THE LONG-RANGE FUTURE OF THE SCIENTIFIC EXPLORATION OF MARS. Mars Exploration Program Analysis Group (MEPAG) Executive Committee: J. Johnson[1], D. Beaty[2], B. Bussey[3], P. Christensen[4], V. Hamilton[5], S. Hubbard[6], M. Meyer[3], G. Ori[7], L. Pratt[8], R. Zurek[2], S. Diniega[2], L. Hays[2], [1]John Hopkins University, Applied Physics Laboratory, Laurel, MD 20723 (Jeffrey.R.Johnson@jhuapl.edu), [2]Mars Program Office, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109 (David.W.Beaty@jpl.nasa.gov), [3]NASA HQ, [4]Arizona State University, [5]Southwest Research Institute, [6]Stanford University, [7]IRSPS (Italy), [8]Indiana University.

Introduction: Current planning for the scientific exploration of Mars is organized around three broad scientific goals [1]: *(I)* Determine whether Mars has ever supported life; *(II)* Understand the processes and history of climate on Mars; *(III)* Understand the origin and evolution of Mars as a geological system. In addition, MEPAG carries a fourth, implementation-oriented goal, which is *(IV)* Prepare for human exploration.

The vision of what the Mars Exploration Program (MEP) would or could look like in 2050 is dependent on what happens in each of the above goal areas, modified by the potential for "disruptive" discoveries, based on ongoing as well as upcoming missions (such as NASA's 2020 Mars rover, ESA's ExoMars missions, and ISRO's next Mars mission). There are many pathways and contingencies, none of which can be described completely here. For the purpose of this document we assume basic engineering success for potential future missions (including Mars Sample Return (MSR)), that the international public remains interested in Mars exploration, and that by 2050 humans have successfully landed on the martian surface. Although implementation is not discussed here, the potential future science investigations may be most effectively pursued under international collaborations and/or utilizing "commercial" payload space, and are generally helped with a robust, concerted NASA Mars Exploration Program.

Possible scientific lines of inquiry after 2017:

Goal I (Life). The search for evidence that life existed on Mars in the past (whether or not it also exists today) would be dominated by the *MSR campaign*. Evidence of ancient microbial life is likely difficult to observe without samples in terrestrial laboratories. The result of these analyses would provide the single most important scientific disruption to consider in future planning (discussed below). The search for modern life is focused on the high-precision *measurement of trace gases* in the martian atmosphere, which could generate evidence of one or more refugia that could potentially be followed up by other missions. In addition, there are various hypothesis-driven proposals for specific tests of extant life in various martian environments. A discovery in this area would also be highly disruptive.

Goal II (Climate). Our current strategy involves ongoing *orbital monitoring of atmospheric dynamics* (including the transfer of mass and energy to/from the polar ice caps), atmosphere-surface interactions, and developing an understanding of extreme weather events (causes, magnitudes, predictability). By 2050, as long as orbital and landed assets capable of monitoring the martian weather have been adequately replenished so as to extend the temporal baseline and increase temporal and spatial coverage, we expect that sufficient data sets and predictive algorithms will exist for support of site characterization and human exploration.

Goal III (Geology). Martian geology is complicated by significant spatial and temporal variations in composition, mineralogy, hydrology, and landform evolution. In order to understand Mars as a global geological system, multiple landings in multiple geologic provinces are required, with sufficient high-resolution orbital data for characterizing the geologic context of in situ measurements. (This is no different than trying to interpret the geology of the Earth from a small handful of landings.) Importantly, MSR would provide answers for at least one site in the context of new information on the precise ages and ranges of geochemical and hydrological environments experienced by the samples.

Goal IV (Prep. for Human Explor.). The risk of sending a human mission to the martian surface can be significantly reduced by acquiring certain specific data sets [2]. This allows the mission to be designed to a narrower set of constraints, rather than to the total width of the uncertainty envelope. Whether a data set is required depends on the magnitude of the risk reduction that can be achieved, and the cost of engineering against the adverse consequences (which changes as our understanding of risk and risk tolerance evolves).

Primary pathways into the future: For purposes of the planning associated with this workshop, we assume that MSR has been completed, and the samples have been analyzed initially, by 2030-2035. We postulate that the results from these samples will constitute a Branch point in our long-range planning, that revolves around the following question: *Do the samples contain either permissive or definitive evidence of martian life?* This Branch point has implications for observations in situ and orbital investigations, and for human exploration plans. We also note that there are other types of observations that respond to objectives and priorities that are independent of the life question – some of those parallel science tracks are discussed below (within Branch #3).

Branch #1: MSR discovers life: *If MSR were to deliver evidence of ancient life in the sample suite, our scientific objectives would immediately diversify from "find the life" to "characterize the life", "how did it originate", "does it persist to the present", "how do we begin interacting with it", etc.* These types of big questions are not currently in the MEPAG Goals Document [1] nor within the MEP design because the motivation for them does not currently exist.

What would the MEP look like in this kind of environment? How would this change our science objectives and priorities within all areas of Mars science, not just the life-focused questions (i.e., Goal I within the MEPAG Goals Document [1])? In particular, one imagines that the need to characterize life and learn of its origin and evolution would require treating the exploration of the geologic and climatological context of any lifeforms and their habitat as a high priority.

The implications of this Branch for the human exploration of Mars are complicated. Even though MSR is designed as a test for ancient biosignatures, the positive discovery of past life would increase the possibility that life exists there today, with concomitant ramifications for planetary protection strategies. Thus, such a powerful discovery could trigger a delay in human exploration to first allow additional robotic investigation -- the first interaction of humans with another life form would need to be planned carefully.

Branch #2: MSR does not discover life: *What does the MEP future look like if MSR comes up empty on the life question?* Given the single sampling site currently planned for Mars 2020, how does the strategy for life detection evolve, if it continues to be a goal? It could focus on more of "survey"-type studies for past habitable environments exposed at the surface. Or it could focus more on drilling to access the subsurface, which may have been a better candidate both for habitability and preservation. In that realm the results from the ExoMars rover will influence future efforts for near-subsurface investigations.

Certainly investigations of Mars aside from the life question would increase the priority of non-MSR-dependent science. In achieving those investigations of the past and present environment, the generated information could continue to advance our understanding of the limitations on where life does develop.

An interesting implication of this Branch is that it would ease (but not eliminate) the planetary protection concerns related to the human exploration of Mars. This may have the effect of enabling and accelerating sending humans to the martian surface.

Branch #3: Science Enabled by Strategies that are Not Dependent on MSR: What is the future of the sectors of Mars science that are independent of the sample return studies? *Many geologic and climate focused science questions (i.e., elements Goals II and III within the MEPAG Goals Document [1]) have priorities that would remain high whether or not examined in the context of life.* For example, understanding the Martian climate over the planet's history adds to our understanding of climate cycles and interactions, and to models of atmospheric processes and components, many of which are relevant to human exploration studies. Determining how the formation and evolution of the lithosphere is revealed in the geologic record through analyses of surface mineralogy, impact history, seismology, and volatile evolution in both polar and equatorial regions improves our understanding of Mars as a geologic system and its place in the Solar System. Such studies are relevant for advancing studies of terrestrial environments as well as for the larger-scale study of planetary atmospheres (i.e., comparative climatology). Other important investigations include Mars seismological science or identification of construction materials and in situ resources for human exploration.

Although these scientific objectives have value independent of the life question, a key issue for discussion is the stability of the MEP in an environment geared dominantly towards non-life questions . In this instance, the "survey"-type study may also be a way to understand more about Mars as a system and could involve interdisciplinary research that could be key to long-term stability.

Breakdown into larger Thrusts. The above analysis naturally lends itself to the breakdown of the next several decades into four partially overlapping thrusts that will be described more fully at the workshop: *(1)* The MSR Thrust. We assume that the samples can be delivered to Earth and analyzed by about 2030-2035. *(2)* The pre-human-driven exploration Thrust. This is likely to overlap MSR, and the overall timeline will be driven by the timing of humans to the martian surface. *(3)* The non-MSR science Thrust, that runs in parallel. *(4)* The human exploration Thrust.

References: [1] MEPAG (2015) *Mars Scientific Goals, Objectives, Investigations, and Priorities: 2015*, http://mepag.nasa.gov/reports.cfm; [2] MEPAG and S-BAG, (2012), *Humans to the Martian System Summary of Strategic Knowledge Gaps (P-SAG)*, http://mepag.nasa.gov/reports.cfm.