Mars 2020 Science Definition Team Report: Presentation to CAPS

Sept. 4, 2013
Jack Mustard, David Des Marais, John Grant

On behalf of the
2020 Mars Rover Science Definition Team

NOTE: The content of this presentation is drawn from the SDT’s text report, and for further information, the interested reader is referred there (http://mepag.jpl.nasa.gov/reports/mep_report.html).

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Mars 2020 Science Definition Team Report:

Part 1. Introduction, Context, Constraints, Assumptions, and Objective A

Jack Mustard, Brown University

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Seeking signs of past life

Prepare for human exploration

Two major in situ science objectives

Returnable cache of samples

Coordinated, nested context and fine-scale measurements

Coring system

Geologically diverse site of ancient habitability

Efficient surface operations, one Mars-year lifetime

Improved EDL for landing site access

MSL heritage rover
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
Recap of SDT Process and Key Concepts
<table>
<thead>
<tr>
<th>Scientific Theme</th>
<th>NASA’s Mars Exploration Program Scientific Theme: Seeking Signs of Life (Decadal Survey, MEPAG, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highest Priority Science Goal</td>
<td>Following the MSL, MAVEN, ExoMars, and InSight missions, to address in detail the questions of habitability &amp; the potential origin and evolution of life on Mars. (Planetary Decadal Survey–Mars Chapter)</td>
</tr>
<tr>
<td>Next Step To Achieve Highest Priority Science Goal</td>
<td>To explore on the surface an ancient site relevant to the planet’s early habitability with sophisticated context, contact, and spatially coordinated measurements in order to perform detailed exploration of sites on Mars that could reveal past habitability and biosignature preservation potential.</td>
</tr>
<tr>
<td>Mars 2020 Science Definition Team Task</td>
<td>With this overarching strategy in mind, to define detailed objectives, measurements, payload options and priorities &amp; an integrated mission concept for a 2020 rover mission to address: A. past habitability, B. potential biosignature preservation, C. progress toward sample return, &amp; D. contributed technology/human exploration payloads.</td>
</tr>
</tbody>
</table>
### Mission Objectives & Assumptions

#### MISSION OBJECTIVES

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

**B** Assess the biosignature preservation potential within the selected geological environment and search for potential biosignatures.

**C** Demonstrate significant technical progress towards the future return of scientifically selected, well-documented samples to Earth.

**D** Provide an opportunity for contributed Human Exploration & Operations Mission Directorate (HEOMD) or Space Technology Program (STP) participation, compatible with the science payload and within the mission’s payload capacity.

**Note:** The phrasing of Objectives A and B above is modified slightly from that given in the SDT charter, and the analysis in this package is organized along the lines of the above objectives statements.

#### ASSUMPTIONS & CONSTRAINTS

1. **Launch in 2020**

2. **Instrument cost nominal limit of $100M (including margin/reserves)**
   - ~$80M for SMD instruments
   - ~$20M for contributed elements
   - Surface operations costs and science support equipment (e.g., arm) not included in the above limits

3. **Utilize MSL Sky Crane EDL flight systems and Curiosity-class roving capabilities**
   - Address potential value and cost for improving access to high-value science landing sites

4. **Mission lifetime of one Mars year (~690 Earth days)**

5. **Mission pre-project will provide additional constraints on payload mass, volume, data rate, and configuration**
Deciphering geologic processes and history and assessing habitability:

1. Provides science results in its own right

2. Lays the foundation for objective B (Assessing potential for preservation of biosignatures, and seeking potential biosignatures)

3. Lays the foundation for objective C (careful selection of well-documented samples for MSR)
Key Concepts
Habitability and Potential Biosignatures

Introduction – Key Concepts

Adapted from Tori Hoehler

**Potential Biosignature Assemblage**

- **Organics**
  - Biomarker organic molecules
  - (organic matter features)

- **Minerals**
  - Biominerals
  - (composition & morphology consistent with biological activity)

- **Macro Structures/Textures**
  - Stromatolite
  - (macroscale rock fabrics & structures)

- **Micro Structures/Textures**
  - Microfossils
  - (microscale rock of mineral fabrics and structures)

- **Chemistry**
  - Possible microbial enrichment of REE in carbonate
  - (evidence of chemical equilibria or disequilibria)

- **Isotopes**
  - Isotopic record
  - (stable isotopic patterns)

**Preservation (Two Issues)**

**Preservation of the Evidence of a Prior Habitable Environment**
Evidence for the criteria above are preserved as geological or geochemical proxies, or may not be preserved at all.

**Preservation of Biosignatures**
If life existed in the past, biosignatures will exist today ONLY if conditions were favorable for biosignature preservation.
Pre-Conditions that must have been met:

- Past habitable environment
- Potential for biosignature preservation

Possible evidence of any past life:

- Existence of potential biosignature

Past life detected:

- Recognition of definitive biosignature

Proposed Mars 2020 Rover

Mars Sample Return

Labs on Earth
**Optimize: Science Return; Progress Toward NASA Goals**
Investigation Strategies & Measurements

Options Priorities

Mission Objectives Assumptions Guidelines Constraints

Investigation Strategies & Measurements

Instruments Support Equipment Tech Demos

Reference Payload(s)

Flight System Landing Site Ops Concept

Mission Concept
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.
What kinds of in situ observations and measurements are required?

Full details of the required observations at a particular site cannot be predicted precisely. However, the types of observations that are likely to be critical are well understood, as shown by the following examples among two broad rock classes.

### Relevant Features When Interpreting Water-laid or Water-altered Rocks

- Lateral/vertical changes in a sedimentary deposit or hydrothermal sediments
- Physical variations in a mineral phase: texture, crystal habit, or residence in veins/ layers/ cement/ clasts / concretions
- Inferred salinity gradient in a saline mineral assemblage
- Variations in detectable organic matter: host mineralogy, concentration, spatial arrangement
- Sedimentary structures and textures, associated mineralogical variations
- Mineral transition across a zone of alteration
- Sequence of vein-fill deposits
- Proximal-distal trends at a hydrothermal vent

### Relevant Features When Interpreting Unaltered Igneous Rock

- Petrologic character: ultramafic to granitic, mineralogic, trace element properties
- Age
- Type and intensity of aqueous alteration [if they are unaltered (see above) this bullet is not relevant]
- Type of occurrence: outcrop, “subcrop,” or float
- Igneous setting: intrusive, extrusive
- Grain size, chemical variation in minerals
- Degree of weathering
- Degree of impact shock metamorphism, including brecciation

*After E2E-iSAG*
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:

**Available of CHNOPS elements** (beyond those species present in the atmosphere) and electron donors

- **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

**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 properties** (e.g., salinity, pH, and temperature)

- **Protection from radiation** (e.g. planetary dipole field)

**Water energy** (quiet vs. high energy - implications for stabilization of microbial communities)

- **Rate of burial** (e.g. lacustrine - implications for establishment of microbial communities)

*Adapted from Tori Hoehler*
Evidence of an ancient environment’s characteristics lie in the mineralogy, chemistry, texture, and structure of the rocks. The evidence is subject to alteration over time.

Environments typically vary spatially and in time, which manifests as spatial variations in the rock record.

• Ability to measure mineralogy, chemistry, texture and structure of the rocks.
  __
• Ability to make sufficient quantity and quality of measurements to decipher the record of ancient environments and subsequent alteration

• Mobility (e.g., range, ability to navigate rough terrain and slopes, etc.)
• Ability to perform and integrate measurements across multiple scales
  __

Assessing habitability and preservation potential at a site with a record of an astrobiologically relevant ancient environment requires a rover that can navigate the terrain to conduct lateral and stratigraphic surveys across multiple scales and targets.
“Well documented” means that the appropriate geologic measurements have been carried out across the exploration area to provide maximum constraints on the interpretation of the sample analysis.

**SDT FINDING**

To ensure that a site, or samples from it, are “well documented” requires using the rover’s tools and instruments to make a sufficient quantity, variety and quality of geologic observations to interpret past environmental conditions and understand spatial and temporal relationships in the geologic record.

**QUANTITY OF GEOLOGIC OBSERVATIONS**

- Rocks and soils (regolith fines) within reach
  - Which ones to focus on?
- Targeted Remote Sensing observations
  - Which ones to touch?
- Contact observations
  - Which ones to sample?

*After E2E-iSAG*
Seventeen different categories of measurements were identified from two community workshops (see Appendix) and evaluated for responsiveness to the four objectives of the Mars 2020 mission.

- Contact mineralogy
- Context imaging
- Elemental chemistry
- Microscopic imaging
- Context mineralogy
- Atmospheric trace gas detection
- Contact organic detection/characterization
- Stable Isotopic ratios
- Organic characterization in processed samples
- Mineralogy in processed samples
- Redox potential
- Subsurface characterization
- Geochronology
- Remnant Magnetic Properties
- Radiation environment
- Regolith/dust properties
- Meteorology
The ability to spatially correlate variations in rock composition with fine scale structures and textures is critical for geological and astrobiological interpretations.
These are the measurement priorities for effectively and efficiently characterizing the geology of a site, assessing habitability, and supporting the informational/decisional needs of Objectives B and C.

- **Required Measurements:**
  - Context imaging
  - Context mineralogy
  - Fine-scale imaging of arm work volume
  - Fine-scale elemental chemistry of arm work volume
  - Fine-scale mineralogy of arm work volume

- **Additional “Baseline” Measurements**
  - Organic detection
  - Subsurface characterization

- **Additional Desirable Measurements (unranked)**
  - Geochronology (absolute age dating)
  - Redox potential in target material
  - Isotopic ratios in target material
  - Surface physical properties (e.g., regolith; dust)
  - Paleomagnetic data

*Priorities determined using the traceability matrix*
Detection of organic matter helps to characterize meteoritic inputs, hydrothermal processes, and other potential processes that might form abiotic (pre-biotic?) organic matter.

Acquiring rock samples that contain organic matter is a very high priority for MSR scientific objectives 1, 3-6 and 8 of the E2E-iSAG report.
Knowledge of **structure** and **composition** of subsurface materials could augment identification and refine context of targets for detailed measurement.

### Subsurface Structure

**Problem:**
- Information on setting is gained from limited outcrops accessible to threshold instruments. MER experience shows that considerable time spent traversing to outcrops could be saved by better knowledge of stratigraphy.

**Example:**
- Opportunity crossed multiple contacts as it traversed the onlap of sulfate-bearing deposits onto Noachian terrain; unclear relationship of units at Cape York
- 3D structure would inform a continuous cross-section, providing context

**Relevant measurements:**
- Lateral, depth variation in structure, density, conductivity; depth of discontinuities

**Examples:** ground-penetrating radar

### Subsurface Composition

**Problem:**
- Lithologies of interest for detailed measurement or sampling can be hidden from threshold instruments by centimeters or more of dust or regolith

**Example:**
- Spirit discovered high concentrations of silica where a stuck wheel removed a few cm of overburden
- Ability to sense to ~ >5 cm depth by design could detect scientifically important lithologies that would otherwise not be investigated

**Relevant measurements:**
- Detection at depth of key minerals or associated elements – sulfates (S), silica (Si), carbonates (C), highly hydrated minerals (H) – can pinpoint key locations for sampling and/or evaluation of stratigraphy

**Examples:** gamma-ray spectrometer, neutron spectrometer, trenching tool
Mars 2020 Science Definition Team Report:

Part 2. Objectives B and C

David Des Marais, NASA Ames Research Center

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Options and Priorities to Achieve

**Objective B**

Assess the potential for preservation of biosignatures within the selected geological environment and search for potential biosignatures.
To search for potential biosignatures, it is necessary to (a) identify sites that very likely hosted past habitable environments, (b) identify high biosignature preservation potential materials to be analyzed for potential biosignatures, and (c) perform measurements to identify potential biosignatures or materials that might contain them.
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.
Certain minerals and rock types are more effective than others for enhancing the preservation of biosignatures in Earth’s geologic record.

An assessment of Biosignature Preservation Potential (BPP) should consider the minerals and rock types that might contain Potential Biosignatures (PBS).
Biosignatures must “run a gauntlet” of processes through geologic time that can either lower or elevate their BPP.

**GEOLOGIC TIME**

<table>
<thead>
<tr>
<th>Environment of PBS Formation</th>
<th>Initial Sequestration of PBS in a Geologic Deposit</th>
<th>Long-term sequestration of PBS</th>
<th>Surface exposure to impacts, erosion and/or weathering of the host deposit</th>
</tr>
</thead>
<tbody>
<tr>
<td>e.g., microorganisms degrade or recycle organic and mineral PBS*, OR PBS preservation is enhanced in reducing environments that minimize degradation of organics and/or reduced minerals</td>
<td>e.g., degrade PBS by microorganisms*, reactions with minerals, dissolution, compaction, etc. OR preserve PBS by rapid burial and/or entombment in impermeable matrices</td>
<td>e.g., degrade PBS by microorganisms*, oxidation, radiolysis, dissolution, thermal degradation, impact, deformation, chemical replacement due to migrating fluids, etc. OR preserve PBS by desiccation, sequestration in impervious host rock, low irradiation, and benign temperatures and pressures</td>
<td>...same examples as those indicated for long-term sequestration of PBS</td>
</tr>
</tbody>
</table>

*Thereby at least partially replacing PBS from the initial environment of formation with a new set of PBS

Assessing the potential for preservation of any given type of biosignature requires interpretation of past geological environments and processes. This interpretation requires measurements of rock chemistry, mineralogy, oxidation state, and rock texture, morphology and context.
The strategy first to evaluate habitability and BPP in an area, and then to search for PBS, though logical, is typically not practical during rover operations. Because a rover rarely returns to previously visited locations, it must complete all observations before it moves to the next location. Accordingly, evaluations of habitability and BPP and any measurements of PBS must be executed concurrently before leaving a particular location.

Although it would be logical to assess habitability and biosignature preservation potential before seeking potential biosignatures, for practical considerations, evidence for all three would be sought concurrently during exploration at a particular rover location.
Different types of organic matter measurements provide different levels of confidence in a biological origin for the organic matter (OM)*

- Distributions of identifiable molecular structures and/or components (if macromolecular)
- Isomer ratios of amino acids
- Molecular mass distribution of organic components
- Compound specific isotopic composition
- Aliphatic/aromatic ratio
- Organic functionalization (polar/nonpolar)
- C, H, O, S, N, Cl ratios of organic matter
- Fine scale OM distribution in materials
- Stable isotopic composition of organic carbon
- Basic molecular bond information
- Presence of organic carbon (compounds with C-H bonds)
- Presence of reduced carbon (e.g., graphite, diamonds)

* The level of confidence provided by a given measurement varies depending on the specific details (e.g. degree of thermal degradation) of the sample being investigated.
## Ability to Characterize Reduced Carbon Compounds That Might Be Present in Planetary Materials

### High characterization capability

<table>
<thead>
<tr>
<th>Estimated Detection Limits (volume fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
</tr>
<tr>
<td>N/A (other than Rock Abrasion Tool)</td>
</tr>
<tr>
<td>Interrogation of rock cores, powders, drill, fines, etc.</td>
</tr>
<tr>
<td>Body-mounted Raman</td>
</tr>
</tbody>
</table>

### Intermediate

- Body-mounted Raman

### Specialized/limited information

- Diffuse Reflectance FTIR
- Pyrolysis-GCMS, Laser-Desorption MS
- Liquid chrom./MS w/ liquid extraction, sample derivatization, etc.
- Capillary Electrophoresis with Laser-Induced Fluorescence
- Colorimetric and fluorescence assays (with compound-specific detection limits)

### Sample Processing Requirements

- Interrogation of rock cores, powders, drill, fines, etc.
- Body-mounted Raman
- Diffuse Reflectance FTIR
- Pyrolysis-GCMS, Laser-Desorption MS
- Liquid chrom./MS w/ liquid extraction, sample derivatization, etc.
- Capillary Electrophoresis with Laser-Induced Fluorescence
- Colorimetric and fluorescence assays (with compound-specific detection limits)
Value of organic characterization:

- The complexity and diversity of organic compounds can help to characterize processes that are very important for habitability and any life. A more thorough characterization of a sample’s organic components will access more of this important information that is stored in a sample’s organic components.
- Characterization and molecular analysis of organic matter helps to characterize more precisely any meteoritic inputs, hydrothermal processes, and other abiotic processes that create organic matter.
- The caching and return of samples bearing organic carbon provides critical insight into the origin of organic carbon signatures in Martian meteorites (e.g. ALH84001, Steele et al. 2012a,b, Agee et al., 2013).
- Confidence in interpretation of the other five classes of biosignatures is greatly enhanced if any associated organic matter is analyzed more thoroughly.
- Organic matter characterization of bulk and molecular components would help to constrain the assessment of processes that influence various types of BPP.

Additional *in situ* organic detection and characterization of organic matter, such as provided by a second spectroscopic technique, would significantly improve our understanding of biosignature preservation potential and ability to detect potential organic biosignatures.
• Required Measurements
  – Context imaging
  – Context mineralogy
  – Fine-scale imaging – co-registered with Mineralogy
  – Elemental chemistry (mapping at fine scale is desired)
  – Fine-scale Mineralogy
  – Reduced C detection
  – Organic detection method #1

• Additional “Baseline” Measurements
  – Organic detection method #2 (enables characterization)

• Additional Desirable Measurements
  – Organic molecular analysis (characterization)

• Other Required Capabilities:
  – Ability to remove rock coating and weathering layers
Options and Priorities to Achieve

Objectives C

Objective C

Demonstrate significant technical progress toward the future return of scientifically selected, well-documented samples to Earth.
Reasons for returning samples for analysis on Earth...

- Perform definitive detection of a biosignature. As the range of measurements that can be accommodated on a single rover is extremely limited, neither the detection of a PBS nor the non-detection of one would be considered definitive until performed in a lab.
- Use advanced instrumentation not amenable for flight to Mars
- Employ techniques requiring complex sample preparation
- Use a virtually unlimited array of different instruments, including future instruments not yet even designed
- Gain the ability to run sequential analyses and replicate analyses in different labs.

Adapted from iMARS (2008); NRC Decadal Survey (2011)

From *Vision and Voyages for Planetary science in the Decade 2013-2022*:
Committee on the Planetary Science Decadal Survey; National Research Council, March 2011

“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, 2012) for the critical role returned samples will play in the scientific exploration of Mars.
Have there been any very recent new findings that could alter the logic leading to the conclusions of those reports?

- **Post-Decadal Survey Discovery of Recurring Slope Lineae (RSLs)**
  - Might be signs of present-day surface release of liquid water. However, understanding of RSL is too immature to conclude that exploring them *in situ* is more compelling for astrobiology than sample return. Also, their possible “special region” status could place complex and/or costly Planetary Protection constraints on potential missions to RLSs.

- **Recent MSL and MER mission results**
  - Discovery of sedimentary rocks containing reducing components, water-formed conglomerates, phyllosilicate minerals, water-deposited minerals in veins, etc., reinforces inference of past habitability and of BPP; provides even stronger support for the need for sample return!

- **Recent Mars meteorite results**
  - Findings of abiotic macromolecular carbon (with N, O, H) in martian meteorites, and of abundant water in NWA7034, confirm availability of compounds needed for life, and show that organic PBS can be preserved near the martian surface. Provides support for Mars’ BPP; emphasizes need for sophisticated analyses capabilities on Earth.

None of the discoveries of the last decade have changed the fundamental rationale for Mars Sample Return.
Demonstrate significant technical progress toward the future return of scientifically selected, well-documented samples to Earth.

Because of the overall importance of Mars Sample Return to NASA’s strategic objectives, the Mars 2020 mission is expected to make significant technical progress towards MSR.

How does the SDT interpret “significant technical progress”?

As shown on the following slides, delivering scientifically selected martian samples to Earth involves a series of functional steps (spanning several missions) that must be completed in order, beginning with the selection and acquisition of samples.
If we don’t advance to here we would need to send another rover in the future, with science and sampling capability, to complete the first step of MSR.

<table>
<thead>
<tr>
<th>Options for Technical Progress Towards MSR</th>
<th>New Capability?</th>
<th>Consistent with Proposed Mars-2020 Resources?</th>
<th>Resulting contribution to MSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select Samples (for future collection)</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Select Samples &amp; Assemble Demonstration Cache</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Select Samples &amp; Assemble Returnable Cache</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

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.

**Significant technical progress by Mars 2020 towards the future return of samples to Earth within the mission constraints demands the development and deployment of a sampling and encapsulation system and the assembly of a cache of scientifically selected, well-documented samples packaged in such a way that they could be returned to Earth.**
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.
A cache that merits returning in a scientific sense is one that has the potential to achieve the scientific objectives of sample return identified by E2E-iSAG (2012).

**Scientific Objectives in Priority Order**

<table>
<thead>
<tr>
<th>Priority</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Critically assess any evidence for past life or its chemical precursors, and place detailed constraints on the past habitability and the potential for preservation of the signs of life</td>
</tr>
<tr>
<td>2</td>
<td>Quantitatively constrain the age, context and processes of accretion, early differentiation and magmatic and magnetic history of Mars.</td>
</tr>
<tr>
<td>3</td>
<td>Reconstruct the history of surface and near-surface processes involving water.</td>
</tr>
<tr>
<td>4</td>
<td>Constrain the magnitude, nature, timing, and origin of past planet-wide climate change.</td>
</tr>
<tr>
<td>5</td>
<td>Assess potential environmental hazards to future human exploration.</td>
</tr>
<tr>
<td>6</td>
<td>Assess the history and significance of surface modifying processes, including, but not limited to: impact, photochemical, volcanic, and aeolian.</td>
</tr>
<tr>
<td>7</td>
<td>Constrain the origin and evolution of the martian atmosphere, accounting for its elemental and isotopic composition with all inert species.</td>
</tr>
<tr>
<td>8</td>
<td>Evaluate potential critical resources for future human explorers.</td>
</tr>
</tbody>
</table>

**Sample Types in Priority Order**

<table>
<thead>
<tr>
<th>Priority</th>
<th>Sample Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>Subaqueous or hydrothermal sediments (EQUAL PRIORITY)</td>
</tr>
<tr>
<td>1B</td>
<td>Hydrothermally altered rocks or Low-T fluid-altered rocks</td>
</tr>
<tr>
<td>2</td>
<td>Unaltered Igneous rocks</td>
</tr>
<tr>
<td>3</td>
<td>Regolith</td>
</tr>
<tr>
<td>4</td>
<td>Atmosphere, rocks with trapped atmosphere</td>
</tr>
</tbody>
</table>

**Mandatory:** Determine if the surface and near-surface materials contain evidence of extant life
**Key engineering factors for M2020 cache design**

**Interfaces to downstream elements**
- Transfer equipment (arm, etc.)
- Mars Ascent Vehicle/Orbiting Sample

**Long-term storage in Mars surface environment**
- External or internal to rover
- Nominal or anomalous retrieval by later mission

**Thermal design and history of cache environment over time**
- Characterize exchange of volatiles into or out of the samples
- Analyze/predict thermal history of the cache

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**The Cache Enables Future Science**

The ability to collect compelling samples for potential future return

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*Information Source: Whetsel/Parrish*
Direct excerpts from the current NASA Procedural Requirement document for PP related to the returning a sample cache

5.3.3 PP Category V. The Earth return portion of a Mars Sample Return mission is classified as “Restricted Earth return,” with all outbound portions required to meet associated requirements.

5.3.3.2 Unless specifically exempted, the outbound leg of the mission shall meet PP Category IVb requirements. This provision is intended to avoid “false positive” indications in a life-detection and hazard-determination protocol, or in the search for life in the sample after it is returned.

a. A “false positive” could prevent distribution of the sample from containment and could lead to unnecessary increased rigor in the requirements for all later Mars missions.

5.3.2.2 PP Category IVb. Lander systems designed to investigate extant Martian life shall comply with all of the requirements of PP Category IVA and also with one of the following requirements:

EITHER

a. The entire landed system is restricted to a surface biological burden level of ≤ 30 spores (see 5.3.2.4) or to levels of biological burden reduction driven by the nature and sensitivity of the particular life-detection experiments, whichever are more stringent, and protected from recontamination.

OR

b. The subsystems which are involved in the acquisition, delivery, and analysis of samples used for life detection are sterilized to these levels. Methods for preventing recontamination of the sterilized subsystems and preventing contamination of the material to be analyzed is provided.

Information Source: K. Buxbaum
Measurements required by the 2020 Mars Rover to achieve Objective C are almost identical to those required for Objectives A and B.

- **Required Measurements**
  - Context imaging
  - Context mineralogy
  - Fine-scale imaging of arm work volume
  - Elemental chemistry of arm work volume
  - Fine-scale mineralogy of arm work volume

- **Additional “Baseline” Measurements**
  - Organic detection

**UNRANKED Additional Possible Measurements Below the Baseline**

- Observations of the Collected Sample
- Magnetometer
- Age Dating
Mars 2020 Science Definition Team Report:

Part 3. Landing Site Considerations

John Grant, National Air and Space Museum

NOTE: The content of this presentation is drawn from the SDT’s text report, and for further information, the interested reader is referred there (http://mepag.jpl.nasa.gov/reports/mep_report.html).

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New science goals and objectives require a new landing site selection process.

**MSR Suggested Criteria** vs. **MSL Science Criteria** vs. **2020 Science Criteria**

- **Search for Habitability**
- **Search for Potential Biosignatures**
- **Biosignature Preservation**
- **In-Place Igneous Rocks**

...are all required to satisfy MSR science objectives.

Outcropping igneous rocks are usually found in rocky, uneven locations with scarps, buttes, boulders – obvious landing challenges.

*Columbia Hills – outcropping volcanics*

*Slide from 2020 Project Science, post SDT*
• Pressure cycle very favorable for 2020
  – Mars orbit eccentricity transfers CO₂ from polar caps to atmosphere
  – Atmosphere significantly more dense than for MSL landing

• More density = capability to land safely at higher elevation

• 2020 atmosphere provides significant “no cost” improvements to landing elevation for same mass

• Expect 2020 unmargined capability up to 0.5 km elevation, -0.5 km margined
  – Some variability depending on landing site specific characteristics
  – Generic atmosphere assumptions believed to be conservative
• Previous landing sites (e.g. Gale, Gusev, Meridiani) merit consideration as landing sites for Mars-2020, science Objectives B and C are different from those of prior missions and discoveries to date do not warrant pre-selection of any prior landing sites as the Mars-2020 landing site.

• There is also a growing inventory of diverse data available for evaluating the relative merits of varied existing and new candidate landing sites that will shed new light on their potential when evaluated by the broad expertise of the science community.

• If the 2020 mission carries Range Trigger, Terrain Relative Navigation (TRN), and/or Terminal Hazard Avoidance (THA) capabilities (discussed later), it will be able to access landing sites that could not have been considered or suggested previously.

• The SDT recommends that a landing site selection process be conducted, which would gather community input on candidate field sites and on critical decisions that will influence mission design and final site selection.

Mars 2020 would be the first mission to cache samples for possible return to Earth and may require a landing site selection process differing from those previous and tailored to a diverse set of scientific goals. It is therefore crucial to involve the broad expertise of the science community in proposing and evaluating candidate sites for the 2020 rover, thereby leading to science community consensus on the optimal site for meeting the mission goals.
• E2E-iSAG observed that to maximize returned sample science, the MSR sample collection would need to include *unaltered igneous rocks collected from outcrop*.

• E2E-iSAG evaluated the ~65 landing sites proposed for MSL, and found ~10 where *outcrops* of both igneous rocks and sedimentary/ hydrothermal rocks appear to be present at the same landing site. However, most of these sites would not be accessible to the MSL system as applied (see Slides 105-106).

• If unaltered igneous rocks in outcrop is a threshold-level landing site requirement (final decision on this to be reached by later groups/activities), then there may not be a sufficient population of sites to choose from given MSL as-flown EDL capabilities.

**Reconciling the Issue:** one or both of the following steps needs to be taken:

1. Relax the E2E-iSAG-proposed landing site criterion to *unaltered igneous rocks collected from either outcrop or float*. The latter would have adverse science consequences for the sample caching objective of Mars 2020.

2. Improve the MSL as-flown EDL system to increase the number of sites that can be accessed.

**SDT FINDING**

Access to unaltered igneous rocks as float is considered a threshold-level field site requirement, but requiring that they be collected from known stratigraphic context would add significant science risk to the mission—it may be impossible to access a suitable field site using ‘as applied’ MSL capabilities.
<table>
<thead>
<tr>
<th>Reference Landing Site</th>
<th>Stressing Parameter</th>
<th>TRN† Required</th>
<th>THA† Required</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holden Crater</td>
<td>Latitude (-26° S)</td>
<td>Maybe – land closer to layers</td>
<td>No</td>
<td>Pushes southerly lat limits; TRN might enable “land on”</td>
</tr>
<tr>
<td>Jezero Crater</td>
<td>Rock Abundance</td>
<td>No</td>
<td>Yes</td>
<td>&gt;1% failure without THA</td>
</tr>
<tr>
<td>Nili Fossae</td>
<td>Elevation (-0.6 km)</td>
<td>Yes</td>
<td>Yes (No if smaller ellipse)</td>
<td>Landing ellipse ranges up to 0 km elevation, 6% area scarps</td>
</tr>
<tr>
<td>E Margaritifer</td>
<td>Inescapable Hazards</td>
<td>Yes</td>
<td>Probably Not</td>
<td>&gt;3% of landing ellipse is inescapable, 99% success with 300 m divert</td>
</tr>
<tr>
<td>NE Syrtis</td>
<td>Scarps</td>
<td>Yes</td>
<td>Maybe</td>
<td>&gt;4% ellipse scarps, 99% success with 300 m divert</td>
</tr>
<tr>
<td>Melas Chasma</td>
<td>Landing Ellipse Size Wind</td>
<td>Yes</td>
<td>Probably</td>
<td>V. Marineris - Wind and Relief Issues? (ellipse size)</td>
</tr>
</tbody>
</table>

**Six potential landing/field sites are identified as “stressors” on landing capabilities and encompass a sufficiently large population of candidate sites (>60, see table in Appendix 6) as to ensure high priority candidates remain as constraints evolve. These form an envelope which includes accommodation of the prior MER and MSL landing sites and many of the > 60 other sites between 30°N and 30°S that have been proposed by the science community for MSL and future missions.**

*The threshold engineering requirements defined by these reference sites enable access to prior landing sites in Gale, Gusev, and Meridiani*

† TRN = Terrain-Relative Navigation; THA = Terminal Hazard Avoidance.
• Terrain Relative Navigation (TRN) allows improved accuracy of estimated location of vehicle during entry
• Could be used to avoid hazard areas within a landing ellipse by diverting around these hazards
• Enables access to landing sites that would otherwise be ruled out due to rock, scarp, and ripple hazards (see NE Syrtis example below)
- Terminal Hazard Avoidance (THA) is a combination of autonomous, real-time hazard detection and guided avoidance.
- Enables access to landing sites with hazards that might not be visible in orbiter images, such as rocks and small-scale high slopes (see Jezero Crater example below).
The combination of range trigger and TRN effectively makes Gale crater “land on” the lower slopes of Mt. Sharp.

The SDT concludes that Range Trigger should be a threshold capability and strongly recommends inclusion of TRN as highest priority baseline to help ensure access to a sufficient number of high priority sites and to reduce science risk related to site selection. Terminal Hazard Avoidance (THA) has less impact on access to unique classes of sites and is considered “enhanced.”

From Matt Golombek

From Matt Golombek
Possible Landing Site Selection Process Timeline

*(derived in Post-SDT time period—not an SDT product)*

- **2013**
  - Preliminary Eng. Req.
  - SDT Report

- **2014**
  - 1st LS Workshop

- **2015**
  - Investigation Selection

- **2016**
  - Phase B end
  - 2nd LS Workshop

- **2017**
  - Phase C end
  - 3rd LS Workshop

- **2018**
  - Selection/LS Target
  - 4th LS Workshop

- **2019**
  - Project Rec., Peer Review, HQ Selection
  - 5th LS Workshop

- **2020**
  - L-1 yr Oct
  - March

- **Timeline Details**
  - 9/9/2013
  - 2020 Mars Rover Science Definition Team
Site selection for the Mars 2020 mission must satisfy the aspirations of \textit{in situ} science and creating a returnable cache.

A process to perform careful and full evaluation of diverse new and existing candidate landing sites is warranted.

The expertise of the science community can assist in making critical decisions about landing sites early enough in the mission design phase to limit costs for capabilities that are not adopted (e.g., if community consensus finds that sites that need TRN can be eliminated from consideration for a Mars 2020 landing site, then TRN can be descoped before incurring significant costs).
Mars 2020 Science Definition Team Report:


Jack Mustard, Brown University

NOTE: The content of this presentation is drawn from the SDT’s text report, and for further information, the interested reader is referred there (http://mepag.jpl.nasa.gov/reports/mep_report.html).

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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>
<thead>
<tr>
<th>2020s</th>
<th>2030s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proof of Concept</td>
<td>Validation</td>
</tr>
</tbody>
</table>

**2020 Rover**

**ISRU O₂ Production**
- Demonstration of CO₂ collection in actual Mars environment reduces future risks. O₂ 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

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

- Human Sub-Scale Validation Demos
  - Land Large Payload
  - Advanced Aeroassist
  - Supersonic Retro-Propulsion
  - ISRU O₂ Production and Use
  - Surface power

**Human Systems Development**

-取得大气下层数据可降低EDL不确定性与风险
-理解长期大气行为可降低未来EDL风险
-证明微生物污染检测对未来载人任务的重要性
#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

- 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 top-priority measurements that address HEOMD strategic knowledge gaps also benefit Mars science.
## High Priority Candidate STMD Payloads

<table>
<thead>
<tr>
<th>Instrument/Demo</th>
<th>Description</th>
<th>Forward Benefits</th>
<th>STP Priority</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range Trigger</td>
<td>Software for parachute deployment based on range to target</td>
<td>Precision landing, site access</td>
<td>H</td>
<td>SMD</td>
</tr>
<tr>
<td>Terrain-relative Navigation (TRN)(^1)</td>
<td>Divert to avoid a priori hazards and/or get closer to science targets</td>
<td>Precision landing, site access, pinpoint landing</td>
<td>H(^2)</td>
<td>STMD HEO</td>
</tr>
<tr>
<td>MEDLI</td>
<td>EDL instruments as flown on MSL</td>
<td>Inform future applications and developments</td>
<td>H</td>
<td>STMD HEO</td>
</tr>
<tr>
<td>MEDLI +Up(^3)</td>
<td>Parachute deployment, operation and drag observations</td>
<td>Inform future applications and developments</td>
<td>H</td>
<td>STMD</td>
</tr>
</tbody>
</table>

1. Recommended instantiation for 2020 would be location determination only — enhancements could include altimetry, velocimetry, and/or real-time hazard avoidance.

2. To be considered by the Landing Site subteam in Phase II.


### SDT Finding

The high-priority technology payloads, based on benefit and risk are: Range Trigger, Terrain-Relative navigation, and MEDLI/MEDLI+Up.
Reference Payloads

Mission
Objectives
Assumptions
Guidelines
Constraints

Options
Priorities

Investigation
Strategies &
Measurements

Instruments
Support Equipment
Tech Demos

Reference Payload(s)

Flight System
Landing Site
Ops Concept

Mission
Concept
The measurements that would be required to meet the geology and habitability, biosignatures, and caching objectives are similar. Thus, these three objectives are compatible and well-suited to be assigned to the same mission.
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>
<thead>
<tr>
<th>Functionalities Required</th>
<th>Blue Straw Payload</th>
<th>Orange Straw Payload</th>
<th>$ High, Med, Low</th>
<th>$ High, Med, Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context imaging</td>
<td>Mastcam-like</td>
<td>Mastcam-like</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Context Mineralogy</td>
<td>UCIS-like</td>
<td>mTES-like</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Elemental Chemistry</td>
<td>APXS-like</td>
<td>μXRF-like</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Fine-scale imaging</td>
<td>MAHLI-like</td>
<td>MMI-like</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Fine-scale mineralogy</td>
<td>Green Raman-like</td>
<td>Deep UV-like</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Organic Detection</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science support equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology payload elements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Threshold Total (SMD funded)</strong></td>
<td>~90</td>
<td>~90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional Instrument Options</td>
<td>GPR</td>
<td>GPR</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>HEO contributed payload</td>
<td>ISRU</td>
<td>ISRU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology payload elements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Baseline Total (SMD funded)</strong></td>
<td>~105</td>
<td>~105</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

**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
• The SDT has been asked to "describe priorities for scaling the mission concept either up or down (in cost and capability)."

• Many of the threshold measurements can be implemented by a range of instruments that vary in cost and performance.

• Thus, to first order, scaling either up or down can be accomplished within the SDT’s vision of the mission by NASA selecting either higher or lower cost/performance instruments in each measurement category, and/or by selection of an instrument from the “baseline” and “enhancement” set.

This trade and cost scaling needs to be done as part of evaluating the response to the AO, not by this SDT.
Threshold Measurements and Capabilities

All measurements below of “good” quality

- **Context Imaging**
  - Panoramic color and stereo/ranging capabilities for science and operations

- **Context Mineralogy**
  - Survey outcrop-scale mineralogy
  - Identify mineralogy and abundances

- **Fine-scale Mineralogy**
  - Identify major, minor, and trace minerals and related features and textures

- **Fine-Scale Elem. Chemistry**
  - Identify elemental abundances

- **Fine-scale Imaging**
  - Determine fine-scale details, textures, and structures

- **Organic Detection**
  - Detect and measure organic materials and compounds with good sensitivity

It is assumed that ~2-3 instruments would be located on the mast, with the remainder located on the arm, but some of these measurements can be performed from either position.

Science Support Functions

- **Sample Cache**
- **Rock/Regolith Coring Tool**
  - For sample acquisition

- **Sample Encapsulation/Caching**
  - Encapsulation dust-tight

- **Surface Preparation Tool**
  - Brushing and grinding capabilities

- **Sampling Support**
  - blanks/standards
  - Extra bits

- **Sample Cleanliness**
  - Sample purity to <40 ppb Earth-sourced organics
**Baseline Measurements and Capabilities**

**At least some measurements below of “better” quality**

- **Context Imaging**
  Panoramic color and stereo/ranging capabilities for science and operations

- **Context Mineralogy**
  Survey outcrop-scale mineralogy
  Identify mineralogy and abundances

- **Fine-scale Imaging**
  Determine fine-scale details, textures, and structures

- **Fine-scale Mineralogy**
  Identify major, minor, and trace minerals and related features and textures

- **Fine-Scale Elem. Chemistry**
  Identify elemental abundances

- **Organic Detection**
  Detect and measure organic materials and compounds with good sensitivity

---

**Science Support Functions**

- **Sample Cache**
- **Sample Encapsulation/Caching**
  - Encapsulation air-tight
- **Surface Preparation Tool**
  Brushing and grinding capabilities

- **Rock/Regolith Coring Tool**
  For sample acquisition

- **Sampling Support**
  - blanks/standards
  - Extra bits

- **Sample Cleanliness**
  Sample purity to <10 ppb Earth-sourced organics

- **Capability to Observe Cores**
  Use instruments on cores

---

**Range Trigger**
Improved EDL error ellipse.

**ISRU**
Collect CO2. Analyze dust size and shape

**TRN**
Improved EDL—terrain hazards

**7th Measurement**
To be decided by competition among subsurface sensing, or organic detection method #2,
Mission Concept
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.

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

Multiple strategies to improve on the modeled, reference operations scenarios
Will be available as the proposed mission is further developed.

“You can get anything you want, but you can’t get everything you want.”

Quantity of
Field Work
e.g.,
3 km total driving
20 samples
full complement of fieldwork
(1 core per characterized target)

Quantity of
Coring/Caching
e.g.,
5 km total driving
34 samples
2 cores per characterized target

Quantity of
Driving
e.g.,
15 km total driving
20 samples
2 cores per characterized target

669 sols
1 Mars Year

SDT FINDING

SDT MAJOR FINDING

9/9/2013
Strawman Spacecraft Accommodation
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

CRUISE/ APPROACH
- 8 to 9-month cruise
- Arrive Jan/Mar 2021
- No changes from MSL (equivalent checkout capability, etc.)

LAUNCH
- Atlas V Class
- Period: Jul/Aug 2020

*EDL in work
This mission concept preserves maximum MSL heritage. The payload and a few specific elements are unique to the Mars 2020 rover concept.
Conclusions
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.
Seeking signs of past life

Prepare for human exploration

Two major *in situ* science objectives

Returnable cache of samples

Coordinated, nested context and fine-scale measurements

Coring system

Geologically diverse site of ancient habitability

Efficient surface operations, one Mars-year lifetime

Improved EDL for landing site access

MSL heritage rover
The 2020 Mars Rover mission offers many important advances relative to MER and MSL:

- **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**

Potential to land on high priority scientific targets previously out of reach, shorten drive distances.
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
Backup Material
## SDT Roster

<table>
<thead>
<tr>
<th>Name</th>
<th>Professional Affiliation</th>
<th>Interest/Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chair</strong></td>
<td></td>
<td>--------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Mustard, Jack</td>
<td>Brown University</td>
<td>Generalist, geology, Remote Sensing, MRO, MEPAG, DS, MSS-SAG</td>
</tr>
<tr>
<td><strong>Science Members (n = 16)</strong></td>
<td></td>
<td>--------------------------------------------------------------------------------------</td>
</tr>
<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-SSG, MSL(SAM), EXM, P-SAG</td>
</tr>
<tr>
<td>Carr, Michael</td>
<td>USGS, ret.</td>
<td>Geology, Hydrology, ND-SAG, E2E, P-SAG, Viking, MER, PPS</td>
</tr>
<tr>
<td>Des Marais, 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, MRO, MSL, MGS, cameras, E/PO</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>
</tr>
<tr>
<td>Ming, Doug</td>
<td>NASA JSC</td>
<td>Geochemistry, MSL (CHEMIN, SAM), MER, PHX</td>
</tr>
<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 (T.C.)</td>
<td>Princeton Unv.</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>
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<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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<td>Treiman, Allen</td>
<td>LPI</td>
<td>Meteorites, Samples, Igneous Petrology</td>
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<td><strong>HEO/OCT representatives (n = 3)</strong></td>
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<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 HQ</td>
<td>technology development, planning for humans to Mars</td>
</tr>
<tr>
<td><strong>Ex-officio (n = 7)</strong></td>
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<tr>
<td>Meyer, Michael</td>
<td>NASA HQ</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>
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<td>Mars 2020 Program Executive</td>
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<tr>
<td>David Beaty</td>
<td>JPL</td>
<td>Acting Project Scientist, Mars Program Office, JPL</td>
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<tr>
<td>Deborah Bass</td>
<td>JPL</td>
<td>Acting Deputy Proj. Sci, Mars Program Office, JPL</td>
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<tr>
<td>Jim Garvin</td>
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</tr>
<tr>
<td>Mike Wargo</td>
<td>NASA</td>
<td>HEO Mission Directorate</td>
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<tr>
<td><strong>Observer (n = 1)</strong></td>
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<tr>
<td>Jorge Vago</td>
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<td><strong>Supporting resources (n = 2)</strong></td>
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<tr>
<td>Wallace, Matt</td>
<td>JPL</td>
<td>Deputy Project Manager, 2020 Surface Mission, designated engineering liaison</td>
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<td>Milkovich, Sarah</td>
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<td>SDT documentarian, logistics</td>
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<tr>
<td>AO</td>
<td>Announcement of Opportunity</td>
<td>MSR</td>
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<tr>
<td>APXS</td>
<td>Alpha-Particle X-ray Spectrometer</td>
<td>mTES or mini-TES</td>
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<tr>
<td>CCBU</td>
<td>ChemCam Body Unit</td>
<td>IR</td>
</tr>
<tr>
<td>CE</td>
<td>Compute Element</td>
<td>OCM</td>
</tr>
<tr>
<td>CheMin</td>
<td>Chemistry &amp; Mineralogy X-Ray Diffraction/X-Ray Fluorescence Instrument</td>
<td>ODY</td>
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<tr>
<td>CHNOPS</td>
<td>carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur</td>
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<tr>
<td>CPU</td>
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</tr>
<tr>
<td>EDL</td>
<td>Entry, Descent, and Landing</td>
<td>RAD</td>
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<td>EPC</td>
<td>Electronic Power Conditioner</td>
<td>RAT</td>
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<td>EXM</td>
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<tr>
<td>HA</td>
<td>Terminal Hazard Avoidance</td>
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<td>ISRU</td>
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<tr>
<td>LVS</td>
<td>Lander Vision System</td>
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<tr>
<td>MAHLI</td>
<td>Mars Hand Lens Imager</td>
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<tr>
<td>Mastcam</td>
<td>Mast Camera, an MSL instrument</td>
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<tr>
<td>MEDLI</td>
<td>MSL Entry Descent and Landing Instrument</td>
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<td>MEDLI+</td>
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<td>MEPAG</td>
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<td>μXRF</td>
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