Why multiple landed missions to Mars are crucial to understanding the evolution of terrestrial planet habitability: key next steps in advance of the Decadal Survey

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Why Multiple Landed Missions are Crucial in Understanding the Evolution of Mars: Sample Return is the Beginning not the End

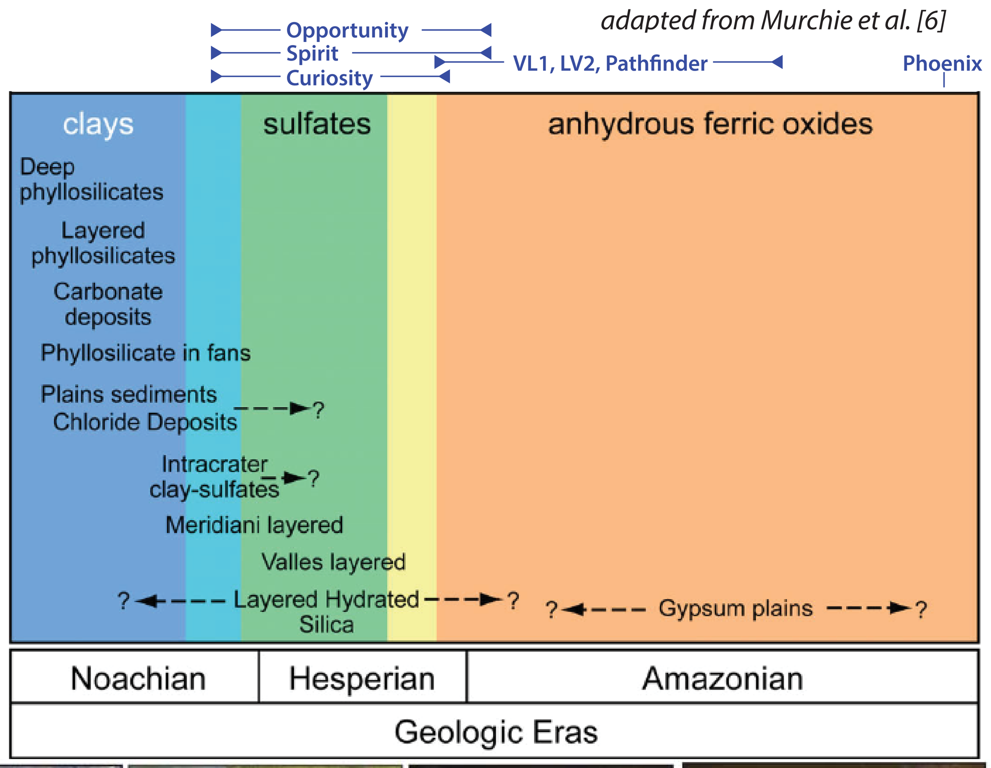
Mars has unique value for solar system and exoplanet science because it provides the **only well-preserved record of a habitable terrestrial planet (rock+atmosphere) during its first two billion years**,. It could host life now, underground. It allows us to link evolution to the driving exogeneous and endogenous processes. Key questions about the evolution of terrestrial planet habitability include

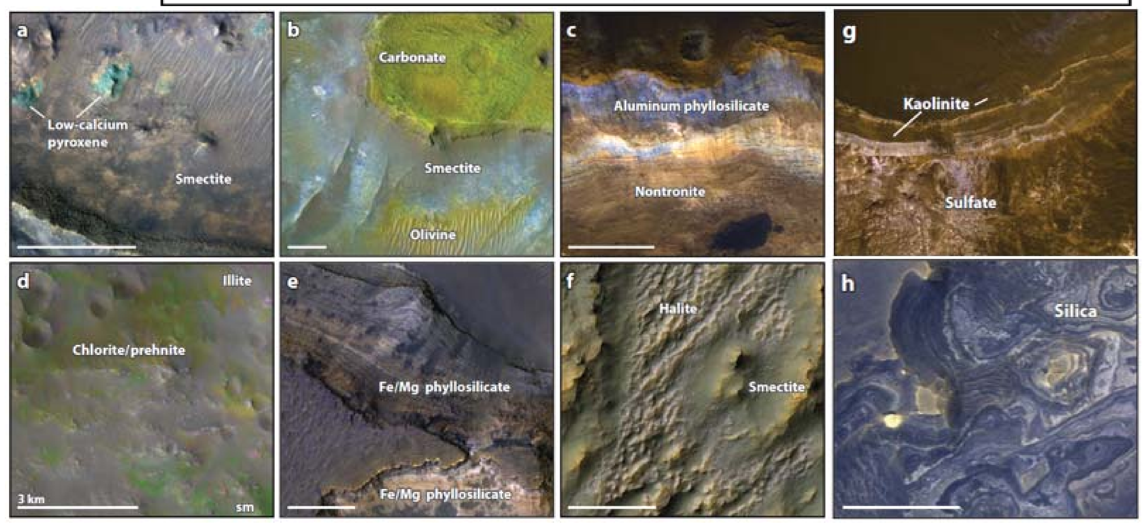
- What were the timing and effects of stellar evolution on atmospheres?
- What were the timing and effects of large impacts on atmospheres?
- What is the effect of magnetic field loss on atmospheric loss rates and composition?
- What has been the evolution of Martian atmospheric composition and volatiles?
- How does the history of volcanism and tectonics affect habitability?
- How do cycles of obliquity and eccentricity influence long-term climate?

Importantly, **no single stratigraphy on Mars records all 2 billion years of ancient time**. Moreover, as on Earth, orbital data has shown the record of Mars first two billion years is diverse, with multiple habitable environments, varying in space and time across the planet. MRO reveals a rich geologic record from ancient Mars. Mars, like Earth, was diverse and rocks record **over a dozen aqueous chemical environments varying in space and time**. Which environment to sample and examine? Which will reveal the most about Mars history? Which is most likely to preserve life? The answer is many, debated but likely all, and we don't know enough.

Thus, **interrogation of multiple geologic sections is needed to understand the time evolution of the Mars system and controlling processes as well as to search for life**.

adapted from Murchie et al. [6]





Recommended Actions for MEPAG Now

1. Endorse a **lean, international sample return** conducted as **rapidly** and **cost-effectively** as possible
   Recommended action: an official finding from this meeting endorsing this approach

2. Develop the **list** of **high priority science measurements/missions** to take place **during the years of sample return**
   Recommended action: convene a team(s) now to examine and report back to MEPAG in advance of the Decadal Survey. Consider convening one team for small missions of opportunity (the "scrappy" team; smallsats, ballast mass, international ride-alongs, etc.) and one team for competitive Discovery/New Frontiers-level science

3. **Pathways** after sample return: **consider multiple 2020 science outcomes** and assume a lean, international sample return: what science comes next, including landed science? **Plan the Mars Exploration Program after sample return: hypothesis-driven and responsive to discovery**
   Recommended action: conduct a series of MEPAG discussions in advance of this Decadal survey. Develop a "MEP Pathways After Sample Return" consensus white paper.

4. **Engage multi-laterally with commerical companies and non-traditional international partners** (ESA is traditional for Mars; ISRO, JAXA, KARI, UAESA, and CNSA are not traditional) to understand timing and conditions needed to bring science payloads along on international and commercial Mars endeavors
   Recommended action: strengthen the international and commerial role in MEPAG. A commercial Mars advisory board (ala LEAG)? International reps, esp. from Asia, on MEPAG advisory board?

Objectives, Needed Measurements, Missions: Mars as a Linchpin for Terrestrial Planet Evolution

adapted from Ehlmann et al., [2]

Science Objectives	Measurements Needed
Determine environmental conditions and geologic settings with liquid water indicated by hydrated minerals	Cm-scale stratigraphy Sub-mm scale petrology (mineralogy+texture)
Establish Martian geochemical cycles for volatiles and their sinks	Identify H, C, S, Cl, and N-bearing mineral phases Determine Fe redox state Measure H, C, S, N, and Cl bulk isotopes
Timing and effects of key processes (solar, impact, orbital, endogenous)	Age from radiogenic isotopes in situ
Geophysical evolution of heat flow and the structure of the interior	Multiple measurements of heat flux Multiple seismic stations

Mission Concepts

- Multiple MER-like rover mission (solar, simultaneous build)
- Mars drop, precision hopping, or helicopter?
- multi-site sample return

Key Points

(1) Sample return should be done with the knowledge that a subset of important questions about Mars' evolution and the search for life will remain outstanding, necessating a complementary program of future in situ science (or additional sample returns), collecting the data above

(2) ongoing miniaturization of increasingly sophisticated instruments means that some measurements previously the province of MSL-class or sample return class only should be reconsidered for smaller class missions

(3) small dropped payloads [e.g., 7], novel, non-rover mobility systems should be examined for utility as Mars mobile science platforms

Example Missions During the Era of Sample Return (2020-2030)

Using the ballast mass of MSR missions: Mars-drop on M2020 and sample return missions (fetch rover, MAV)for D/H and light isotopes (with TLS), in situ chemistry of ancient terrains, images of geological formations

Secondary payloads: Small-satellites for Phobos-Deimos science, monitoring Mars atmospheric escape, monitoring Mars weather, communications network

Other Discovery and New Frontiers competed efforts

Instruments of Opportunity on International Satellites to Mars

Example Missions After the Era of Sample Return (2030-2040)

Multiple Reconnaissance Rovers to explore ancient Martian stratigraphies, use petrology to determine environmental conditions, measure light isotopes, and perhaps age-dating

Follow the Ice landed missions to understand the volatiles present in the subsurface, possible presence of modern aquifers, examination for extant life, and resources for ISRU

Next generation orbiter for communications, gravity science (ala GRAIL), SWIR+MIR high resolution imaging spectroscopy, shorter wavelength radar

Your mission here...

References

A large number of members of the planetary science community have highlighted the importance of multi-ple missions of landed exploration on Mars to answer the most fundamental science questions about terres-trial planet evolution, including a 2018 white paper to the National Academies Astrobiology strategy com-mittee [1; 15 authors], a JGR-Planets paper highlight-ing key questions about terrestrial planet evolution answerable on Mars and the measurements needed to address them [2; 46 authors], a report at the February 2017 Vision 2050 meeting [3; 19 authors], and multi-ple abstracts at the 2011 Mars Program Planning workshop [e.g., 4,5].

[1] Ehlmann et al. "Mars as a Linchpin for the Understanding the Habitability of Terrestrial Planets", white paper to the Natl. Academies Comm on the Astrobiology Science Strategy [2] Ehlmann et al., 2016, JGR-Planets, [3] Ehlmann et al., "Mars Exploration Science in 2050" abstract, presentation [4] Wray, 2011 "The Scientific Necessity of Landing at Diverse Sites on Mars" [5] Niles et al., 2011 "Multiple Smaller Missions as a Direct Pathway to Mars Sample Return" [6] Murchie et al., 2016. JGR-Planets [7] Staehle et al., 2014, Mars CubeSat/NanoSat Workshop, presentation