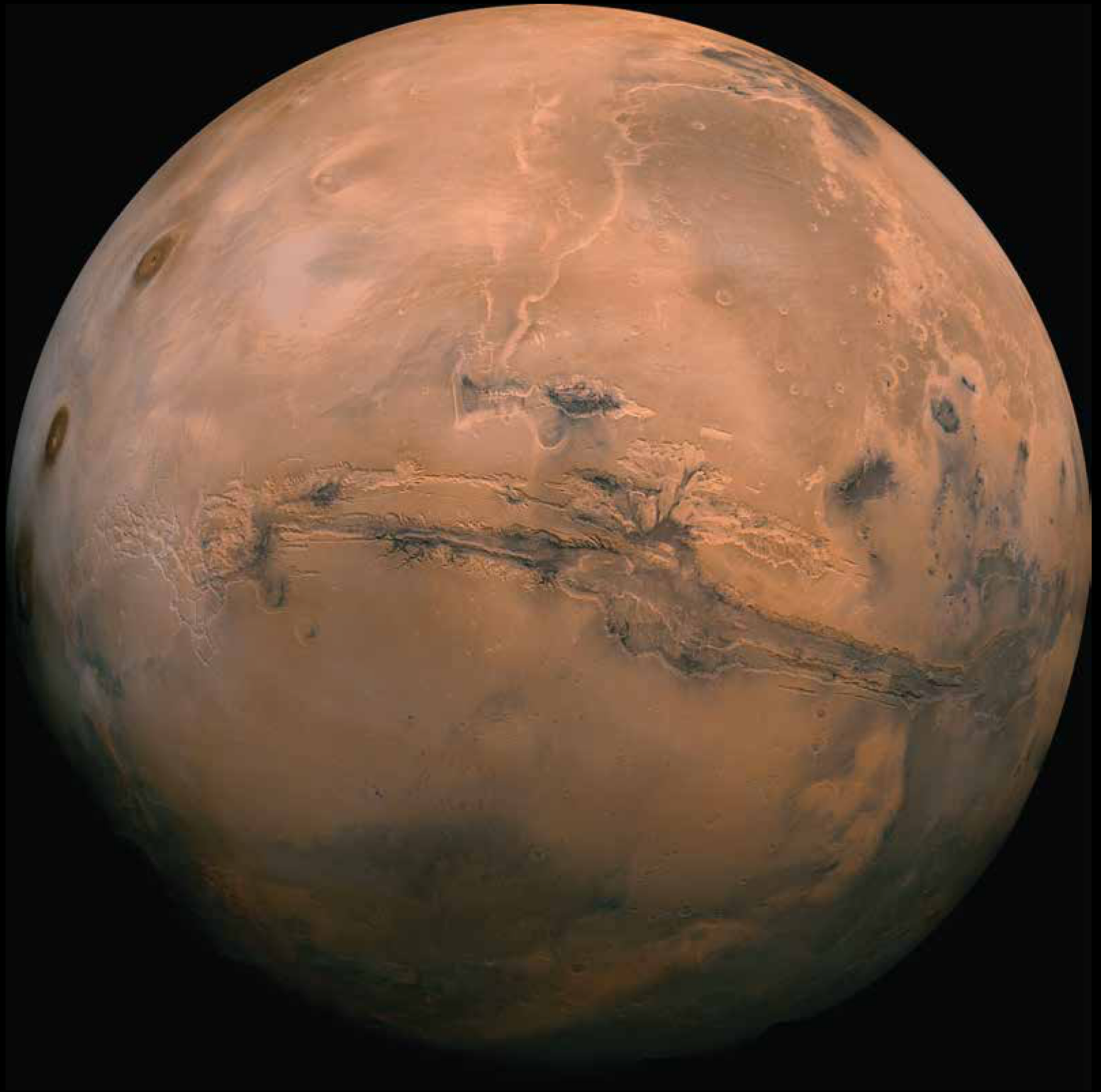




Mars Exploration Science Themes, Goals and Objectives

Table of Contents

Introduction	3
Science Goals, Objectives and Supporting Rationale	3
1. Life and Habitability	5
1.1 Extant Life	5
1.2 Modern Habitability	6
1.3 Ancient Life	6
1.4 Past Habitability	7
1.5 Organic Chemistry	7
2. Ice, Weather and Climate	8
2.1 Modern Ice and Volatiles	8
2.2 Modern Weather	9
2.3 Relict Ice	10
2.4 Climate Evolution	10
3 Geology	11
3.1 Modern Surface Processes	11
3.2 Crustal Geology	11
3.3 Geochronology	12
3.4 Martian Interior	12
3.5 Martian Moons	13
References	13

Mars Exploration Science Themes, Goals, and Objectives

Introduction

NASA's Mars Exploration Program (MEP) maintains a long-standing set of overarching goals for Mars science, informed in part by community input through documents such as the MEPAG Goals Document (MEPAG, 2025), the National Academies Planetary Science and Astrobiology Decadal Survey (PSADS; NASEM, 2024), and COSPAR planetary protection knowledge gaps (Spry et al., 2024), among others. As the scientific understanding of Mars has grown and NASA's ambitions have expanded, these goals have served as a durable foundation for prioritizing Mars investigations. The Mars Future Plan (MEP, 2024) represented a decadal-scale outlook for the Program with science themes that collectively encompass discovery-driven Mars science and the emerging needs of human exploration. The work presented here is built on the foundation of the Future Plan and represents a continuation of the long-standing MEP science goals.

As the Agency evolves its human exploration goals, and as its successful robotic missions to Mars continue to address high-priority questions across science disciplines, it is periodically necessary to ensure the MEP's program-level science goals and objectives are current. Identifying and framing of high-level science objectives will simultaneously support discovery science, prepare for human explorers, and inform planetary protection policy.

Science Goals, Objectives and Supporting Rationale

Following in line with the historical structure and nomenclature, MEP science objectives fall under three broad themes:

- Life and Habitability
- Ice, Weather and Climate
- Geology

To ensure overlap of the broad range and number of objectives and investigations proposed throughout the literature, the Program science goals are drafted at a high level, with a singular goal tied to each theme:

Science Theme	Science Goal
Life and Habitability	1. Determine the astrobiological potential of Mars and the processes that govern the preservation of organic and physical biosignatures
Ice, Weather and Climate	2. Characterize the past and present state of the Martian atmosphere, its interactions with the surface and processes controlling weather, climate, distribution of volatiles, and radiation environment
Geology	3. Determine the nature, origin, structure, composition, and evolution of the crust and the interior of Mars and its moons

Within each theme and goal, several objectives are defined (Tables 1 and 2), established by leveraging community documents and the priorities, goals, objectives, and investigations therein. Following a comprehensive survey and assessment of lower-level inputs, and with the high-level goals defined, objectives have been established to strike an additional level of specificity.

In addition to defining the objectives by themselves, supporting rationale is included, which describes each objective's relevance to three areas: discovery science, planetary protection, and preparation for human exploration. The rationale provides a straightforward link to how each objective is tied to those areas.

Moving one layer deeper, objectives have been further assessed at subcategories of planetary protection (forward contamination, backward contamination and contamination control) as well as preparation for human exploration (science return and human risk reduction). The format for objective rationale is as follows:

- *Science rationale*
- *Planetary Protection rationale [F, B, C]*
 - *[F]orward contamination*
 - *[B]ackward contamination*
 - *[C]ontamination control*
- *Preparation for Human Exploration rationale [S, E]*
 - *[S]cience: Maximizing science return*
 - *[E]ngineering: Human risk reduction*

Note, the abbreviated letters are shown in the title of each rationale header where sufficient relevancy is noted.

The resulting objectives form a coherent, strategic framework that supports mission formulation, technology development priorities, and knowledge gap closure for the coming

decade. They maintain continuity with the scientific foundations established by the community while aligning with NASA's current strategic direction for Mars exploration.

1. Life and Habitability

Determine the astrobiological potential of Mars and the processes that govern the preservation of organic and physical biosignatures

1.1 Extant Life

Determine if Mars currently harbors extant life

- Science: The search for life beyond Earth remains one of the fundamental pursuits of planetary exploration. No surface or near-surface environment on Mars is currently known to satisfy all conditions required for the replication of terrestrial organisms. However, certain locations may lie within the habitability envelope of putative Martian organisms with physiological tolerances at or beyond those of any known terrestrial life. Detection of extant life on Mars—defined here as organisms that are metabolically active or in a dormant but viable state—would represent a paradigm shift in our understanding of life in the universe and advance understanding of life's fundamental requirements, the universality of biochemical principles, and the conditions needed for the origin of life.
- Planetary Protection [F, B, C]: Viable organisms in the near-surface regolith or within globally circulating dust would pose a significant biological risk to the terrestrial biosphere through human missions or sample return. Conversely, the existence of extant life on Mars would raise profound ethical questions about the conduct of future exploration, and the risks of forward contamination by terrestrial organisms. The presence of life would demand novel mitigation strategies to prevent biological contamination. Human activity itself could irreversibly alter the biological baseline of sites visited given that forward contamination of terrestrial life is unavoidable with human exploration missions.
- Preparation for Human Exploration [S, E]: The discovery of extant life on Mars would carry immediate and practical consequences for human exploration. Martian life represents a direct biohazard to astronauts and would complicate the return of crew to Earth, potentially requiring complex containment and quarantine protocols. Beyond crew safety, the presence of a viable Martian biosphere would impose new constraints on in situ resource utilization (ISRU). Although human explorers will contribute to life detection investigations, baseline measurements of near-surface habitability, potential biosignatures, and microbial viability with precursor robotic missions will help interpret any future findings. There will be increased ambiguity in differentiating between Martian and terrestrial signals following a human presence on the surface.

1.2 Modern Habitability

Characterize the modern habitability of Martian environments

- Science: Characterizing current habitability conditions on Mars informs what locations have the highest biological potential today. It provides the important physical and chemical context necessary to recognize and interpret potential biosignatures and allows prioritization of candidate habitable environments for further exploration. Modern habitability assessments also enable investigations of environments that are rare on Earth, thereby expanding our understanding of the potential boundary conditions of life. In addition, the possibility of habitable environments in the deep subsurface must be considered.
- Planetary Protection [F, C]: Improved understanding of modern Martian habitability constrains the environments in which terrestrial microorganisms could survive and propagate, enabling more targeted planetary protection measures. In addition, in situ habitability assessments will provide a baseline for estimating the likelihood of extant life in other locations not yet directly sampled. An improved understanding of modern-day habitability would impact planetary protection requirements for robotic and human missions derived from conservative, worst-case assumptions or based primarily on extrapolations from imperfect terrestrial analogs.
- Preparation for Human Exploration [S, E]: Knowledge of modern Martian habitability has implications for landing site selection and would impact operational parameters for human explorers if environmental conditions are suitable for life. This knowledge also informs where astronauts would be permitted to work, what equipment and tools could be deployed, and how samples must be handled.

1.3 Ancient Life

Search for physical or chemical signatures of ancient life in environments that have a high potential for past habitability and preservation of biosignatures

- Science: Prior missions have obtained compelling evidence that Mars was once habitable, during time periods for which the terrestrial geological record has been largely destroyed or overprinted. Mars preserves a potentially unique window into processes in the early solar system that may or may not have been conducive to the origin of life. Evidence of ancient Martian life would constrain the timing of, and prebiotic conditions required for, the origins of life. Lack of evidence, while simply indicating life never took hold on Mars, could also be explained by biosignature degradation, sampling bias, or a fundamental decoupling between habitability and the conditions that allow life to begin.

- Planetary Protection [F, B, C]: Evidence of ancient life would elevate concerns about forward biological contamination, given the possibility that surviving lineages exist in unexplored, cryptic, or subsurface environments. This could result in changes to forward and backward contamination policies. Lack of evidence amidst broad sample coverage would reduce the probability of extant life, providing empirical justification for relaxing forward and backward planetary protection requirements, both for humans and for robotic missions.
- Preparation for Human Exploration: <Lesser tie-in>

1.4 Past Habitability

Constrain the evolution of habitability over geologic timescales

- Science: Early Mars was warmer and wetter than the present, as evidenced by the presence of robust valley network systems, crater lakes, widespread deposits of secondary minerals, and other geomorphic evidence. Studies of these environments across different ages and geologic context would provide important insights about the evolution of a once widely habitable world. Mars may have been transiently habitable in the geologically recent past under different orbital configurations. Mars represents a planetary-scale case study with implications for understanding how such transitions occur on other terrestrial planets.
- Planetary Protection: <Lesser tie-in>
- Preparation for Human Exploration: <Lesser tie-in>

1.5 Organic Chemistry

Assess the extent of biotic or abiotic organic chemical evolution

- Science: Characterizing the organic inventory in Martian environments that are otherwise sterile helps us understand the extent of abiotic organic chemical evolution, which is relevant for better understanding the origin of life. It also provides a more complete understanding of the abiotic ‘background,’ against which chemical biosignatures must be recognized. The chemical and structural properties of abiotic organic compounds near the surface also provide clues of possible transformation processes (e.g., radiolytic, oxidative) that may affect chemical signatures of life. Even if Mars is sterile, characterizing the organic inventory helps us understand organic chemical evolution in habitable environments, past and present.
- Planetary Protection [F, B]: Understanding the organic inventory and whether it is abiotic, biotic, and/or prebiotic would help inform forward and backward contamination

requirements, allowing them to evolve from largely conservative, precautionary assumptions to more evidence-based risk management.

- Preparation for Human Exploration: <Lesser tie-in>

2. Ice, Weather and Climate

Characterize the past and present state of the Martian atmosphere, its interactions with the surface and processes controlling weather, climate, distribution of volatiles, and radiation environment

2.1 Modern Ice and Volatiles

Identify and characterize the emplacement, exchange and evolution of present-day water ice and other volatiles at or near the Martian surface

- **Science:** Water and other volatiles (most notably CO₂) are fundamental regulators of Martian climate, geology, and habitability. Determining how modern-day reservoirs—at or near the surface—were emplaced and how they exchange between the atmosphere and surface on both short (diurnal, seasonal) and longer (multiannual) time-scales is essential for reconstructing Mars’ environmental history, assessing past and present habitability, and understanding planetary evolution. Observations of atmospheric ices (water and CO₂ clouds) as well as surface ice provide constraints on the energy balance of the Martian system. Studying interannual variability informs us about seasonal or annual trends in the accumulation or loss of volatiles.
- **Planetary Protection [F, B]:** Regions that preserve and contain water ice at and near the surface at present are generally considered regions of greater habitability potential. These regions, therefore, warrant greater scrutiny to protect potential Martian life, minimize the risk to terrestrial life, and avoid irreversible contamination by the same. As such, a choice to explore in such locations would affect both forward and backward planetary protection protocols.
- **Preparation for Human Exploration [S, E]:** Water ice found at and near the surface is an attractive resource for future human explorers, both for survivability purposes as well as propellant generation (ISRU). Hence, the choice of where to send humans to Mars may depend on finding areas with nearby, accessible water reservoirs to leverage. Conversely, the instability and heterogeneous distribution of subsurface ice may present a challenge to safe landing and construction of basic infrastructure. Constraints on the nature of near-surface water ice and its spatial distribution will help ensure astronauts are able to precisely target locations where such deposits are readily accessible with minimal traverse necessary. Monitoring surface temperatures at candidate landing sites, especially those containing microenvironments or

habitable niches, may facilitate investigation of the diurnal and seasonal surface-atmosphere exchange of water.

2.2 Modern Weather

Characterize the state and controlling processes of the present-day weather, climate, and radiation environment

- Science: There is significant variability in the present-day Martian atmosphere across multiple timescales, driven by seasonal and diurnal variability in atmospheric dust, which is known to interact with the Martian water cycle, impact radiative balance, and influence circulation on both small and large spatial scales. Year-over-year variability in the atmosphere, which arises from as-yet-not-understood feedback between dust lifting, transport, and solar input, is far more pronounced on Mars than elsewhere in the solar system. Mars' global circulation transports dust, water vapor, and other trace species around the planet, but the mechanics of transport, especially at smaller scales, are poorly constrained. Ionized species in the upper atmosphere interact with the planet's magnetic field, thus directly linking atmospheric, geologic and (potentially) biologic processes together. Many atmospheric processes are similar to those on Earth, but characterizing where they differ, and the effect of those differences on circulation and weather, helps us understand how atmospheres behave, physically and dynamically, under conditions different from Earth.
- Planetary Protection [E, B, C]: Lower atmospheric circulation can loft and carry dust and potential microbes to distances far from their source. Forward contamination from human explorers may inadvertently spread invasive biota to regions of the planet some distance away from their physical location; thus, weather-driven transport processes must be understood to quantify the extent of such contamination, ensuring future investigations can discriminate between endemic and introduced life.
- Preparation for Human Exploration [S, E]: The process of entry, descent, and landing requires knowledge of atmospheric density and wind, especially when pinpoint landing is desired. These values require regular, global observation of atmospheric conditions, including wind, pressure, and temperature. Upper atmospheric conditions, and knowledge of space weather and the state of the magnetosphere, will provide needed insight into the radiation environment to be experienced by astronauts in Mars orbit and/or on the surface. Improved dust characterization and developing the ability to monitor and predict local and regional weather will enhance crewed surface planning and operations to ensure physiological safety, as well as protection of sensitive equipment and infrastructure.

2.3 Relict Ice

Understand the emplacement and evolution of past ice reservoirs at the Martian surface and within the crust over geologic time

- Science: Ice reservoirs (water and CO₂), likely present across much of Mars' geologically recent past, and of which some remain today, are important aspects of the climate system that preserve a record of past climate(s) over astronomical timescales. The location, volume and composition of relict ice is necessary to determine ice redistribution over Mars' recent history and will help reconstruct past climate states, including potentially habitable scenarios. Older ice reservoirs are present today deep beneath the surface (and often mixed with sediment). Assessing trapped gases, refractory composition and volume, and isotopic composition in layered ice deposits can provide insight into previous orbital configurations and climatic states. These deposits may also serve as a natural laboratory to understand volatile chemistry in conditions that have no similar terrestrial analog.
- Planetary Protection: <Lesser tie-in>
- Preparation for Human Exploration [E]: Relict water ice represents a resource that shares overlap with near-surface ice. However, it is distinguished by factors such as its overburden or depth to ice (many meters to kilometers) and higher bulk sediment fraction due to sublimation lag or aeolian deposition. It is likely that these deeper deposits will serve a more substantial role for longer surface stays.

2.4 Climate Evolution

Find evidence for the state of Mars' early climate, the factors that controlled it, and how it evolved from the past to the present

- Science: The transition of Mars from an early warm and wet environment to the present cold, dry desert is an enduring puzzle and influences our understanding of Martian habitability, climate and geology, and that of other terrestrial planets in our solar system and beyond. There is evidence of liquid water at the surface in the past, both from geomorphological and mineralogical observations, but the timeline of atmospheric loss (including water lost to space) is only weakly constrained. Whether early Mars was persistently warm and wet, or only episodically habitable, and the duration of liquid water on the Martian surface, remain open questions. The climate's link to interior processes (solidification of the core, loss of Mars' magnetic field, volcanic outgassing) means that studying Mars' evolving climate over time is complementary to studying the change in the geological and geodynamical evolution of the planet.
- Planetary Protection: <Lesser tie-in>

- Preparation for Human Exploration: <Lesser tie-in>

3 Geology

Determine the nature, origin, structure, composition, and evolution of the crust and the interior of Mars and its moons

3.1 Modern Surface Processes

Identify and characterize the processes that are actively shaping the present-day surface of Mars

- Science: Modern surface change involves those processes that shape the present-day landscape, modify surface properties, and enable the transport of material across the surface. Among these are aeolian activity (dust lifting, saltation, sedimentation) impact events, mineral deliquescence/efflorescence, freeze-thaw cycles, and CO₂ frost/water ice mass wasting. Both physical and chemical weathering affect surface materials and their properties. Key questions surround the formation, composition, and behavior of dust in the Martian environment, including how such processes drive erosion or surface burial. Terrestrial analogs cannot provide complete explanations due to fundamental physical differences (gravity, environment) and the absence of widespread biology, thus studying these processes at Mars is crucial.
- Planetary Protection [E, B, C]: Knowledge of modern aeolian transport on Mars may affect forward planetary protection policies as they relate to contaminant dispersal from landed assets (i.e., forward contamination) as well as containment regarding returned sample/cargo or human explorers (i.e., backward contamination). Transported contaminants can also be trapped in environments that later become habitable, (e.g., spores can become reanimated).
- Preparation for Human Exploration [S, E]: Dust and other materials mobilized at the surface constitute potential hazards for astronaut health and engineering systems as well as remote sensing instrumentation. Understanding the dynamic nature of the surface and the propensity for destabilization and mass wasting is important for safe landing(s) and operations.

3.2 Crustal Geology

Study the key processes that have modified the Martian crust over geologic time

- Science: Crustal geology details Mars' volcanic and sedimentary histories from its state today and dating back to the earliest primordial crust—a record far better

preserved on Mars than on Earth. The aim is to understand the imprint and interplay of the different processes that shaped the crust, including aeolian, volcanic, tectonic, hydrological, and impact processes. This includes unraveling source-to-sink processes, and the nature, timing, and duration of past water activity. Additionally, it aims to understand past-to-present processes operating within the crust, such as tectonism and hydrothermal activity.

- Planetary Protection: <Lesser tie-in>
- Preparation for Human Exploration [S, E]: Characterization and assessment of hazardous minerals and/or potentially toxic elements at or beneath the surface is essential to ensure health and safety of human explorers. Geotechnical surveys and evaluation of potential landing sites will ensure exploration sites are safe for landing, traverse and operations. Additionally, areas of geologic interest should be identified to maximize science returned by human exploration (e.g., modern groundwater systems for the search for extant life).

3.3 Geochronology

Determine the timing of construction and modification of the crust

- Science: Determining the age and timing of key geologic events is important for understanding the entire history of Mars. Examples include basin-forming impacts, formation of large volcanic provinces, and the timing of large-scale fluvial episodes. Geochronology enables ground truthing of crater density ages as well as understanding crustal emplacement, modification, sedimentation history, diagenesis, lithification, and exhumation. It can also constrain modern processes such as erosion or tectonic rates tied to surface exposure dating.
- Planetary Protection: <Lesser tie-in>
- Preparation for Human Exploration: <Lesser tie-in>

3.4 Martian Interior

Understand how Mars' interior structure, composition, and dynamics relate to Mars' formation and subsequent evolution

- Science: Knowledge of how Mars' interior evolved throughout its history and how its composition and evolution are different from other terrestrial planets will provide fundamental insights into the processes that govern planetary differentiation, habitability, and the diversity of rocky worlds both within and outside of our solar system. Additionally, studying the history of the Martian dynamo, the loss of the global magnetic

field, and how this affected the loss of Mars' atmosphere will constrain the timeline of Mars' climate evolution. Understanding the current differentiation and thermal state of the planet's interior, and how it evolved through time will elucidate the exchange of material and heat between the interior and surface, which governs volcanic and tectonic activity and provides a unique record of early planetary evolution.

- Planetary Protection: <Lesser tie-in>
- Preparation for Human Exploration: <Lesser tie-in>

3.5 Martian Moons

Understand the formation and evolution of the Martian planetary system

- Science: Advancing our knowledge of the Martian moons includes elucidating their origin and age, providing insight into the formation and evolution of Mars itself, including accretion and impact processes. Characterizing the structure and composition of the moons helps us understand the dynamic processes involved in evolution of the early solar system (e.g., asteroid capture). Improving our knowledge of the orbital evolution of Phobos and Deimos would provide insight into the evolving interior structure of Mars.
- Planetary Protection: <Lesser tie-in>
- Preparation for Human Exploration: <Lesser tie-in>

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Table 1: MEP Science Goals and Objectives with full descriptive headers. Objectives colored in orange have greatest overlap with Agency priorities of advancing human exploration and/or planetary protection.

MEP Science Goals & Objectives				
Science Themes	Science Goals	Science Objectives† (shorthand)	Science Objectives†	
Life and Habitability	1. Determine the astrobiological potential of Mars and the processes that govern the preservation of organic and physical biosignatures	1.1 Extant Life	Determine if Mars currently harbors extant life	
		1.2 Modern Habitability	Characterize the modern habitability of Martian environments	
		1.3 Ancient Life	Search for physical or chemical signatures of ancient life in environments that have a high potential for past habitability and preservation of biosignatures	
		1.4 Past Habitability	Constrain the evolution of habitability over geologic timescales	
		1.5 Organic Chemistry	Assess the extent of biotic or abiotic organic chemical evolution	
Ice, Weather and Climate	2. Characterize the past and present state of the Martian atmosphere, its interactions with the surface and processes controlling weather, climate, distribution of volatiles, and radiation environment	2.1 Modern Ices and Volatiles	Identify and characterize the emplacement, exchange and evolution of present-day water ice and other volatiles at or near the Martian surface	
		2.2 Modern Weather	Characterize the state and controlling processes of the present-day weather, climate, and radiation environment	
		2.3 Relict Ice	Understand the emplacement and evolution of past ice reservoirs at the Martian surface and within the crust over geologic time	
		2.4 Climate Evolution	Find evidence for the state of Mars' early climate, the factors that controlled it, and how it evolved from the past to the present	
Geology	3. Determine the nature, origin, structure, composition, and evolution of the crust and the interior of Mars and its moons	3.1 Modern Surface Processes	Identify and characterize the processes that are actively shaping the present-day surface of Mars	
		3.2 Crustal Geology	Study the key processes that have modified the Martian crust over geologic time	
		3.3 Geochronology	Determine the timing of construction and modification of the crust	
		3.4 Martian Interior	Understand how Mars' interior structure, composition, and dynamics relate to Mars' formation and subsequent evolution	
		3.5 Martian Moons	Understand the formation and evolution of the Martian planetary system	
†All objectives are aligned with the sustained, decade-long exploration program in understanding of the history and evolution of Mars, while those in orange indicate objectives with greatest overlap with agency priorities of advancing human exploration and/or planetary protection.				

[†]All objectives are aligned with the sustained, decade-long exploration program in understanding of the history and evolution of Mars, while those in orange indicate objectives with greatest overlap with agency priorities of advancing human exploration and/or planetary protection.

Table 2: MEP Science Goals and Objectives with traceability to the MEP Future Plan and NASEM Decadal Survey. Areas of substantive tie-in to aspects of planetary protection and/or preparation for human exploration are indicated. Objectives colored in orange have greatest overlap with Agency priorities of advancing human exploration and/or planetary protection.

MEP Science Goals & Objectives with Traceability

Science Themes	Science Goals	Science Objectives [†] (shorthand)	MEP Future Plan	Decadal	Planetary Protection			Preparation for Human Exploration	
					Forward	Backward	Contamination Control	Science [§]	Engineering
Life & Habitability	1. Determine the astrobiological potential of Mars and the processes that govern the preservation of organic and physical biosignatures	1.1 Extant Life	S1, S2	Q9, Q11	X	X	X	X	X
		1.2 Modern Habitability	S1, S2, S3	Q10	X		X	X	X
		1.3 Ancient Life	S1, S3	Q9, Q11	X	X	X		
		1.4 Past Habitability	S1, S3	Q10					
		1.5 Organic Chemistry	S1, S2	Q9	X	X			
Ice, Weather and Climate	2. Characterize the past and present state of the Martian atmosphere, its interactions with the surface and processes controlling weather, climate, distribution of volatiles, and radiation environment	2.1 Modern Ices and Volatiles	S2, S3	Q6, Q9	X	X		X	X
		2.2 Modern Weather	S2, S3	Q6	X	X	X	X	X
		2.3 Relict Ice	S2, S3	Q6					X
		2.4 Climate Evolution	S3	Q6, Q10					
		3.1 Modern Surface Processes	S2, S3	Q5	X	X	X	X	X
Geology	3. Determine the nature, origin, structure, composition, and evolution of the crust and the interior of Mars and its moons	3.2 Crustal Geology	S2, S3	Q5, Q10				X	X
		3.3 Geochronology	S3	Q3, Q5					
		3.4 Martian Interior	S3	Q3, Q5					
		3.5 Martian Moons	S3	Q3					

[†]All objectives are aligned with the sustained, decade-long exploration program in understanding of the history and evolution of Mars, while those in orange indicate objectives with greatest overlap with agency priorities of advancing human exploration and/or planetary protection.

[§]All objectives will have some 'baseline' science value in preparing for human exploration, e.g., identifying regions of scientific interest for future landed missions, or serving to maximize efficiency of human activities. Objectives marked here indicate a more substantial scientific role for human exploration beyond the baseline.