MEPAG Tiger Team Report On Mars Human-Mission Science Objectives

Presentation to NASEM Committee On Mars Human-Mission Science Objectives
26 April 2024

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Full report available at *https://www.lpi.usra.edu/mepag/reports/reports/MHMSOTT-report-rev-1-r.pdf*

Task Request And Process

- Mars Exploration Program Analysis Group (MEPAG) was asked by Joel Kearns (head of ESSIO at NASA HQ) to identify science objectives for human Mars missions, as input into annual NASA evaluation and revision of Moon to Mars Architecture Definition Document (M2M ADD)
- Purpose was to provide rapid input, anticipating that a planned NASEM study on related topics will provide comprehensive and long-term input that will be well-vetted through the scientific community
- MEPAG formed a group to respond, as a Tiger Team (TT) due to the rapid turnaround requested
- Initial request to MEPAG, 28 July 2023; report submitted, 27 September 2023; rev 1 submitted 24 October 2023
- Tiger team membership:

Bruce Jakosky, Univ. of Colorado, chair
Sydney Do, JPL
Bethany Ehlmann, Caltech
Jim Head, Brown Univ.
Mike Hecht, MIT
Jen Heldmann, NASA/Ames
Tom McCollom, Univ. of Colorado
Mike Mellon, Cornell
Michael Mischna, JPL
Allan Treiman, LPI
Robin Wordsworth, Harvard
Aileen Yingst, PSI
Richard Zurek, JPL

Key Process-Related Takeaway Points

- NASA should incorporate science into planning both early and on a regular/ongoing basis
- NASA should engage with the full Mars science community to get wide input and develop consensus
- NASA architecture team should include integration with human health and performance, planetary protection issues and their communities

Some Of The Key Ground Rules And Assumptions

- We assumed that this is the first input of what should become an ongoing and regular interaction between scientists, engineers, and mission architects; infusion of science cannot be a one-time discussion or interaction
- We focused on the *planetary science* objectives that can be addressed at Mars.
- Science objectives are chosen to focus on high-value science where humans on Mars can contribute substantially or may be necessary; emphasis is NOT “well, humans are going anyways, what can we have them do that might be useful?”
- Prioritization of science objectives for Mars will require significant discussion with and input from the Mars science community; such discussion was not possible within the abbreviated timeframe of this tiger-team activity.
- There was minimal opportunity for vetting of the draft report with the community; we did get feedback from the MEPAG steering committee and from a presentation at a virtual MEPAG meeting.

Key Issues Addressed In Report

- Areas In Which Human Involvement Will Be Particularly Effective Or Necessary
- Science Objectives For Human Missions To Mars
- Example Mission Concepts and Function/Use Cases
- Other Important Aspects Of Human Exploration Of Mars
    - Robotic Missions Coordinated With Human Missions Would Be Of Great Value To The Overall Program
    - “Site-Agnostic” Activities That Should Be Done At Any/Every Site
    - Potential Value Of Teleoperation At Remote Sites
    - Example Human Tool Development Needed For Science Priorities

Some Of The Areas In Which Human Involvement Will Be Particularly Effective Or Necessary

Based on the science objectives and measurements, human involvement is judged to be particularly effective and/or necessary for:

- Field geological investigation of the history of a site, informed by the astronaut's ability to respond immediately to local discovery, the context of potential samples (and requiring a comprehensive astronaut field- and classroom-training program), and ability to instantly integrate disparate scales and relationships
- Intelligent sample selection and triage based on field investigation and observations
- Identifying issues/processes not identified in remote observations made in preparation for human missions (i.e., where we got it wrong ahead of time, and how we should modify plans accordingly)
- Ability to access a wider variety of terrains in a dramatically shorter time and sample more effectively than with robotic missions
- Preliminary analysis while on the surface, to get preliminary results, to inform planning/replanning for ongoing measurements and field work, and to ensure that the most valuable samples are returned to Earth; will require *in situ* lab facilities
- Troubleshooting when issues arise (as they certainly will)

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- Identif ... nan missio ... gly)

Category	Perseverance Rover	Apollo 17
Distance travelled	~ 22 km	~ 36 km
Mass of samples collected	~ 0.4 kg (23 samples)	~ 110 kg
Duration of mission	~ 3 years	~ 3 days

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Science Objectives For Mars (additional detail on following charts)

High-Level Objectives (not expected to change in the foreseeable future)**:**

- ***Astrobiology:*** Determine if life ever developed on Mars, including assessment of the extent of organic, abiotic chemical evolution and the distribution of liquid-water environments and their habitability over time
- ***Climate and volatiles:*** Understand the processes and history of water and climate change on Mars, including the timing of major events and transitions from the ancient environment through more recent geological times and into the modern climate
- ***Geology/Geophysics/Geochemistry:*** Understand the physical record of planetary evolution from planetary formation until today and the processes driving the evolution of the surface, crust, and interior of Mars and how they compare to Earth and other planets

- These science objectives follow directly from the NASEM Planetary Science Decadal Survey, MEPAG Science Goals and Objectives Document, and MASWG future-Mars-program report; they will not necessarily match one-to-one with these previous documents, as the latter were all developed to specifically and explicitly address the robotic exploration program
- Does not include potential science or engineering measurements required in preparation for human missions

Detailed Science Objectives For Mars Human Exploration (1 of 3)

Astrobiology: Determine if life ever developed on Mars, including assessment of the extent of organic, abiotic chemical evolution and the distribution of liquid-water environments and their habitability over time

- **Search for evidence of *present* Martian life in high-potential environments**, sampling at multiple locations and depths and synthesizing contextual information from diverse sources in real time.
- **Search for evidence of *past* Martian life and/or organics in high-potential environments**, looking for multiple, independent biosignatures and iteratively performing field studies and *in situ* laboratory analyses.
- **Determine whether any life present in Martian materials might share ancestry with Earth** through measurement of any biomolecules as part of the organic chemical inventory to assess their function (including, for ancient life, their pre-degradation form).
- **Determine the duration and persistence of surface and sub-surface habitable environments on Mars**, past and present, by examining the record of environmental conditions (e.g., T, pH, Eh, water activity), availability of essential nutrients, and other relevant factors.

Detailed Science Objectives For Mars Human Exploration (2 of 3)

Climate and volatiles: Understand the processes and history of climate change on Mars, including the timing of major events and transitions from the ancient environment through more-recent geological times and into the modern climate.

- **Determine the nature of Mars' enigmatic early climate and Noachian-Hesperian transition** (i.e., continuously vs. episodically warm, top-down vs. bottom-up hydrological cycle) via field and laboratory analyses of the geologic record at representative locations (e.g., in the southern highlands); understand the processes responsible for the changing climate
- **Determine if Mars ever possessed a northern ocean** via field and laboratory analyses near the location of proposed ancient shorelines.
- **Understand the processes driving geologically recent climate change on Mars** via field and sample analysis of mid- to high-latitude ice and polar deposits.
- **Establish whether liquid water is present on Mars today in the subsurface** by performing geochemical and geophysical measurements of ices and recent hydrous minerals over multiple locations; characterize water activity at the surface, in the subsurface, and at mineral/ice interfaces.
- **Understand the nature, including the drivers, of variability in the current climate (e.g., large dust storms) and trace-gas composition** and their relevance to earlier climate change.

Detailed Science Objectives For Mars Human Exploration (3 of 3)

Geology/Geophysics/Geochemistry: Understand the physical record of planetary evolution from the first billion years until today and the processes driving the evolution of the crust and interior of Mars and how they compare to Earth and other planets.

- **Map and measure the geological, chemical, mineralogical, and hydrological characteristics of Mars' stratigraphic record** to provide insight into the range and diversity of environments and the timing of major geologic transitions.
- **Identify the current and historical rates of impacts,** in order to understand the planetary geochronology as well as its implications for climate history.
- **Identify and classify tectonic and volcanic landforms** and provide fundamental constraints on lithospheric properties via field mapping, petrographic and chemical analysis and dating of target locations identified from orbit.
- **Determine the fundamental nature of the ancient crust on Mars (e.g., volcanic or sedimentary?)** via *in situ* measurements of crustal composition and mineralogy with accompanying radiometric dating at key locations.
- **Understand the nature of recent and ongoing geological processes**, through examination of Amazonian terrains combined with analysis of modern phenomena

Implementing Science Requirements With Example Missions

- Technical/engineering implementation should flow from analysis of requirements necessary to achieve science objectives for specific selected sites (i.e., architecting from the right)
- We developed Example Use Cases to allow consideration of a range of implementation requirements. Similar objectives may be achievable at different sites or by different implementation approaches
- Focus is on individual missions that can address specific science objectives and not on implementation *per se*. The sites chosen here were meant to explore the range of possibilities. Previously visited sites (e.g., Columbia Hills) were generally not included but are possibilities, especially for short-stay, early missions given their known environments.
- Missions explored were (*not in a priority order*):
    a. Hesperian-Amazonian Climate History - Utopia Planitia
    b. Mid-/high-latitude ice
    c. Valles Marineris
    d. Recent volcanism – Cerberus Fossae
    e. Ancient water-altered southern highlands
    f. Cave exploration mission
- ***This set of use cases is representative, not exhaustive!***
- ***Given the complexity of Mars' evolutionary history and the tremendous diversity of environments on Mars, no single site can address all of the high-priority science goals.***

Example Mission Concept: Hesperian-Amazonian Climate History - Utopia Planitia (1 of 3)

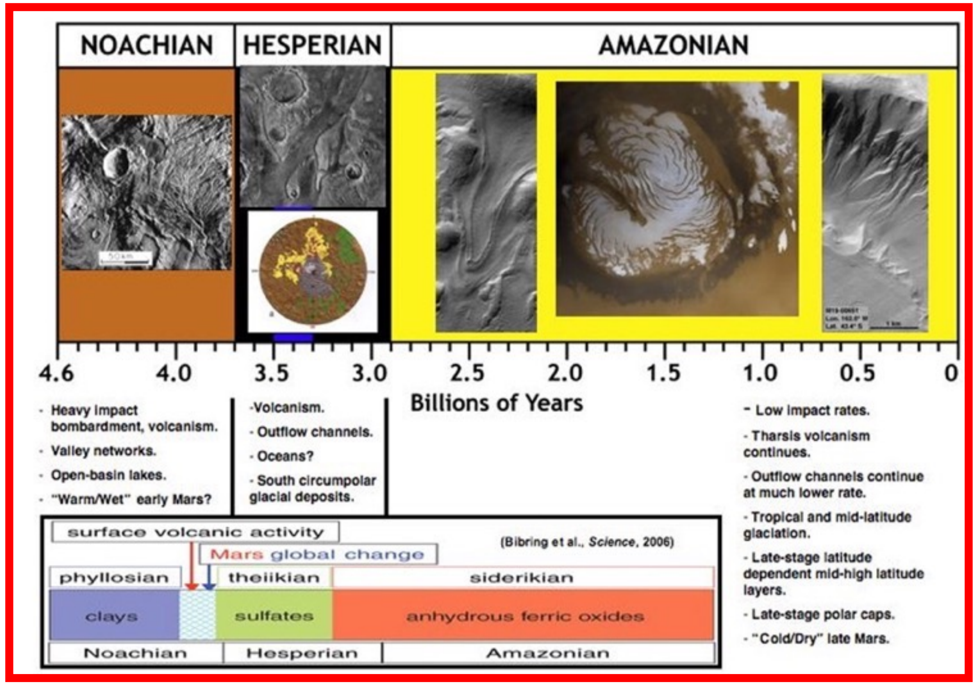
The geologic record of water and climate change on Mars is critical to the understanding of the history of the Martian atmosphere, and the possible presence of candidate habitable environments.

Mission Goals: Address 4 key questions:

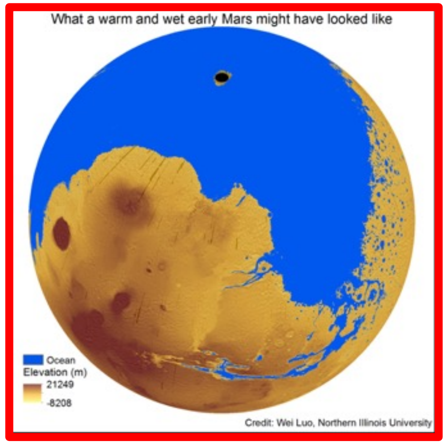
- How did Mars evolve from its early warmer and wetter climate into the hyper-arid, hypothermal desert of today?
- Did Mars have oceans in the northern lowlands in the Late Noachian and Late Hesperian, and if so, what was their extent?
- Was Amazonian Mars dominated by spin-axis/orbital-parameter cycles inducing glacial climate cycles and when was the most recent glacial phase?
- Did this evolution produce habitable environments?

Mission duration 30 days minimum to address the following two major objectives; longer duration would allow investigation of additional types of sites:

- Explore and return samples from the highest candidate oceanic shorelines and their vicinity for evidence of the presence, nature and duration of an ocean or oceans.
- Explore and return samples from the lowest-latitude candidate Late Amazonian glacial deposit to assess their nature, sequence, cementation, and post-emplacement modification.



Geologic and mineralogic history of Mars.



Hypothesized extent of oceans.

Mars in an ice age.

Hesperian-Amazonian Climate History - Utopia Planitia (2 of 3)

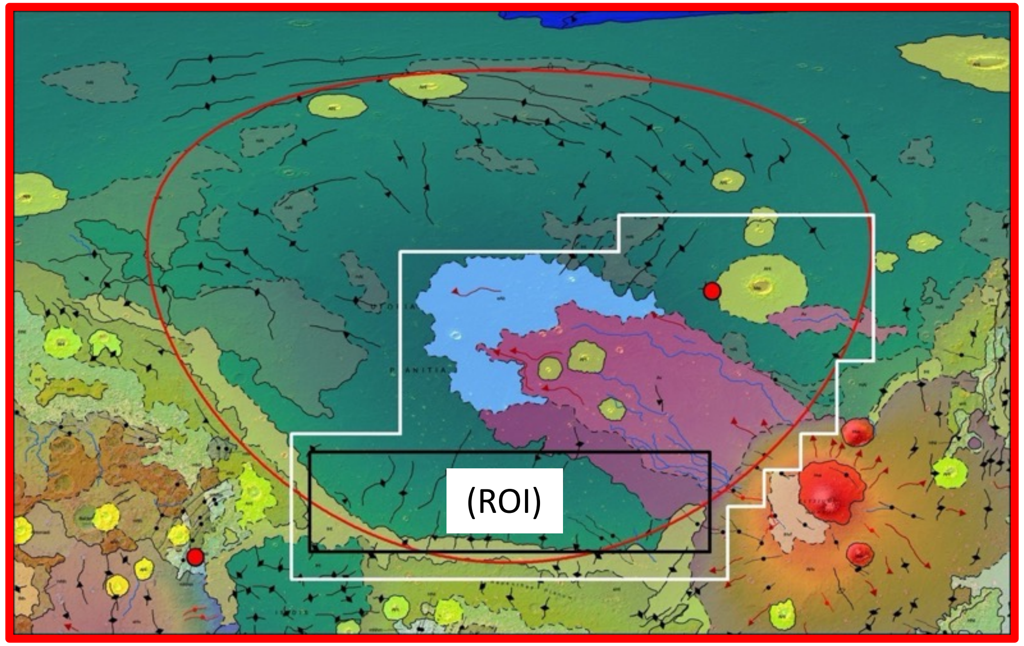
On the basis of globally extensive site-selection criteria, we recommend the Southern Utopia Planitia Region of Interest (ROI).

<u>Capabilities required</u>:

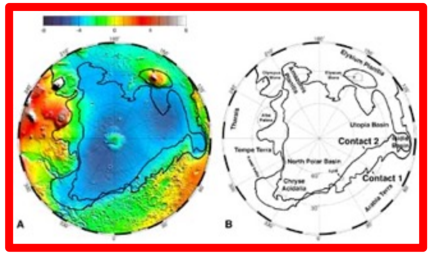
- Targeted landing with ability to traverse 25 km N and 25 km S
- <u>Oceans Deposits/Features</u>: Access to proposed shorelines, small pitted cones, impact ejecta stratigraphy, pedestal craters, possible tsunami deposits, etc.; specific sample locations identified in orbital images and surface/rover observations.
- <u>Glacial Period Deposits</u>: Access to range of transition facies identified in orbital images & surface/rover observations.

<u>Unique Characteristics</u>:

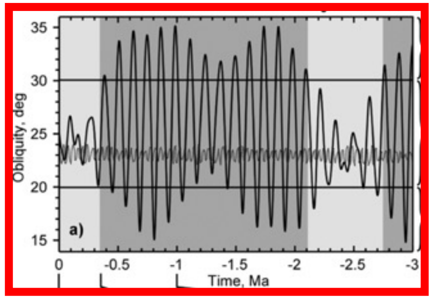
- Calls on unique human capabilities for site assessment, sample selection.
- Addresses two different but fundamentally important problems in Mars climate history.
- Characterized by specific scientific goals and targets linked clearly to the overarching question.
- Calls on previous orbital/surface exploration results to guide site selection, traverse planning and sampling strategy.
- Very high likelihood of success; demonstrates pinpoint landing for future exploration.



Geologic map of Southern Utopia showing ROI.



Previously proposed ocean shorelines



Mars obliquity cycles for the last 3 Ma.

Example Mission Concept Function And Use Case: Hesperian-Amazonian Climate History – Utopia Planitia (3 of 3)

Use Cases

- Crew takes excursions to sites located ~25 km north and south from landing location
- At each site, crew:
  - Identifies and analyzes candidate rock and soil samples using mobile and handheld in situ instruments
  - Collects multiple rock and regolith samples
  - Collects multiple soil cores to 2m depth
  - Digs trenches >2 m depth and collects samples from depth
- Crew further analyzes collected samples with in-situ laboratory equipment
- Crew selects and prepares selected samples for Earth return

(a). Hesperian-Amazonian Climate History Ref. Mission

Functions

- Visit multiple diverse sample collection sites, located potentially 50 km apart
- Analyze candidate rock and soil samples with in situ instruments
- Collect and store multiple surface and subsurface rock and soil samples from multiple geologic units/features at each site
- Analyze collected samples with in situ instruments to select samples for Earth return
- Prepare selected samples for Earth return
- Transport selected samples to Earth

Element Allocation

- Crew
- Surface mobility
- xEVA and associated sample collection tools (including soil coring and trenching tools)
- Sample handling and preparation equipment
- In-situ remote sensing instruments (e.g. high resolution cameras, shortwave infrared and midinfrared spectral imagers, ground-penetrating radar, neutron spectrometer)
- Laboratory and handheld analytical instruments (e.g. chemistry, vis/shortwave IR micro-imager, other to-be-developed instruments)
- Sample containment and storage equipment

Characteristics and Needs

- Explore likely candidate oceanic shorelines and lowest-latitude candidate Late Amazonian glacial deposit within Utopia Planitia
- Gather multiple rock and soil samples from multiple locations, located up to 50 km apart
- Return collected samples to Earth

Mars Science Objectives & Goals

Astrobiology

- Search for evidence of present Martian life in high-potential environments
- Search for evidence of past Martian life and/or organics in high-potential environments
- Determine whether any life present in Martian materials might share ancestry with Earth
- Determine the history of the habitability of Mars at its surface and in the subsurface

Climate and Volatiles

- Determine the nature of Mars' enigmatic early climate and Noachian-Hesperian transition
- Determine if Mars ever possessed a northern ocean
- Understand the processes driving recent climate change
- Establish whether liquid water is present on Mars today in the subsurface
- Understand the nature, including the drivers, of variability in the modern climate

Geology/Geophysics/Geochemistry

- Map and measure the geologic, chemical, mineralogical, & hydrological characteristics of Mars' stratigraphic record
- Identify the current and historical rate of impacts
- Identify and classify tectonic and volcanic landforms
- Determine the fundamental nature of the ancient crust
- Understand the nature of recent and ongoing geological processes

Some General Observations From The Example Use Cases

- These representative use cases demonstrate that high-science value can be achieved by missions with humans. However, there are potentially a large number of additional or alternative missions that could be examined; specific targets and requirements would need to come out of in-depth studies and discussions with scientists and mission architects.
- To address the most-compelling science objectives will require exploration of diverse environments; for example:
  - Multiple locales with differing mineralogy and/or morphology; some of these may necessitate multiple or extended traverses (e.g., ~50 km or more when combined) and/or advanced teleoperated robots
  - Icy Terrains, with their unique challenges to drilling, preserving and returning volatile samples
  - Steep exposures, difficult access (e.g., cliff walls, caves, deep subsurface)
- Returning carefully selected rock/regolith samples, plus atmospheric and possibly volatile-rich samples, is a high priority for all sites; careful characterization of the sampled environment (e.g., geological and environmental context) is vital.
- Many of the considered sites would yield important science from a short-stay mission; longer stays will yield more, and in most cases much more (particularly where access is difficult or requires visiting multiple locations).
  - Precursor missions, robotic or with humans, to a site could expedite follow-up studies; the programmatic ability to react to discoveries is essential.

Prioritization Of Potential Missions?

- Tiger Team charge included: “Considering multiple human missions to Mars’ surface, suggest prioritization of the lower-level science objectives as to what may be done in earlier vs. later missions”
- Prioritization based on science requires developing a consensus within the community
  - The community-wide discussions that can lead to a consensus were not possible within the short timeframe of the Tiger Team
  - Prioritizing among the six mission concepts presented in the report is not appropriate – they are examples, developed in order to have a wide range of science objectives that could drive technology and planning, and are not a menu from which a first mission could be chosen
  - Criteria for prioritizing science objectives have not been defined; no single site can address all of the high-priority science objectives
- Prioritization based on technological readiness could not be done by the Tiger Team
  - Our committee did not have appropriate technical expertise or time to evaluate mission concepts on their technological readiness
  - Technological capabilities are constantly improving, and it’s not straightforward to predict what capabilities will be available even in just a few years or when decisions on mission capabilities need to be made
  - Engineering requirements for human landing sites have not been defined

Findings And Recommendations (1 of 2)

- *Finding:* Vital science can be accomplished by humans on Mars that would be much harder or impossible to do with robotic spacecraft; the capabilities of human missions have the potential to change both the objectives and the priorities – and can definitely accelerate the pace – for Mars scientific exploration.
- *Finding:* To be effective in achieving science by humans operating on Mars, the interaction between the science and exploration communities cannot be a one-time, one-direction (toss it over the transom) input. There needs to be an *ongoing dialog/discussion/exchange* between the communities to ensure programmatic success.
- *Finding:* As illustrated by the Example Use Cases, individual, specific missions can achieve high-value science. Our list of mission concepts, while necessarily incomplete, should serve to catalyze discussions within and between the science and exploration communities.
- *Finding:* Although there is overlap with the MEPAG or Decadal science goals and objectives, human-mission goals do not necessarily match one-to-one with them, especially at the level of individual measurements or research tasks; the former were derived assuming robotic missions only, and the capabilities of human missions will support fundamentally broader objectives.
- *Finding*: Given the complexity of Mars' evolutionary history and the tremendous diversity of environments on Mars, no single site can address all of the high-priority science goals; this was evident in development of the *Example Use Cases*.
- *Finding:* For most of the *Example Use Cases* developed here, either shorter- or longer-duration missions could be accommodated, with the difference being the amount of returned science; either short- or long-duration missions would provide compelling, fundamental science

Findings And Recommendations (2 of 2)

- *Recommendation:* Interactions between the scientific and exploration communities should be regular and should include both formal and informal discussions; a once-per-year input from MEPAG or from the science community to the M2M ADD revisions, while necessary, for example, would not be adequate.
- *Recommendation:* Feed-forward from Moon to Mars should include science flow-down as well as technology flow-down.
  - Feed forward from the Moon to Mars has linkages between anticipated scientific results, learning how to do field science on a planetary body, utilizing mobility and concurrent robotic capabilities effectively, nature and utilization of required field and hand-held instrumentation, and characteristics of required on-the-surface laboratory capabilities.
  - The goal is to learn from experience; no new requirements are being placed on the lunar missions or program.
- *Recommendation:* The overall Mars architecture should be sufficiently flexible/robust to accommodate multiple mission concepts; specific requirements for mission duration, up-mass and nature of samples to be returned, mobility and trafficability, field equipment, in-habitat laboratory equipment, etc., are likely to be site specific.
- *Recommendation:* An ongoing Mars exploration program (data analysis and robotic missions) is needed to advance human missions through development of science objectives and implementations; for site selection, hazard detection, and traverse planning; for characterization of the Martian environment; to allow integration of human-site with global results; and to respond to architecture needs and changes as they emerge.
- *Recommendation:* NASA should plan an appropriate organizational path in response to these recommendations, including:
  - Engagement across the multiple NASA directorates and leaders of the M2M program
  - Regular interaction and feedback with the broader Mars science communities, including explicitly engaging with the full diversity of their members
  - Regular formal and informal interaction between the NASA and external communities for science, human factors, technology, and engineering/architecture.

Backup Charts

Key Parts Of Charge To Tiger Team

(Quoted verbatim from request; full statement of request in full report)

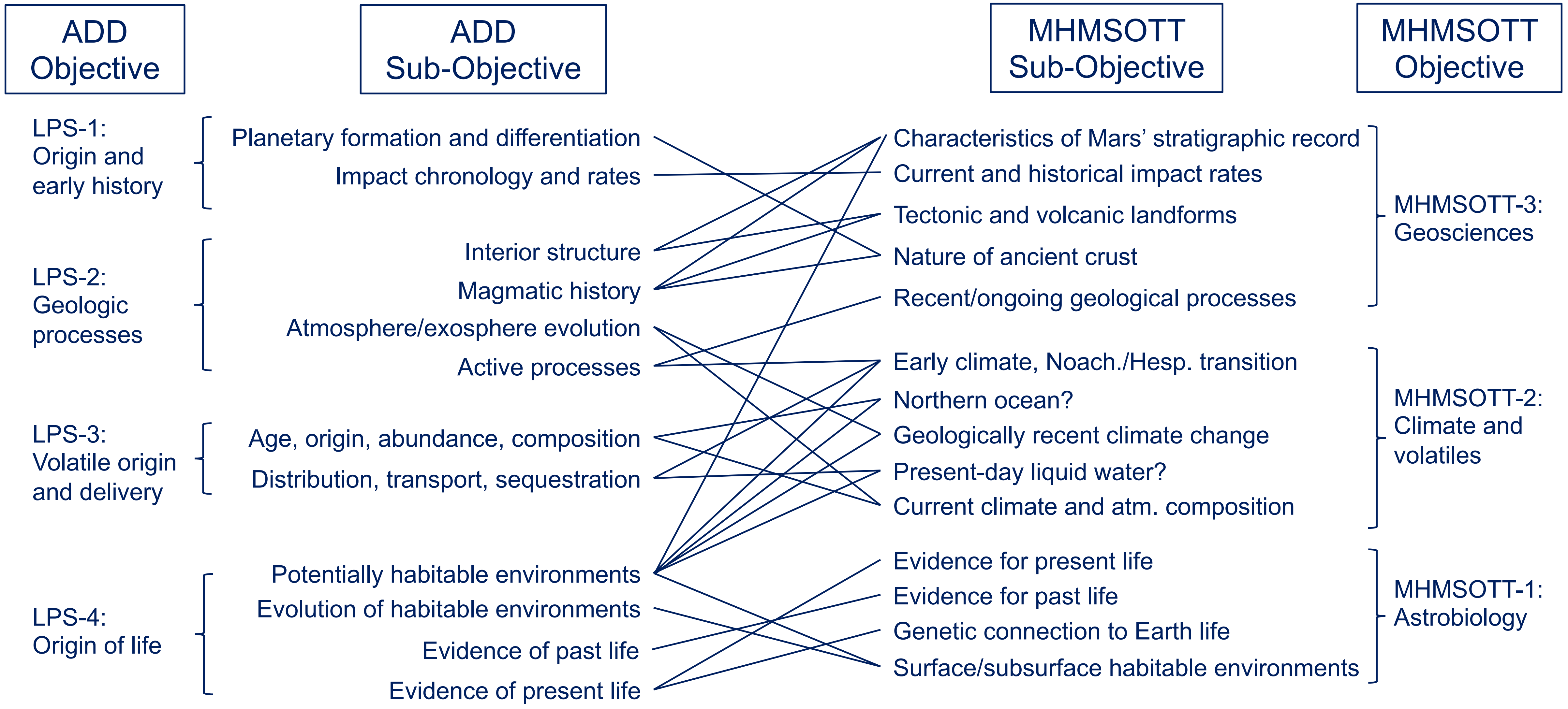
- Identify lower level (more detailed) science objectives that should be addressed in the “Humans to Mars” Campaign Segment. These should be at the scale of Strategic Research topics or Strategic Investigations in a Decadal Survey. MEPAG may identify new lower-level science objectives which are not, for example, existing Planetary Science and Astrobiology (Origins Worlds and Life) strategic research topics. The “Humans to Mars Campaign” first mission would take place (notionally) in 2039.
- Considering multiple human missions to Mars’ surface, suggest prioritization of the lower-level science objectives as to what may be done in earlier vs later missions.
- Suggest, for each lower-level science objective, “use cases” (as defined in the publicly available NASA ADD).
- If time is available, suggest “characteristics & needs” for each lower-level science objective.

Implementing Science Requirements With Example Missions

Site Selection for Science for Missions with Humans at Mars

- ***Given the complexity of Mars' evolutionary history and the tremendous diversity of environments on Mars, no single site can address all of the high-priority science goals.***
  - As with the Apollo missions, specific sites will address specific science objectives
- Each site, chosen to address a specific set of science objectives, will determine required mission capabilities. These capabilities will need to be defined by iterative discussions among scientists, engineers, technologists and architects. Relevant factors include:
  - Size of crew and duration of stay
  - Range of mobility, laterally to access multiple surface targets and vertically when drilling or digging is required
  - Access to difficult terrain; availability of resources
  - Locations for autonomous field measurements
  - Complexity and characteristics of required field and laboratory instrumentation, including within the habitat
  - Planetary protection requirements that are likely to be site specific
- Trades between sites, capabilities, and mission objectives will require inputs from and iteration between engineering, science, and technology

Connecting ADD Science Objectives To MHMSOTT Science Objectives – Strongest Connections Only *



* *MHMSOTT = Mars Human Missions Science Objectives Tiger Team, this report; lines show comparison between LPS and MHMSOTT objectives; there is not a one-to-one relationship due to interconnections between components of the complex environmental system*