POSSIBLE SCIENCE PRIORITIES FOR MARS SAMPLE RETURN.

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Introduction: The return of Martian samples to Earth has long been recognized to be an essential component of a cycle of exploration that begins with orbital reconnaissance and *in situ* surface investigations. Major questions about life, climate and geology would involve answers from state-of-the-art laboratories on Earth. Spacecraft instrumentation could not perform critical measurements such as precise radiometric age dating, sophisticated stable isotopic analyses and definitive life-detection assays. Returned sample studies could respond radically to unexpected findings, and returned materials could be archived for study by future investigators with even more capable laboratories. Unlike Martian meteorites, returned samples could be acquired with known context from selected sites on Mars according to the prioritized exploration goals and objectives.

Scientific Objectives: The ND-MSR-SAG proposed the following 11 high-level scientific objectives for MSR based on the objectives, investigations and priorities described in MEPAG (2006). Determine the chemical, mineralogical, and isotopic composition of the crustal reservoirs of C, N, S and other elements with which they have interacted, and characterize C-, N-, and S-bearing phases down to submicron spatial scales in order to document processes that can sustain habitable environments on Mars, both today and in the past. Assess the evidence for pre-biotic processes and/or life on Mars by characterizing the signatures of these phenomena in the form of structure/morphology, biominerals, organic molecular isotopic compositions, and their geologic contexts. Interpret the conditions of Martian water-rock interactions through the study of their mineral products. Constrain the absolute ages of major Martian crustal geologic processes, including sedimentation, diagenesis, volcanism/plutonism, regolith formation, hydrothermal alteration, weathering, and cratering. Understand paleoenvironments and the history of near-surface water on Mars by characterizing the clastic and chemical components, depositional processes, and post-depositional histories of sedimentary sequences. Constrain the mechanisms of early planetary differentiation and the subsequent evolution of the Martian core, mantle, and crust. Determine how the Martian regolith is formed and modified and how and why it differs from place to place. Characterize the risks to future human explorers in the areas of biohazards, material toxicity, and dust/granular materials, and contribute to the assessment of potential *in-situ* resources to aid in establishing a human presence on Mars. For the present-day Martian surface and accessible shallow subsurface environments, determine the state of oxidation as a function of depth, permeability, and other factors in order to interpret the rates and pathways of chemical weathering, and the potential to preserve the chemical signatures of extant life and pre-biotic chemistry. Interpret the initial composition of the Martian atmosphere, the rates and processes of atmospheric loss/gain over geologic time, and the rates and processes of atmospheric exchange with surface condensed species. For Martian climate-modulated polar deposits, determine their age, geochemistry, conditions of formation, and evolution through the detailed examination of the composition of water, CO_2, and dust constituents, isotopic ratios, and detailed stratigraphy of the upper layers of the surface.

Sample Types: MSR would have its greatest value if the rock samples were collected as suites of samples that represent the diversity of the products of various planetary processes. Martian ***sedimentary materials*** likely contain a complex mixture of chemical precipitates, volcanic tephra, impact glass, igneous rock fragments, and phyllosilicates. Sediment samples would be needed to achieve definitive measurements of life detection, observations of critical mineralogic and geochemical patterns and occluded trace gases at the submicron scale. Samples of ***hydrothermally altered rocks*** on Earth provide water, nutrients and chemical energy necessary to sustain microorganisms, and they can preserve fossils in their mineral deposits. Hydrothermal processes substantially affect the mineralogic and volatile composition of the crust and atmosphere. Chemical alteration processes occurring at near-surface ambient conditions (typically < ~20°C) create ***low temperature altered rocks*** that include, among other things, aqueous weathering, palagonitization and a variety of oxidation reactions. Understanding the conditions under which alteration processes proceed at low temperatures would provide important insight into the near-surface hydrological cycle, and the mass fluxes of volatile compounds. ***Igneous rocks*** are expected to be primarily lavas and shallow intrusive rocks of basaltic composition. They would be critically important for investigations of the geologic evolution of the Martian surface and interior because their geochemical and isotopic compositions constrain both the composition of mantle source regions as well as the processes that affected magmas during their generation, ascent, and emplacement. ***Regolith*** samples have recorded interactions between the crust and the atmosphere, the nature of rock fragments, dust and sand particles that have been moved over the surface, H_2O and CO_2 migration between ice and the atmosphere, and processes involving fluids and sublimation. Regolith studies would help to facilitate future human exploration by assessing toxicity and potential resources. ***Polar ice*** samples would constrain the present and past climatic conditions as well as elucidate cycling of water. Short cores could help to resolve climate variability in the last few 10^5 to 10^6 years. ***Atmospheric gas*** samples would help to document the composition or the atmosphere as well as the processes that influenced its origin and evolution. Trace organic gases, such as methane and ethane, could be analyzed for their abundance, distribution, and their relationship to a potential Martian biosphere. Returned samples of Ne, Kr, CO_2 and CH_4 and C_2H_6 would confer major scientific benefits. Analyses of the chemistry and mineralogy of Martian ***dust*** would help to elucidate the weathering and alteration history of Mars. Given the global homogeneity of Martian dust, a single sample from anywhere would likely be representative of the planet as a whole. A ***depth-resolved suite*** of samples should be obtained from depths of cm to several m within the regolith or from a rock outcrop in order to investigate trends in the abundance of oxidants (e.g., OH, HO_2, H_2O_2 and peroxy radicals) and the preservation of organic matter. ***Other sample suites*** would include rock breccias that might sample rock types that would otherwise not be available locally, volcanic tephra consisting of fine-grained regolith material or layers and beds possibly delivered from beyond the landing site, and meteorites whose alteration history could be determined and thereby provide insights into Martian climatic history.

Sample Attributes that Affect Science Value:

The following key factors associated with locating, sampling, storing and returning samples could influence strongly their value for achieving MSR science objectives.

1. *Sample size.* A full program of scientific investigations would be expected to require samples of at least 8 g for both rock and regolith. To support the required biohazard testing, each sample should be increased by about 2 g, leading to an optimal sample size of about 10 g. However, textural studies of some types of sample heterogeneities might need one or more larger samples of ~20 g. Material should remain to be archived for future investigations.

2. *Sample encapsulation.* To preserve the scientific usefulness of returned samples, they should not commingle, each sample should be linked uniquely to its documented field context, and rock samples should remain mechanically intact. A smaller number or mass of carefully managed samples would be far more valuable than larger number or mass of poorly managed samples. The encapsulation for at least some of the samples should be airtight to retain volatile components.

3. *Number of samples.* Studies of heterogeneities between samples could provide as much or more information about processes as detailed studies of a single sample. The minimum number of samples needed to address the scientific objectives of MSR would be 26 (20 rock, 3 regolith, 1 dust, 2 gas), in the case of recovery of the MSL cache. These samples would be expected to have a mass of about 350 g, and with sample packaging, the total returned mass would be expected to be about 650 g.

4. *Sample acquisition system.* This system should sample both weathered exteriors and unweathered interiors of rocks, sample continuous stratigraphic sequences of outcrops that might vary in their hardness, relate the orientation of sample structures and textures to those in outcrop surfaces, bedding planes, stratigraphic sequences, and regional-scale structures, and maintain the structural integrity of samples. A mini-corer and a scoop would be the most important collection tools. A gas compressor and a drill would have lower priority but would be needed for specific kinds of samples.

5. *Degree of selectivity of samples and documentation of field context.* The scientific value of MSR would depend critically upon the ability to select wisely the relatively few returned samples from the vast array of materials it would encounter. MSR objectives would probably need at least two kinds of *in situ* observations (color imaging, microscopic imaging), and possibly as many as five (also mineralogy, elemental analysis and reduced carbon analysis). No significant difference exists in the observations that would be needed for sample selection vs sample documentation. Revisiting a previously occupied site might result in a reduction in the number of instruments that would be carried by MSR.

6. *Sample temperature.* Some key species are sensitive to temperatures exceeding those attained at the surface. Examples include organic material, sulfates, chlorides, clays, ice, and liquid water. MSR's objectives could most confidently be met if the samples would be kept below -20°C, and with less confidence if they would be kept below +20°C. Significant damage, particularly to biological studies, would occur if the samples reach +50°C for 3 hours. Temperature monitoring during return would allow any changes to be evaluated.

7. *Diversity of the returned collection.* The diversity of the suites of returned samples should be commensurate with the diversity of rocks and regolith encountered. This guideline should substantially influence landing site selection and rover operation protocols. It would be scientifically acceptable for MSR to visit only a single landing site, but returning samples from two independent landing sites would be much more valuable.

8. *Surface operations.* In order to collect the suites of rocks indicated by the MSR objectives, the lander should have significant surface mobility, the capability to assess the diversity of surface materials, and the ability to select samples that span that diversity. Depending on the geological character of the landing site, it is expected that a minimum of 6-12 months of surface operation would be needed in order to reconnoiter a site and identify, characterize and collect a set of samples.

9. *Effects of the MSL/ExoMars caches upon MSR planning.* The decision to direct the MSR mission to retrieve the MSL or ExoMars cache conceivably might alter other aspects of the MSR mission. However, given the limitations of the MSL cache, the differences in planetary protection requirements for MSL and MSR, the possibility that the MSR rover might not be able to retrieve the MSL cache, and the potential for MSR to make its own discoveries, the MSR landed spacecraft should have its own capability to characterize and collect at least some of returned samples.

10. *Planetary protection.* A scientifically compelling first MSR mission could be designed without including the capability to access and sample a special region, defined as a region within which terrestrial organisms are likely to propagate. Unless MSR could land pole-ward of 30 degrees latitude, access very rough terrain, or achieve a significant subsurface penetration (e.g. >5 m), MSR would be unlikely to be able to use incremental special regions capabilities. Planetary protection draft test protocols should be updated to incorporate advances in biohazard analytic methodology. The statistical principles that govern mass requirements for subsampling returned samples these analyses should be reassessed.