Geochemistry, Meteorites & Missions

Professor Mark A. Sephton, Earth Science & Engineering
Presentation Outline

The Planetary Geologist

- E.g. - The Life Marker Chip
- Knowledge Transfer
- Use of Analogues
- Organic Matter
- Minerals
Rise of the Planetary Geologist

Mariner 9 was an Orbiter that reached Mars in 1971, becoming the first spacecraft to orbit another planet.

"Mariner 9 cameras took thousands of pictures. A whole new world was taking shape. NASA called in a new type of scientist – Planetary Geologists."
Integrating field and sample science

Science questions

Select field site

Understand field relationships, geology of site to be sampled

Select Samples

Analyze Samples on Earth

INTEGRATE

Science answers

“The integration of field and sample science is critical to answering complex geological/astrobiological questions.”

McLennan et al. 2012. Astrobiology, 12, 175-230
Hierarchical need for information

Putting together effective sample suites requires collecting information in the field on many more rock and soil candidates than the number eventually collected.

Example:

McLennan et al. 2012. Astrobiology, 12, 175-230
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Knowledge Transfer

Use of Analogues

Organic Matter

Minerals
The Life Marker Chip

Life Marker Chip

- Detects organic compounds
- Uses an antibody array
- Specific and sensitive

(a) End to End demonstrator at Uni. Leicester
(b) SPS system, flight-like inlet volume (top), waste chamber (bottom),
(c) flight-like bellows pump from AS,
(d) flight-like fluid cartridges,
(e) proof of concept silicon nitride waveguide.

Conventional organic geochemistry extraction

- Eglinton 1969
- Remove surface
- Powder
- Organic solvent
  - Free compounds
  - “Like dissolves like”
- Demineralizing acids
  - Kerogen
Life Marker Chip Detector relies on antibodies which are proteins so new water-based solvents are needed.

New solvents

Surfactant solutions
- Organic additives with water loving and water hating parts
- Spontaneously form spheres with analyte inside
- Polysorbate 80 for Mars - Court et al. 2010

Subcritical Water
- Polarity changes with temperature and pressure
- Polar compounds at low temperatures
- Hydrocarbons at high temperatures
- Tuneable for selective extraction
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Knowledge Transfer

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Minerals
Unconventional solutions to unconventional oil

- Global resources.
- Dominated by heavy oil.
- Politically stable.
- Difficult to extract.
- Water use
- Steam assisted recovery

Aqueous vs surfactant solvents

Thanks to UK Space Agency

MeOH/H$_2$O P80 1.5 g/l

MeOH/H$_2$O

H$_2$O

Court et al. 2010, Planet Space Sci 58, 1470–1474
Subcritical Water

Thanks to UK Space Agency

Montgomery et al. 2013, Fuel 113, 426-434

(James Lewis – Figure)
The Planetary Geologist

E.g. - The Life Marker Chip

Knowledge Transfer

Use of Analogues

Organic Matter

Minerals
The use of analogues

BBC - Mission to Mars (2013)
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Knowledge Transfer

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Minerals
Organic Matter on Mars

Non-biological
- Life’s precursors
- Diverse structures

Life
- Biological
- Delicate
- Specific structures

Fossil life
- Robust remnants
- Degraded and metamorphosed
- Stable structures
Life constitution

<table>
<thead>
<tr>
<th>Bacterium</th>
<th>% wt</th>
<th>No types of each molecule</th>
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</thead>
<tbody>
<tr>
<td>Water</td>
<td>70</td>
<td>1</td>
</tr>
<tr>
<td>Inorganic ions</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Small organic molecules</td>
<td>6</td>
<td>750</td>
</tr>
<tr>
<td>Very large organic</td>
<td>22</td>
<td>5 000</td>
</tr>
</tbody>
</table>

Most of the molecules in a living system

- Very large organic molecules
- Macromolecules

Macromolecules can be subdivided into four different types:

- Lipids
- Carbohydrates
- Proteins
- Nucleic acids

Macromolecules are products of combining many individual organic units

- Hydrocarbon-dominated units
- Sugars or polyols
- Amino acids
- Nucleobases, etc.
Meteorite constitution

Carbonaceous chondrites
  • Up to 5% organic matter

Meteoritic organic matter
  • 25% solvent soluble or “free”
  • 75% insoluble, macromolecular
  • $C_{100}H_{71}O_{12}N_3S_2$ (Hayatsu et al. 1977)

- 25% soluble
- 75% insoluble, macromolecular

- Aliphatics
- Aromatics
- Carboxylic acids
- Amino acids

Free molecules | Macromolecular material
Mars & degradation

No organic molecules detected by Viking GC-MS
2.4 x 10^8 g carbon comes to Mars each year via meteorites

Oxidative degradation
- Units lost, residues produced
  Benner et al. 2000 PNAS 97, 2425–2430
  - A) pentane, B) toluene, C) kerogen
Kerogen Evolution

- Types I to III appear biological
- All kerogen types approach origin
- Mature and degraded kerogens less faithful

- Type IV kerogens are highly degraded
Meteorite & type IV organic matter

Murchison (CM2)
- LMW units
- Alkyl benzenes
- Thiophenes
- Phenols
- PAH

Type IV kerogen
- LMW units
- Alkyl benzenes
- Thiophenes
- Phenols
- PAH
- Residual n-alkanes

Note strong similarities
Good preservation highly desirable

Matthewman et al. 2012 Astrobiology 13, 324-333
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- Organic Matter

- Minerals
Earth’s organic matter

- 90% of that accumulating is in coastal margins
- Intimately associated with mineral surfaces

Mineral hosted organics

- 83% organic matter on minerals is irreversibly adsorbed
  > Hedges & Keil 1995
- Organic content directly related to minerals surface area
- Equivalent to a monolayer coating (0.86 mgCorg m\(^{-2}\))
  > Meyer 1984
### Minerals

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Surface area $m^2/g$</th>
<th>Organic coating $mg/g$</th>
<th>Irreversible $mg/g$</th>
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</thead>
<tbody>
<tr>
<td>Ferrihydrite</td>
<td>134</td>
<td>120.6</td>
<td>76.3</td>
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<tr>
<td>JSC Mars-1</td>
<td>106</td>
<td>95.4</td>
<td>96.5</td>
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<tr>
<td>Smectite</td>
<td>52.7</td>
<td>47.4</td>
<td>37.9</td>
</tr>
<tr>
<td>Dunite</td>
<td>2.8</td>
<td>2.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Volcanic tuff</td>
<td>13.7</td>
<td>12.3</td>
<td>9.9</td>
</tr>
<tr>
<td>Volcanic tuff &amp; Mg sulfate (1:3)</td>
<td>11.3</td>
<td>10.2</td>
<td>8.1</td>
</tr>
</tbody>
</table>

- Surface areas of Martian mineral analogues calculated by Pommerol et al. (2009).
- Data can be used to predict monolayer organic contents.
- Phyllosilicates are particularly important minerals for the entombment and preservation of organic matter. Phyllosilicate formation requires water and therefore conditions that are conducive to life.
- Such deposits are important targets for life search missions.

Mars minerals in time

The OMEGA/Mars Express imaging spectrometer
- Bibring et al. 2006, Science 312, 400 - 404

Recognized mineralogically and temporally-distinct areas on Mars
- Phyllosilicates
- Sulfates
- Ferric oxides

Will organic contents be directly related to mineral surface as on Earth?
<table>
<thead>
<tr>
<th>Name</th>
<th>Area</th>
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</thead>
<tbody>
<tr>
<td>Dr Gareth Collins</td>
<td>Impact Cratering</td>
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<tr>
<td>Dr Richard Court</td>
<td>Astrobiology</td>
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<td>Dr Matthew Genge</td>
<td>Meteoritics</td>
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<td>Surface processes</td>
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<td>Dr Adrian Muxworthy</td>
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<td>Prof Mark Rehkamper</td>
<td>Geochemistry</td>
</tr>
<tr>
<td>Prof Mark Sephton</td>
<td>Organic Geochemistry</td>
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</tbody>
</table>
Mars Extracts

Thank you ...