Astrobiology and NASA's Proposed Mars 2020 Rover

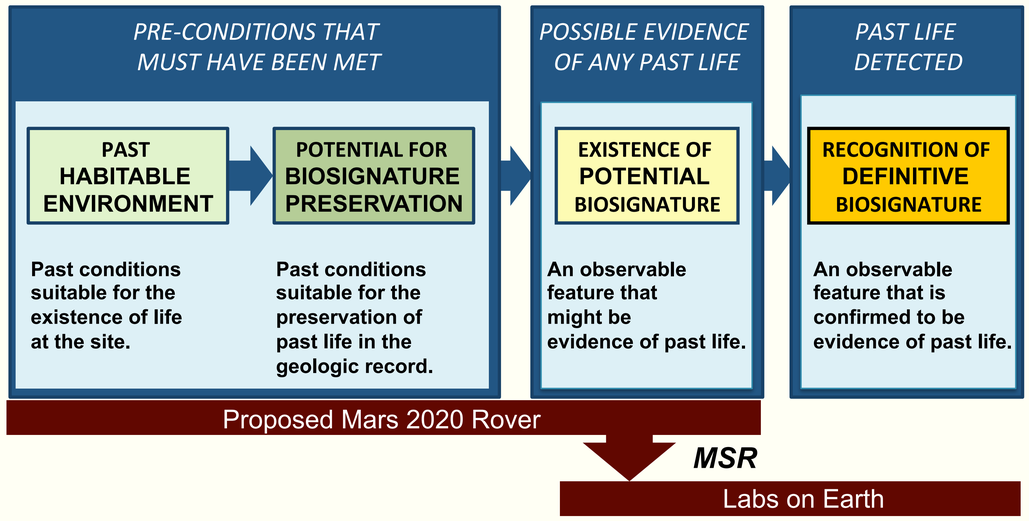
David J. Des Marais and The 2020 Mars Science Definition Team*

* J. F. Mustard (chair), M. Adler, A. Allwood, D.S. Bass, D.W. Beaty, J.F. Bell III, W.B. Brinckerhoff, M. Carr, D.J. Des Marais, B. Drake, K.S. Edgett, J. Eigenbrode, L.T. Elkins-Tanton, J.A. Grant, S. M. Milkovich, D. Ming, C. Moore, S. Murchie, T.C. Onstott, S.W. Ruff, M.A. Sephton, A. Steele, A. Treiman. http://mepag.jpl.nasa.gov/reports/MEP/Mars_2020_SDT_Report_Final.pdf

Strategy for Detecting Past Life on Mars

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.

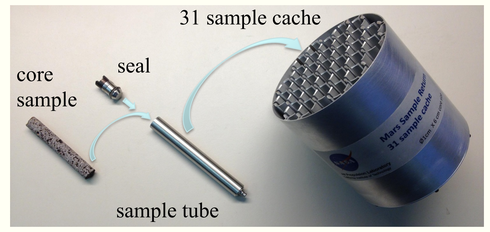
Although it would be logical to assess habitability and biosignature preservation potential before seeking potential biosignatures, for practical considerations, evidence for all three would be sought concurrently during exploration at a particular rover location.



Definitive Biosignatures

Finding and Recognizing Definitive Biosignatures

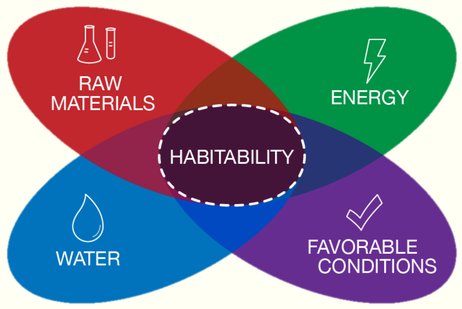
A biosignature (a "definitive biosignature") is an object, substance and/or pattern whose origin specifically requires a biological agent. A thorough characterization and definitive discovery of martian biosignatures would require analysis of samples returned to Earth.



Past Habitable Environments

Habitability

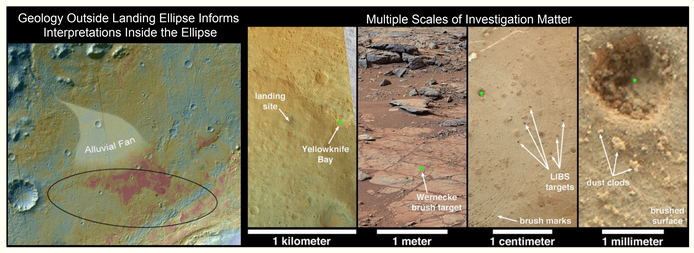
To assess the habitability of a past environment, the rover must be able to examine the geologic record of that environment and evaluate the following characteristics of that environment:



Preservation of the Evidence of a Prior Habitable Environment

Evidence for the habitability criteria are preserved as geological or geochemical proxies, or may not be preserved at all.

Integrate Observations Across Kilometer to Millimeter Scales



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.

Types of <u>In Situ</u> Observations and Measurements

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 these examples among two broad rock classes.

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

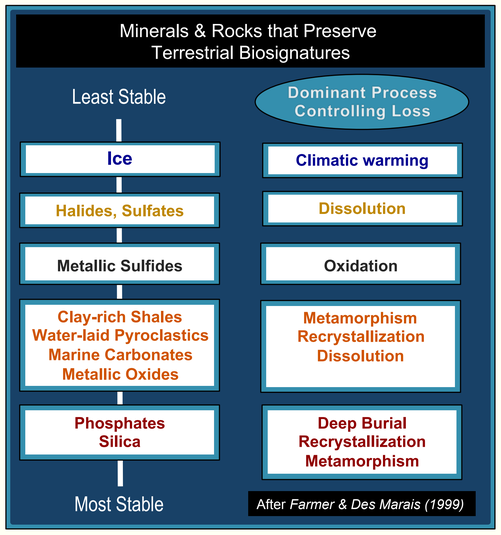
- Lateral/vertical changes in a sedimentary deposit or hydrothermal sediments
- Physical variations in a mineral phase: texture, crystal habit, or residence in veins/ layers/ cement/ clasts / concretions
- Inferred salinity gradient in a saline mineral assemblage
- Variations in detectable organic matter: 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

Biosignature Preservation Potential

Preservation of Biosignatures



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).

If life existed in the past, biosignatures will exist today ONLY if conditions were favorable for biosignature preservation.

The Effect of Geologic Time

Biosignatures must "run a gauntlet" of processes through geologic time that can either lower or elevate their BPP.

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.

GEOLOGIC TIME

Environment of PBS Formation	Initial Sequestration of PBS in a Geologic Deposit	Long-term sequestration of PBS	Surface exposure to impacts, erosion and/or weathering of the host deposit
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	e.g., degrade PBS by microorganisms*, reactions with minerals, dissolution, compaction, etc. OR preserve PBS by rapid burial and/or entombment in impermeable matrices	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	…same examples as those indicated for long-term sequestration of PBS

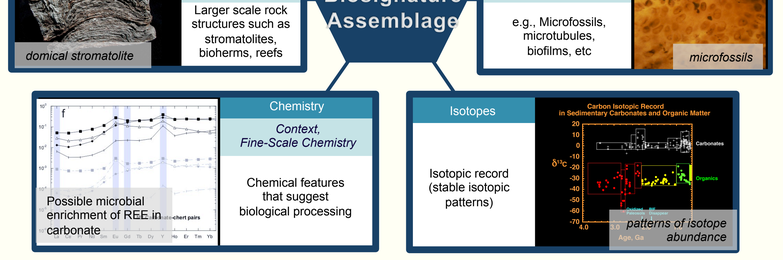
** Thereby at least partially replacing PBS from the initial environment of formation with a new set of PBS*

Potential Biosignatures

Categories of Potential Biosignatures Hypothesized to Exist in Martian Rocks

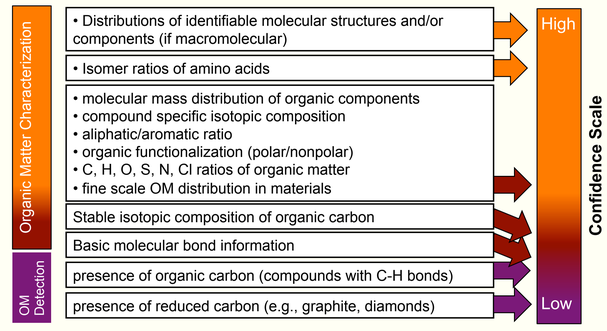
These hypothesized potential Martian biosignatures represent independently observable features.

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.



Finding and Recognizing Potential Biosignatures

Strategies for detecting ancient PBS can involve a range of optical or analytical measurements. Yet not all measurement types have the same diagnostic potential. Some measurements, such as detecting organic carbon, are suggestive but not definitive. Other measurement types provide greater confidence as to whether the feature under investigation has been produced by biological activity. Features that provide intermediate levels of confidence include elemental ratios and molecular mass distributions of organic compounds. When multiple types of measurements are combined, the ability to establish the presence of any PBS improves. For some features the probability of a non-biological origin is so remote that they represent single point diagnostic characteristics. Complex biological molecular structures, e.g., oligomers or polymers, represent such highest confidence biosignatures.



Mars 2020 Rover Science Strategy

Field Strategy

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.

Fundamental Principles of Field Assessment of Past Environments	Capabilities that a Rover Would Need
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.	• 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
Environments typically vary spatially and in time, which manifests as spatial variations in the rock record.	• **Mobility** (e.g., range, ability to navigate rough terrain and slopes, etc.) • Ability to **perform and integrate measurements across multiple scales**

Cross-Cutting Instrument Suite

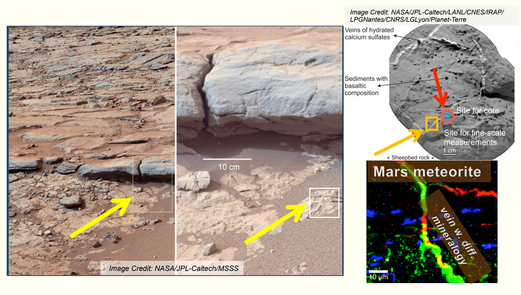
The measurements that would be required to meet the geology and habitability, biosignatures, and caching objectives are similar. Thus, these three objectives are compatible and well-suited to be assigned to the same mission.

SDT Measurement Recommendations & Priorities

Objective A *Geology*	Objective B *Biosignatures*	Objective C *Caching*
THRESHOLD		
Measurements/Capabilities	**Measurements/Capabilities**	**Measures/Capabilities**
•Context Imaging •Fine-Scale Imaging •Context Mineralogy •Fine-Scale Elem Chem •Fine-scale Mineralogy	•Context Imaging •Fine-Scale Imaging •Context Mineralogy •Fine-Scale Elem Chem •Fine-scale Mineralogy •Reduced/Organic C detection	•Context Imaging •Fine-Scale Imaging •Context Mineralogy •Fine-Scale Elem Chem •Fine-scale Mineralogy
BASELINE OPTIONS Enhanced-capability instrument(s) in THRESHOLD category **OR** add one of the following:		
•Subsurface Sensing •Organic C detection	•2nd method of Organic C Detection	•Organic C Detection
ENHANCED OPTIONS Enhanced-capability instrument(s) in THRESHOLD category **AND** an additional BASELINE or		
	•Molecular Analysis	

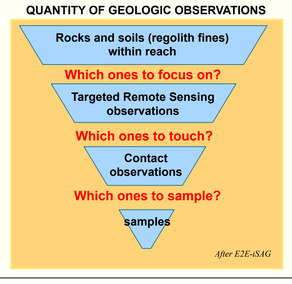
Spatially Correlateable Measurements

The ability to spatially correlate variations in rock composition with fine scale structures and textures is critical for geological and astrobiological interpretations



Well-documented Samples

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.



Preparation of a Returnable Cache

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.