MEPAG Tiger Team Report On Mars Human-Mission Science Objectives

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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
- 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 Takeaway Points

- NASA has stated explicitly that science is one of the three pillars on which the human Moon and Mars program stands; as such, attention needs to be paid now to the role that science can play and how to implement it appropriately in the missions.
- Incorporating science early into project and mission planning is necessary to ensure that the missions will be able to carry out world-class science. If science is added in after the mission architecture and hardware are defined or designed, the missions may not be able to accommodate the elements necessary to support the science.
- Input from science into the architecture planning cannot be a one-time “toss requirements over the transom”. NASA and the science community have to define an appropriate mechanism for ongoing interaction between the groups, in that accommodating the science while also ensuring mission success and astronaut health and safety has to be an iterative process.
- We need to get this right at the Moon with Artemis, not just for its own sake but because how we do things there is likely to feed forward to determine how we operate with human missions at Mars.
- The path forward has to involve ongoing interaction between the broader science communities and the flight-project and architecture-development teams. MEPAG and LEAG can facilitate that interaction on the science side, but (i) interactions have to be broad enough to also include human health and performance and planetary protection, and (ii) NASA leadership has to create and support mechanisms to allow and encourage that interaction.

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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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

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

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

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

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 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.

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