may remain habitable today. The questions of whether the conditions were right for the emergence of life, and whether such emergence occurred, remain open. Several habitats on Mars are high-value targets including paleolacustrine sediments (especially those of Noachian age), hydrothermal deposits (sinters) and serpentinites. The investigation of samples from these types of habitats would significantly advance our understanding of both the history of water on Mars and its capability of supporting the emergence of life.

To develop a strategy for detection of Martian life, one must first identify a set of robust criteria for life detection that form a testable hypothesis. The simplest form of extraterrestrial life detection, with minimal assumptions on the nature of the organism or a potential "alien biochemistry" to be detected, is to understand the possible abiotic organic chemical reactions given the context of the samples, and to look for perturbations to that physiochemical system. Life assists in the detection process in that it is competition-driven to select a relatively small number of the many known organic chemicals produced by abiotic processes. Therefore, anomalous deviations from predicted abiological yields of organic chemicals under given conditions may be the easiest life detection protocol. The assumptions are minimal; life is carbon-based and it chooses only a subset of possible abiotic chemicals available. Therefore, knowing the abiotic reactions that are possible in a certain context provides a baseline value that can be compared to observations of natural Martian systems. If any anomalous concentrations of organics are observed, this anomaly may be a 'biosignature' [4].

The analysis of returned samples would allow for detailed replicate examination of abiotic and potentially biotic hypotheses for the origin of potential biosignatures, in an iterative fashion, ranging from microbial fossils and textures to possible biomolecules to isotopic and other geochemical signatures. The return of martian samples to Earth would allow for a much more comprehensive suite of analyses and at finer spatial scales than is possible through robotic *in situ* measurements, thus greatly enhancing our understanding of the the probability of determining whether life ever existed on Mars.

2. Constraining martian geochronology:

There are currently major sources of uncertainty in the absolute ages of different terrain units on Mars introduced by the use of crater size-frequency distribution models. Developing an accurate chronology requires determining absolute ages of crystallization or impact metamorphism of geological units with known crater frequencies. The precision of absolute age dating tehcniques that can currently be used *in situ* is limited and is insufficient to accurately calibrate crater counts.

3. Planetary evolution (accretion, differentiation, magmatic and magnetic history):

Most of what we know about the accretion and early differentiation of Mars comes from Martian meteorites. However, Martian meteorites provide coverage of limited periods of Martian history, are of unknown provenance, and have unknown original orientations on the

Martian surface. Apart from the 4.4 Ga NWA 7034 regolith breccia and the 4.1 Ga ALH 84001 orthopyroxenite, the other martian meteorites are either ~2.4 Ga, ~1.3 Ga or <0.6 Ga, such that igneous rocks from the Hesperian, reflecting an important phase of volcanic resurfacing of Mars, are missing from the collection. Igneous samples that span the Noachian-Hesperian boundary will assist in constraining the early global differentiation of Mars and the long-term history of silicate differentiation and magmatism, planetary heat loss, and the martian core dynamo.

Paleomagnetic studies of Martian meteorites have two major limitations: (a) the lack of ancient samples and (b) the meteorites' unknown orientations at the time they were magnetized. With respect to (a), the discoveries of magnetization in the Martian crust by the Mars Global Surveyor and in the ~4.16 billion year old meteorite ALH 84001 provide evidence for a dynamo active in at least the Early Noachian epoch [5,6]. However, it is unclear when the dynamo ended. Some studies suggest the end of the dynamo in the Early Noachian (~4.0-4.1 Ga) [7], while others suggest that it lasted into the Hesperian [8]. It has even been proposed that the dynamo originated only after 4.0 Ga [9]. The main obstacle to the resolution of this issue is that only a single Martian meteorite older than 1.3 Ga (ALH 84001) was successfully paleomagnetically analyzed [6]. Paleomagnetic measurements of a suite of returned samples spanning the Noachian to Hesperian would likely establish the lifetime of the dynamo.

With respect to (b), oriented, stratigraphically bound sample suites from known geologic locations could be used to characterize the temporal behavior of any dynamo to test the hypothesis that early Mars experienced plate tectonics and/or true polar wander.

4. Martian atmosphere (origin and evolution): The Martian atmosphere is expected to have been lost over time, so records of the isotopic compositions and/or partial pressures of its key components could be recovered from the analysis of returned samples. Particularly interesting are carbonate minerals, hydrated minerals, and other weathering products, especially phases that are amenable to radiometric age determination. There is also the possibility of analyzing atmospheric gasses, which have been trapped in impact melt or other inclusions. For example, the heavy isotopic compositions of H, Ar, and other species in the present-day relative to ancient reservoirs indicate that a substantial fraction of the atmosphere has been lost through time [10]. The loss of the atmosphere was likely caused by a combination of hydrodynamic escape, erosion by impacts, and possibly severe sputtering and pickup by the solar wind magnetic and electric fields following the death of an early dynamo [11] (see above).

In addition to studying the current Martian atmosphere and ancient trapped gasses in Martian sedimentary, igneous, and impact samples, there is considerable knowledge to be gained by examining the compositions of sedimentary rocks, regoliths, and secondary minerals that are especially sensitive to climatic influences such as obliquity-driven changes. For example, results from NASA's Curiosity Mars rover indicate that it is possible to obtain high resolution chemostratigraphic climate records from rhythmically bedded sedimentary rocks using in situ measurements – a capability that Mars 2020 is also expected to have (e.g., with SuperCam and PIXL). Analysis of selected returned samples from such *in situ* records would be extremely important in confirming and fully understanding such records. As another example, understanding the relationship between sedimentary rock, regolith and secondary mineral compositions and the contemporaneous atmosphere would also greatly expand our understanding of paleoclimatic conditions on Mars by revealing how the sedimentary record responds to such changes. Finally, there is growing capability of applying a variety of radiometric techniques to dating of the time of sedimentation. Obtaining such dates from climate-sensitive sedimentary sequences would greatly help to constrain the timescales of past climate changes.

References:

[1] Vision and Voyages for Planetary Science in the Decade 2013–2022. (2011) National Academies Press. [2]MEPAG E2E-iSAG (2011) Planning for Mars returned sample science: final report of the MSR End-to-End International Science Analysis Group (E2E-iSAG). *Astrobiology* 12:175-230 [3] MEPAG (2015), Mars Scientific Goals, Objectives, Investigations, and Priorities: 2015 at http://mepag.nasa.gov/reports.cfm. [4] A. Steele, F. M. McCubbin, M. D. Fries,. *Meteoritics & Planetary Science* (2016), doi:10.1111/maps.12670. [5] Acuña, M.H. et al. (2008) in *The Martian Surface: Composition, Mineralogy, and Physical Properties*, ed. by J.F. Bell (Cambridge University Press, Cambridge) 242–262. [6] Weiss, B.P. et al (2008) *Geophys. Res. Lett. 35(23)*. [7] Lillis, R.J. et al (2013) *J. Geophys. Res.: Planets 118(7)*, 1488-1511. [8] Milbury, C. et al (2012) *J. Geophys. Res. :Planets 117*, E10. [9] Connerney, J.E.P. (2004) *Space Sci. Rev. 111*, 1-32. [10] Mahaffy, P.R. et al. (2015) *Science, 347*, 412-414. [11] Jakosky, B.M. & Phillips, R.J. (2001) *Nature, 412*, 237-244.