Final Report of the 2020 Mars Rover Science Definition Team (SDT)  
(Jack Mustard, Chair)

Mitch Schulte  
Mars 2020 Program Scientist  
NASA HQ

NOTE: This package is for oral presentation of the SDT’s text report (July 1, 2013). In case of discrepancies, the SDT text report should be judged to be superior.
Mars Rovers

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The proposed Mars 2020 mission would be:

- positioned to capitalize on past strategic investments at Mars, and to set the stage for direct testing of life-related hypotheses
- A crucial element in executing NASA’s strategic plan
- The most important next strategic mission to Mars
- Aligned with Decadal Survey’s priorities for solar system exploration
<table>
<thead>
<tr>
<th><strong>Chair</strong></th>
<th><strong>Professional Affiliation</strong></th>
<th><strong>Interest/Experience</strong></th>
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</thead>
<tbody>
<tr>
<td>Mustard, Jack</td>
<td>Brown University</td>
<td>Generalist, geology, Remote Sensing, MRO, MEPAG, DS, MSS-SAG</td>
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### Science Members (n = 16)

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Interest/Experience</th>
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<tbody>
<tr>
<td>Allwood, Abby</td>
<td>JPL</td>
<td>Field astrobiology, early life on Earth, E2E-SAG, JSWG, MSR</td>
</tr>
<tr>
<td>Bell, Jim</td>
<td>ASU</td>
<td>Remote Sensing, Instruments, MER, MSL, Planetary Society</td>
</tr>
<tr>
<td>Brinckerhoff, William</td>
<td>NASA GSFC</td>
<td>Analytical Chemistry, Instruments, AFL-SGG</td>
</tr>
<tr>
<td>Carr, Michael</td>
<td>USGS ret.</td>
<td>Geology, Hydrology, ND-SAG, E2E, P-SAG, Viking, MER, PPS</td>
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<tr>
<td>DesMarais, Dave</td>
<td>NASA ARC</td>
<td>Astrobio, field instruments, DS, ND-SAG, MER, MSL, MEPAG</td>
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<tr>
<td>Edgett, Ken</td>
<td>MSSS</td>
<td>Geology, geomorph, MPF, MER, MRO, MSL, MGS, cameras</td>
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<tr>
<td>Eigenbrode, Jen</td>
<td>NASA GSFC</td>
<td>Organic geochemistry, MSL, ND-SAG</td>
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<tr>
<td>Elkins-Tanton, Lindy</td>
<td>DTM, CIW</td>
<td>Petrology, CAPS, DS</td>
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<tr>
<td>Grant, John</td>
<td>Smithsonian, DC</td>
<td>geophysics, landing site selection, MER, HiRISE, E2E, PSS</td>
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<tr>
<td>Ming, Doug</td>
<td>NASA JSC</td>
<td>Geochemistry, MSL (CHEMIN, SAM), MER, PHX</td>
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<tr>
<td>Murchie, Scott</td>
<td>JHU-APL</td>
<td>IR spectroscopy, MRO (CRISM), MESSENGER, MSS-SAG</td>
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<tr>
<td>Onstott, Tullis</td>
<td>Princeton UNIV</td>
<td>Geomicrobiology, biogeochemistry</td>
</tr>
<tr>
<td>Ruff, Steve</td>
<td>Ariz. State Univ.</td>
<td>MER, spectral geology, MGS (TES), MER, ND, E2E, JSWG</td>
</tr>
<tr>
<td>Sephton, Mark</td>
<td>Imperial College</td>
<td>Organics extraction and analysis, ExoMars, Astrobiology, E2E</td>
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<tr>
<td>Steele, Andrew</td>
<td>Carnegie Inst., Wash</td>
<td>astrobiology, meteorites, samples, ND-, P-SAG, AFL-SSG, PPS</td>
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<tr>
<td>Treiman, Allen</td>
<td>LPI</td>
<td>Meteorites, Samples, Igneous Petrology</td>
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### HEO/OCT representatives (n = 2)

<table>
<thead>
<tr>
<th>Name</th>
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<th>Interest/Experience</th>
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<tbody>
<tr>
<td>Adler, Mark</td>
<td>JPL</td>
<td>Technology development, MER, MSR</td>
</tr>
<tr>
<td>Drake, Bret</td>
<td>NASA JSC</td>
<td>System engineering, long-lead planning for humans to Mars</td>
</tr>
<tr>
<td>Moore, Chris</td>
<td>NASA</td>
<td>Advanced Engineering Systems</td>
</tr>
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### Ex-officio (n = 6)

<table>
<thead>
<tr>
<th>Name</th>
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<tbody>
<tr>
<td>Meyer, Michael</td>
<td>NASA</td>
<td>Mars Lead Scientist</td>
</tr>
<tr>
<td>Mitch Schulte</td>
<td>NASA</td>
<td>Mars 2020 Program Scientist</td>
</tr>
<tr>
<td>George Tahu</td>
<td>NASA</td>
<td>Mars 2020 Program Executive</td>
</tr>
<tr>
<td>David Beaty</td>
<td>JPL</td>
<td>Acting Project Scientist, Mars Program Office, JPL</td>
</tr>
<tr>
<td>Deborah Bass</td>
<td>JPL</td>
<td>Acting Deputy Proj. Sci, Mars Program Office, JPL</td>
</tr>
<tr>
<td>Jim Garvin</td>
<td>NASA</td>
<td>Mars Program Scientist</td>
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### Supporting resources (n = 2)

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<tr>
<th>Name</th>
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<th>Interest/Experience</th>
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<tbody>
<tr>
<td>Wallace, Matt</td>
<td>JPL</td>
<td>Deputy Project Manager M-2020, designated engineering liason</td>
</tr>
<tr>
<td>Sarah Milkovich</td>
<td>JPL</td>
<td>SDT documentarian, logistics</td>
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### Observer (n = 1)

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<tr>
<th>Name</th>
<th>Affiliation</th>
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<tr>
<td>Vago, Jorge</td>
<td>ESA</td>
<td>Project Scientist, ExoMars</td>
</tr>
</tbody>
</table>

11/25/2013

2020 Mars Rover Science Definition Team
With this overarching strategy in mind, to define detailed objectives, measurements, payload options and priorities & an integrated mission concept for a 2020 rover mission to address:

- **A. past habitability,**
- **B. potential biosignature preservation,**
- **C. progress toward sample return,** &
- **D. contributed technology/HEO payloads.**
**CRUISE/APPROACH**
- 8 to 9-month cruise
- Arrive Jan/Mar 2021
- No changes from MSL (equivalent checkout capability, etc.)

**ENTRY, DESCENT, LANDING**
- MSL EDL system: guided entry and powered descent/Sky Crane
- 25 x 20 km landing ellipse*
- Access to landing sites ±30° latitude, ≤0 km elevation*
- ~950 kg rover
- Technology enhancements under consideration

**SURFACE MISSION**
- Prime mission is one Mars year (669 days)
- Latitude-independent and long-lived power source
- Ability to drive out of landing ellipse
- Direct (uplink/downlink) and relayed (downlink) communication
- Fast CPU and large data storage

*EDL in work*
The SDT envisions a 2020 Mars Rover mission that would:

- **Conduct Rigorous In Situ Science**
  - **Geologic Context and History** Carry out an integrated set of sophisticated context, contact, and spatially-coordinated measurements to characterize the geology of the landing site
  - **In Situ Astrobiology** Using the geologic context as a foundation, find and characterize ancient habitable environments, identify rocks with the highest chance of preserving signs of ancient Martian life if it were present, and within those environments, seek the signs of life

- **Enable the Future**
  - **Sample Return** Place carefully and rigorously-selected samples in a returnable sample cache as the most scientifically, technically, and economically compelling method of demonstrating significant technical progress toward Mars sample return
  - **Human Exploration** Conduct a Mars-surface critical ISRU demonstration to prepare for eventual human exploration of Mars
  - **Technology** Demonstrate technology required for future Mars exploration

- **Respect Current Financial Realities**
  - Utilize MSL-heritage design and a moderate instrument suite to stay within the resource constraints specified by NASA
Options and Priorities to Achieve

Objective A

Explore an astrobiologically relevant ancient* environment on Mars to decipher its geological processes and history, including the assessment of past habitability.

*“Ancient” implies a location where the astrobiologically relevant environment no longer exists, but is preserved in a geologic record.
In order to explore and document geologic processes and history of a site, it is essential to integrate observations from orbital (regional) scales to microscopic (sub-millimeter) scales.

The footprint and spatial resolution of measurements is critical for ensuring observations can be correlated across scales.
To assess the habitability of a past environment, the rover must be able to examine the geologic record of that environment and evaluate the following characteristics of that environment:

**Raw Materials**
- Availability of CHNOPS elements (beyond those species present in the atmosphere) and electron donors

**Energy**
- Energy sources and availability (i.e., mineral suites of mixed valence states for redox energy; proximity to paleosurface for photosynthesis; radiogenic elements for radiolysis)
- Water energy (quiet vs. high energy - implications for stabilization of microbial communities)
- Rate of burial (e.g. lacustrine - implications for establishment of microbial communities)

**Water**
- Water properties (e.g., salinity, pH, and temperature)
- Protection from radiation (e.g. planetary dipole field)
- Amount of water that was present (e.g. mineral-bound or interstitial fluids in subsurface; small/shallow surface water or large/deep surface water body)
- Persistence of the aqueous conditions

**Favorable Conditions**
- Persistence of the aqueous conditions
The ability to spatially correlate variations in rock composition with fine scale structures and textures is critical for geological and astrobiological interpretations.
Options and Priorities to Achieve

Objective B

Assess the potential for preservation of biosignatures within the selected geological environment and search for potential biosignatures.
The existence of evidence for past Martian life requires both a habitable environment and suitable conditions for biosignature preservation. The subsequent recognition of any preserved biosignatures will require the combination of a capable rover and advanced analysis of returned samples on Earth.
These hypothesized potential Martian biosignatures represent independently observable features.

The 2020 Mars Rover must have the capability to detect as many of these signatures as possible to have a credible chance to find evidence of past life on Mars, because:

1. We cannot anticipate which of these (if any) will be present or well-preserved…
2. …therefore we cannot anticipate which categories will provide the most information.
3. Confidence in confirming biological origin(s) increases as more categories are detected.
Options and Priorities to Achieve

Objective C

Demonstrate significant technical progress toward the future return of scientifically selected, well-documented samples to Earth.
The analysis of carefully selected and well documented samples from a well characterized site [on Mars] will provide the highest scientific return on investment for understanding Mars in the context of solar system evolution and addressing the question of whether Mars has ever been an abode of life.”

The SDT concurs with the detailed technical and scientific arguments made by the Decadal Survey (2011) and MEPAG (most recently summarized in E2E-iSAG, 2011) for the critical role returned samples will play in the scientific exploration of Mars.
Of the options shown above, only the **assembly of a returnable sample cache** achieves a major milestone of MSR.

**Note:** A variety of candidate MSR technology demonstrations were identified and evaluated during the Mars Program Planning Group effort in 2012. Those demonstrations were not addressed again by this SDT.
The SDT concludes that three attributes are essential to making a cache returnable:

1. The cache has enough scientific value to merit returning.
2. The cache complies with planetary protection requirements.
3. The cache is returnable in an engineering sense.
Options and Priorities to Achieve

Objective D

Provide an opportunity for contributed HEOMD or Space Technology Program (STP) participation, compatible with the science payload and within the mission’s payload capacity.
### 2010 National Space Policy: Humans to Mars by mid-2030s

<table>
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<tr>
<th>2020s</th>
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<tr>
<td>Proof of Concept</td>
<td>Validation</td>
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#### 2020 Rover

**ISRU O$_2$ Production**
- Demonstration of CO$_2$ collection in actual Mars environment reduces future risks. O$_2$ production is critical path of future human missions

**MEDLI+**
- Obtaining data lower in atmosphere reduces EDL uncertainties and risks

**Surface Weather**
- Understanding of long-term atmosphere behavior reduces future EDL risks

**Biomarker**
- Demonstrate detection of microbial contamination for future human missions

**Human Sub-Scale Validation Demos**
- Land Large Payload
- Advanced Aeroassist
- Supersonic Retro-Propulsion
- ISRU O$_2$ Production and Use
- Surface power

**Future demonstration of sub-scale human relevant systems and technologies necessary to reduce risk and feed forward to human flight systems development**

**Human Systems Development**
#1 HEO Priority: ISRU Demo

- Utilizing locally produced consumables (e.g. oxygen for ascent) provides great leverage for human exploration of Mars.

- Key technical issue: Data needed to support performance and reliability assessments, before we bet the lives of a crew of astronauts on it.

- Much progress can be made in Mars environmental chambers on Earth, but some things require information from a Mars surface mission.
  - Testing in the actual relevant environment (discover unknown unknowns)
  - Most important general area of concern is the dust environment, which varies in unpredictable ways, and could have severe consequences on a future ISRU systems.

NOTE:
This kind of demo can be run on a non-interference basis with science ops.

The Importance of Supporting Atmospheric Data

- Need to understand regional dust context to understand WHY and HOW dust is affecting the ISRU demo.
- Needed to interpret data from the demo to apply to other places/times
- Data of value (priority order): Wind, Pressure, Temperature

In-Situ Resource Utilization is the HEOMD top priority demonstration for the 2020 Mars Rover
In the proposed mission concept, science & human preparation objectives have synergy in three significant ways:

1. The instruments required for the science objectives are relevant to many SKGs.

2. The measurements/demos proposed by HEO satisfy some Mars science objectives.

3. A returnable cache of samples, if properly selected, would be of major interest to both.

The 2020 Mars Rover offers excellent opportunities for synergy between planetary science and preparation for human exploration objectives.
The measurements required to meet Objectives A – C are nearly identical. Thus, these three objectives are highly integrated and compatible with a common mission.

Measurements or demonstrations associated with Objective D would enhance the value of the mission to HEO, ST, and SMD.
The priority of baseline options depends on budget scaling up or down, and the strength of the proposals submitted in response to the AO.

<table>
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<th>Functionalities Required</th>
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<th>Orange Straw Payload</th>
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<td>Mastcam-like</td>
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<td>Deep UV-like</td>
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<td>Science support equipment</td>
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**Threshold Total (SMD funded)**
- ~90
- ~90

**Additional Instrument Options**
- GPR
- ISRU

**HEO contributed payload**
- GPR
- ISRU

**Technology payload elements**
- Includes range trigger and TRN

**Baseline Total (SMD funded)**
- ~105
- ~105

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Cost totals are instruments only; do not include science support equipment.

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Baseline and Threshold Options

A baseline mission would include one or more of the following (not listed in priority order):

- Superior capabilities (e.g., resolution, range of minerals detected, accuracy) for instruments in the threshold measurements category: “superiority” to be evaluated in the instrument competition
- A second organic detection capability complementary to the first one
- An instrument that measures subsurface structure or composition
Planning Considerations Related to the Surface Operations Scenario
Plausible mission scenarios can be found throughout this triangle –

trading drive distance, total number of cached samples, & number of cached samples within a characterized suite

– to suit a variety of possible landing sites.

The charter-specified objectives for Mars 2020 can be achieved with the mission concept proposed at a variety of different landing sites.

Multiple strategies to improve on the modeled, reference scenarios are available as the mission is further developed.
Primary Technical Conclusions

- The **measurements** needed to explore a landing site on Mars to interpret habitability and the potential for preservation of biosignatures and to select samples for potential future return to Earth are identical.

- Significant technical progress towards MSR requires a returnable cache.

- Arm- and mast-mounted instrument data are necessary and sufficient to achieve the required science.

- An instrument set capable of the following measurements would be the foundation of an efficient, lower cost rover.
  - Context Imaging
  - Context mineralogy
  - Fine-scale imaging
  - Fine-scale elemental chemistry
  - Fine-scale mineralogy
  - Organic detection

- The payload needed to achieve the three scientific objectives of the mission fill much, but not all, of an MSL heritage rover. This creates valuable opportunity for HEO to address long-lead strategic knowledge gaps.
The 2020 Mars Rover mission offers many important advances relative to MER and MSL:

- Potential to land on high priority scientific targets previously out of reach, shorten drive distances
- Payload designed to recognize potential biosignatures in outcrop
- Measurements of fine-scale mineralogy, chemistry, and texture in outcrop (petrology)
- The ability to collect compelling samples for potential future return
- Prepare for the future human exploration of Mars