Understand Mars as a system

- LIFE
- BIOSPHERE
- CLIMATE
- GEOLOGICAL PROCESSES & DEPOSITS

??
Astrobiology

Concepts of Life in the Contexts of Mars

- Information storage and replication
- Energy harvesting and transduction
- Organic biosynthesis

EVOLUTION
Requirements to Sustain Life

- Raw Materials (C,H,O,N,P,S, key metals, e-)
- Energy (light, chemical)
- Solvent (water)
- Clement Conditions (T, pH, S, etc.)

Adapted from T. Hoehler

\[ H = \text{HABITABLE CONDITIONS} \]
Productivity modulated by energy availability ...

Biomass Density: Pacific Ocean Sediments

Log (cells·mL⁻¹)

Depth (mbsf)

(Kallmeyer et al., AGU 2009)
Conditions That Could Sustain Life on Mars: Changes Over the Eons

4.5  3.8?  Today

Billions of Years Ago

(Des Marais et al., 2008)
Propagation is possible

Mars’ surface environment today

(NASA/JPL Special Regions Science Advisory Group, 2006)
Early Earth

- Thermal Escape
- H, H_2O, CO_2, N_2
- Sunlight
- Photochemical Reactions
- H_2O, CO_2, N_2
- Volcanic Outgassing
- Oceans
- Recycle
- Carbonate Rocks

Early Mars

- Thermal Escape
- H, H_2O, CO_2, N_2
- Sunlight
- Photochemical Reactions
- C, O, N Nonthermal Escape
- Volcanic Outgassing
- Surface Water
- H_2O, ? CO_2, ?
- Regolith
- Carbonate Rocks
The land area of the Earth is approximately equal to the total surface of Mars.

The land area of Africa is about the same as the total surface of the Moon.
Early climates were wetter and perhaps also somewhat warmer
Bonneville Crater
Columbia Hills
Basaltic Plains
Columbia Memorial Station (Lander)
West Spur
Plains
Husband Hill
Home Plate
Region
Spirit’s Traverse in Gusev Crater
“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.

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.
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.
Summary

• Mars system science: address interactions between geological, climate (and life?) processes over spatial and temporal scales

• “Habitability” spans orders of magnitude; this range matters in our search for life

• Integrate observations across broad spatial and temporal scales: site selection, landed remote sensing, contact science, sample selection, in-depth sample analysis

• An optimal human-robot synergy addresses challenges at all scales of observation

adapted from A. Pohorille
Understand Mars as a system.
Biosignatures: What We Look For…

- Body Fossils
- Biofabrics
- Chemical Fossils (Biomarkers)
- Gases
- Biominerals

Des Marais (2014)
End
Life’s Basic Functions

- Information Storage and Replication
- Energy Harvesting and Transduction
- Organic Biosynthesis

Evolution (descent with modification)

Light and/or Reactants

Heat and/or Products

CO₂

Organic Matter

Des Marais (2014)
Solvent for life

- Life requires self-organization of organic matter mediated by non-covalent interactions...
- Interactions must be well balanced; this implies a high dielectric constant and a robust solvophobic effect
- The solvent should support life over sufficiently wide ranges of T & P (& pH?)
- The solvent must be chemically active

adapted from A. Pohorille
Mineralogical Traces of Early Habitable Environments

- Water (availability, activity, composition), Energy (level, flux), Temp., pH, Salinity

(These factors combine to determine how habitable a system may be)

Energy balance analysis

Energy Demand = f (T, pH, fluid comp., self-repair)

Energy Supply = f (T, pH, fluid comp., & host matrix)

Biomass Abundance Estimate

Extremes in T, pH, salinity, radiation, etc. impose substantial energy demands

(T. Hoehler, 2011)
Features created by life

Biosignatures: features created ONLY by life

Cell-like morphologies
Organic matter, sedimentary
Rock micro- & macrofabrics
Minerals, some morphologies
Stable isotopic patterns

Features created by nonbiological processes

Features created ONLY by nonbiological processes

Crustal C inventory
Bulk crustal oxidation state
Thermo- & radiochem. products
Minerals: ign., met. & most sed.
Isotopic equilibria, most

Ambiguous features
Different types of organic matter measurements provide different levels of confidence in a biological origin for the organic matter (OM)*

<table>
<thead>
<tr>
<th>Organic Matter Characterization</th>
<th>Confidence Scale</th>
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<tbody>
<tr>
<td><strong>High</strong></td>
<td></td>
</tr>
<tr>
<td>• Distributions of identifiable molecular structures and/or components (if macromolecular)</td>
<td></td>
</tr>
<tr>
<td>• Isomer ratios of amino acids</td>
<td></td>
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<tr>
<td>• Molecular mass distribution of organic components</td>
<td></td>
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<tr>
<td>• Compound specific isotopic composition</td>
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<tr>
<td>• Aliphatic/aromatic ratio</td>
<td></td>
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<tr>
<td>• Organic functionalization (polar/nonpolar)</td>
<td></td>
</tr>
<tr>
<td>• C, H, O, S, N, Cl ratios of organic matter</td>
<td></td>
</tr>
<tr>
<td>• Fine scale OM distribution in materials</td>
<td></td>
</tr>
<tr>
<td><strong>Stable isotopic composition of organic carbon</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Basic molecular bond information</strong></td>
<td></td>
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<tr>
<td><strong>OM Detection</strong></td>
<td></td>
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<tr>
<td>• Presence of organic carbon (compounds with C-H bonds)</td>
<td></td>
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<tr>
<td>• Presence of reduced carbon (e.g., graphite, diamonds)</td>
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</tbody>
</table>

* 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.

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2020 Mars Rover Science Definition Team
Earth's Carbon Budget

Biosphere, Oceans and Atmosphere

- 3.7 x 10^{18} moles

Crust

Organics

- 1200 x 10^{18} moles

- Host rocks:
  - Clays & Shales 68%
  - Carbonates 14%
  - Sands 10%

Carbonates

- 6000 x 10^{18} moles

Mantle

- ~20,000 x 10^{18} moles

Des Marais (2001)
Minerals & Rocks that Preserve Fossil Records

Residence Time

- <1x10^4 yrs: Least Stable - Ice; Dominant Process: Climatic warming
- <1x10^6 yrs: Halides, sulfates; Dissolution
- <2x10^8 yrs: Metallic sulfides; Oxidation
- <3.5x10^8 yrs: Clay-rich shales, water-laid pyroclastics, marine carbonates, metallic oxides; Metamorphism, Recrystallization, Dissolution
- <3.8x10^8 yrs: Phosphates, silica; Deep burial, Recrystallization, Metamorphism

Most Stable