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Sample Science Traceability Matrix (SSTM) for *Perseverance´*s Mars Sample Return Collection

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Abstract

The Mars Sample Return (MSR) Campaign aims to retrieve a set of carefully selected and documented samples collected by NASA's *Perseverance* rover in and around Jezero crater on Mars and deliver this set to Earth for comprehensive laboratory analyses. To emphasize the immense scientific return of this unique collection, this work presents a Sample Science Traceability Matrix (SSTM), a systematic framework that aligns each sample with the MSR Campaign's defined science objectives, sub-objectives, and critical research questions. The SSTM explicitly connects prioritized goals—including geologic history, astrobiology, planetary evolution, and human exploration science—to each of the individual samples gathered in and around Jezero Crater on Mars. This matrix offers a structured, quantitative method to assess each sample's capacity to address key scientific questions, while highlighting synergies across the sample suite and showcasing the overall value of the collection. The SSTM provides a valuable tool for guiding future sample analyses and identifying the most impactful samples that could be

collected in the future to complete the set collected by the Mars 2020 mission. It also supports the next phase of Mars sample science, and informs strategies for future Mars exploration missions.

1. Introduction

Returning samples from Mars to Earth for detailed laboratory studies has long been a priority goal of the planetary science community (National Academies of Sciences, Engineering, and Medicine, 2022). The Mars Sample Return (MSR) Campaign is a joint strategic initiative between the US National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). Its aim is to retrieve a diverse set of carefully selected, documented, and hermetically sealed Martian samples collected by NASA's Mars 2020 *Perseverance* rover and transport them to Earth for detailed scientific analyses (Beaty et al., 2019; Grady et al., 2020; Haltigin et al., 2022; Carrier et al., 2025). If successful, this would mark the first-ever return of samples from another planet, a historic milestone for planetary exploration. This report provides a Sample Science Traceability Matrix (SSTM) that showcases how well these samples can address the highest priority science questions of the community.

The *Perseverance* rover is currently exploring Jezero crater on Mars and the surrounding area to meet the goals of the planetary science community, in large part through the collection of samples. Once on Earth, these samples, preserved in a controlled environment, would enable future researchers to address an enormous number of the major questions in planetary science. These include decoding Mars's geological history, constraining its past habitability, searching for potential biosignatures of ancient life, providing unprecedented insights into early solar system processes, planetary differentiation, volatile cycling, and the emergence of habitable environments (Simon et al., 2023; Bosak et al., 2024; Hausrath et al., 2024; Zorzano et al., 2024; Borg et al., 2025; Grady et al., 2025; Herd et al., 2025; McSween et al., 2025; Sephton et al., 2025; Swindle et al., 2025; Udry et al., 2025; Weiss et al., 2025). Ultimately, MSR could transform our understanding of planetary evolution and profoundly inform the search for life beyond Earth. These goals were ranked among the most important in planetary science by the last two Planetary Science Decadal Surveys (National Academies of Sciences, Engineering, and Medicine, 2022; National Research Council., 2011).

MSR also serves as a technological and operational bridge to future human exploration. By characterizing *in situ* resources (e.g., volatiles and water-bearing minerals) and environmental hazards (e.g., dust and toxic elements or molecules), it contributes essential data for risk mitigation in crewed missions to Mars (Whetsel et al., 2025). Furthermore, MSR plays a pivotal role in advancing planetary protection protocols—ensuring that both forward contamination (Earth to Mars) and backward contamination (Mars to Earth) are meticulously managed (Kminek et al., 2022; Siegel et al., 2025). Thus, MSR is a vital proving ground for sample handling and biosecurity technologies that will underpin future robotic and human missions to Mars and future sample return from other planetary environments.

The iMOST (International MSR Objectives and Sample Team) defined seven scientific objectives for MSR based on two decades of previously published international priorities (Beaty et al., 2019): 1) interpret the primary geologic processes and history that formed the Martian geologic record, with an emphasis on the role of water; 2) assess and interpret the potential biological history of Mars, including assaying returned samples for the evidence of life; 3) quantitatively determine the evolutionary timeline of Mars; 4) constrain the inventory of Martian volatiles as a function of geologic time and determine the ways in which these volatiles have interacted with Mars as a geologic system; 5) reconstruct the processes that have affected the origin and modification of the interior, including the crust, mantle, core and the evolution of the Martian dynamo; 6) understand and quantify the potential martian environmental hazards to future human exploration and the terrestrial biosphere; and 7) evaluate the type and distribution of *in situ* resources to support potential future Mars exploration.

Building upon these foundational science objectives, the MSR Sample Receiving Project (SRP) tasked the Measurement Definition Team 1 (MDT-1) (Carrier et al., 2025) with refining the scientific strategy in light of the actual sample collection cached by the *Perseverance* rover at Jezero Crater (Farley et al., 2020; Farley and Stack, 2022, 2023, 2024a, 2024b; Simon et al. 2023; Bosak et al., 2024; Hausrath et al., 2024; Zorzano et al., 2024; Herd et al., 2025). This updated framework focuses on identifying and prioritizing key investigations, measurements, and analytical protocols to be conducted at the Sample Receiving Facility (SRF) (Carrier et al., 2025). The MDT-1 strategy organizes investigations under four primary science objectives:

1. Geologic History – Reconstruct the formation and alteration history of the returned samples to transform our understanding of the geological processes and environments of Mars;
2. Astrobiology – Determine the astrobiological significance of the Martian geological record represented by the samples;
3. Planetary Evolution – Provide new insights into planetary-scale formation and evolution in the inner Solar System; and
4. Science for Future Human Missions – Identify and characterize potential risks and opportunities for future human missions.

These objectives are in turn divided into multiple sub-objectives, investigations, and research questions.

The purpose of this work is to develop a Sample Science Traceability Matrix (SSTM) to explicitly link the scientific objectives, sub-objectives, investigations and research questions to the specific samples collected by the *Perseverance* rover. The SSTM ensures that each sample directly addresses priority science questions, reinforcing the scientific basis for sample return within the broader MSR mission framework (Beaty et al., 2019). This work presents the sample matrix corresponding to those cases for which Initial Reports (Farley and Stack, 2022, 2023, 2024a, 2024b) were publicly available at the time of manuscript submission. The proposed metric is generalizable and can be applied to subsequently acquired samples once their Initial Reports are released. Furthermore, the SSTM framework provides a consistent basis for evaluating future samples collected by *Perseverance*.

The SSTM serves as a strategic framework for evaluating the scientific value of the samples collected by *Perseverance*. This matrix highlights the significance of a unique suite of Martian samples, collected from documented locations and contextualized within a geological framework informed by *in situ* and remote observations. It enhances the interpretation of the entire sample collection by identifying opportunities for comparative analyses across suites of multiple specimens and synergies that would be missed through isolated investigations of single samples. This integrative approach is especially critical for reconstructing the geologic history of Jezero Crater and for understanding variations in past habitability in space and time. Furthermore, the SSTM informs considerations and current gaps in knowledge relevant to future human exploration, including potential hazards and *in situ* resource availability. The SSTM also points out which samples are especially valuable and, for those left unsealed, what would be lost if they were replaced because of their importance to specific types of scientific studies. Information in the matrix also supports logistical planning and decisions on sample storage, handling, transport, and prioritization for return to Earth as well as the definition of analytical instrumentation needs, curation protocols, and scientific priorities at Earth-based facilities. Overall, the SSTM provides a coherent view of the collective scientific value of the *Perseverance* sample collection.

2. The Mars 2020 mission samples

The *Perseverance* rover continues to expand its scientifically significant collection of geological samples from the ancient and diverse terrains in and around Jezero Crater on Mars (see Figure 1). These samples are being systematically acquired by the sampling system on *Perseverance* (Moeller et al., 2021), and the local environments of these samples are being analyzed using the rover's instrument payload that includes PIXL (Alwood et al., 2020), SHERLOC, (Barthia et al., 2021), WATSON (Edget et al., 2019), SuperCam (Wiens et al. 2021), Mastcam-Z (Bell et al., 2021), RIMFAX (Hamran et al.,2021), and MEDA (Rodriguez-Manfredi et al., 2021). This payload enables detailed *in situ* characterization of mineralogy, elemental and organic chemistry, texture, the geological and atmospheric environment, prior to sampling and caching. The entire sampling campaign—from site selection to abrasion, coring, sealing, and preliminary analyses—has been thoroughly documented in mission reports, publicly released datasets by the NASA Mars 2020 Science Team and publications that describe sample suites acquired during earlier rover campaigns (Farley et al., 2020; Farley and Stack, 2022, 2023, 2024a, 2024b; Simon et al., 2023; Bosak et al., 2024; Hausrath et al., 2024; Zorzano et al., 2024; Siljeström et al. 2024; Weiss, et al. 2024), with five sampling campaigns to date (Herd et al., 2025; see also Figure 1). Samples from the Crater Floor Campaign represent a suite of igneous rocks with varying degrees of aqueous alteration (Scheller et al., 2022; Liu et al., 2022; Tosca et al., 2025), potentially linked through common petrogenetic origins (Wiens et al., 2022). In contrast, Fan Front samples preserve fluvial to deltaic sediments deposited from the Jezero watershed, alongside regolith materials that may record both globally transported dust and locally sourced clasts (Stack et al., 2024; Bosak et al., 2024; Hausrath et al., 2024). Upper Fan samples chronicle the final stages of aqueous activity in the region (Kizovski et al., 2025; Weiss et al. 2024), while Margin Campaign samples provide evidence of lacustrine, shoreline, or early igneous processes (Farley and Stack, 2022, 2023, 2024a, 2024b; Hurowitz et al., 2025; Siljeström et. al. 2024;

Williford et al., 2024; Herd et al., 2025). At the time of writing of this article, the rover is conducting the Crater Rim Campaign (Mayhew et al., 2025; Klidaras et al., 2025).

The samples collected by *Perseveranc*e at Jezero Crater are distributed across two distinct caches: the Three Forks depot cache, as detailed in Czaja et al. (2023) and the primary cache stored by the rover. The Three Forks cache contains samples from the Máaz and Séítah formations of the crater floor, sedimentary rocks from the Fan Front, a regolith sample, an atmospheric sample, and a witness tube for contamination knowledge, see Figure 2-(Left). In addition to this atmospheric sample, all sealed sample tubes contain a headspace volume with Martian atmosphere (Zorzano et al., 2024), offering opportunities to address atmospheric questions (e.g., volatiles, noble gases, and isotope ratios). Samples from the Crater Floor represent ancient igneous rocks that contain a record of near surface alteration with high potential for reconstructing early Martian geologic and aqueous history, while samples from the Fan Front represent different sub-aqueous and fluvial regimes. *Perseverance*'s main cache includes a duplicated collection of all the Three Forks samples (with the exception of the atmospheric sample) augmented by a broader and evolving collection of sedimentary rocks collected during the Fan Top campaign, carbonate-bearing rocks from the margin of the crater collected during the Margin Campaign, and unique samples from the crater rim, including what are expected to be some of the oldest collected during the Crater Rim Campaign (see Figure 2-right). Fo paired samples, the core collected that contained more material or sampled more significant or interesting features was retained in *Perseverance*'s cache (Czaja et al., 2023).

The mission has also deployed Witness Tube Assemblies (WTAs), which are versions of sample tubes that contain an assembly including inert but adsorbent materials to monitor potential forward contamination from Earth and to provide contamination knowledge for samples returned to Earth. These tubes were periodically deployed in the same manner as sample tubes and exposed to rover operations, producing a control to distinguish indigenous Martian organic and inorganic materials from any terrestrial contamination—a critical requirement for planetary protection and scientific fidelity (Moeller et al., 2021). The WTAs were not incorporated into the SSTM evaluation; however, they are essential as controls for organic analyses.

The current assessment of the scientific value of the samples detailed here is grounded in *in situ* observations conducted by the *Perseverance* rover, integrated with a comprehensive interpretation of the geological context, including context from orbital observations. Based on the current understanding of the geologic context and formation mechanisms of the materials in the collected samples, the SSTM shows that the returned samples have the potential to address all of the established scientific objectives and investigations of the MSR campaign. The following section presents a summary of the resulting SSTM resolved to the sub-investigation level. The complete SSTM, extended to the level of individual research questions, can be found in the Supplementary Information.

At the time of writing, the *Perseverance* rover has collected 30 samples and 3 witness tubes (WTAs). Figure 3 presents a mosaic of workspace environments corresponding to each acquired sample. The drilled boreholes produced during sampling measure approximately 2.7 cm in diameter, while the cylindrical rock cores collected within the sample tubes are about 1.3 cm in diameter and up to ~7 cm in length. The abraded surface patches created for investigation of the characteristics of the sampled material using the rover's instruments measure about 5 cm in diameter. For contextual reference, two images include portions of the rover: the Main River workspace shows the rover arm in the process of acquiring a sample from the target rock, whereas the Bell Island workspace depicts the sampling site alongside a rover wheel. Table 1 provides a summary of samples collected to date as well as sampling details and lithology. Starting with the Bell Island sample (sol 1552), samples have not been sealed immediately after acquisition. This strategy was implemented to allow for future substitutions given the limited number of available empty sample tubes and uncertainty about what materials might be encountered during future campaigns outside of Jezero crater. Such swaps—where the unsealed sample may be discarded and replaced with a new one—would be made to optimize the diversity and value of the sample collection. This includes acquiring new rock samples of opportunity or increasing the sample mass of the already sampled lithologies.

3. Sample Science Traceability Matrix (SSTM)

The SSTM was created based on the output of the MSR MDT-1 (Carrier et al., 2025). It was organized into four main goals (1. Geologic History, 2. Astrobiology, 3. Planetary Evolution, and 4. Human Exploration), each of which includes several objectives and sub-objectives, and each sub-objective includes one or more research questions. The SSTM team then assessed the ability of each sample (Table 1) to address these questions. This assessment is indicated in the SSTM by scores ranging from 0 to 4. The scores are visually represented by colors from white to dark green and an equivalent scale of empty, partial or full circles for a color-independent scale. The rationales for assigning each value varied with the research question (see Supplementary Information), but in general, a score of 4 signifies that the sample could fully address the question(s); a score of 3 indicates that the sample could address the question(s) at least moderately, but not completely; a score of 2 suggests that the sample could at least partially address the question(s), but with notable gaps; a score of 1 reflects that the sample could only minimally address the question(s); and a score of 0 means that sample does not contain materials that can be used to address that question. This visual and numerical system summarizes the science values of the samples to specific research questions.

To provide the most useful information for various present and future stakeholders, versions of the SSTM were produced at three different degrees of granularity. The most granular has assessments at the level of individual research questions (Supplementary Information), the next has assessments at the level of research questions, but grouped into investigation topics (Figures 4–7), and the last has assessments at the level of sub-objectives (Figures 8 and 9). The scores of 0 to 4 for the SSTM at the level of research question are based on the assignment rationales given in the full SSTM in the Supporting Information. The scores for the less granular version of the SSTM were calculated by averaging all of the scores of the questions within a given sub-objective and then rounding that value up to the nearest integer. The same color and circle scales are used for these values.

This exercise produced a set of matrices for both sets of samples, those in the Three Forks Cache and those onboard the *Perseverance* rover. The complete SSTMs, organized at the level of individual science questions and including the specific assignment rationale for each question, are provided in the Supplementary Information due to their extensive size. Here, we present higher-level overview SSTMs: at the Investigation topic level for the cache currently stored within *Perseverance* (Section 3.1), and at the sub-objective level for both the *Perseverance* and Three Forks caches (Section 3.2).

3.1 SSTM matrix of *Perseverance* rover cache at the level of sub-investigations.

i) Objective 1: Geologic History

A suite of samples from Jezero crater with known stratigraphic and geologic contexts can resolve key questions about Mars's history. Igneous rocks from the crater floor, potentially ~3.8–3.9 Ga, contain minerals suitable for radiometric dating, providing the first field-contextualized absolute ages for early Martian magmatism and planetary evolution. Sedimentary rocks from the Jezero crater delta capture aqueous processes and volatile cycling, offering constraints on the duration and intermittency of surface water, redox conditions, and climate transitions during the Noachian–Hesperian. Together, igneous and sedimentary samples enable reconstruction of Mars's geologic, climatic, and volatile history, anchoring its timeline and addressing fundamental questions about planetary climate and habitability, see Figure 4. The radiometric ages of samples collected from key crater-retaining surfaces would help calibrate the crater counting chronology of Mars (Bosak et al. 2024).

Specific examples of scoring criteria for research questions are provided below (see the supplementary information for the complete scoring criteria description).

Example: 1.1.1 Mineral Characterization
4 = Igneous rocks with well-preserved mineralogy suitable for absolute age determination.
3 = Regolith or sedimentary samples containing large igneous clasts or potential igneous fragments.
2 = Sedimentary, mid-sized grain/sandstone samples.
1 = Fine-grained sandstone or sedimentary rocks.
0 = Atmosphere or fine-grained mudstone not amenable to mineral characterization.

Example: 1.2.2 Detrital Mineralogy and Crystal Chemistry
4 = Grain sizes > 1 mm, providing clear mineralogical context.
3 = Mid sand-sized grains with discernible detrital minerals.
2 = Fine sand-sized grains with partial mineralogical information.
1 = Smaller siliciclastic sediment not fully representative of depositional context.
0 = Atmosphere or samples not part of delta, margin, or fan deposits.

ii) Objective 2: Astrobiology

A carefully curated suite of samples from Jezero Crater—collected from sedimentary, igneous, and aqueously altered rocks with well-constrained geologic and stratigraphic contexts—provides an unparalleled record of Mars's early watery environments. Jezero preserves evidence of ancient lake and delta systems active over 3.5 billion years ago, ages for which Earth has almost no well-preserved analogs due to tectonic recycling and erosion. By targeting these specific rocks, scientists can reconstruct the habitability of Mars through deep time, search for the signatures of organic evolution, and probe for prebiotic or biological processes in a setting uniquely suited to capture the planet's early chemical and environmental history, see Figure 5.

An example of scoring criteria for one of the research questions of this goal is provided below (see the supplementary information for the complete scoring criteria description).

Example 2.2.2 Martian Organic Biomarkers
4 = Materials contain detectable organic compounds, providing direct evidence of Martian organic chemistry.
3 = Fine-grained materials or other substrates with high potential for preserving organic compounds, such as aqueously deposited sediments or clay minerals that protect organics from degradation.
2 = Materials with medium to low potential for organic preservation, including coarser sediments or moderately altered rocks.
1 = Materials with very low potential for preserving organics, including most regolith or heavily weathered surfaces.
0 = Materials with no potential for preserving Martian organic compounds, such as highly oxidized surfaces or atmospheric dust.

iii) Objective 3: Planetary Evolution

A well-characterized suite of igneous and sedimentary rocks from Jezero Crater, collected with precise stratigraphic and geologic context—including samples from the crater floor, delta, and the surrounding rim—provides an unprecedented record of early planetary processes on Mars. The igneous rocks, potentially older than 3.8–3.9 Ga, represent some of the oldest unmetamorphosed materials available, while sedimentary deposits capture aqueous and chemical interactions over 3.5 billion years ago. Samples from the crater rim may expose even older crustal materials, offering insight into the formation and differentiation of Mars's early crust and mantle. Together, these rocks allow scientists to investigate how terrestrial planets differentiate, generate and sustain a magnetic field, respond to repeated impact events, and evolve toward habitability. By capturing ancient magmatic, impact, and surface processes in a single, well-preserved location, the Jezero collection uniquely enables reconstruction of Mars' early interior, magnetic history, and surface evolution—filling gaps that Earth's highly reworked and overprinted rock record cannot address, see Figure 6.

An example of the scoring criteria for one of the research questions of this goal is provided below (see the supporting information for the complete scoring criteria description).

3.1.4 Crystallization Ages
4 = Igneous rocks and conglomerates containing diverse igneous clasts, providing strong constraints on crystallization history.
3 = Regolith derived from multiple sources offering moderate constraints on igneous crystallization.
2 = Possible igneous rocks with limited contextual or mineralogical information.
1 = Sandstones or other sedimentary rocks that provide minimal information on crystallization ages.
0 = Silt, finer-grained sediments lacking clear igneous context.

iv) Objective 4: Human Exploration

A carefully collected suite of samples from Jezero Crater, with well-constrained geologic and stratigraphic context, provides critical insights for planning human missions across Mars. The collection includes igneous rocks, sedimentary deposits, aqueously altered materials, and regolith, each revealing chemical composition, mineral resources, and potential hazards. Regolith samples are especially valuable for understanding *in situ* resources, such as water, oxygen, and building materials, and for assessing mechanical properties relevant to landing and construction. Analyses of these samples also inform the risks posed by toxic minerals, chemical substances (e.g., perchlorates), and fine atmospheric dust, which could impact both human health and equipment. By characterizing these materials, the Jezero collection helps guide mission planning and safety protocols for landings on Mars beyond this specific crater, see Figure 7.

Because all samples may contain chemical hazards, water, and propellants in solid, liquid, or gaseous form, each sample was assigned a qualification score of 4. All other investigations are fully covered with the regolith sample.

3.2 Sample caches, high level overview: SSTM of the Three Forks and Rover caches at the level of Science Objectives.

In this section we present high-level overview matrices illustrating the scientific value of the cache currently stored aboard Perseverance (Figure 8) and of the cache deposited at Three Forks (Figure 9).

4. Discussion

By the end of its mission, the rover will have collected up to 36 scientifically curated samples and 5 witness tubes from Jezero Crater—an ancient lake-delta system within a crater, with an eroded crater rim exposing ancient crustal rocks and a more recent igneous crater floor (Mangold et al., 2021), see Figure 1. Ten of these samples (including one WTA) were strategically deposited at the Three Forks depot cache as a contingency for the MSR campaign, while the rest remain onboard *Perseverance* for eventual retrieval and return to Earth. The *Perseverance* rover's cache represents a landmark achievement in planetary science, offering an unprecedented scientific resource for understanding Mars' geological and astrobiological history. As a mobile laboratory equipped with cutting-edge rover instrumentation, *Perseverance* is implementing a highly selective sample collection strategy designed to optimize scientific return across geological, chemical, temporal, and environmental dimensions (Farley et al., 2020; Sun et al., 2023).

This assessment of the scientific value of *Perseverance* samples with respect to specific high-priority research questions did not incorporate sample mass (or rock length; see Table 1) as a parameter in the evaluation. Nevertheless, the physical mass of samples remains a critical consideration for downstream analyses, particularly those involving destructive techniques such as isotopic or molecular characterization of solvent extracts, which consume sample material and for some measurements can require relatively large mass amounts. Therefore, future strategies for sample allocation, handling and analysis must explicitly incorporate sample mass alongside this SSTM framework to optimize the balance between maximizing scientific return and preserving material for subsequent investigations (e.g., Carrier et al. 2025). Moreover, the MSR strategy emphasizes not just sample collection, but also forward planning for Earth-based analysis. These efforts are supported by the development of stringent curation protocols and facility design considerations already underway (McCubbin et al., 2025).

The SSTM clearly shows the extraordinary value of the diverse sample collection to answer the high-priority scientific questions that were previously defined, over the past decades of exploration, by the community. The cache deposited at Three Forks meets the scientific goals of such a mission (Czaja et al., 2023), but the value of *Perseverance*´s cache is much greater.

4.1 Sample diversity

The SSTM shows how the diversity of the sample suite is aligned with science goals that include astrobiology, geochronology, and planetary differentiation studies (e.g., McSween et al., 2025; Herd et al., 2025; Simon et al., 2023; Bosak et al., 2024; Hausrath et al., 2024). The diversity and complementary nature of the sample collection showcases the rigor of this selection process based on the technical capabilities of the Mars 2020 rover and broad expertise of the Mars 2020 science team. Since landing in February 2021, *Perseverance* has traversed more than 39 km (as of this writing). Its sampling mechanism has drilled cores up to 7.4 cm deep, sealing them in titanium tubes for contamination-controlled caching (Moeller et al., 2021). The rover's analytical payload allows *in situ* geochemical and mineralogical assessment, enabling targeted sampling decisions informed by the surrounding geological context (see Farley and Stack, 2022; 2024a; 2024b).

Jezero Crater was chosen as the landing and exploration site precisely because of its well-preserved sedimentary environments and evidence of aqueous alteration—ideal conditions for hosting and preserving biosignatures. *Perseverance*'s traverse encompasses terrains representing billions of years of Martian history, including igneous, sedimentary, and potentially hydrothermal precipitates (Stack et al., 2020; Hickman-Lewis et al., 2022; Beck et al. 2025), see Figure 1. This temporal and spatial diversity is essential for understanding the planet's evolving habitability, crustal evolution, and surface-atmosphere interactions.

Each sample tube retains "headspace gas", sealing a Martian atmosphere fraction with the rock or soil sample. This gas can reveal *in situ* volatile release or contamination. A dedicated atmospheric sample tube offers unprecedented access to Mars' atmospheric isotopic composition, essential for understanding escape processes, potential biosignatures, and for calibrating Earth-based remote sensing (Swindle et al., 2025). The headspace gas in all tubes and any returned WTAs may also be able to be used to address some or all atmospheric questions.

The SSTM matrix shows that each sample is uniquely valuable: igneous rocks offer radiometric dating anchors; sedimentary units like "*Hazeltop*" contain hydrated minerals that inform about the water cycle; and regolith samples contribute to ISRU studies. Governed by the astrobiological interest in early habitable environments and the potential to search for signals of prebiotic and biological processes, the sample set heavily emphasizes aqueous environments, fluviodeltaic sedimentary rocks, and aqueously altered igneous rocks. The samples from Jezero Crater capture records of aqueous activity and the deposition of fluviolacustrine and deltaic sedimentary rocks on Mars, potentially spanning the late Noachian through Hesperian periods. The collection includes igneous rocks, which enable absolute age dating, carbonate-bearing units that may record climate signals, and deposited salts such as perchlorates and sulfates, which provide evidence of past water–rock interactions.

However, early Noachian crust, potential hydrothermal vent deposits, and impactites may be underrepresented in the sample collection. No duplicate atmospheric sample exists—introducing a single-point failure risk, but it might be mitigated at least in part by collecting headspace gas from the WTAs and sample tubes.

The sample collection not only advances Mars science, but it also underpins mission design for both robotic and human missions. This cache will aid hazard prediction and mitigation for astronauts: dust toxicity, perchlorate content, and grain morphology can inform spacesuit design, habitat shielding and dust mitigation strategies, and permissible exposure limits. Also this cache can help prepare simulants, as the detailed mineral and grain-scale analysis of the samples will enable more realistic Mars soil analogs for rover mobility, ISRU trials, and Extravehicular Activity (EVA) preparation.

4.2 Cross-sample science

The Perseverance rover has enabled the most geologically and geochemically diverse and carefully tailored planetary sample return effort ever attempted. Although each sample is irreplaceable, tied to its location with geospatial and analytical context, the collective value of multiple samples boosts the scientific return exponentially even if any specific sample cannot be returned. By targeting both igneous and sedimentary rocks, along with atmospheric and regolith samples, this collection establishes a strong foundation for investigating Mars' geological history, surface processes, habitability and potential organic evolution on a broad range of spatiotemporal scales (Farley et al., 2020).

Before human missions can safely land and operate on Mars, key questions about the present-day environment, as well as the variability and reactivity of the Martian atmosphere, should be addressed. How do seasonal and diurnal cycles influence the abundance of water vapor, oxygen, methane, and other trace gases? How do UV radiation, solar illumination, and atmospheric dust affect photochemical and catalytic reactions? What are the size, shape, and chemical composition of micrometer-sized dust particles, and can they carry an electrical charge? The space suit materials carried as calibration targets for the SHERLOC instrument on *Perseverance* can begin to answer some of these questions (Fries et al., 2022), but returning samples is key to closing many of the existing strategic knowledge gaps that exist for sending humans to Mars. Understanding these factors is essential for assessing *in situ* resource availability, environmental hazards, and the reliability of life-support systems.

One key potential of this tailored sample collection is to study the seasonal and diurnal variability of atmospheric gases—particularly water vapor, oxygen, methane, argon, krypton, xenon, and other trace species—which *in situ* measurements have shown to fluctuate over time (Conrad et al., 2016; Webster et al., 2018; Trainer et al., 2019; Savijärvi et al., 2019). The sampling strategy includes an atmospheric sample, headspace gases from rock cores, and sealed witness tubes, some of which were collected under differing solar illumination, UV flux, and atmospheric dust conditions—all parameters monitored by the MEDA instrument onboard *Perseverance*. These factors may influence photochemical and catalytic reactions in the Martian atmosphere (Atreya et al., 2007, 2011; Lefèvre & Forget, 2009). To date, the full collection encompasses two Martian years of headspace gas samples, providing a valuable record for understanding current climate dynamics, atmospheric processes, and the implications for future human exploration.

Perseverance has found that rocks in the *Bright Angel* region of Jezero Crater — represented by the Sapphire Canyon sample —are uniquely organic-rich relative to other targets that have been measured in Jezero crater by SHERLOC, providing another example of a mudstone on Mars outside of Gale crater that contains significant quantities of organic carbon (Hurowitz et al., 2025; Murphy et al., 2025). Mass spectrometry analyses conducted by the Curiosity rover in Gale Crater have detected a variety of organic compounds in aqueously deposited and aeolian rocks. These compounds include aliphatic and aromatic molecules, such as long-chain alkanes, thiophenes, benzene, toluene, and small carbon chains like propane and butene (Ming et al., 2014; Freissinet et al., 2015; Eigenbrode et al., 2018; Szopa et al. 2020; Millan et al. 2021; Millan et al. 2022; Stern et al. 2022; Freissinet et al., 2025). The presence of these organic molecules, preserved in ancient lacustrine mudstones, suggests that Gale Crater may have provided habitable conditions in Mars's distant past. *Perseverance*'s SHERLOC instrument lacks comparable sensitivity (e.g., Scheller et al., 2024; Bosak et al., 2024), emphasizing the importance of sample return for organic detections and analyses to understand processes that delivered, formed and destroyed organic matter on Mars throughout its history. Furthermore, *Curiosity*'s detections of organic compounds in rocks from past habitable environments, as well as in rocks that are typically not considered to be good organic preservers such as aeolian bedforms (Millan et al. 2021) underscore the need to compare the organic inventories of different lithologies. Igneous rocks are generally expected to contain minimal, but measurable, indigenous organics (Schmitt-Kopplin et al., 2023; Steele et al., 2012; 2018; 2022), so those collected by *Perseverance* may serve as critical background controls for constructing the abiotic baseline and interpreting any organic detections in the fine-grained and other aqueously deposited sedimentary rocks from Jezero crater, where the formation and preservation of organic compounds and biosignatures would have been favored (Summons et al., 2011; McMahon et al., 2018; Bosak et al., 2021; 2024). This comparative approach between fine-grained sedimentary rocks and igneous rocks has been successfully applied to test and correct the earliest record of organic biomarkers on Earth (French et al., 2015). Accordingly, a similar comparative approach can be applied to returned Mars samples to strengthen interpretations of the origin of detected organics — whether they are indigenous, exogenous, or formed under habitability-supporting conditions. Analyses of the MSR collection that compare the organic contents and molecular diversities, mineral indicators of past redox gradients, and isotopic composition of organic and inorganic materials will provide additional constraints on and abiotic controls for environments where prebiotic or metabolic processes were possible or even took place. Moreover, the analysis of minerals such as carbonates and the volatiles and isotopic compositions of hydrated phases such as sulfate minerals from different depositional settings will provide constraints on past aqueous activity, paleoenvironmental chemistry and climate conditions, and volatile evolution. The accompanying geochronological analyses can then help estimate the timing and duration of aqueous activity on the surface and subsurface of Jezero crater (Ehlmann & Edwards, 2014; Bosak et al., 2024).

Sampling along stratigraphic sequences—from crater rim units to deltaic deposits—provides a critical means to reconstruct sedimentary pathways and better understand the environmental evolution of Jezero Crater (Stack et al., 2020). Variations in grain size, mineralogy, and geochemistry along these sequences reveal the relative contributions of fluvial, lacustrine, aeolian, and intermittent volcanic processes in shaping the crater's sedimentary architecture. Coarser sediments derived from the crater rim suggest episodic high-energy transport events, such as flooding or debris flows, whereas finer-grained deltaic deposits indicate lower-energy depositional environments within standing water bodies. Intermittent volcanic activity likely contributed ash layers, tephra, or localized lava flows, leaving distinct mineralogical and geochemical signatures—including feldspar, pyroxene, and volcanic glass—that can be distinguished from purely sedimentary inputs. By integrating sedimentary and volcanic records, researchers can reconstruct paleo-hydrological gradients, sediment transport processes, and episodic environmental changes, offering a more complete picture of Jezero Crater's geologic and climatic history. Notably, these kinds of scientific investigations are not achievable with a single sample, but rather they require a collection.

Paleomagnetic analyses of all igneous samples and coarser-grained sedimentary rocks within the MSR collection would enable reconstruction of the Martian magnetic field's history across geological time. By examining natural remnant magnetization (NRM) preserved in these rocks—particularly those with well-defined crystallization ages or depositional contexts—scientists can assess changes in the intensity and direction of Mars' ancient dynamo (Weiss et al. 2025). Comparing magnetization across samples of varying ages and lithologies, from older volcanic units to younger sedimentary deposits containing detrital magnetic grains, would provide critical constraints on the onset, duration, and eventual cessation of Mars' global magnetic field. This, in turn, offers valuable insight into the planet's thermal evolution, core dynamics, and implications for atmospheric retention and planetary habitability.

The analysis of the full collection would be invaluable for preparing for human exploration by providing the first opportunity to study pristine and contextualized Martian materials in terrestrial laboratories. Unlike with the study of martian meteorites or single point grab-and-go missions, the broad geological context provided by the MSR sample suite will enable a better understanding of the types and prevalence of potential geochemical hazards and/or areas of high resource utilization potential. Detailed characterization of igneous rocks, sedimentary deposits, aqueously altered materials, and regolith will reveal their chemical composition, mineralogy, mechanical properties, and potential hazards such as perchlorates, fine dust, and reactive minerals. Preliminary studies investigating the inflammatory potential of an array of astromaterials indicate that even relatively slight variations in sample geophysicochemical properties can lead to statistically disparate responses in vitro and in vivo; which indicates the potential for disparate health outcomes as well (Harrington et al., 2019). Given that it is unknown how the body will respond to the compounded exposures of radiation, microgravity, and potentially dust and perchlorates, studying these variables simultaneously before astronauts are on the surface could be a way to mitigate potential risk (Wang et al., 2025). Furthermore, astronaut physical safety can be enhanced by understanding regolith variability and atmospheric interactions—including dust adherence and electrostatic charging. This information could mitigate operational risks to the astronauts by informing material selections, infrastructure and suit design, and standard operating procedures. Physical properties such as hardness, cohesiveness, and density could also guide the feasibility of construction and resource extraction using Martian materials. Taken together, these complete datasets could hold significant value for landing site selection on Mars, in situ resource utilization strategies, and the design of habitats, life-support systems, protective measures, and counter measures. By providing a comprehensive and high-fidelity record of surface materials, the MSR collection will bridge robotic reconnaissance and human exploration.

5. Conclusions

Together, this carefully chosen suite of samples positions the MSR campaign to address interlinked scientific questions across multiple disciplines, from geologic history and planetary evolution to astrobiology and human exploration. By providing a systematically documented and context-rich collection, the MSR campaign establishes a robust foundation for reconstructing Mars' habitability, surface and climate evolution, and potential resources for future exploration. The SSTM measures this value by linking each sample to specific science objectives and critical research questions, enabling a quantitative assessment of their capacity to address high-priority investigations. The overall conclusion of this effort is that the diverse set of samples collected by the Mars 2020 mission can meet all of the objectives for Mars sample science detailed by the planetary science community. This framework also highlights synergies across the sample suite that would maximize scientific return.

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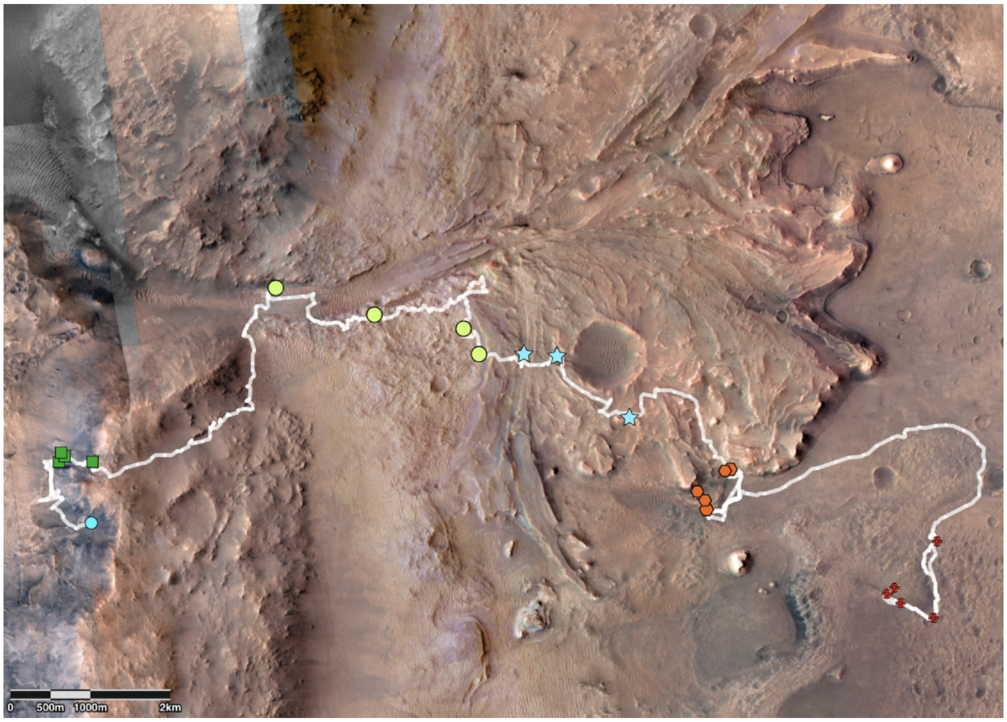

Figure 1: Satellite image of the Jezero Crater floor, delta, valley and rim, showing the Perseverance rover's traverse (white line), rover position (cyan circle) as of September 8th, 2025, and sample acquisition sites by campaigns: red asterisks show samples from the Crater Floor campaign, orange hexagons from the Fan Front campaign, blue stars from the Fan Top campaign, lime green circles represent the Margin campaign, while the dark green squares are samples from the Crater Rim Campaign. Credit: CAMP.

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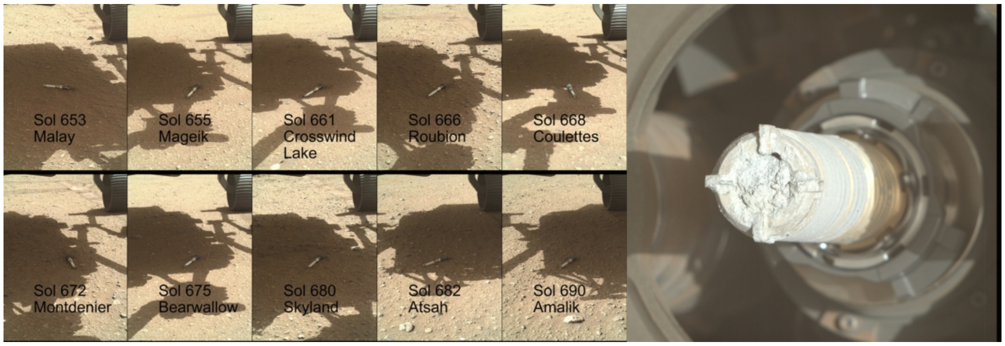

Figure 2: (Left) Three Forks Cache: This photomontage shows each of the sample tubes annotated with the name of each sample and the Martian day, or sol, that it was deposited, as viewed by the WATSON camera. Credit: NASA/JPL-Caltech/MSSS. (Right) Sealing the "Green Gardens" sample collected from a rock dubbed "Tablelands" along the rim of Jezero Crater on Feb. 16, 2025. The sample was sealed on March 2. Credit: NASA/JPL-Caltech/ASU/MSSS.

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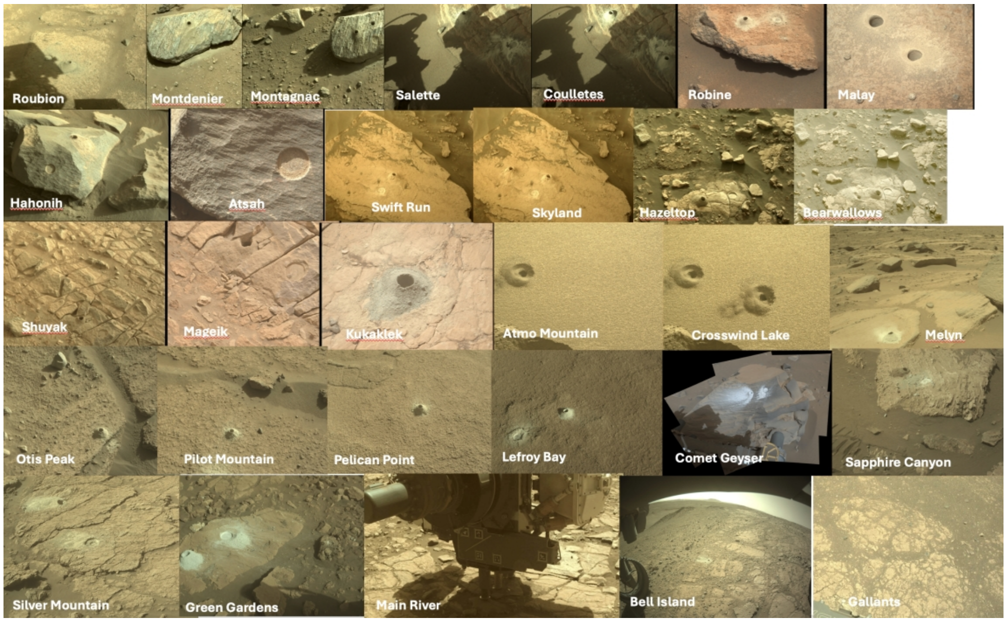

Figure 3: Mosaic of the workspaces where the samples were collected. Drilled holes for sample acquisition measure approximately 2.7 cm in diameter, and the abraded patch about 5 cm in diameter. For contextual reference in relation to sampling activities and documentation, two images include parts of the rover. As of this article's submission, Initial Reports for all samples up to Sapphire Canyon have been publicly released (Farley and Stack, 2022, 2023, 2024a, 2024b). This study focuses on the samples for which publicly available Initial Reports exist. Future updates may extend the analysis to the most recently acquired samples. Image credit: NASA/JPL-Caltech/ASU/MSSS.

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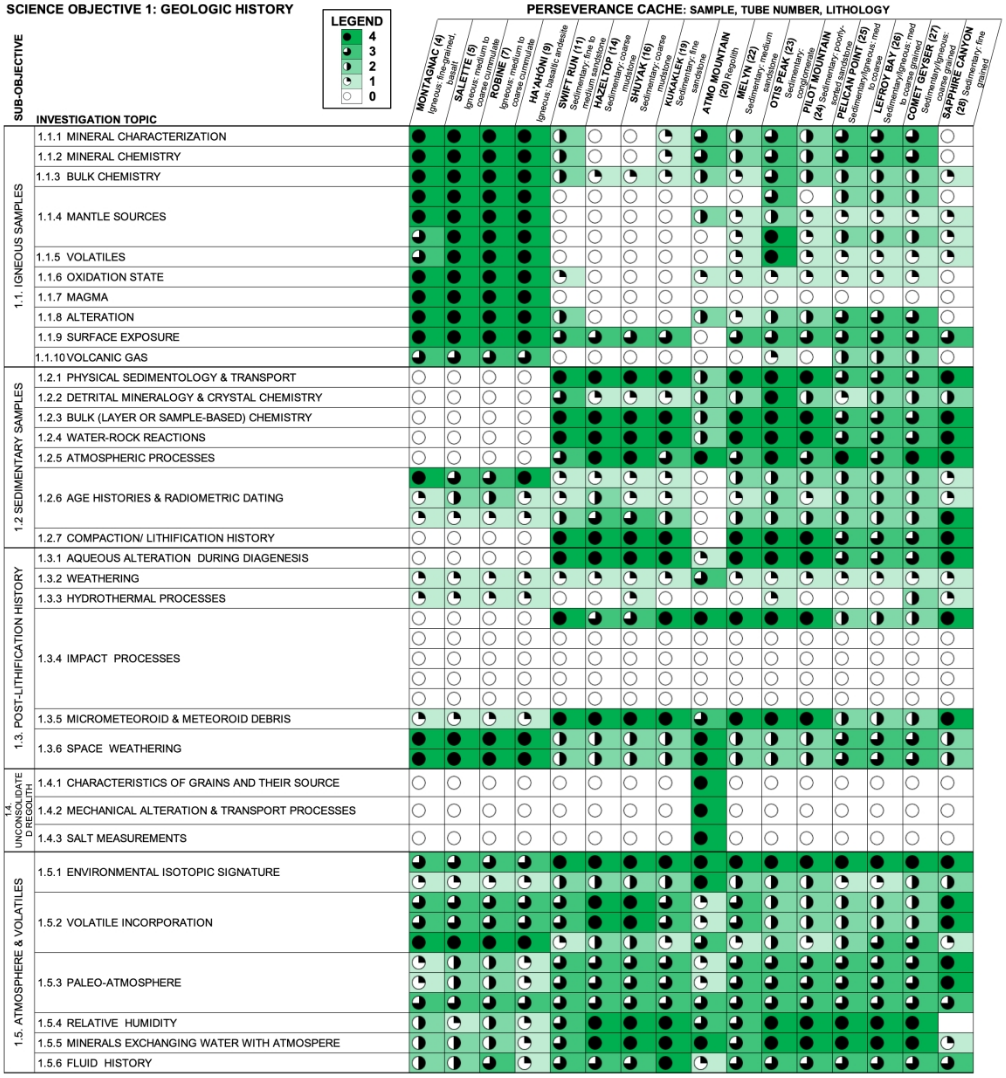

SCIENCE OBJECTIVE 1: GEOLOGIC HISTORY

LEGEND
● 4
◕ 3
◑ 2
◔ 1
○ 0

PERSEVERANCE CACHE: SAMPLE, TUBE NUMBER, LITHOLOGY

SUB-OBJECTIVE	INVESTIGATION TOPIC	MONTAGNAC (4) Igneous: fine-grained, basalt	SALETTE (5) Igneous: medium to coarse cummulate	ROBINE (7) Igneous: medium to coarse cummulate	HA'AHÓNI (9) Igneous: basaltic andesite	SWIFT RUN (11) Sedimentary: fine to medium sandstone	HAZELTOP (14) Sedimentary: coarse mudstone	SHUYAK (16) Sedimentary: coarse mudstone	KUKAKLEK (19) Sedimentary: fine sandstone	ATMO MOUNTAIN (20) Regolith	MELYN (22) Sedimentary: medium sandstone	OTIS PEAK (23) Sedimentary: conglomerate	PILOT MOUNTAIN (24) Sedimentary: poorly-sorted sandstone	PELICAN POINT (25) Sedimentary/Igneous: med to coarse	LEFROY BAY (26) Sedimentary/Igneous: med to coarse grained	COMET GEYSER (27) Sedimentary/Igneous: coarse grained	SAPPHIRE CANYON (28) Sedimentary: fine grained
1.1. IGNEOUS SAMPLES	1.1.1 MINERAL CHARACTERIZATION	●	●	●	●	◑	○	○	◔	◕	◑	◕	◑	◕	◕	◕	○
	1.1.2 MINERAL CHEMISTRY	●	●	●	●	◑	○	○	◔	◕	◑	◕	◑	◕	◕	◕	○
	1.1.3 BULK CHEMISTRY	●	●	●	●	◑	◔	◔	◔	◑	◔	◕	◑	◑	◑	◑	◔
	1.1.4 MANTLE SOURCES	●	●	●	●	○	○	○	○	○	○	◕	○	◑	◑	◑	○
		●	●	●	●	○	○	○	○	◑	◔	◑	◔	◔	◔	◔	◔
		◕	●	●	●	○	○	○	○	○	◔	●	◔	◑	◑	◑	◔
	1.1.5 VOLATILES	◕	●	●	●	○	○	○	○	○	◔	●	◔	◔	◔	◔	◔
	1.1.6 OXIDATION STATE	●	●	●	●	◔	○	○	○	◔	◔	◔	◔	◔	◔	◔	○
	1.1.7 MAGMA	●	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○
	1.1.8 ALTERATION	●	●	●	●	◑	○	○	○	◑	◔	◑	◑	◕	◕	◕	○
	1.1.9 SURFACE EXPOSURE	●	●	●	●	◕	◕	◕	◕	○	◕	◕	◕	◕	◕	◕	◕
	1.1.10 VOLCANIC GAS	◕	◕	◕	◕	○	○	○	○	○	○	◔	○	◑	◑	◑	○
1.2 SEDIMENTARY SAMPLES	1.2.1 PHYSICAL SEDIMENTOLOGY & TRANSPORT	○	○	○	○	●	●	●	●	◑	●	●	●	◕	◕	◕	●
	1.2.2 DETRITAL MINERALOGY & CRYSTAL CHEMISTRY	○	○	○	○	◕	◔	◔	◔	◑	◑	●	◑	◔	◑	◑	◑
	1.2.3 BULK (LAYER OR SAMPLE-BASED) CHEMISTRY	○	○	○	○	●	●	●	●	◑	●	●	●	◕	◕	◕	●
	1.2.4 WATER-ROCK REACTIONS	○	○	○	○	●	●	●	●	◑	●	●	●	◕	◕	◕	●
	1.2.5 ATMOSPHERIC PROCESSES	○	○	○	○	◕	●	●	◕	●	◕	●	◕	●	◕	●	●
	1.2.6 AGE HISTORIES & RADIOMETRIC DATING	●	◕	◕	●	◔	◔	◔	◔	○	◑	◑	◑	◑	◑	◑	◔
		◔	◑	◑	◔	◔	◑	◔	◔	○	◔	◑	◔	◑	◑	◑	◔
		◔	◔	◔	◔	◑	◕	◕	◑	○	◑	◑	◑	◑	◑	◑	●
	1.2.7 COMPACTION/ LITHIFICATION HISTORY	○	○	○	○	●	●	●	●	○	●	●	●	◕	◕	◕	●
1.3. POST-LITHIFICATION HISTORY	1.3.1 AQUEOUS ALTERATION DURING DIAGENESIS	○	○	○	○	●	●	●	●	◔	●	●	●	◕	◕	◕	●
	1.3.2 WEATHERING	◔	◔	◔	◔	◔	◔	◔	◔	◕	◔	◔	◔	◔	◔	◔	◔
	1.3.3 HYDROTHERMAL PROCESSES	◔	◔	◔	◔	○	○	◔	○	○	○	◔	○	○	○	◑	◔
	1.3.4 IMPACT PROCESSES	○	○	○	○	●	◕	◕	●	●	●	●	●	◑	◑	◑	●
		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	1.3.5 MICROMETEOROID & METEOROID DEBRIS	◔	◔	◔	◔	●	●	●	●	◕	●	●	●	◑	◑	◑	●
	1.3.6 SPACE WEATHERING	●	●	●	●	◑	◑	◑	◑	●	◑	◑	◑	◕	◕	◕	◑
		●	●	●	●	◑	◑	◑	◑	●	◑	◑	◑	◕	◕	◕	◑
1.4. UNCONSOLIDATED REGOLITH	1.4.1 CHARACTERISTICS OF GRAINS AND THEIR SOURCE	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○
	1.4.2 MECHANICAL ALTERATION & TRANSPORT PROCESSES	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○
	1.4.3 SALT MEASUREMENTS	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○
1.5. ATMOSPHERE & VOLATILES	1.5.1 ENVIRONMENTAL ISOTOPIC SIGNATURE	◕	◕	◕	◕	●	●	●	●	●	●	●	●	●	●	●	●
		◔	◔	◔	◔	◑	◑	◑	◑	●	◑	◑	◑	◔	◔	◑	◑
	1.5.2 VOLATILE INCORPORATION	◕	◕	◕	◕	◕	●	●	◕	◔	◕	◑	◑	◑	◑	◑	●
		◕	◕	◕	◕	◕	●	●	◕	◔	◕	◑	◑	◑	◑	◑	●
		●	●	●	●	◔	◑	◑	◔	◕	◔	◑	◔	◑	◕	◕	◔
	1.5.3 PALEO-ATMOSPHERE	◔	◑	◑	◔	◕	◕	◕	◕	◔	◕	◕	◕	◕	◕	◕	●
		◔	◑	◑	◔	◕	◕	◕	◕	◔	◕	◕	◕	◕	◕	◕	●
		◕	◕	◕	◕	◕	◕	◕	◕	◕	◕	◕	◕	◕	◕	◕	◕
	1.5.4 RELATIVE HUMIDITY	◑	◔	◑	◔	◕	●	●	●	◕	◕	●	●	●	●	●	
	1.5.5 MINERALS EXCHANGING WATER WITH ATMOSPERE	◑	◑	◑	◔	◕	●	●	●	●	◕	●	●	●	●	●	◔
	1.5.6 FLUID HISTORY	◑	◑	◕	◔	◕	◕	◕	●	◔	◕	◕	◕	◕	◕	◕	◕

Figure 4: Sample Science Traceability Matrix (SSTM) at the level of sub investigations for Science Objective 1 (Geologic History) and the samples in the Perseverance rover cache. See text for an explanation of what the different number values mean (and corresponding colors and symbols).

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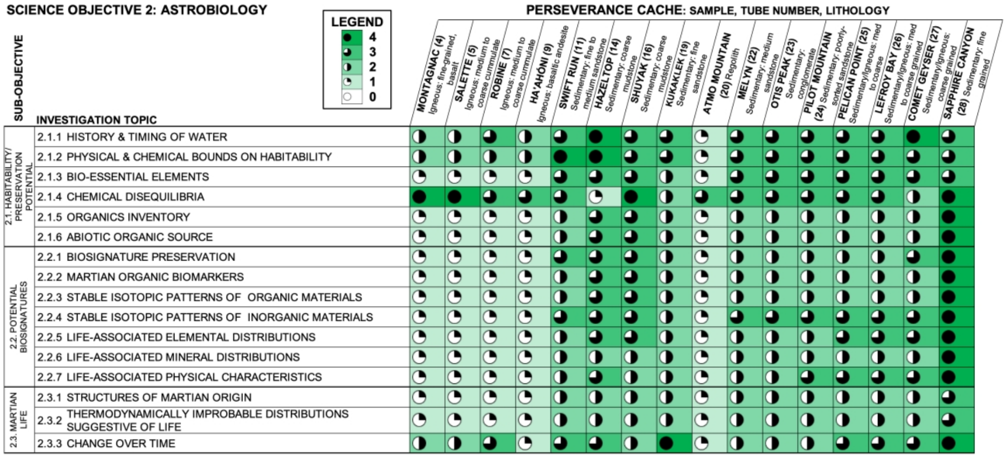

SCIENCE OBJECTIVE 2: ASTROBIOLOGY

LEGEND
● 4
◕ 3
◑ 2
◔ 1
○ 0

PERSEVERANCE CACHE: SAMPLE, TUBE NUMBER, LITHOLOGY

SUB-OBJECTIVE	INVESTIGATION TOPIC	MONTAGNAC (4) Igneous: fine-grained, basalt	SALETTE (5) Igneous: medium to coarse cummulate	ROBINE (7) Igneous: medium to coarse cummulate	HA'AHÓNI (9) Igneous: basaltic andesite	SWIFT RUN (11) Sedimentary: fine to medium sandstone	HAZELTOP (14) Sedimentary: coarse mudstone	SHUYAK (16) Sedimentary: coarse mudstone	KUKAKLEK (19) Sedimentary: fine sandstone	ATMO MOUNTAIN (20) Regolith	MELYN (22) Sedimentary: medium sandstone	OTIS PEAK (23) Sedimentary: conglomerate	PILOT MOUNTAIN (24) Sedimentary: poorly-sorted sandstone	PELICAN POINT (25) Sedimentary/Igneous: med to coarse	LEFROY BAY (26) Sedimentary/Igneous: med to coarse grained	COMET GEYSER (27) Sedimentary/Igneous: coarse grained	SAPPHIRE CANYON (28) Sedimentary: fine grained
2.1. HABITABILITY/ PRESERVATION POTENTIAL	2.1.1 HISTORY & TIMING OF WATER	2	2	3	2	3	4	3	3	1	3	3	3	3	3	4	3
	2.1.2 PHYSICAL & CHEMICAL BOUNDS ON HABITABILITY	2	2	2	2	4	4	3	3	1	3	3	3	3	3	3	3
	2.1.3 BIO-ESSENTIAL ELEMENTS	1	1	1	1	3	3	3	2	1	3	3	3	3	3	3	3
	2.1.4 CHEMICAL DISEQUILIBRIA	4	4	3	3	3	1	4	2	3	3	3	3	3	3	2	4
	2.1.5 ORGANICS INVENTORY	1	1	1	1	2	3	3	2	1	2	2	2	2	2	2	4
	2.1.6 ABIOTIC ORGANIC SOURCE	1	1	1	1	2	3	3	2	1	2	2	2	2	2	2	4
2.2. POTENTIAL BIOSIGNATURES	2.2.1 BIOSIGNATURE PRESERVATION	1	1	1	1	3	3	3	2	1	2	2	2	2	2	3	4
	2.2.2 MARTIAN ORGANIC BIOMARKERS	1	1	1	1	2	3	3	2	1	2	2	2	2	2	2	4
	2.2.3 STABLE ISOTOPIC PATTERNS OF ORGANIC MATERIALS	1	1	1	1	2	3	3	2	1	2	2	2	2	2	2	4
	2.2.4 STABLE ISOTOPIC PATTERNS OF INORGANIC MATERIALS	1	1	1	1	3	3	3	2	1	3	3	3	3	3	3	4
	2.2.5 LIFE-ASSOCIATED ELEMENTAL DISTRIBUTIONS	1	1	1	1	2	3	3	2	1	2	2	2	3	3	3	4
	2.2.6 LIFE-ASSOCIATED MINERAL DISTRIBUTIONS	1	1	1	1	2	2	2	2	1	2	2	2	2	2	2	4
	2.2.7 LIFE-ASSOCIATED PHYSICAL CHARACTERISTICS	1	1	1	1	2	3	2	2	1	2	2	3	3	3	3	4
2.3. MARTIAN LIFE	2.3.1 STRUCTURES OF MARTIAN ORIGIN	1	1	1	1	2	2	2	2	1	2	2	2	2	2	2	3
	2.3.2 THERMODYNAMICALLY IMPROBABLE DISTRIBUTIONS SUGGESTIVE OF LIFE	1	1	1	1	2	2	2	2	1	2	2	2	2	2	2	3
	2.3.3 CHANGE OVER TIME	2	2	3	1	3	3	2	4	1	2	2	2	3	3	3	4

Figure 5: Sample Science Traceability Matrix (SSTM) at the level of sub investigations for Science Objective 2 (Astrobiology) and the samples in the Perseverance rover cache. See text for an explanation of what the different number values mean (and corresponding colors and symbols).

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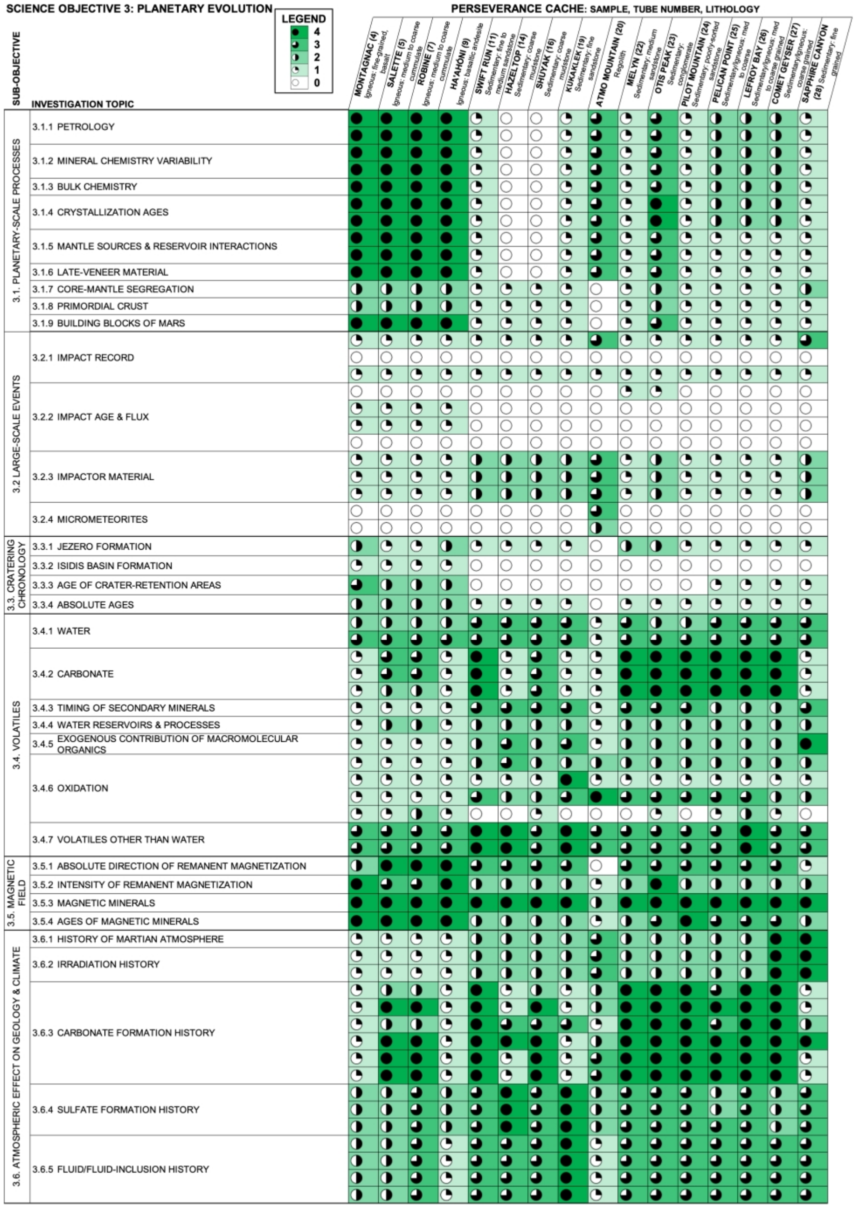


SCIENCE OBJECTIVE 3: PLANETARY EVOLUTION

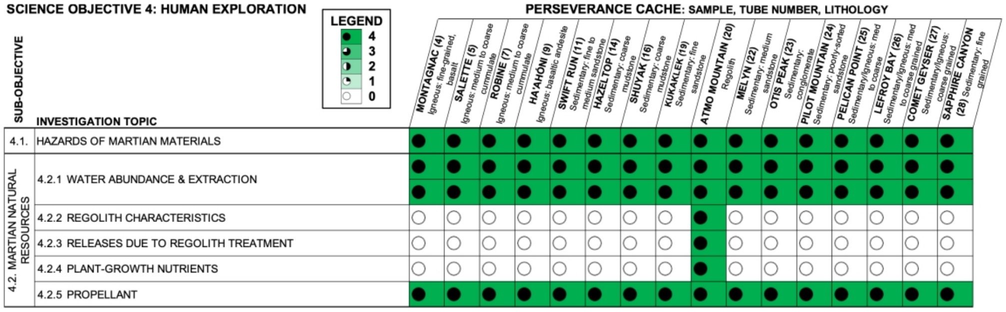
LEGEND
● 4
◕ 3
◑ 2
◔ 1
○ 0

PERSEVERANCE CACHE: SAMPLE, TUBE NUMBER, LITHOLOGY

SUB-OBJECTIVE	INVESTIGATION TOPIC	MONTAGNAC (4) Igneous: fine-grained, basalt	SALETTE (5) Igneous: medium to coarse cummulate	ROBINE (7) Igneous: medium to coarse cummulate	HA'AHÓNI (9) Igneous: basaltic andesite	SWIFT RUN (11) Sedimentary: fine to medium sandstone	HAZELTOP (14) Sedimentary: coarse mudstone	SHUYAK (16) Sedimentary: coarse mudstone	KUKAKLEK (19) Sedimentary: fine sandstone	ATMO MOUNTAIN (20) Regolith	MELYN (22) Sedimentary: medium sandstone	OTIS PEAK (23) Sedimentary: conglomerate	PILOT MOUNTAIN (24) Sedimentary: poorly-sorted sandstone	PELICAN POINT (25) Sedimentary/Igneous: med to coarse	LEFROY BAY (26) Sedimentary/Igneous: med to coarse grained	COMET GEYSER (27) Sedimentary/Igneous: coarse grained	SAPPHIRE CANYON (28) Sedimentary: fine grained
3.1. PLANETARY-SCALE PROCESSES	3.1.1 PETROLOGY	●	●	●	●	◔	○	○	◔	◕	◔	◕	◔	◑	◑	◑	◔
		●	●	●	●	◔	○	○	◔	◕	◔	◕	◔	◑	◑	◑	◔
	3.1.2 MINERAL CHEMISTRY VARIABILITY	●	●	●	●	◔	○	○	◔	◕	◔	◕	◔	◑	◑	◑	◔
		●	●	●	●	◔	○	○	◔	◕	◔	◕	◔	◑	◑	◑	◔
	3.1.3 BULK CHEMISTRY	●	●	●	●	◔	○	○	◔	◕	◔	◕	◔	◑	◑	◑	◔
	3.1.4 CRYSTALLIZATION AGES	●	●	●	●	◔	○	○	◔	◕	◔	●	◔	◑	◑	◑	◔
		●	●	●	●	◔	○	○	◔	◕	◔	●	◔	◑	◑	◑	◔
	3.1.5 MANTLE SOURCES & RESERVOIR INTERACTIONS	●	●	●	●	◔	○	○	◔	◕	◔	◕	◔	◔	◔	◔	◔
		●	●	●	●	◔	○	○	◔	◕	◔	◕	◔	◔	◔	◔	◔
	3.1.6 LATE-VENEER MATERIAL	●	●	●	●	◔	○	○	◔	◕	◔	◕	◔	◔	◔	◔	◔
	3.1.7 CORE-MANTLE SEGREGATION	◑	◑	◑	◑	◔	◔	◔	◔	○	◔	◑	◔	◔	◔	◔	◑
	3.1.8 PRIMORDIAL CRUST	◑	◑	◑	◑	◔	◔	◔	◔	○	◔	◑	◔	◔	◔	◔	◔
	3.1.9 BUILDING BLOCKS OF MARS	●	●	●	●	◔	◔	◔	◔	○	◔	◕	◔	◔	◔	◔	◔
3.2 LARGE-SCALE EVENTS	3.2.1 IMPACT RECORD	◔	◔	◔	◔	◔	◔	◔	◔	◕	◔	◔	◔	◔	◔	◔	◕
		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
		◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔	◔
	3.2.2 IMPACT AGE & FLUX	○	○	○	○	○	○	○	○	○	◔	◔	○	○	○	○	○
		◔	◔	◔	◔	○	○	○	○	○	○	○	○	○	○	○	○
		◔	◔	◔	◔	○	○	○	○	○	○	○	○	○	○	○	○
		○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	3.2.3 IMPACTOR MATERIAL	◔	◔	◔	◔	◑	◑	◑	◑	◕	◔	◑	◔	◔	◔	◔	◑
		◔	◔	◔	◔	◑	◑	◑	◑	◕	◔	◑	◔	◔	◔	◔	◑
		◔	◔	◔	◔	◑	◑	◑	◑	◕	◔	◑	◔	◔	◔	◔	◑
	3.2.4 MICROMETEORITES	○	○	○	○	○	○	○	○	◕	○	○	○	○	○	○	○
		○	○	○	○	○	○	○	○	◑	○	○	○	○	○	○	○
3.3. CRATERING CHRONOLOGY	3.3.1 JEZERO FORMATION	◑	◔	◔	◑	◔	◔	◔	◔	○	◑	◑	◔	◔	◔	◔	◔
	3.3.2 ISIDIS BASIN FORMATION	◔	◔	◔	◔	○	○	○	○	○	○	○	○	○	○	○	○
	3.3.3 AGE OF CRATER-RETENTION AREAS	◕	◑	◑	◑	○	○	○	○	○	○	○	○	◔	◔	◔	◔
	3.3.4 ABSOLUTE AGES	◑	◑	◑	◑	◔	◔	◔	◔	○	◔	◔	◔	◔	◔	◔	◔
3.4. VOLATILES	3.4.1 WATER	◑	◑	◑	◑	◕	◕	◕	◕	◔	◕	◑	◑	◕	◕	◕	◕
		◕	◕	◕	◕	◕	◕	◕	◕	◔	◕	◕	◕	◕	◕	◕	◕
	3.4.2 CARBONATE	◔	◕	◕	◔	●	◔	◕	◔	◔	●	●	●	●	●	●	◔
		◔	◕	◕	◔	●	◔	◕	◔	◔	●	●	●	●	●	●	◔
		◔	◑	◑	◔	●	◔	◕	◔	◔	●	●	●	●	●	●	◔
	3.4.3 TIMING OF SECONDARY MINERALS	◔	◔	◔	◔	◕	◕	◕	◕	◔	◕	◕	◕	◑	◑	◑	◕
	3.4.4 WATER RESERVOIRS & PROCESSES	◔	◑	◑	◔	◑	◑	◑	◑	◔	◑	◑	◑	◑	◑	◑	◑
	3.4.5 EXOGENOUS CONTRIBUTION OF MACROMOLECULAR ORGANICS	◔	◔	◔	◔	◑	◕	◑	◕	◔	◑	◑	◑	◑	◑	◑	●
	3.4.6 OXIDATION	◔	◔	◔	◔	◑	◕	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑
		◔	◔	◔	◔	◔	◔	◔	●	◔	◔	◔	◔	◔	◔	◔	◔
		◔	◔	◔	◔	◕	◑	◑	◕	●	◕	◕	◕	◕	◕	◑	◑
		◔	◔	◑	◔	○	○	◔	○	○	○	◔	○	◔	◑	◔	○
	3.4.7 VOLATILES OTHER THAN WATER	◕	◕	◕	◕	●	●	◕	●	◕	◕	◕	◕	◕	●	◕	◕
		◕	◕	◕	◕	●	●	◕	●	◕	◕	◕	◕	◕	●	◕	◕
3.5. MAGNETIC FIELD	3.5.1 ABSOLUTE DIRECTION OF REMANENT MAGNETIZATION	◑	●	●	●	◕	◕	◕	◕	○	◕	◕	◕	◕	◕	◕	◔
	3.5.2 INTENSITY OF REMANENT MAGNETIZATION	●	◕	◕	●	◑	◑	◑	◑	◔	◑	●	◑	◑	◑	◑	◑
	3.5.3 MAGNETIC MINERALS	●	●	●	●	●	●	●	●	◑	●	●	●	●	●	●	●
	3.5.4 AGES OF MAGNETIC MINERALS	●	●	●	●	◑	◑	◑	◑	◔	◑	◕	●	◕	◕	◕	◑
3.6. ATMOSPHERIC EFFECT ON GEOLOGY & CLIMATE	3.6.1 HISTORY OF MARTIAN ATMOSPHERE	◔	◔	◔	◔	◑	◑	◑	◑	◕	◑	◑	◑	◑	◑	●	●
	3.6.2 IRRADIATION HISTORY	◔	◔	◔	◔	◑	◑	◑	◑	◕	◑	◑	◑	◑	◑	●	●
		◔	◔	◔	◔	◑	◑	◑	◑	◕	◑	◑	◑	◑	◑	●	●
	3.6.3 CARBONATE FORMATION HISTORY	◔	◑	◑	◔	●	◔	◑	◔	◑	●	●	●	◕	●	●	◔
		◔	●	●	◔	●	◔	●	◔	◑	●	●	●	●	●	●	◔
		◔	◑	◑	◔	●	◕	◕	◕	◔	●	●	●	◕	●	●	◑
		◔	●	●	◔	●	●	●	◔	◑	●	●	●	●	●	●	●
		◔	●	●	◔	●	◔	●	◔	◕	●	●	●	●	●	●	◔
		◔	●	●	◔	●	◔	●	◔	◕	●	●	●	●	●	●	◔
	3.6.4 SULFATE FORMATION HISTORY	◑	◑	◕	◑	◕	●	◕	●	◑	◕	◕	◕	◑	◕	◑	◕
		◑	◑	◕	◑	◕	●	◕	●	◑	◕	◕	◕	◑	◕	◑	◕
		◑	◑	◕	◑	◕	●	◕	●	◑	◕	◕	◕	◕	◕	◑	◕
	3.6.5 FLUID/FLUID-INCLUSION HISTORY	◑	◑	◕	◔	◕	◕	◕	●	◔	◕	◕	◕	◕	◕	◕	◕
		◑	◑	◕	◔	◕	◕	◕	●	◔	◕	◕	◕	◕	◕	◕	◕
		◑	◑	◕	◔	◕	◕	◕	●	◔	◕	◕	◕	◕	◕	◕	◕
		◑	◑	◕	◔	◕	◕	◕	●	◔	◕	◕	◕	◕	◕	◕	◕

Figure 6: Sample Science Traceability Matrix (SSTM) at the level of sub investigations for Science Objective 3 (Planetary Evolution) and the samples in the Perseverance rover cache. See text for an explanation of what the different number values mean (and corresponding colors and symbols).

338x477mm (195 x 195 DPI)



SCIENCE OBJECTIVE 4: HUMAN EXPLORATION

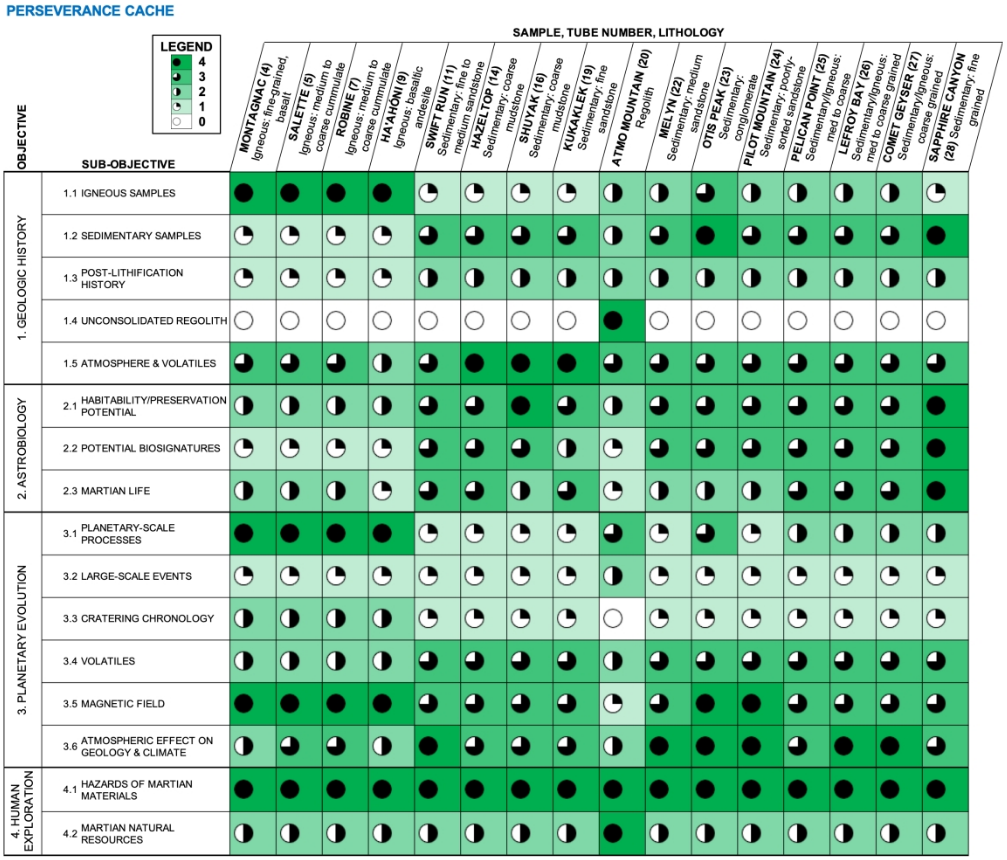
LEGEND
● 4
◕ 3
◑ 2
◔ 1
○ 0

PERSEVERANCE CACHE: SAMPLE, TUBE NUMBER, LITHOLOGY

SUB-OBJECTIVE	INVESTIGATION TOPIC	MONTAGNAC (4) Igneous: fine-grained, basalt	SALETTE (5) Igneous: medium to coarse cummulate	ROBINE (7) Igneous: medium to coarse cummulate	HA'AHÓNI (9) Igneous: basaltic andesite	SWIFT RUN (11) Sedimentary: fine to medium sandstone	HAZELTOP (14) Sedimentary: coarse mudstone	SHUYAK (16) Sedimentary: coarse mudstone	KUKAKLEK (19) Sedimentary: fine sandstone	ATMO MOUNTAIN (20) Regolith	MELYN (22) Sedimentary: medium sandstone	OTIS PEAK (23) Sedimentary: conglomerate	PILOT MOUNTAIN (24) Sedimentary: poorly-sorted sandstone	PELICAN POINT (25) Sedimentary/Igneous: med to coarse	LEFROY BAY (26) Sedimentary/Igneous: med to coarse grained	COMET GEYSER (27) Sedimentary/Igneous: coarse grained	SAPPHIRE CANYON (28) Sedimentary: fine grained
4.1.	HAZARDS OF MARTIAN MATERIALS	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
4.2. MARTIAN NATURAL RESOURCES	4.2.1 WATER ABUNDANCE & EXTRACTION	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	4.2.2 REGOLITH CHARACTERISTICS	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○
	4.2.3 RELEASES DUE TO REGOLITH TREATMENT	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○
	4.2.4 PLANT-GROWTH NUTRIENTS	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○	○
	4.2.5 PROPELLANT	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Figure 7: Sample Science Traceability Matrix (SSTM) at the level of sub investigations for Science Objective 4 (Human Exploration) and the samples in the Perseverance rover cache. See text for an explanation of what the different number values mean (and corresponding colors and symbols).

338x103mm (195 x 195 DPI)



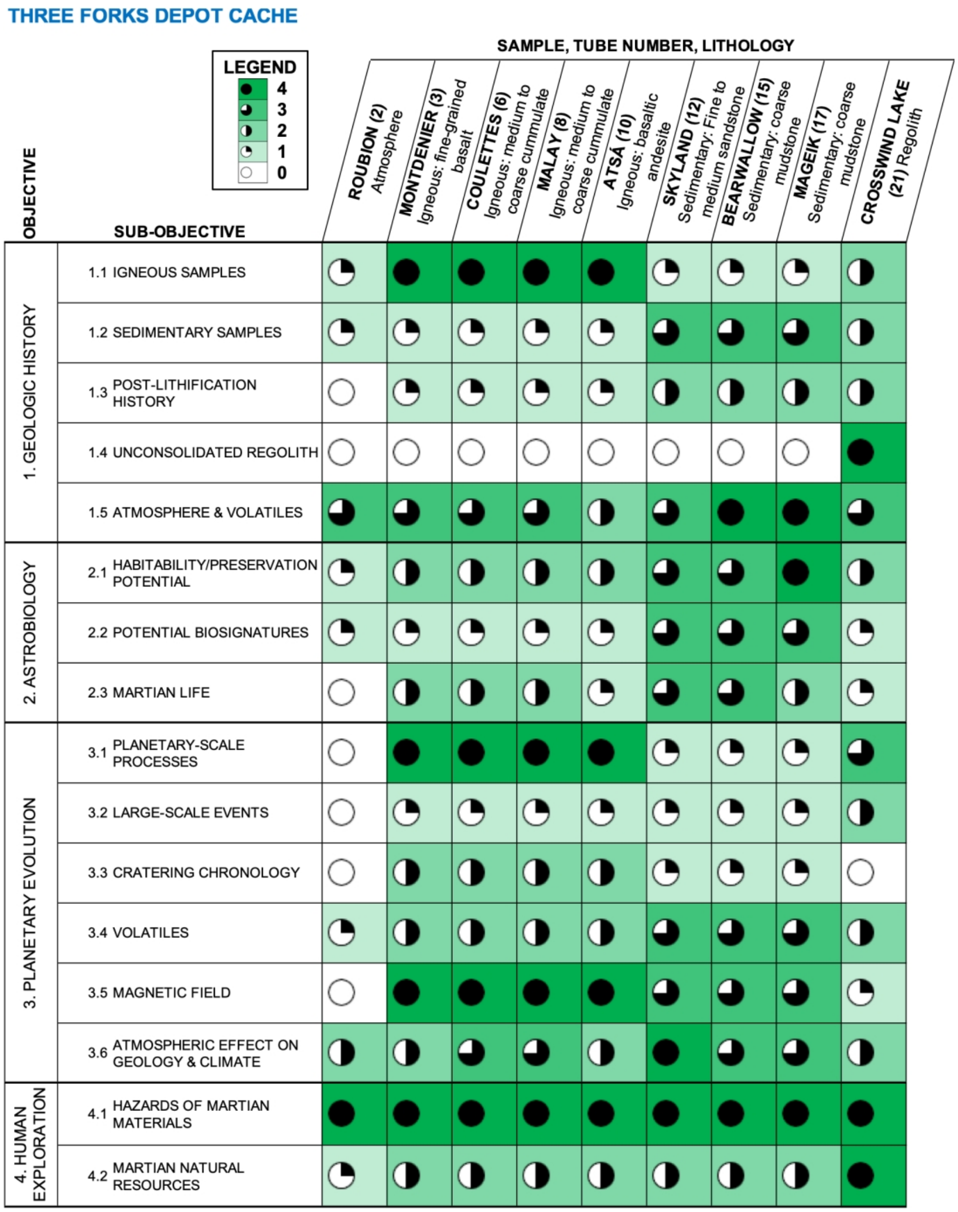
PERSEVERANCE CACHE

LEGEND
- ● 4
- ◕ 3
- ◑ 2
- ◔ 1
- ○ 0

OBJECTIVE	SUB-OBJECTIVE	**MONTAGNAC (4)** Igneous: fine-grained, basalt	**SALETTE (5)** Igneous: medium to coarse cummulate	**ROBINE (7)** Igneous: medium to coarse cummulate	**HA'AHÓNI (9)** Igneous: basaltic andesite	**SWIFT RUN (11)** Sedimentary: fine to medium sandstone	**HAZELTOP (14)** Sedimentary: coarse mudstone	**SHUYAK (16)** Sedimentary: coarse mudstone	**KUKAKLEK (19)** Sedimentary: fine sandstone	**ATMO MOUNTAIN (20)** Regolith	**MELYN (22)** Sedimentary: medium sandstone	**OTIS PEAK (23)** Sedimentary: conglomerate	**PILOT MOUNTAIN (24)** Sedimentary: poorly-sorted sandstone	**PELICAN POINT (25)** Sedimentary/Igneous: med to coarse	**LEFROY BAY (26)** Sedimentary/Igneous: med to coarse grained	**COMET GEYSER (27)** Sedimentary/Igneous: coarse grained	**SAPPHIRE CANYON (28)** Sedimentary: fine grained
1. GEOLOGIC HISTORY	1.1 IGNEOUS SAMPLES	4	4	4	4	1	1	1	1	2	2	3	2	2	2	2	1
	1.2 SEDIMENTARY SAMPLES	1	1	1	1	3	3	3	3	2	3	4	3	3	3	3	4
	1.3 POST-LITHIFICATION HISTORY	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2
	1.4 UNCONSOLIDATED REGOLITH	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
	1.5 ATMOSPHERE & VOLATILES	3	3	3	2	3	4	4	4	3	3	3	3	3	3	3	3
2. ASTROBIOLOGY	2.1 HABITABILITY/PRESERVATION POTENTIAL	2	2	2	2	3	3	4	3	2	3	3	3	3	3	3	4
	2.2 POTENTIAL BIOSIGNATURES	1	1	1	1	3	3	3	2	1	3	3	3	3	3	3	4
	2.3 MARTIAN LIFE	2	2	2	1	3	3	2	3	1	2	2	2	3	3	3	4
3. PLANETARY EVOLUTION	3.1 PLANETARY-SCALE PROCESSES	4	4	4	4	1	1	1	1	3	1	3	1	2	2	2	2
	3.2 LARGE-SCALE EVENTS	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1
	3.3 CRATERING CHRONOLOGY	2	2	2	2	1	1	1	1	0	1	1	1	1	1	1	1
	3.4 VOLATILES	2	2	2	2	3	3	3	3	2	3	3	3	3	3	3	3
	3.5 MAGNETIC FIELD	4	4	4	4	3	3	3	3	1	3	4	4	3	3	3	3
	3.6 ATMOSPHERIC EFFECT ON GEOLOGY & CLIMATE	2	3	3	2	4	3	3	3	2	4	4	4	3	4	4	3
4. HUMAN EXPLORATION	4.1 HAZARDS OF MARTIAN MATERIALS	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	4.2 MARTIAN NATURAL RESOURCES	2	2	2	2	2	2	2	2	4	2	2	2	2	2	2	2

Figure 8: Sample Science Traceability Matrix (SSTM) at the level of Objectives for all four of the goals and the samples in the Perseverance rover cache. See text for an explanation of what the different number values mean (and corresponding colors and symbols).

338x289mm (195 x 195 DPI)



THREE FORKS DEPOT CACHE

LEGEND

●	4
◕	3
◑	2
◔	1
○	0

		SAMPLE, TUBE NUMBER, LITHOLOGY								
OBJECTIVE	SUB-OBJECTIVE	**ROUBION (2)** Atmosphere	**MONTDENIER (3)** Igneous: fine-grained basalt	**COULETTES (6)** Igneous: medium to coarse cummulate	**MALAY (8)** Igneous: medium to coarse cummulate	**ATSÁ (10)** Igneous: basaltic andesite	**SKYLAND (12)** Sedimentary: Fine to medium sandstone	**BEARWALLOW (15)** Sedimentary: coarse mudstone	**MAGEIK (17)** Sedimentary: coarse mudstone	**CROSSWIND LAKE (21)** Regolith
1. GEOLOGIC HISTORY	1.1 IGNEOUS SAMPLES	◔	●	●	●	●	◔	◔	◔	◑
	1.2 SEDIMENTARY SAMPLES	◔	◔	◔	◔	◔	◕	◕	◕	◑
	1.3 POST-LITHIFICATION HISTORY	○	◔	◔	◔	◔	◑	◑	◑	◑
	1.4 UNCONSOLIDATED REGOLITH	○	○	○	○	○	○	○	○	●
	1.5 ATMOSPHERE & VOLATILES	◕	◕	◕	◕	◑	◕	●	●	◕
2. ASTROBIOLOGY	2.1 HABITABILITY/PRESERVATION POTENTIAL	◔	◑	◑	◑	◑	◕	◕	●	◑
	2.2 POTENTIAL BIOSIGNATURES	◔	◔	◔	◔	◔	◕	◕	◕	◔
	2.3 MARTIAN LIFE	○	◑	◑	◑	◔	◕	◕	◑	◔
3. PLANETARY EVOLUTION	3.1 PLANETARY-SCALE PROCESSES	○	●	●	●	●	◔	◔	◔	◕
	3.2 LARGE-SCALE EVENTS	○	◔	◔	◔	◔	◔	◔	◔	◑
	3.3 CRATERING CHRONOLOGY	○	◑	◑	◑	◑	◔	◔	◔	○
	3.4 VOLATILES	◔	◑	◑	◑	◑	◕	◕	◕	◑
	3.5 MAGNETIC FIELD	○	●	●	●	●	◕	◕	◕	◔
	3.6 ATMOSPHERIC EFFECT ON GEOLOGY & CLIMATE	◑	◑	◕	◕	◑	●	◕	◕	◑
4. HUMAN EXPLORATION	4.1 HAZARDS OF MARTIAN MATERIALS	●	●	●	●	●	●	●	●	●
	4.2 MARTIAN NATURAL RESOURCES	◔	◑	◑	◑	◑	◑	◑	◑	●

Figure 9: Sample Science Traceability Matrix (SSTM) at the level of Objectives for all four of the goals and the samples in the Three Forks Depot cache. See text for an explanation of what the different number values mean (and corresponding colors and symbols).

229x289mm (195 x 195 DPI)

Table 1. Summary of samples collected to date as well as sampling details and lithology.

Sample number	Date sealed (m/d/y)	Sol sealed	Sample name	Feature name	Sampling location	Current location[a]	Sample Height (cm)	Sample type
1	8/6/2021	164	Roubion	Roubion	Crater Floor	TFD	n/a	Atmosphere
2	9/6/2021	194	Montdenier	Rochette	Crater Floor	TFD	5.98	Igneous
3	9/8/2021	196	Montagnac	Rochette	Crater Floor	Rover	6.14	Igneous
4	11/15/2021	262	Salette	Brac	Crater Floor	Rover	6.28	Igneous
5	11/24/2021	271	Coulettes	Brac	Crater Floor	TFD	3.30	Igneous
6	12/22/2021	298	Robine	Issole	Crater Floor	Rover	6.08	Igneous
7	1/31/2022	337	Malay	Issole	Crater Floor	TFD	3.07	Igneous
8	3/7/2022	371	Ha'ahóni	Sid	Crater Floor	Rover	6.50	Igneous
9	3/13/2022	377	Atsá	Sid	Crater Floor	TFD	6.00	Igneous
10	7/7/2022	490	Swift Run	Skinner Ridge	Delta Front	Rover	6.69	Sedimentary
11	7/12/2022	495	Skyland	Skinner Ridge	Delta Front	TFD	5.85	Sedimentary
12	7/27/2022	509	Hazeltop	Wildcat Ridge	Delta Front	Rover	5.97	Sedimentary
13	8/3/2022	516	Bearwallow	Wildcat Ridge	Delta Front	TFD	6.24	Sedimentary
14	10/2/2022	575	Shuyak	Amalik	Delta Front	Rover	5.55	Sedimentary
15	11/16/2022	619	Mageik	Amalik	Delta Front	TFD	7.36	Sedimentary
16	11/29/2022	631	Kukaklek	Hidden Harbor	Delta Front	Rover	4.97	Sedimentary
17	12/2/2022	634	Atmo Mountain	Observation Mountain	Delta Front	Rover	5.30	Mixed sed. and ign. grains
18	12/7/2022	639	Crosswind Lake	Observation Mountain	Delta Front	TFD	5.30	Mixed sed. and ign. grains
19	3/30/2023	749	Melyn	Berea	Upper Fan	Rover	6.04	Sedimentary
20	6/23/2023	832	Otis Peak	Emerald Lake	Upper Fan	Rover	5.77	Sedimentary
21	9/15/2023	913	Pilot Mountain	Dream Lake	Upper Fan	Rover	6.00	Sedimentary
22	9/25/2023	923	Pelican Point	Hans Amundsen Memorial Workspace	Margin Unit	Rover	6.10	Sedimentary or altered igneous
23	10/21/2023	949	Lefroy Bay	Turquoise Bay	Margin Unit	Rover	4.70	Sedimentary or altered igneous
24	3/12/2024	1088	Comet Geyser	Bunsen Peak	Margin Unit	Rover	5.78	Sedimentary or altered igneous
25	7/21/2024	1215	Sapphire Canyon	Cheyava Falls	Neretva Vallis	Rover	6.2	Sedimentary
26	1/28/2025	1401	Silver Mountain	Shallow Bay	Crater Rim	Rover	2.91	Igneous/impactite
27	3/2/2025	1433	Green Gardens	Tablelands	Crater Rim	Rover	7.19	Serpentinite
28	3/10/2025	1441	Main River	Broom Point	Crater Rim	Rover	4.32	Igneous/impactite
29	TBD	TBD	Bell Island	Pine Pond	Crater Rim	Rover	1.7-5	Igneous/impactite
30	TBD	TBD	Gallants	Salmon Point	Crater Rim	Rover	1.91	Igneous or sedimentary

[a] TFD = Three Forks sample depot, Rover = onboard the Perseverance rover

SCIENCE OBJECTIVE 1: GEOLOGIC HISTORY

SUB-OBJECTIVE	INVESTIGATION TOPIC	RESEARCH QUESTIONS	ASSIGNMENT RATIONALE	**PERSEVERANCE CACHE:** SAMPLE, TUBE NUMBER, LITHOLOGY															
				MONTAGNAC (4) Igneous: fine-grained basalt	**SALETTE (5)** Igneous: medium to coarse cummulate	**ROBINE (7)** Igneous: medium to coarse cummulate	**HA'AHÓNI (9)** Igneous: basaltic andesite	**SWIFT RUN (11)** Sedimentary: fine to medium sandstone	**HAZELTOP (14)** Sedimentary: coarse mudstone	**SHUYAK (16)** Sedimentary: coarse mudstone	**KUKAKLEK (19)** Sedimentary: fine sandstone	**ATMO MOUNTAIN (20)** Regolith	**MELYN (22)** Sedimentary: medium sandstone	**OTIS PEAK (23)** Sedimentary: conglomerate	**PILOT MOUNTAIN (24)** Sedimentary: poorly-sorted sandstone	**PELICAN POINT (25)** Sedimentary/Igneous: medium to coarse grained	**LEFROY BAY (26)** Sedimentary/Igneous: medium to coarse grained	**COMET GEYSER (27)** Sedimentary/Igneous: coarse grained	**SAPPHIRE CANYON (28)** Sedimentary: fine grained
1.1. IGNEOUS SAMPLES	1.1.1 MINERAL CHARACTERIZATION	What is the diversity of the mineralogy of martian igneous rocks?	4=igneous rock; 3=regolith or coarse-grained sedimentary rock with 'large' igneous clasts or if it is a possible igneous sample; 2=medium-grained sedimentary rock; 1=fine grained sandstone; 0=atmosphere or fine grained sedimentary rock/mudstone	4	4	4	4	2	0	0	1	3	2	3	2	3	3	3	0
	1.1.2 MINERAL CHEMISTRY	What is the variability of the mineral chemistry of martian igneous rocks?	4=igneous rock; 3=regolith or coarse-grained sedimentary rock with 'large' igneous clasts or if it is a possible igneous sample; 2=medium-grained sedimentary rock; 1=fine grained sandstone; 0=atmosphere or fine grained sedimentary rock/mudstone	4	4	4	4	2	0	0	1	3	2	3	2	3	3	3	0
	1.1.3 BULK CHEMISTRY	What is the diversity of bulk chemistry of martian igneous rocks?	4=igneous rock, 3=conglomerate, 2=regolith or coarse-grained sedimentary with 'large' igneous clasts or if it is a possible igneous sample, 1=fine grained sedimentary rock, 0=atmosphere	4	4	4	4	2	1	1	1	2	1	3	2	2	2	2	1
	1.1.4 MANTLE SOURCES	What is the nature of the mantle source(s) of the martian igneous rocks?	4=igneous rock; 3=likely igneous clasts in conglomerate; 2=highly weathered possible igneous rock; 0=atmosphere and other non-igneous samples	4	4	4	4	0	0	0	0	0	0	3	0	2	2	2	0
		What other processes (e.g., crustal assimilation, metasomatism) involved in their formation affect these igneous rocks?	4=igneous rock; 3=likely igneous clasts in conglomerate; 2=regolith/conglomerate; 1=medium-grained, poorly sorted sandstones; 0=atmosphere or mudstone	4	4	4	4	0	0	0	0	2	1	2	1	1	1	1	1
		What is the radiometric age of the igneous rocks? Has the mantle of Mars changed over time?	4=igneous rock or contains multi-mineralogic igneous rock fragments, 3=primary minerals are present but has evidence of being disturbed; 2=significantly disturbed gneous rock or uncertainty about sedimentary vs. igneous origin; 1=coarse- to medium-grained sandstone or other fine-grained sedimentary rock, 0=atmosphere or regolith or mudstone	3	4	4	4	0	0	0	0	0	1	4	1	2	2	2	1
	1.1.5 VOLATILES	How did the volatile budget of the martian interior vary as a function of time and location?	4=igneous or conglomerates with igneous clasts, 3=igneous minimally altered/gechronology is limited due to the clast size, 1=atmosphere/ med. Sandstone or altered/doubt igneous, 0=regolith, fine sandstones & mudstones	3	4	4	4	0	0	0	0	0	1	4	1	1	1	1	1
	1.1.6 OXIDATION STATE	What are the main controls on the oxidation state of martian magmas and how does magma oxidation state vary as a function of time and mantle source characteristics?	4=igneous rock; 1=regolith or medium-grained/poorly sorted sandstones or altered igneous rocks or rocks of possible, but uncertain igneous origin; 0=atmosphere or mudstone	4	4	4	4	1	0	0	0	1	1	1	1	1	1	1	0
	1.1.7 MAGMA	How fast is the magma ascent, emplacement, and solidification on Mars?	4=igneous rock; 0=non igneous rock or atmosphere	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0
	1.1.8 ALTERATION	To what extent have igneous rocks been altered (e.g., by hydrothermal, near-surface weathering, contact metamorphism)?	4=igneous rock; 3=rock of possible igneous or sedimentary origin; 2=sedimentary rock or regolith but has 'large' igneous clasts; 1=medium grained sedimentary rock; 0=atmosphere or fine grained sedimentary rock	4	4	4	4	2	0	0	0	2	1	2	2	3	3	3	0
	1.1.9 SURFACE EXPOSURE	What is the surface exposure history of igneous (and other) rocks in Jezero crater and the surrounding region?	4=igneous rocks; 3=sedimentary rocks; 0=regolith or atmosphere	4	4	4	4	3	3	3	3	0	3	3	3	3	3	3	3
	1.1.10 VOLCANIC GAS	What is chemistry and species of precipitates from volcanic gas/late magmatic fluid?	4=unaltered igneous rock; 3=altered igneous rock; 2=rock of possible igneous coarse grained sedimentary origin; 1=conglomerate; 0=atmosphere	3	3	3	3	0	0	0	0	0	0	1	0	2	2	2	0
1.2 SEDIMENTARY SAMPLES	1.2.1 PHYSICAL SEDIMENTOLOGY & TRANSPORT	What are the sedimentary facies and transport processes?	4= sedimentary rock; 3= possible sedimentary rock; 2 =regolith; 0= igneous rock or atmosphere	0	0	0	0	4	4	4	4	2	4	4	4	3	3	3	4
	1.2.2 DETRITAL MINERALOGY & CRYSTAL CHEMISTRY	Which sediments were transported from outside of the crater?	4=Rocks with grains > mm-sized; 3=rocks of mid sand sized; 2=rocks of fine sand sized or regolith; 1=smaller silisiclastic sedimentary rocks; 0=atmosphere, igneous rocks, or not a sedimentary rock that is part of margin/fan/delta front	0	0	0	0	3	1	1	1	2	2	4	2	1	2	2	2
	1.2.3 BULK (LAYER OR SAMPLE-BASED) CHEMISTRY	Which elements were enriched or depleted because of weathering, transport, sedimentation, and diagenetic processes?	4=sedimentary rock; 3=possible sedimentary rock; 2=regolith; 0=igneous rock or atmosphere	0	0	0	0	4	4	4	4	2	4	4	4	3	3	3	4
	1.2.4 WATER-ROCK REACTIONS	What was the (early? And middle?) diagenetic history of the sedimentary samples?	4=sedimentary rock; 3=possible sedimentary rock; 2=regolith; 0=igneous rock or atmosphere	0	0	0	0	4	4	4	4	2	4	4	4	3	3	3	4
	1.2.5 ATMOSPHERIC PROCESSES	What is the contribution of the atmosphere to the water inventory of the sedimentary samples?	4=atmosphere or sedimentary rock samples with many salts/grains or regolith; 3=medium sized, pooly sorted, conglomerates; 0=not a sedimentary rock	0	0	0	0	3	4	4	3	4	3	4	3	4	3	4	4
	1.2.6 AGE HISTORIES & RADIOMETRIC DATING	What is the age history of the sample? (absolute mineral formation ages of different phases (primary and secondary), and relative ages of cross-cutting cements?	4=volcanic rock; 3=coarse grained, likely plutonic rock; 2=cement present, significant secondary mineralogy or chemical precipitate or coarse grained sedimentary rock; 1=sand or finer grained sediment with minimial obvious cement; 0=atmosphere or regolith	4	3	3	4	1	1	1	1	0	2	2	2	2	2	2	1
		What is the exposure age of the sample?	4=rock sample comes from an exposed stable surface/feature; 2=outcrop with coarse silicate grains; 1=outcrop of other type; 0=atmosphere or regolith	1	2	2	1	1	2	1	1	0	1	2	1	2	2	2	1
		How might that affect the breakdown of organics?	4=organics detected and comes from understood geological setting; 3=organics possibly preserved and lithology conducive to organic preservation; 2=some potential to preserve organics; 1=other rock; 0=regolith or atmosphere	1	1	1	1	2	3	3	2	0	2	2	2	2	2	2	4
	1.2.7 COMPACTION/ LITHIFICATION HISTORY	What is the lithification history of the sedimentary samples (e.g., how deeply were they buried? How hard are they?)?	4=sedimentary rock sample; 3=rock of possible sedimentary or igneous origin; 0=atmosphere or regolith or igneous rock	0	0	0	0	4	4	4	4	0	4	4	4	3	3	3	4
1.3. POST-LITHIFICATION HISTORY	1.3.1 AQUEOUS ALTERATION DURING DIAGENESIS	What was the late diagenetic history of the sedimentary samples?	4=sedimentary rock sample; 3=rock of possible sedimentary or igneous origin; 1=regolith; 0=atmosphere or igneous rock	0	0	0	0	4	4	4	4	1	4	4	4	3	3	3	4
	1.3.2 WEATHERING	What processes occurred during physical and chemical weathering of the samples under subaerial conditions?	4=probable paleosol; 3=regolith; 1=all other samples that have some evidence of near-surface weathering; 0=atmosphere	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	1
	1.3.3 HYDROTHERMAL PROCESSES	How have hydrothermal processes altered the rock post-lithification?	4=abundant serpentines and hydrothermal minerals; 3=some serpentines and hydrothermal minerals; 2=relatively abundant serpentine; 1=evidence of aqueous activity in rocks emplaced before impact; 0=atmosphere or no evidence for hydrothermal minerals	1	1	1	1	0	0	1	0	0	0	1	0	0	0	2	1
	1.3.4 IMPACT PROCESSES	What is the contribution of impact-generated sediments to the martian sedimentary record?	4=regolith or fine- to coarse-grained sandstone or conglomerate; 3=finer grained sedimentary rock; 2=rock of possible sedimentary or igneous origin; 0=igneous rock or atmosphere	0	0	0	0	4	3	3	4	4	4	4	4	2	2	2	4
		Is there fracturing and veining that results from impacts?	4=rock that contains impact related veining; 0=rock with no evidence of impact related veining or atmosphere or regolith	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Did impact processes result in hydrothermal alteration?	4=rock with impact features and evidence of hydrothermal alteration; 0=all other rock samples, regolith, or atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Are there shock phases resulting from impacts?	4=rock containing shock phases or are otherwise likely impactite; 0=all other rock samples, regolith, or atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Is there information in returned samples that can constrain the timing of impact processes relative to other processes?	4=rock with impact features and evidence of hydrothermal alteration; 0=all other rock samples, regolith, or atmosphere	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1.3.5 MICROMETEOROID & METEOROID DEBRIS	What is the contribution of micrometeoroids and meteoroid debris to the sediments?	4=sedimentary rocks; 3=regolith; 2=rocks of possible sedimentary or igneous origin.; 1=igneous rocks; 0=atmosphere	1	1	1	1	4	4	4	4	3	4	4	4	2	2	2	4
	1.3.6 SPACE WEATHERING	What evidence is there of radiolytic processing resulting from cosmic radiation or space weathering in the samples?	4=igneous rocks or regolith; 3=rocks of possible sedimentary or igneous origin; 2=sedimentary rocks; 0=atmosphere	4	4	4	4	2	2	2	2	4	2	2	2	3	3	3	2
		Are there non-organic or organic ways to assess radiative processing?	4=igneous rocks or regolith; 3=rocks of possible sedimentary or igneous origin; 2=sedimentary rocks; 0=atmosphere	4	4	4	4	2	2	2	2	4	2	2	2	3	3	3	2
1.4. UNCONSOLIDATED REGOLITH	1.4.1 CHARACTERISTICS OF GRAINS AND THEIR SOURCE	What is the mineralogy, chemistry, age distribution, and trace element signatures of the regolith grains?	4=regolith; 0=all other solid samples and atmosphere	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
	1.4.2 MECHANICAL ALTERATION & TRANSPORT PROCESSES	What mechanical alteration and transport processes have influenced the properties of the martian regolith?	4=regolith; 0=all other solid samples and atmosphere	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
	1.4.3 SALT MEASUREMENTS	What is the composition of salts present in the martian regolith?	4=regolith; 0=all other solid samples and atmosphere	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
1.5. ATMOSPHERE & VOLATILES	1.5.1 ENVIRONMENTAL ISOTOPIC SIGNATURE	Which phases retain a geochemical/isotopic signature of the environment in which they formed?	4=sedimentary rock or regolith containing mineral phases from various provenance; 3=igneous rocks altered after crystallisation; 0=atmosphere	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4
		Which phases exchanged volatiles with the modern martian atmosphere?	4=atmosphere (for constraints) or regolith; 3=poorly consilidated sedimentary rock; 2=consolidated sedimentary rock; 1=igneous rock	1	1	1	1	2	2	2	2	4	2	2	2	1	1	2	2
	1.5.2 VOLATILE INCORPORATION	What is the volatile content incorporated into the solids at the different stages of their formation?	4=atmosphere (for constraints) or mudstone; 3=igneous rocks and fine sandstone; 2=coarse sandstone or conglomerate; 1=regolith	3	3	3	3	3	4	4	3	1	3	2	2	2	2	2	4
		How did the different formation processes influence the incorporation?	4=atmosphere (for constraints) or mudstone; 3=igneous rocks and fine sandstone; 2=coarse sandstone or conglomerate; 1=regolith	3	3	3	3	3	4	4	3	1	3	2	2	2	2	2	4
		What is the redox state of Fe in the volatile-bearing Fe phases?	4=igneous rock; 3=regolith with Fe-bearing phases or Fe-bearing clays; 2=sedimentary rock with minor amount of Fe-phases; 1=sedimentary rock likely without Fe-phases; 0=atmosphere	4	4	4	4	1	2	2	1	3	1	2	1	2	3	3	1
	1.5.3 PALEO-ATMOSPHERE	What were the volatiles of the paleo-atmosphere?	4=materials deposited at or close to the surface and contain structural or other volatile elements, or atmosphere (for contraints); 3=materials deposited at or close to the surface that contain fewer volatile phases; 2=igneous samples that contain phases produced by aqueous alteration; 1=igneous samples that contain fewer alteration phases or regolith; 0=no volatiles present	1	2	2	1	3	3	3	3	1	3	3	3	3	3	3	4
		Which phases retain a geochemical/isotopic signature of the environment in which they formed?	4=materials deposited at or close to the surface and contain structural or other volatile elements, or atmosphere (for contraints); 3=materials deposited at or close to the surface that contain fewer volatile phases; 2=igneous samples that contain phases produced by aqueous alteration; 1=igneous samples that contain fewer alteration phases or regolith; 0=no volatiles present	1	2	2	1	3	3	3	3	1	3	3	3	3	3	3	4
		Which phases exchanged volatiles with the modern martian atmosphere?	4=atmosphere (for context); 3=samples that contain salts; 0=solid sample with no salts	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	1.5.4 RELATIVE HUMIDITY	How does the Mars atmospheric relative humidity change over time?	4=atmosphere and rock or regolith with multiple signs of aqueous alteration events and sedimentation/precipitation; 3=rocks with moderate signs of aqueous alteration; 2=rocks with some signs of aqueous alteration; 1=few signs of aqueous alteration; 0=no use for this purpose	2	1	2	1	3	4	4	4	3	3	4	4	4	4	4	
	1.5.5 MINERALS EXCHANGING WATER WITH ATMOSPERE	Are there minerals that exchange water with the atmosphere and record seasonal changes in relative humidity?	4=atmosphere and rock or regolith with multiple signs of aqueous alteration events and sedimentation/precipitation; 3=rocks with moderate signs of aqueous alteration; 2=rocks with some signs of aqueous alteration; 1=few signs of aqueous alteration; 0=no use for this purpose	2	2	2	1	3	4	4	4	4	3	4	4	4	4	4	1
	1.5.6 FLUID HISTORY	What can we learn about Mars paleo-atmosphere, fluid history, composition & chemistry by studying fluid inclusions?	4=sample with large amounts of fluid inclusion bearing minerals; 3=sample with moderate amounts of fluid inclusion bearing minerals; 2=sample with small amounts of fluid inclusion bearing minerals; 1=sample with minor amount of fluid inclusion bearing minerals; 0=atmosphere	2	2	3	1	3	3	3	4	1	3	3	3	3	3	3	3

SCIENCE OBJECTIVE 2: ASTROBIOLOGY

PERSEVERANCE CACHE: SAMPLE, TUBE NUMBER, LITHOLOGY

SUB-OBJECTIVE	INVESTIGATION TOPIC	RESEARCH QUESTIONS	ASSIGNMENT RATIONALE	**MONTAGNAC (4)** Igneous: fine-grained basalt	**SALETTE (5)** Igneous: medium to coarse cummulate	**ROBINE (7)** Igneous: medium to coarse cummulate	**HA'AHÓNI (9)** Igneous: basaltic andesite	**SWIFT RUN (11)** Sedimentary: fine to medium sandstone	**HAZELTOP (14)** Sedimentary: coarse mudstone	**SHUYAK (16)** Sedimentary: coarse mudstone	**KUKAKLEK (19)** Sedimentary: fine sandstone	**ATMO MOUNTAIN (20)** Regolith	**MELYN (22)** Sedimentary: medium sandstone	**OTIS PEAK (23)** Sedimentary: conglomerate	**PILOT MOUNTAIN (24)** Sedimentary: poorly-sorted sandstone	**PELICAN POINT (25)** Sedimentary/Igneous: medium to coarse grained	**LEFROY BAY (26)** Sedimentary/Igneous: medium to coarse grained	**COMET GEYSER (27)** Sedimentary/Igneous: coarse grained	**SAPPHIRE CANYON (28)** Sedimentary: fine grained
2.1. HABITABILITY/PRESERVATION POTENTIAL	2.1.1 HISTORY & TIMING OF WATER	What was the history and timing of water (surface, groundwater, etc.) with respect to sample formation, deposition, and alteration, and does sufficient water exist presently to permit current life?	4=materials strongly hydrated and contain minerals produced during aqueous alteration or aqueously deposited rocks; 3=materials contain some minerals produced during aqueous alteration, but not in environments that support extensive life; 2=materials contain some hydrated minerals, depositional environments not consistent with life or altered postdepositionally; 1=regolith; 0=no solids	2	2	3	2	3	4	3	3	1	3	3	3	3	3	4	3
	2.1.2 PHYSICAL & CHEMICAL BOUNDS ON HABITABILITY	What are the physical and chemical conditions (e.g., temperature, pH, salinity, Eh) of ancient or modern environments that show evidence of aqueous alteration or other indicators of potential habitability?	4=materials strongly hydrated and contain minerals produced during aqueous alteration or aqueously deposited rocks; 3=materials contain some minerals produced during aqueous alteration, but not in environments that support extensive life; 2=materials contain some hydrated minerals, depositional environments not consistent with life or altered postdepositionally; 1=regolith; 0=no solids	2	2	2	2	4	4	3	3	1	3	3	3	3	3	3	3
	2.1.3 BIO-ESSENTIAL ELEMENTS	What was and is the availability and distribution of bio-essential elements, as we currently understand them?	4=sample that contains a large inventory of bioessential elements that are readily available; 3=sample that contains many bioessential elements that are readily available; 2=sample contains some bioessential elements that are available; 1=sample contains few bioessential elements or elements are not readily available to biology; 0=contains no bioessential elements or no such elements are available	1	1	1	1	3	3	3	2	1	3	3	3	3	3	3	3
	2.1.4 CHEMICAL DISEQUILIBRIA	Is there evidence of chemical disequilibria or chemical species that could be a potential catabolic reaction pairing in Mars conditions that could serve as a source of energy for ancient or modern life?	4=sample contains strong evidence of or the potential for chemical disequilibria or catabolic reaction pairs; 3=sample contains moderate evidence of or the potential for chemical disequilibria or catabolic reaction pairs; 2=sample contains weak evidence of or the poential for chemical disequilibria or catabolic reaction pairs; 1=sample contains only weak potential for chemical disequilibria or catabolic reaction pairs; 0=no potential for catabolic reaction pairs	4	4	3	3	3	1	4	2	3	3	3	3	3	3	2	4
	2.1.5 ORGANICS INVENTORY	What is the total inventory of indigenous (non-contaminant) organic materials, and what factors led to their preservation or degradation?	4=materials contain organic compounds; 3=materials are fine-grained or otherwise have a high potential for the preservation of organic compounds; 2=materials have medium to low potential for the preservation of organic compounds; 1=materials have a very low potential for the preservation of organic compound and regolith; 0=no potential for preservation of martian organic compounds	1	1	1	1	2	3	3	2	1	2	2	2	2	2	2	4
	2.1.6 ABIOTIC ORGANIC SOURCE	Which of the indigenous (non-contaminant) organic materials have an abiotic source?	4=materials contain organic compounds; 3=materials are fine-grained or otherwise have a high potential for the preservation of organic compounds; 2=materials have medium to low potential for the preservation of organic compounds; 1=materials have a very low potential for the preservation of organic compound and regolith; 0=no potential for preservation of martian organic compounds	1	1	1	1	2	3	3	2	1	2	2	2	2	2	2	4
2.2. POTENTIAL BIOSIGNATURES	2.2.1 BIOSIGNATURE PRESERVATION	Were the environmental conditions conducive to preservation or degradation of biosignatures?	4=materials contain organic compounds; 3=materials are fine-grained or otherwise have a high potential for the preservation of organic compounds; 2=materials have medium to low potential for the preservation of organic compounds; 1=materials have a very low potential for the preservation of organic compound and regolith; 0=no solid sample	1	1	1	1	3	3	3	2	1	2	2	2	2	2	3	4
	2.2.2 MARTIAN ORGANIC BIOMARKERS	Does the organic matter in the samples contain compounds, molecular patterns, or spatial distributions of organic molecules that are consistent with a martian and biological origin?	4=materials contain organic compounds; 3=materials are fine-grained or otherwise have a high potential for the preservation of organic compounds; 2=materials have medium to low potential for the preservation of organic compounds; 1=materials have a very low potential for the preservation of organic compound and regolith; 0=no potential for preservation of martian organic compounds	1	1	1	1	2	3	3	2	1	2	2	2	2	2	2	4
	2.2.3 STABLE ISOTOPIC PATTERNS OF ORGANIC MATERIALS	Do the isotopic patterns present in the detected organic materials reflect a martian and/or biologic source?	4=materials contain organic compounds; 3=materials are fine-grained or otherwise have a high potential for the preservation of organic compounds; 2=materials have medium to low potential for the preservation of organic compounds; 1=materials have a very low potential for the preservation of organic compound and regolith; 0=no potential for preservation of martian organic compounds	1	1	1	1	2	3	3	2	1	2	2	2	2	2	2	4
	2.2.4 STABLE ISOTOPIC PATTERNS OF INORGANIC MATERIALS	Do the samples contain isotopic variations between or within inorganic materials that might be indicative of life of martian origin?	4=sample contains minerals with a suggested biological origin and were deposited under conditions that could have allowed biology; 3=rocks contain minerals that can be analyzed geochemically, but depositional conditions not conducive to preservation of biological signals; 2=rocks contain minerals with elements in different redox states; 1=material unlikely to preserve inorganic biosignatures; 0=no potential for the preservation of inorganic biosignatures	1	1	1	1	3	3	3	2	1	3	3	3	3	3	3	4
	2.2.5 LIFE-ASSOCIATED ELEMENTAL DISTRIBUTIONS	Do the samples contain elemental distributions consistent with formation through biological processes or biological presence of martian origin?	4=sample contains minerals with a suggested biological origin and were deposited under conditions that could have allowed biology; 3=rocks contain minerals that can be analyzed geochemically, but depositional conditions not conducive to preservation of biological signals; 2=rocks contain minerals with elements in different redox states; 1=material unlikely to preserve inorganic biosignatures; 0=no potential for the preservation of inorganic biosignatures	1	1	1	1	2	3	3	2	1	2	2	2	3	3	3	4
	2.2.6 LIFE-ASSOCIATED MINERAL DISTRIBUTIONS	Do the samples contain mineral distributions consistent with formation through biological processes or biological presence of martian origin?	4=sample contains minerals with a suggested biological origin and were deposited under conditions that could have allowed biology; 3=rocks contain minerals that could be made biologically; but depositional conditions not conducive to preservation of biological signals; 2=rocks contain minerals with elements in different redox states; 1=material unlikely to preserve mineral biosignatures; 0=no solid material	1	1	1	1	2	2	2	2	1	2	2	2	2	2	2	4
	2.2.7 LIFE-ASSOCIATED PHYSICAL CHARACTERISTICS	Do the samples contain structures, textures, or morphological features that could have been formed through biological processes or biological presence of martian origin?	4=rocks contain features consistent with some biological processes; 3=rocks have features that can enable good preservation of structures and textures/fossils; 2=rocks contain materials that can preserve textural biosignatures ; 1=material unlikely to preserve textural biosignatures; 0=no solid material	1	1	1	1	2	3	2	2	1	2	2	3	3	3	3	4
2.3. MARTIAN LIFE	2.3.1 STRUCTURES OF MARTIAN ORIGIN	Do the samples contain 1) known geologically short-lived biomolecules (or molecular structures with biomolecular characteristics such as functionalization, polymerization, isomeric excesses, and electrical conductivity), or 2) cell-like structures of martian origin that would indicate contemporary or relatively recent life based on analogy to life on Earth?	4=rocks contain recognizable molecules or cell-like structures; 3=rocks contain any organics; 2=rocks have a high potential to preserve organics or cell-like structures; 1=material unlikely to preserve molecular biosignatures and cell-like structures; 0=no solid material	1	1	1	1	2	2	2	2	1	2	2	2	2	2	2	3
	2.3.2 THERMODYNAMICALLY IMPROBABLE DISTRIBUTIONS SUGGESTIVE OF LIFE	Does the inventory of potential biomolecules of martian origin display any aspect of thermodynamically improbable elemental abundances, molecules, or molecular suites – including through their spatial distributions – which, when compared against the abiotic background, would suggest involvement of a living system?	4=rocks contain recognizable thermodynamically improbable organic molecules; 3=rocks contain any organic molecules; 2=rocks have a high potential to preserve organic molecules; 1=material unlikely to preserve molecular biosignatures; 0=no solid material	1	1	1	1	2	2	2	2	1	2	2	2	2	2	2	3
	2.3.3 CHANGE OVER TIME	Does the sample change over time, with or without the addition of external stimuli, in a way that is only explainable by biological processes?	4=contains significant salt conent and has high potential for fluid inclusions; 3=contains moderate amounts of salts and a moderate potential for fluid inclusions; 2=contains minor amounts of salt and has a weak potential for fluid inclusions; 1=no evidence of salts but a weak potential for fluid inclusions; 0=no solid material	2	2	3	1	3	3	2	4	1	2	2	2	3	3	3	4

SCIENCE OBJECTIVE 3: PLANETARY EVOLUTION

SUB-OBJECTIVE	INVESTIGATION TOPIC	RESEARCH QUESTIONS	ASSIGNMENT RATIONALE	**PERSEVERANCE CACHE:** SAMPLE, TUBE NUMBER, LITHOLOGY															
				MONTAGNAC (4) Igneous: fine-grained basalt	**SALETTE (5)** Igneous: medium to coarse cummulate	**ROBINE (7)** Igneous: medium to coarse cummulate	**HA'AHÓNI (9)** Igneous: basaltic andesite	**SWIFT RUN (11)** Sedimentary: fine to medium sandstone	**HAZELTOP (14)** Sedimentary: coarse mudstone	**SHUYAK (16)** Sedimentary: coarse mudstone	**KUKAKLEK (19)** Sedimentary: fine sandstone	**ATMO MOUNTAIN (20)** Regolith	**MELYN (22)** Sedimentary: medium sandstone	**OTIS PEAK (23)** Sedimentary: conglomerate	**PILOT MOUNTAIN (24)** Sedimentary: poorly-sorted sandstone	**PELICAN POINT (25)** Sedimentary/Igneous: medium to coarse grained	**LEFROY BAY (26)** Sedimentary/Igneous: medium to coarse grained	**COMET GEYSER (27)** Sedimentary/Igneous: coarse grained	**SAPPHIRE CANYON (28)** Sedimentary: fine grained
3.1. PLANETARY-SCALE PROCESSES	3.1.1 PETROLOGY	What is the diversity of the mineralogy of martian igneous rocks?	4=igneous rock or impactite; 3=clast within conglomerate or regolith; 2=possible igneous rock; 1=sandstone; 0=mudstone or atmosphere	4	4	4	4	1	0	0	1	3	1	3	1	2	2	2	1
		What does variation in time and location tell us about igneous processes on Mars?	4=igneous rock or impactite; 3=clast within conglomerate or regolith; 2=possible igneous rock; 1=sandstone; 0=mudstone or atmosphere	4	4	4	4	1	0	0	1	3	1	3	1	2	2	2	1
	3.1.2 MINERAL CHEMISTRY VARIABILITY	What is the diversity of mineral major, minor, and trace chemistry of martian igneous rocks?	4=igneous rock or impactite; 3=clast within conglomerate or regolith; 2=possible igneous rock; 1=sandstone; 0=mudstone or atmosphere	4	4	4	4	1	0	0	1	3	1	3	1	2	2	2	1
		How does this diversity inform about igneous processes?	4=igneous rock or impactite; 3=clast within conglomerate or regolith; 2=possible igneous rock; 1=sandstone; 0=mudstone or atmosphere	4	4	4	4	1	0	0	1	3	1	3	1	2	2	2	1
	3.1.3 BULK CHEMISTRY	What is the diversity of bulk major, minor and trace chemistry of martian igneous rocks?	4=igneous rock or impactite; 3=clast within conglomerate or regolith; 2=possible igneous rock; 1=sandstone; 0=mudstone or atmosphere	4	4	4	4	1	0	0	1	3	1	3	1	2	2	2	1
	3.1.4 CRYSTALLIZATION AGES	What is the range of crystallization and modification ages of martian igneous rocks?	4=igneous rocks and conglomerate with diverse igneous clasts; 3=regolith; 2=possible igneous rock; 1=sandstone; 0=siltstome and finer or atmosphere	4	4	4	4	1	0	0	1	3	1	4	1	2	2	2	1
		What does that range tell us about the thermochemical evolution of the martian interior?	4=igneous rocks and conglomerate with diverse igneous clasts; 3=regolith; 2=possible igneous rock; 1=sandstone; 0=siltstome and finer or atmosphere	4	4	4	4	1	0	0	1	3	1	4	1	2	2	2	1
	3.1.5 MANTLE SOURCES & RESERVOIR INTERACTIONS	What is the nature of the mantle source(s) of martian igneous rocks?	4=igneous rocks and conglomerate with diverse igneous clasts; 3=regolith; 2=possible igneous rock; 1=sandstone; 0=siltstome and finer or atmosphere	4	4	4	4	1	0	0	1	3	1	3	1	1	1	1	1
		What interactions between reservoirs (e.g., crustal assimilation, metasomatism) have been involved in their formation?	4=igneous rocks and conglomerate with diverse igneous clasts; 3=regolith; 2=possible igneous rock; 1=sandstone; 0=siltstome and finer or atmosphere	4	4	4	4	1	0	0	1	3	1	3	1	1	1	1	1
	3.1.6 LATE-VENEER MATERIAL	Is there any evidence of late-veneer material into the original composition of Mars?	4=igneous rocks and conglomerate with diverse igneous clasts; 3=regolith; 2=possible igneous rock; 1=sandstone; 0=siltstome and finer or atmosphere	4	4	4	4	1	0	0	1	3	1	3	1	1	1	1	1
	3.1.7 CORE-MANTLE SEGREGATION	What is the timing and the condition of core-mantle segregation and following magma ocean stage?	4=unaltered pre-Noachian igneous rocks; 2=younger igneous rocks and conglomerate bearing igneous clasts; 1=medium to fine-grained sedimentary rocks; 0=regolith or atmosphere sample	2	2	2	2	1	1	1	1	0	1	2	1	1	1	1	2
	3.1.8 PRIMORDIAL CRUST	What was the composition of the primordial crust of Mars?	4=pre-Jezero igneous feldspar bearing lithology; 3=pre-Jezero igneous rock; 2=other igneous rock; 1=other solid sample rock sample; 0=atmosphere or regolith	2	2	2	2	1	1	1	1	0	1	2	1	1	1	1	1
	3.1.9 BUILDING BLOCKS OF MARS	What were the building blocks of Mars?	4=igneous rock; 3=conglomerate with igneous clasts; 1=in place rock sample; 0=atmosphere or regolith	4	4	4	4	1	1	1	1	0	1	3	1	1	1	1	1
3.2 LARGE-SCALE EVENTS	3.2.1 IMPACT RECORD	What conditions of impact shock (including peak pressure, temperature and dwell time) are recorded in rocks on Mars?	4=rock with strong evidence of impact; 3=rock with moderate evidence of impact, or regolith; 2=rock with weak evidence of impact 1=all rocks with no evidence of impact, 0=atmosphere	1	1	1	1	1	1	1	1	3	1	1	1	1	1	1	3
		Are any high-pressure polymorphs preserved?	4=if lithology and geological context suggests impact origin and have sand-sized or greater grain sizes; 1=if geological context includes impact; 0=no indication of impact origin or atmopshere	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Are impact melts preserved?	4=rock with strong evidence of impact; 3=rock with moderate evidence of impact; 2=rock with weak evidence of impact 1=all rocks with no evidence of impact, 0=atmosphere	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	3.2.2 IMPACT AGE & FLUX	What are the ages of impact-affecting martian rocks?	4=rock that has unambiguous rover evidence of shock deformation or melting; 3=rock that has rover evidence for impact fracturing or brecciation; 2=rock that has possible rover evidence for impact fractuing (e.g. possilbe megabreccia); 1=sample is from within 0.5 crater radii of crater or contains pebble sized grains from outside Jezero; 0=no rover evidence for impact effects or atmosphere sample	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
		Do these impact ages cluster at certain periods, or are they distributed more evenly through time?	NOTE: Need a lot of samples to assess clustering so none are a 4. 3=likely impactite; 1=rock might have impact shock effects; 0=no evidence of or possibility of recording shock events or atmopshere	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
		How does the impact flux on Mars compare to that on the Moon?	NOTE: Need a lot of samples to assess clustering so none are a 4. 3=likely impactite; 1=rock might have impact shock effects; 0=no evidence of or possibility of recording shock events or atmopshere	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
		Was there a period of Late heavy bombardment on Mars?	NOTE: Need a lot of samples to assess clustering so none are a 4. 2=likely impactite of old age; 1=rock might have impact shock effects; 0=no evidence of or possibility of recording shock events or atmopshere	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3.2.3 IMPACTOR MATERIAL	What are the origin and composition of the material from the impacting objects on Mars?	4=rock of clear impact origin; 3=impactite or regolith sample (regolith tends to have a mixture of crustal components, including impact components); 2=fine-grained sedimentary samples that may better represent martian crust; 1=all other rock samples; 0=atmosphere sample	1	1	1	1	2	2	2	2	3	1	2	1	1	1	1	2
		How does this compare to impactor material found on other planetary bodies, such as the Moon?	4=rock of clear impact origin; 3=impactite or regolith sample (regolith tends to have a mixture of crustal components, including impact components); 2=fine-grained sedimentary samples that may better represent martian crust; 1=all other rock samples; 0=atmosphere sample	1	1	1	1	2	2	2	2	3	1	2	1	1	1	1	2
		Have the impactor materials changed over time?	4=rock of clear impact origin; 3=impactite or regolith sample (regolith tends to have a mixture of crustal components, including impact components); 2=fine-grained sedimentary samples that may better represent martian crust; 1=all other rock samples; 0=atmosphere sample	1	1	1	1	2	2	2	2	3	1	2	1	1	1	1	2
	3.2.4 MICROMETEORITES	What is the recent (short time) flux of interplanetary dust (micrometeorites) flux at the martian surface?	4=sample containing clear evidence of micrometeorites; 3=sample likely containing micrometeorites, and regolith; 2=sample containing possible evidence of micrometeorites; 1=samples containing weak evidence of micrometeorites; 0=samples unlikely to contain micrometeorites or atmosphere sample	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
		How do interplanetary organics and low temperature phases in micrometeorites survive at their entry in the martian atmosphere and their subsequent evolution in the martian regolith or in sedimentary rocks?	4=sample containing clear evidence of micrometeorites; 3=sample likely containing micrometeorites, and regolith; 2=sample containing possible evidence of micrometeorites; 1=samples containing weak evidence of micrometeorites; 0=samples unlikely to contain micrometeorites or atmosphere sample	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
3.3. CRATERING CHRONOLOGY	3.3.1 JEZERO FORMATION	When did Jezero crater form?	4=Jezero impact ejecta outside jezero or impact melt; 2=igneous rock from crater floor (places lower bound on Jezero age) or igneous rock outside Jezero (places upper bound) or sandstone samples closest to Belva crater inslide Jezero crater; 1=other sedimentary rocks; 0=regolith or atmosphere sample	2	1	1	2	1	1	1	1	0	2	2	1	1	1	1	1
	3.3.2 ISIDIS BASIN FORMATION	When did the Isidis basin form?	4=Samples of Isidis ejecta; 1=LCP basement, olivine-carbonate unit, and basalts (place lower bound on age of Isidis); 0=non-igneous rocks, regolith, and atmosphere	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
	3.3.3 AGE OF CRATER-RETENTION AREAS	What is the age of one or more martian geologic surface units with known crater retention ages?	4=Igneous rock clearly from the regional olivine-carbonate unit; 3=sample of igneous crater floor (Maaz unit – complicated by complex history of exhumation and burial of crater floor); 2=Seitah unit from crater floor (may or may not be the same as the regional olivine-carbonate unit; 1=rock that is of uncertain origin, either sedimentary or igneous; 0=sedimentary rocks, regolith, and atmosphere sample	3	2	2	2	0	0	0	0	0	0	0	0	1	1	1	1
	3.3.4 ABSOLUTE AGES	What are the absolute ages of the individual impact craters on Mars?	3=igneous rock for which geological context suggest age reflect impact or highly distrubed by impact (i.e., Jezero rim); 2=igneous sample from Jezero crater floor (places lower bound on Jezero age) or igneous rock from outside Jezero (places upper bound); 1=sedimentary rocks; 0=regolith or atmosphere sample	2	2	2	2	1	1	1	1	0	1	1	1	1	1	1	1
3.4. VOLATILES	3.4.1 WATER	How much water is present in the samples, and in what phases is the water found?	4=high detected presence of structural water or hydrated minerals; 3=moderate amount of structural water or hydrated minerals; 2=small amount of structural water or hydrated minerals; 1=no detectable amount of structural water or hydrated minerals, but a reasonable chance of some (including atmospheric water)	2	2	2	2	3	3	3	3	1	3	2	2	3	3	3	3
		Where is the water/OH sited in the hydrated minerals?	4=high detected presence of structural water or hydrated minerals; 3=moderate amount of structural water or hydrated minerals; 2=small amount of structural water or hydrated minerals; 1=no detectable amount of structural water or hydrated minerals, but a reasonable chance of some; 0=atmosphere sample	3	3	3	3	3	3	3	3	1	3	3	3	3	3	3	3
	3.4.2 CARBONATE	How much carbonate is present and how did it form?	4=rock with abundant carbonate-coated grains and carbonates in pores or veins; 3=rock with detrital carbonate grains; 2=rock with detected, but not abundant carbonates; 1=rock sample; 0=atmosphere	1	3	3	1	4	1	3	1	1	4	4	4	4	4	4	1
		What is its cation composition?	4=rock with abundant carbonate-coated grains and carbonates in pores or veins; 3=rock with detrital carbonate grains; 2=rock with detected, but not abundant carbonates; 1=rock sample; 0=atmosphere	1	3	3	1	4	1	3	1	1	4	4	4	4	4	4	1
		Is there an atmospheric signature in the carbonates?	4=rock with abundant carbonate-coated grains and carbonates in pores or veins, or atmosphere sample; 3=rock with detrital carbonate grains; 2=rock with detected, but not abundant carbonates; 1=rock sample	1	2	2	1	4	1	3	1	1	4	4	4	4	4	4	1
	3.4.3 TIMING OF SECONDARY MINERALS	What is the relative timing of the formation of the different secondary phases?	4=sedimentary with large amounts of secondary minerals; 3=sedimentary rock with lesser amount of secondary minerals; 2=rock of possible sedimentary or igneous origin; 1=igneous rock wiht few secondary minerals, or regolith; 0 = no solid materials	1	1	1	1	3	3	3	3	1	3	3	3	2	2	2	3
	3.4.4 WATER RESERVOIRS & PROCESSES	What are the planetary interior reservoirs of water?	4=Noachian coarse-grained igneous basement; 2=coarse cumulate igneous rock or coarse to fine sedimentary rocks; 1=fine-grained volcanic rock or regolith	1	2	2	1	2	2	2	2	1	2	2	2	2	2	2	2
	3.4.5 EXOGENOUS CONTRIBUTION OF MACROMOLECULAR ORGANICS	From what reservoirs, and by what processes, did organics/volatile organics form?	4=materials contain organic compounds; 3=materials are fine-grained or otherwise have a high potential for the preservation of organic compounds; 2=materials have medium to low potential for the preservation of organic compounds; 1=materials have a very low potential for the preservation of organic compound and regolith, 0=no potential for preservation of martian organic compounds	1	1	1	1	2	3	2	3	1	2	2	2	2	2	2	4
	3.4.6 OXIDATION	Are there any nodules/spherules indicating redox gradients?	4=nodules or spherules identified in sample with evidence for redox gradient; 3=nodules or spherules identified in sample; 2= sedimentary rock or regolith; 1 = igneous rock; 0=no solids materials	1	1	1	1	2	3	2	2	2	2	2	2	2	2	2	2
		What is the oxidation state of the samples?	4=little evidence of reduced materials; 3=little evidence of oxidized materials; 2=both oxidized and reduced minerals in roughly equivalent amounts; 1=both oxidized and reduced minerals; 0=no solid materials	1	1	1	1	1	1	1	4	1	1	1	1	1	1	1	1
		Is there an atmospheric oxidizing agent?	4=atmospheric sample or regolith; 3=fine- to medium grained sandstone or conglomerate; 2=coarse mudstone; 1=igneous rocks	1	1	1	1	3	2	2	3	4	3	3	3	3	3	2	2
		Did perchlorate on the martian surface form via oxidation by atmospheric ozone?	4=evidence of a large amount of perchlorates; 3=moderate amount of perchlorates; 2=small amount of perchlorates; 1=tentative detection of perchlorates; 0=sample contains no perchlorates	1	1	2	1	0	0	1	0	0	0	1	0	1	2	1	0
	3.4.7 VOLATILES OTHER THAN WATER	What other volatiles are captured by minerals?	4=samples with abundant sulfate minerals, carbonate minerals, iron oxides or other phases; 3=samples with detected sulfate minerals, Cl phases and iron oxide phases, carbonates may be present and even abundant; 2=samples with measureable S, Cl, and Na; 1=other rock samples; 0=atmosphere sample	3	3	3	3	4	4	3	4	3	3	3	3	3	4	3	3
		Which reservoirs do these volatiles come from?	4=samples with abundant sulfate minerals, carbonate minerals, iron oxides or other phases, also atmosphere sample; 3=samples with detected sulfate minerals, Cl phases and iron oxide phases, carbonates may be present and even abundant; 2=samples with measureable S, Cl, and Na; 1=other rock samples	3	3	3	3	4	4	3	4	3	3	3	3	3	4	3	3
3.5. MAGNETIC FIELD	3.5.1 ABSOLUTE DIRECTION OF REMANENT MAGNETIZATION	What is the absolute direction of the remanent magnetization in bulk samples with respect to a known martian reference frame?	4=oriented samples of untilted igneous bedrock; 3=oriented samples of untilted sedimentary bedrock; 2=oriented samples of float modestly rotated with respect to surrounding bedrock (Jezero samples) OR oriented samples of massive possibly tilted bedrock without paleohorizontal indicators; 1=oriented samples of float rocks not transported from their formation locations; 0 = atmosphere sample or regolith (completely unoriented)	2	4	4	4	3	3	3	3	0	3	3	3	3	3	3	1
	3.5.2 INTENSITY OF REMANENT MAGNETIZATION	What is the intensity of the remanent magnetization in bulk samples?	4=fine grained igneous rocks and/or sediments with coarse igneous clasts; 3=coarse grained igneous rock; 2=sedimentary rocks; 1=regolith (fine fragment that are likely altered); 0=atmosphere sample or regolith (completely unoriented)	4	3	3	4	2	2	2	2	1	2	4	2	2	2	2	2
	3.5.3 MAGNETIC MINERALS	What is the nature, the size range, and the quantity of magnetic minerals in igneous and sedimentary rocks?	4=all igneous and sedimentary rocks; 2=regolith; 0=no solid sample	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4
	3.5.4 AGES OF MAGNETIC MINERALS	What is the crystallization age, cooling age and/or modification age of the magnetic minerals in igneous and sedimentary rocks?	4=igneous rock; 3=possible igneous rock; 2=conglomerate with igneous clasts; 1=regolith; 0=finer grained sedimentary rocks and atmosphere	4	4	4	4	2	2	2	2	1	2	3	4	3	3	3	2
3.6. ATMOSPHERIC EFFECT ON GEOLOGY & CLIMATE	3.6.1 HISTORY OF MARTIAN ATMOSPHERE	How and when have changes in the martian atmosphere taken place?	4=atmosphere sample, samples with significant salt content; 3=regolith; 2=sedimentary rock or possible sedimentary rock; 1=igneous rock	1	1	1	1	2	2	2	2	3	2	2	2	2	2	4	4
	3.6.2 IRRADIATION HISTORY	What is the irradiation history of the martian atmosphere?	4=atmosphere sample, samples with significant salt content; 3=regolith; 2=sedimentary rock or possible sedimentary rock; 1=igneous rock	1	1	1	1	2	2	2	2	3	2	2	2	2	2	4	4
		What is the history of photochemistry and atmospheric loss?	4=atmosphere sample, samples with significant salt content; 3=regolith; 2=sedimentary rock or possible sedimentary rock; 1=igneous rock	1	1	1	1	2	2	2	2	3	2	2	2	2	2	4	4
	3.6.3 CARBONATE FORMATION HISTORY	What is the carbonate mineralogy? In what assemblage do they occur?	4=rock with abundant carbonate-coated grains and carbonates in pores or veins; 3=rock with detrital carbonate grains; 2=rock with detected, but not abundant carbonates; 1=rock sample; 0=atmosphere	1	2	2	1	4	1	2	1	2	4	4	4	3	4	4	1
		What is the formation history of carbonates?	4=rock with abundant carbonate-coated grains and carbonates in pores or veins; 3=rock with detrital carbonate grains; 2=rock with detected, but not abundant carbonates; 1=rock sample; 0=atmosphere	1	4	4	1	4	1	4	1	2	4	4	4	4	4	4	1
		What was the pressure of the past atmosphere and how did it develop?	4=rock with abundant carbonate-coated grains and carbonates in pores or veins; 3=rock with detrital carbonate grains; 2=rock with detected, but not abundant carbonates; 1=rock sample; 0=atmosphere	1	2	2	1	4	3	3	3	1	4	4	4	3	4	4	2
		How did carbonates, sulfates, and Cl-bearing phases in Jezero crater form?	4=rock with abundant carbonate-coated grains and carbonates in pores or veins; 3=rock with detrital carbonate grains; 2=rock with detected, but not abundant carbonates; 1=rock sample; 0=atmosphere	1	4	4	1	4	4	4	1	2	4	4	4	4	4	4	4
		What were the carbonate precipitation temperatures?	4=rock with abundant carbonate-coated grains and carbonates in pores or veins; 3=rock with detrital carbonate grains; 2=rock with detected, but not abundant carbonates; 1=rock sample; 0=atmosphere	1	4	4	1	4	1	4	1	3	4	4	4	4	4	4	1
		What was the elemental and isotopic composition of the fluid from which the carbonates formed?	4=rock with abundant carbonate-coated grains and carbonates in pores or veins; 3=rock with detrital carbonate grains; 2=rock with detected, but not abundant carbonates; 1=rock sample; 0=atmosphere	1	4	4	1	4	1	4	1	3	4	4	4	4	4	4	1
	3.6.4 SULFATE FORMATION HISTORY	How has photochemistry in S-bearing atmospheric species on Mars changed over time?	4=rock with very abundant sulfate minerals; 3=rock with abundant sulfur, some evidence for sulfate, 2=igneous or sedimentary rock with sulfur detected, but not abundant sulfate minerals, 1=solid sample present; 0=atmosphere sample	2	2	3	2	3	4	3	4	2	3	3	3	2	3	2	3
		How does Mars atmospheric photochemistry compare to the Earth's Archean period?	4=rock with very abundant sulfate minerals; 3=rock with abundant sulfur, some evidence for sulfate, 2=igneous or sedimentary rock with sulfur detected, but not abundant sulfate minerals, 1=solid sample present; 0=atmosphere sample	2	2	3	2	3	4	3	4	2	3	3	3	2	3	2	3
		What is the formation history of sulfates and the sulfur cycle on Mars (includes volcanic degassing, acidic conditions etc.)?	4=rock with very abundant sulfate minerals; 3=rock with abundant sulfur, some evidence for sulfate, 2=igneous or sedimentary rock with sulfur detected, but not abundant sulfate minerals, 1=solid sample present; 0=atmosphere sample	2	2	3	2	3	4	3	4	2	3	3	3	3	3	2	3
	3.6.5 FLUID/FLUID-INCLUSION HISTORY	Do the MSR samples contain fluid inclusions?	4=sample with large amounts of fluid inclusion bearing minerals; 3=sample with moderate amounts of fluid inclusion bearing minerals; 2=sample with small amounts of fluid inclusion bearing minerals; 1=sample with minor amount of fluid inclusion bearing minerals; 0=sample with no amount of fluid inclusion bearing minerals, or atmosphere	2	2	3	1	3	3	3	4	1	3	3	3	3	3	3	3
		What is elemental and isotopic composition of noble gases and nitrogen trapped in these fluid inclusions?	4=sample with large amounts of fluid inclusion bearing minerals or atmosphere sample; 3=sample with moderate amounts of fluid inclusion bearing minerals; 2=sample with small amounts of fluid inclusion bearing minerals; 1=sample with minor amount of fluid inclusion bearing minerals; 0=sample with no amount of fluid inclusion bearing minerals	2	2	3	1	3	3	3	4	1	3	3	3	3	3	3	3
		Did the elemental and isotopic composition of noble gases in the Mars atmosphere evolve with time?	4=sample with large amounts of fluid inclusion bearing minerals or atmosphere sample; 3=sample with moderate amounts of fluid inclusion bearing minerals; 2=sample with small amounts of fluid inclusion bearing minerals; 1=sample with minor amount of fluid inclusion bearing minerals; 0=sample with no amount of fluid inclusion bearing minerals	2	2	3	1	3	3	3	4	1	3	3	3	3	3	3	3
		What is the timing and history of fluid/solid/gas emplacement, and if so, what are the compositions of fluids and solids?	4=sample with large amounts of fluid inclusion bearing minerals; 3=sample with moderate amounts of fluid inclusion bearing minerals; 2=sample with small amounts of fluid inclusion bearing minerals; 1=sample with minor amount of fluid inclusion bearing minerals; 0=sample with no amount of fluid inclusion bearing minerals, or atmosphere	2	2	3	1	3	3	3	4	1	3	3	3	3	3	3	3

SCIENCE OBJECTIVE 4: HUMAN EXPLORATION

PERSEVERANCE CACHE: SAMPLE, TUBE NUMBER, LITHOLOGY

SUB-OBJECTIVE	**INVESTIGATION TOPIC**	**RESEARCH QUESTIONS**		**MONTAGNAC (4)** Igneous: fine-grained basalt	**SALETTE (5)** Igneous: medium to coarse cummulate	**ROBINE (7)** Igneous: medium to coarse cummulate	**HA'AHÓNI (9)** Igneous: basaltic andesite	**SWIFT RUN (11)** Sedimentary: fine to medium sandstone	**HAZELTOP (14)** Sedimentary: coarse mudstone	**SHUYAK (16)** Sedimentary: coarse mudstone	**KUKAKLEK (19)** Sedimentary: fine sandstone	**ATMO MOUNTAIN (20)** Regolith	**MELYN (22)** Sedimentary: medium sandstone	**OTIS PEAK (23)** Sedimentary: conglomerate	**PILOT MOUNTAIN (24)** Sedimentary: poorly-sorted sandstone	**PELICAN POINT (25)** Sedimentary/Igneous: medium to coarse grained	**LEFROY BAY (26)** Sedimentary/Igneous: medium to coarse grained	**COMET GEYSER (27)** Sedimentary/Igneous: coarse grained	**SAPPHIRE CANYON (28)** Sedimentary: fine grained
4.1.	HAZARDS OF MARTIAN MATERIALS	What are the potential physical and chemical hazards to future human explorers from martian materials?	4=any sample because chemical hazards can exist in solid, liquid, or gas phase	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
4.2. MARTIAN NATURAL RESOURCES	4.2.1 WATER ABUNDANCE & EXTRACTION	What is the abundance of water in each of the samples?	4=any sample because water can exist in solids or in gas phase	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
		At what temperatures could this water be extracted?	4=any sample because water can exist in solids or in gas phase	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	4.2.2 REGOLITH CHARACTERISTICS	What are the physical, chemical, and mineralogical characteristics of the regolith that could contribute to its use for human exploration as a building material or plant growth medium?	4=regolith; 0=all other solid samples and atmosphere	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
	4.2.3 RELEASES DUE TO REGOLITH TREATMENT	What elements can be released through aqueous or chemical (e.g., eutectic brines) treatment of rock and soil samples?	4=regolith; 0=all other solid samples and atmosphere	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
	4.2.4 PLANT-GROWTH NUTRIENTS	Which elements/nutrients necessary for plant growth are missing or in low quantity in the regolith sample?	4=regolith; 0=all other solid samples and atmosphere	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0
	4.2.5 PROPELLANT	What components that could be used as propellant are present in the materials?	4=regolith; 0=all other solid samples and atmosphere	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4