Getting humans to Mars, a *possible* future

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Planetary Science Vision 2050
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We envision that it is 2050 and humans are exploring the Martian surface in situ. They survive on Mars for over a year at a time, with crews rotating through. Over a series of missions, a habitat and several support building have been constructed.

Within the latter, crops are grown and resources like fuel are generated, decreasing the amount of basic supplies brought in from Earth and opening missions' "delivery" volumes to more interesting tools and more complicated resources. Although water sufficient for current needs is being sourced from the local region, a second habitat is being planned at higher latitudes where subsurface ice is more easily accessible – at least during the warm seasons.

Support staff monitors conditions at the surface and within the atmosphere 24-7, allowing for weather forecasts and early storm warning systems, which is especially important during the dust storm season. Repeat high resolution imaging, coupled with spectral imaging and radar data, allows for careful geologic mapping of portions of Mars likely to contain resources and/or hazards.

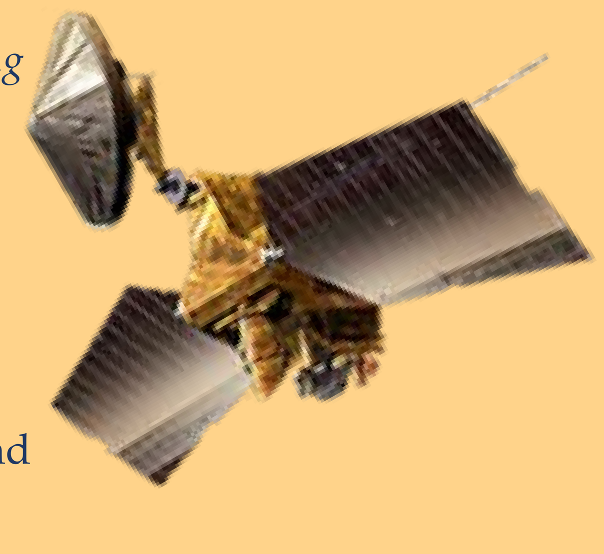
And detailed laboratory experiments, conducted on the martian surface and with martian samples delivered to Earth laboratories, have been and are answering key questions about biological potential and geologic history of surface materials – which feed into high-priority science as well as decisions about in situ resource utilization (ISRU) design and Planetary Protection (PP) protocols.

So what was needed to enable this?

New orbiters in the 2020s were needed to continue the [1-3]

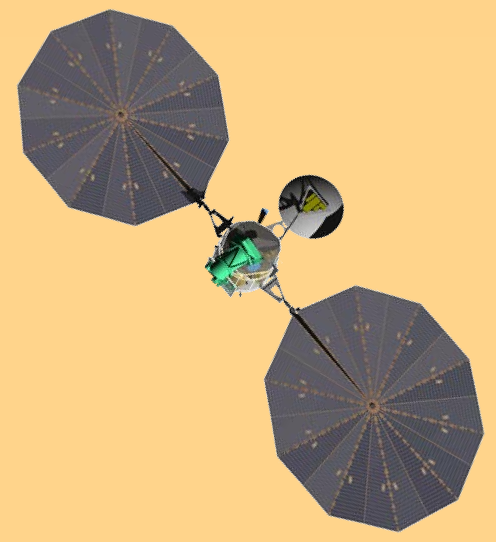
- **high resolution imaging** of the surface for *selection and characterization of potential landing sites;*
- development of the **digital terrain models** (DTMs) for *landing site and construction planning;*
- repeat images in some areas to understand the landscape under different times of day and year, and to monitor for changes;
- **high-resolution spectral map**s of the surface and **near-surface radar scans** to *improve interpretation of the geologic environment* and *identify potential resource deposits* for water and construction materials, as well as try to *avoid materials hazardous to humans or equipment;*
- near-continuous, coarse resolution, **global atmospheric monitoring** for *improved dust storm and weather models;*
- **atmospheric profiles** of volatiles, dust/aerosol content, and temperatures over a long temporal baseline has allowed for much improvement in *atmosphere models* – crucial for creating the context for *weather forecasting* and for enabling more precise and larger-mass *entry, descent, and landing (EDL) technology*. Wind measurements, including near-surface, were also an important new dataset.

Eventually, as a network of communications and reconnaissance satellites was built, we were able to collect the needed information much faster and even to image the surface near-continuously for the *monitoring of the crew and their local surface & atmospheric environment,* and provide *uninterrupted telecommunications* with the crew.



After a decade, MRO imaging, radar, and spectral data of the atmosphere and surface have been used in identifying new present-day processes, as well as characterization of potential landing sites for robotic [e.g., 4] and human missions [5,6].

Mars orbiters launched in the 2020s and later continued many of the datasets started by MRO and ODY, and also made critical new measurements such as near-surface wind and water vapor measurements [1,7].

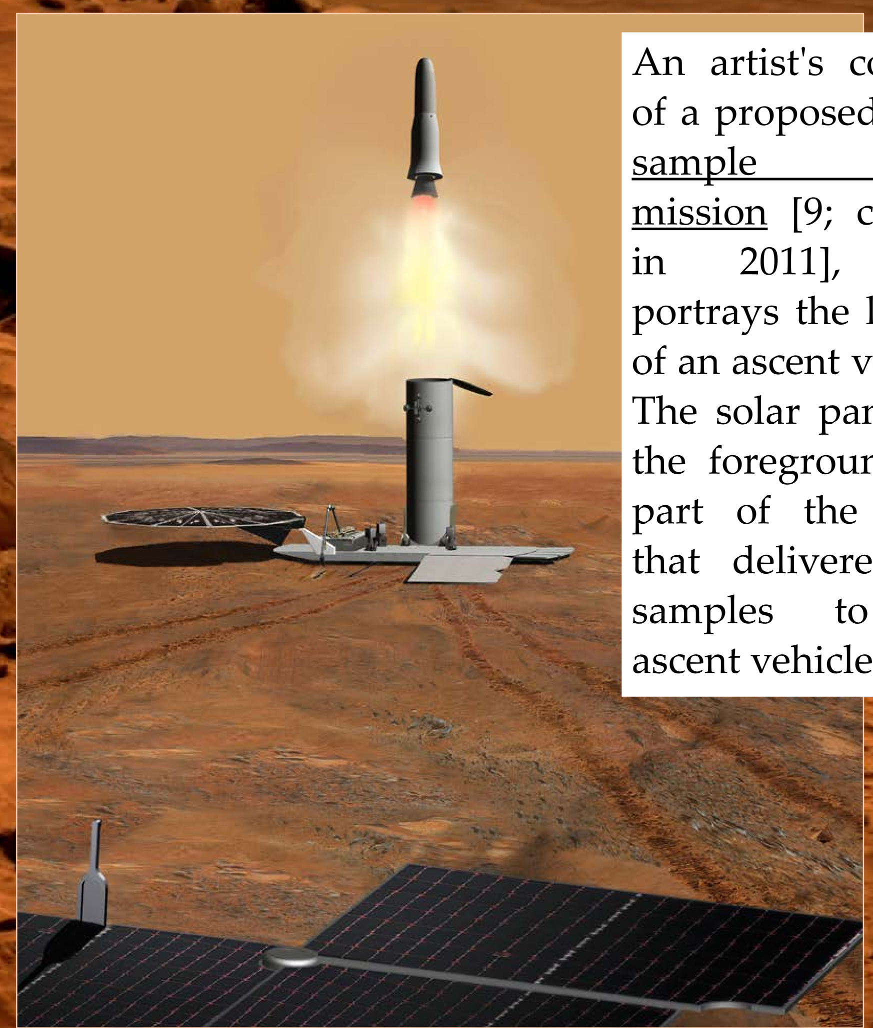


As we intended to set up a base that was revisited, identification of accessible resource reservoirs, and in particular water deposits, was crucial.

- Orbital reconnaissance *identified and characterized plausible resource deposits* within Exploration Zones [5].
- At least one exploration mission to the martian surface was required to define "reserves": deposits for which all of the essential attributes have been defined, such that a known mining/processing system can interact with it with predictable results [10]. In particular, information about the *small-scale surface (upper 1 mm) composition and the subsurface structure/composition of potential reserves* could often only be acquired from **in situ measurement**.
- For critical technical pathways, ISRU engineering experiments, such as the MOXIE experiment on the M-2020 rover [11], yielded sub-scale *demonstrations of the collection and processing of martian constituents* so as to produce resources necessary for the long-term human presence on Mars.
- *Development of the engineering systems* needed to mine and extract the water from one or more categories of martian water deposits (either ice or minerals) required much iteration between terrestrial experiments for definition of the datasets needed, and acquired martian datasets guiding design of the engineering system.

Many of the orbital observations were also necessary for the *identification of Special Regions* [8] and investigation of *whether or not Mars has extant life* (including in the airborne dust, or within specific refugia) – which factored heavily into decisions about where to send humans and how humans should plan to interact with the martian environment (i.e., PP concerns about both *forward and backward contamination*).

A critical enabling data set was delivered by the Mars Sample Return campaign -- the **study of samples** of martian regolith that were returned to Earth had key implications for *geologic studies of Mars* and *possible martian life*, and for whether the regolith and/or airfall dust contained potentially *hazardous concentrations* of certain "poisonous" compounds. [1]



An artist's concept of a proposed Mars sample return mission [9; created in 2011], that portrays the launch of an ascent vehicle. The solar panels in the foreground are part of the rover that delivered the samples to the ascent vehicle.

The Icebreaker Project prototype drill, during a field test in Antarctica in January 2013 [11]. This project is NASA Ames-led and aims to study potential martian-analog niches for life within this harsh terrestrial environment and tested a subsurface sample acquisition and transfer system. Similar engineering experiments were needed to develop possible water-resource acquisition strategies.

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*Report can be downloaded from: http://mepag.nasa.gov/reports.cfm.

A summary of the missions needed to generate these datasets [1-3]:

- **Several Mars orbiters**
  - to replenish imaging & atmosphere observation capabilities (at least one per decade).
  - then incorporating science observations within a telecommunications satellite network, for larger spatial & temporal coverage
  - also needed are atmosphere and radar measurements
- **Mars Sample Return (MSR)**
  - enables measurement of surface material properties and composition
  - crucial for determining planetary protection needs and hazards
- **ISRU-enabling landed missions**
  - a progression of more complicated and larger-scale missions to demonstrate ISRU technologies
  - full-scale ISRU mining and processing

Issues to consider:

- **Time needed to acquire and analyze the needed data.**
  - E.g., HiRISE/MRO imaged ~2% of the surface during 10 years of operation, and by 2017 only a handful of locations have been sampled in situ (and to <10 cm).
  - Decades of work are needed for the creation and refinement of 3D geologic maps as well as development of surface/near-surface process models that feed into identification, mapping, and characterization of resource reservoirs.
- **Continuity of certain datasets.**
  - A long observation baseline is needed to identify and understand trends and deviations (e.g., to separate seasonal cycles from interannual variations within atmospheric measurements).
  - Globally connected systems need to be monitored and studied over a variety of temporal and spatial scales, to be well-modeled.
- **In situ access and data collection will be necessary**.
  - Small-scale characterizations of material composition, heterogeneity, and mechanical properties of surface material
  - Mechanical properties are needed for design of engineering systems that will excavate or drill through these materials to extract resources
  - Direct characterization of sub-surface materials
  - Testing of prototype engineering systems
- **Iteration required between science data acquisition and engineering design.**
  - Especially for optimizing ISRU reserve identification & characterization and the construction of processing equipment.
- **How to best collaborate with partners on large-scale missions** [e.g., 13].
- **How to encourage, incorporate, and recognize the best contributions from all organizations and people** [e.g., 14].