Scientific Rationale for Depot Caching on Mars 2020

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With the concurrence of the Mars Program Office and NASA Headquarters, the Mars 2020 project is moving forward with plans to implement a strategy called adaptive caching for preparation of a collection of samples of Mars for possible return to Earth by a future mission. This document seeks to define adaptive caching and explain why it is the favored strategy from the perspective of science.

The Mars 2020 mission has three scientific objectives: A) explore and characterize the geology of the chosen landing site; B) identify and study an astrobiologically relevant environment, locate rocks with high biosignature preservation potential, and in those rocks, seek signs of possible ancient life; C) using A and B as a guide, select and prepare a collection of the most scientifically valuable specimens for potential future return to Earth.

To meet Objective C, the baseline plan for the Mars 2020 mission is to drill about 15 grams of material from each of ~30 selected rock and regolith samples. A rotary-percussive coring drill with a pre-cleaned sample tube will penetrate about 5 cm into the target material. The core will then be broken off from the rock, and the sample and its tube immediately capped and hermetically sealed to prevent sample exchange and contamination. The sealed tubes will be placed in a storage rack on board the rover and transported until the mission operators choose to deposit them on the Martian surface, where they would await pick-up by a future mission should NASA choose to return them to Earth and be approved to do so.

There has been considerable discussion of the best ways to collect and store the samples on Mars, formally called "caching". Early in the development of the Mars 2020 mission, the notional concept was that the individual sample tubes would be placed in a single caching container on board the rover, and at an appropriate time, this container would be deposited on the surface. As an alternative to this "monolithic" caching approach, the Mars Program Office (MPO) at JPL led a study of "adaptive caching" starting in 2014. In this option, the sample tubes are not housed in a container, but instead are placed directly on the Martian surface. The word "adaptive" here connotes the ability to modify the exact caching strategy as the mission evolves. Indeed, elimination of the caching container opens up a wide option space for how the samples could be deposited, ranging from immediate deposition of tubes after drilling to a strategy in which one or two strategic locations are chosen to deposit the samples in large groups (here called "depot caching").

From the engineering perspective of Mars 2020, there is little difference between the “monolithic” and “adaptive” caching approaches. The samples would be drilled and sealed in precisely the same fashion, the only difference being whether Mars 2020 ejects a single cache container or ejects the tubes individually to the ground. However, as discussed below, the surface operations of Mars 2020 could differ greatly between these two approaches. It is these differences that favor adoption of the adaptive approach.

Before discussing the advantages of adaptive caching for the mission's science return, it is worthwhile noting that the implications of caching strategy for the potential follow-on missions have been given considerable thought by the advance planning engineers in the MPO. For present purposes, it is adequate to note their conclusion that the choice of caching approach does not substantially increase the engineering complexity of those future mission concepts. Similarly, there is no substantial predicted increase in the operational complexity of those missions, at least when employing the depot caching strategy presently baselined by Mars 2020.

There are several ways that adaptive caching can enhance the potential scientific value of the sample collection:

1. In the monolithic caching scenario, the sampling operations of Mars 2020 would terminate once the container is placed on the ground. When in the mission this would occur would be an impactful and difficult decision to be negotiated among multiple stakeholders. Placement on the ground must occur before the end of the mission (or the samples may be trapped on board the rover), and there may be significant pressure to do so within the prime mission. There are plausible and even likely scenarios in which it would occur before the ~30 slots in the container are full. By contrast, adaptive caching offers the potential to continue sampling until all tubes are consumed and well into any extended mission. At the present time, about 40-50 tubes are planned for the rover.

2. The adaptive approach allows future scientists to debate the merit of returning each individual sample, rather than being limited to the entire predefined package in the monolithic container. There are different ways to put together effective sample suites, and the best sample collection probably cannot be designed until all of the samples available to choose from are known. The fact that more samples tubes (40-50) could be available for use than the currently projected capacity of the return flight home (~30) presents a critical opportunity for high-grading and optimizing the collection.

3. Inevitably a mission as complex as Mars 2020 involves tradeoffs between risk and reward. In the case of a monolithic cache, each new sample adds to the value of the rover's cargo. As the samples accumulate, their collective scientific value would approach the threshold at which it is deemed high enough to justify formal consideration of Earth return. At this stage, general conservatism would favor avoidance of further risk (e.g., driving through sand to get to key outcrops), and pressure could be applied to

immediately deposit the cache on the ground in order to "lock-in" mission success. A plausible outcome of this pressure is that the monolithic cache is deposited with the lowest-possible scientific value consistent with returnability. In contrast, the adaptive approach can "off-load" the samples, and their associated risk, at opportune times. For example, one operational strategy could be to collect samples from a first region of interest (ROI), carry them to a second ROI, and deposit them in a depot. In the now "risk-reduced" state, the second ROI could then be explored and sampled in an unencumbered manner, and the new samples then deposited at the original depot. Again in a risk-reduced state, the rover could move to and sample a third ROI, either depositing its samples back at the first depot, or possibly opening a new depot. Exactly how this would unfold depends on the situation on the ground – the perceived value of various scientific targets and acquired samples, the hazards in moving among ROI's, and the general health of the rover.

Along with these benefits, adaptive caching has some real or perceived potential disadvantages. Here we enumerate some of these potential disadvantages, and discuss why the Mars 2020 project has concluded that they do not outweigh the benefits:

1. "The tubes will be impossible for a follow-on mission to locate." JPL’s operational experience with several Mars rovers indicates that locations can be determined very precisely (<1 m) using orbital imagery, and to the ~ cm level using rover cameras.

2. "The tubes will be degraded by windblown sand." The tubes and seals will be required to remain undegraded by sand over a 10-year lifetime on Mars and will be verified by testing to a multiple of this lifetime.

3. Relationship of blanks and witness materials to samples. Mars 2020 will carry and cache 1) “procedural blanks” – likely to be multiple, physically separate aliquots of clean and homogeneous rock simulant, to be drilled and sealed during the surface mission in tubes using the same procedure as that for martian samples, and 2) “witness materials” – likely to be one or more tubes that do not contain a martian rock or regolith sample but permit passive sampling of the ambient contamination environment during the mission. In the baseline depot caching scenario, blanks and witness plates will be deployed together with their associated samples, so they could naturally be selected for return together.

4. Sample temperature. The physical properties of metal sample tubes could allow adaptively cached samples to experience unacceptably high temperatures due to solar heating, possibly causing breakdown of potentially scientifically important Martian substances. In comparison, the greater mass and available surface-coating options of the cache container would reduce this problem for a monolithic cache. Modeling indicates that sample-tube heating is very asymmetric with Mars latitude (worse in the southern hemisphere, given Mars’ current orbital configuration). A promising approach to mitigating problematic heating is to coat the sample tubes with a material of appropriate optical properties (for example, alumina ceramic). The Project Science Office is currently evaluating what temperatures could lead to unacceptable science loss, and how the

coatings may impact other scientific investigations that may be undertaken on the samples. With the help of the newly assembled Mars Returned Sample Science board, significant modeling and science trades will be completed and key design decisions will be made by the end of 2015, in time for the Mars 2020 mission Preliminary Design Review.