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Mars sample return processing: X-Ray Computed Tomography of the Mars 2020 cache

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Introduction

The Mars 2020 rover mission will collect and cache samples from the martian surface for possible retrieval and subsequent return to Earth. If the samples are returned, that mission would present an opportunity to analyze returned Mars samples with geologic context on Mars. In addition, they may provide definitive information about the presence of organic compounds that could shed light on the existence of past or present life on Mars. Mars sample return (MSR) presents unique challenges for the processing and curation of samples [1]. Post-mission analyses will depend on the development of a set of reliable sample handling and analysis procedures that covers the full range of materials that may or may not contain evidence of past or present martian life.

MSR Curation Protocol- Initial scanning by XCT

As part of planning for the initial characterization and subsequent distribution to the scientific community, samples would be analyzed while still sealed in their containers with non-destructive, non-invasive techniques. Hanna et al. (2017) [2] suggest that X-ray Computed Tomography (XCT) may minimally alter samples for most subsequent techniques including organic analyses. The 2014 Report of the Workshop for Life Detection in Samples from Mars [3], published as an update to the 2001 Planetary Protection Draft Test Protocol, incorporates new findings and technological advances through community input. It also includes a comprehensive list of sample handling procedures and analytical measurements for returned Mars samples in the context of life detection and Planetary Protection. Assuming initial established protocols and procedures for controlled processing have been followed, the next step would be to address the methods for characterizing samples. At the top of the list is XCT analysis, would provide a three-dimensional whole sample reference, and would reveal physical heterogeneities at micron-level resolution including fractures, veins, porosity, lithologic and possibly mineralogical based structures. Higher dose X-rays would allow compositional details such as elemental distribution and mineralogy. Both reports [1,2] point out that the effects of increased radiation on the organics in samples would need to be evaluated. Because XCT systems can be configured for a variety of sources, detectors and geometric configurations, a detailed study of a variety of organic materials using multiple instruments is required for this evaluation.

Several recent studies show no alteration of organics [in meteorites] following exposure to synchrotron radiation [4], but work is needed to quantify the effects of laboratory XCT radiation on the types of organics that may be present in returned martian samples at fluences and energies that will allow in situ examination through the Mars 2020 cache tube. Our overall plan is to apply laboratory XCT radiation for a range of energies and fluences to a selection of organic compounds added to Mars analogue regolith material using compositions that reflect a Mars surface material composition. Results will be quantified with techniques appropriate (e.g. mass spectrometry) to better understand which classes of compounds are most susceptible and the subsequent products that may be produced. The materials will be tested using instruments at NASA Johnson Space Center and the Natural History Museum in London.

How Clean is Clean?

Organic contamination, as defined by the 2014 OCP [3] is “any substance that significantly interferes with our ability to detect the presence of martian organic compounds, or prevents our confidently determining that an organic compound is of martian and not terrestrial origin." Of equal concern is the possibility that any preliminary examination may alter what is expected to be a small organic signal that would be difficult to detect at even more energy intensive investigations. To ensure that preliminary interrogations would not diminish detection of a martian indigenous signal, or alter any known contaminants, we will conduct a set of experiments on Tier I compounds [3], which are compounds defined by the 2014 OCP as molecules that are potential contaminants, and likely to be most important to the science goals of the mission. Understanding the degree of alteration of these compounds during exposure to X-ray radiation is critically necessary to allow differentiation of contaminant versus native signal. It is a vital part of the framework for understanding signals that may be the result of alteration, allowing a degree of confidence in our conclusions that is necessary to meet the mission requirements.

Following X-ray exposure, we will define an alteration function based on a range of X-ray energies and intensities for nine isotopically labelled compounds from the Tier I [3] list: Adenine, Glycine, Glucose, Heptacosane, Napthalene, Palmitic acid, Pristane, Pyruvic acid, and Urea. Phased experiments will include pure analytes, analytes with known pure substrate in cache-like containers, and finally analytes with Mars analogue materials in cache-like containers.

Identifying a Mars Analogue:

Mars surface composition is well documented from 40 years of both orbital and landed missions. Most of Mars' surface is covered by a veneer of regolith that is sourced from a mix of martian and extraterrestrial infall materials [5]. Regolith will likely be a significant component of any returned samples collected at or near the surface. An Average Basalt Soil (ABS) reference is available for comparison, which is based on landed mission data [6]. When compared with ABS, analogues such as MMS and JSC Mars-1 are only a moderate compositional approximation. ABS, originally calculated by Taylor and McClennan (2009) [6] using Viking through MER-A and MER-B data, is recently updated by O'Connell-Cooper (2017) [6]. When compared against MSL's ChemMin data, the ABS shows that Mars regolith is likely a global unit with a primarily basaltic composition [6]. Comparing ABS against the average compositions of MMS and JSC Mars-1 along with shergottite EETA79001 Lithology A yields significant differences in Si, Fe, Al, and Mg oxides. As meteoritic infall is a known process impacting Mars surface [7], Allende, and average H and L chondrites were also reviewed. None of the materials alone are satisfactory analogues based on elemental comparison with ABS. Standard materials available from the USGS reference materials program, which included tholeiitic basalt from Iceland (BIR-1) and basalt from Hawaii (BHVO-2) were also considered. All show a range of variation from ABS, with the significant differences of low iron in the terrestrial rocks, and too little silica from meteorite infall materials. We are investigating the use of manufactured simulants [8] which would allow complete control over testing mission-specific analytical parameters and sample handling techniques for future missions.

References:

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