OPTIONS FOR POST-LANDING EXTRACTION OF SOLID-CORE SAMPLES FROM THE NASA-ESA MARS SAMPLE RETURN MISSION.

F. K. Thiessen[1], S. S. Russell[2], N. Dauphas[3], J. J. Barnes[4], L. Bonal[5], J. C. Bridges[6], T. Bristow[7], J. Eiler[8], L. Ferrière[9], T. Fornaro[10], J. Gattacceca[11], B. Hoffman[12], E. J. Javaux[13], T. Kleine[14], H. Y. McSween[15], M. Prasad[16], E. Rampe[17], M. E. Schmidt[18], B. Schoene[19], K. L. Siebach[20], J. Stern[21], N. Tosca[22], and D. Beaty[23]
[1] European Space Agency (ESA/ESTEC), Noordwijk, The Netherlands [2]Natural History Museum, London, UK [3]University of Chicago, USA [4]University of Arizona, USA [5]University of Grenoble, France [6]University of Leicester, UK, [7]NASA AMES USA [8]Caltech, USA [9]Natural History Museum, Vienna, Austria [10]INAF-Astrophysical Observatory of Arcetri, Florence, Italy, [11]CNRS, Aix Marseille Univ, IRD, INRAE, CEREGE Aix-en-Provence, France, [12]University of Bern, Switzerland, [13]Université de Liège, Belgium [14]Max Planck Institute, Germany, [15]University of Tennessee, USA, [16]Colorado School of Mines, USA, [17]NASA JSC, USA, [18]Brock University, Canada, [19]Princeton University, USA, [20]Rice University, USA, [21]NASA Goddard, USA, [22]University of Cambridge, UK. [23]Jet Propulsion Laboratory/California Institute of Technology, USA.

Introduction: NASA-ESA are planning to collect and transport from Mars to Earth a set of samples of martian materials for the purpose of scientific investigation [1]. The samples will have been collected by the Perseverance Rover [2] and consist of a variety of rocks, regolith, and atmospheric gas. Samples will be contained within Ti sample tubes, which will be sealed at the martian surface with a compression-style cap.

The rocks sampled thus far by the Perseverance Rover comprise magmatic rocks like basalt and olivine cumulates that experienced various degrees of secondary aqueous alteration, water-laid detrital sedimentary rocks that show various levels of induration, and regolith that could contain grains from afar transported to the Jezero crater. Additional samples may include hyrothermal rocks or impact breccia. Two main considerations weigh on the strategy that should be adopted for opening the sample tubes when returned on Earth:

(1) Important information is contained in the vertical stratigraphy and textural characteristics of layers in sediments, which can provide important clues for interpreting the depositional setting. For example, in terrestrial lakes, vertical gradation in grain size can reflect the relative density of depositional and lacustrine fluids or gradations in organic matter content can reflect seasonal changes in biological productivity. Fine laminations can sometimes reflect the presence of microbial mats. The method used for opening the tubes must imperatively preserve those fine structures.

(2) Some critical measurements are sensitive to contamination either from the tube, the apparatus used for cutting the tubes, or surrounding potential contaminants present in the isolator. Organic matter is of particular concern given the high stakes involved in any claim for the presence of any form of biotic or prebiotic chemistry on Mars. Inorganic trace element isotopes may provide dates on when Mars was habitable, and these are also vulnerable to contamination. Magnetic contamination should also be minimized during cutting operation and sample handling

Beginning in 2022, an engineering team was tasked with developing the processes needed to open the sample tubes and to extract the solid and gaseous samples. The engineering team was asked to develop engineering priorities associated with this process. Two science teams were asked to develop parallel science priorities: The “Gas Team” evaluated the priorities related to all returned gaseous samples (including the head gas), and the “Rock Team” (the authors of this contribution) evaluated the priorities associated with solid materials contained within the sample tubes. Both teams work under the oversight of a third committee, the Mars Campaign Science Group (MCSG).

The solid samples returned from the martian surface will be the basis for answering the main scientific questions of Mars Sample Return [3].

The rock samples will all have been collected from various outcrops (or perhaps very large blocks of float rock). However, at least some of the rocks are relatively weak (*i.e.* low compressive strength), and are vulnerable to fracturing during drilling and during several dynamic events during the return phase (most importantly, at Earth landing). The regolith sample is unconsolidated. It is anticipated that the mechanical state of each sample, as received in the laboratory on Earth, will be assessed by a method like computed tomography (CT) scanning prior to opening. The decision on how to open each sample tube can therefore be based on geological data collected by the M2020 team, tests done on analogue samples, as well as the penetrative imaging data obtained on Earth during basic characterisation.

The engineering team has proposed a 2-phase process for opening the sample tubes: First, puncture the tube in a way that will allow any gas present to be extracted and captured, then second, cut the metal of the tube in a way that would allow the solid materials to be removed. Regarding cutting the metal of the tubes, three primary mechanisms have been proposed (Fig. 1):

1. A single radial cut to the end of the tube, so that the sample could be tipped out.
2. A radial cut at each end of the tube, which would enable the sample to be potentially pushed out from one end.
3. Two radial cuts and two longitudinal cuts, to reveal the whole sample during cutting.

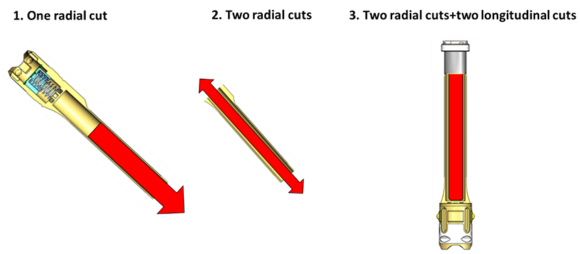

Figure 1. Proposed protocols for opening the sample tubes. The first approach (one radial cut) requires a sharp hard metal wheel, which shears through the tube by slowly rotating and tightening it around the tube. The sample is extracted from the tube by inclining it and controlling the rate of descent with a piston. The second approach involves performing a second cut. Both options 1 and 2 involve the sample sliding out of the tube and incur the risk of losing the part of the chemical and structural layering of the sample. The third approach involves doing two longitudinal cuts on the side of the tube (in addition to the two radial cuts) to expose the whole sample within the tube. It is least likely to disturb the physical integrity of the sample, which stays in place in the tube, but it involves cutting the tube through a white alumina coating. The chance of contamination is higher with this third option. Image courtesy of O. Perez.

Approach: We conclude there are three main considerations:

- Need to minimise (and have knowledge of) contamination
- Need to preserve stratigraphy and other textural relationships
- Need to maximise the recovery of sample material from the tubes and ensure that it ends up in a scientifically useful state.

Minimal cutting (*i.e.*, a single radial cut) was considered optimal to minimise potential contamination of trace elements, especially metals, and organic material from the tubes and cutting tools. The structural integrity of the sample would, however, be best preserved with radial and longitudinal cuts; this is considered especially important for sedimentary rocks that may contain internal structures but are friable. The yield may be maximised by at least two radial cuts. These considerations may conflict, and the approach to be used will depend on the character of each sample.

The preferred opening strategies are summarized in Table 1, which ponders each criterion (structure integrity, chemical integrity, and yield) for three categories of samples (consolidated rocks, friable rocks, and loose regolith). We summarize the Rock Team recommendations at the bottom of each column.

	Consolidated rocks Example: microgabbro	**Friable rocks** Example: detrital sediments, igneous cumulate rocks	**Regolith**
Trace element and organic contamination	1 radial cut	1 radial cut	1 radial cut
Structural integrity of the sample	1 radial cut likely OK Maybe 2 radial cuts in case of jamming	1 radial cut or 2 radial cuts and 2 longitudinal cuts	1 radial cut
Complete retrieval of the sample (including dust)	1 or 2 radial cuts	1 or 2 radial cuts	1 or 2 radial cuts
Rock Team recommendation	1 OR 2 radial cuts	1 radial cut OR 2 radial cuts and 2 longitudinal cuts	1 OR 2 radial cuts

Conclusion: The Rock Sample Team finds that a single approach will not be appropriate for all the rock samples returned by MSR, but instead a flexible and bespoke approach will be needed for each sample tube opening, with all three of the above options available. As a general principle, minimal cutting is favoured as this will also minimize potential contamination. However, an overriding consideration is that the structural integrity of the rock sample is key to understanding its petrology, and this should remain intact, even if this requires more processing.

For regolith samples, a single radial cut followed by tipping out the grains is likely to be appropriate, since this will minimize contamination and there is no need to preserve spatial relationships within the tube. For well consolidated (e.g., some igneous) samples, a radial cut perhaps followed by a second radial cut may be required to extract the sample completely. For sedimentary rocks, and any friable igneous rocks, the decision is more complex because a longitudinal cut may be necessary to observe and preserve structural relationships, but this must be weighed against potentially contributing more contamination.

The physical state of each core (consolidated or friable) will not be known for certain until the samples are bought back to Earth, where CT will reveal the fine structure of the samples and help guide the strategy to be adopted for tube opening. In the next stage of our working group, we will use analogues of M2020 samples to help with planning sample extraction.

Disclaimer: The decision to implement MSR will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process. This document is for informational purposes only.

References: [1] Kminek G., et al. (2022) Astrobiology. S-1-S-4.http://doi.org/10.1089/ast.2021.0198 [2] Farley KA, Stack K. (2022) Mars 2020 Initial Reports, Crater Floor Campaign, August 11, 2022. [3] iMOST report: https://mepag.jpl.nasa.gov/reports.cfm