Habitable Environments of Ancient Mars: Deciphering the Rock Record

John Grotzinger
Modern Mars: Recurring Slope Lineae

McEwan et al., 2014
Rethinking Ancient Mars

- “Mars is a volcanic planet”. But…
  - Layered rocks can be sedimentary.
  - Sedimentary basins are chemical reactors: heat + fluid flow $\rightarrow$ aqueous minerals
  - Sedimentary rocks are the archive of Earth’s early biosphere record.

- “Mars is a glacial planet”. But…
  - No landed mission has ever encountered glacial landforms. Sedimentary deposits lack glacial features.
  - Mars was apparently wet enough, and warm enough, for liquid water to be stable at surface for $10^4$ - $10^6$ years.

- “Noachian $\rightarrow$ Hesperian was a global acidization event”. But…
  - Meridiani (Opportunity rover) was acidic. Gale crater (Curiosity rover) was not.
  - The largest river system on Mars only formed clays despite spanning N$\rightarrow$H boundary. No evidence of layered sulfates in younger history.

- When considering biomarker preservation, texture and petrogenesis are as important as mineralogy.

- Need more (small, cheap) rovers, assigned to “boutique” missions.
Gale Crater and Mt. Sharp
Looking South to Mount Sharp
Mineral Stratigraphy, lower Mt. Sharp
Ancient Lake Beds

Mars (cm-scale)  Earth (cm-scale)
<table>
<thead>
<tr>
<th>Mineral</th>
<th>Rocknest</th>
<th>John Klein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase (~An50)</td>
<td>43%</td>
<td>30%</td>
</tr>
<tr>
<td>Olivine (~Fo58)</td>
<td>20.5%</td>
<td>4.4%</td>
</tr>
<tr>
<td>Augite</td>
<td>16.7%</td>
<td>6.2%</td>
</tr>
<tr>
<td>Pigeonite</td>
<td>11.4%</td>
<td>5.2%</td>
</tr>
<tr>
<td>Magnetite</td>
<td>1.8%</td>
<td>10%</td>
</tr>
<tr>
<td>Anhydrite</td>
<td>1.4%</td>
<td>4.5%</td>
</tr>
<tr>
<td>Pyrhotite</td>
<td>-</td>
<td>1.5%</td>
</tr>
<tr>
<td>Smectite</td>
<td>-</td>
<td>20-30%</td>
</tr>
<tr>
<td>Amorphous material</td>
<td>25-40%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Vaniman et al., 2014
Organic Compounds in Rocks

Fressinet et al., 2015

Chlorobenzene (NIST)
Cumberland (SAM)

Chlorobenzene abundance (pmol, GCMS)

ROCKNEST
JOHN KLEIN
CUMBERLAND
CONFIDENCE HILLS

4 cm

4 mm
“Marias Pass”

- 73% SiO2

- Laminae are 0.5 mm thick

- Very fine grained
Precambrian Banded Iron Formation, Silica-rich Facies
Precambrian Laminated Silica Deposit
Precambrian Laminated Silica Deposit

Microfossils
Hematite-sulfate = shallow water facies
- Nearshore sediments delivered by fluvial input; dense, mafic minerals dominate.
- Oxidant concentration (UV photons, molecular $O_2$) $> [Fe^{2+}]$.
- Fe-oxidation produces hematite and acidity, eventually stabilizing minor jarosite.
- Evaporation of the lake concentrates water to produce Mg, Ca sulfates.

Magnetite-silica = deep water facies
- Offshore sediments are finer, less dense clastics (crystalline silica, feldspars, perhaps some of the opaline silica)
- Oxidant concentration (UV photons, molecular $O_2$) $< [Fe^{2+}]$.
- Less oxic conditions permit the precipitation of authigenic magnetite $> \text{hematite}$.
- Amorphous silica precipitated via interactions with silica-rich source area.

Hurowitz et al., In Review
“Although it necessarily has to be painted with broad brushstrokes, the picture that emerges is of an overall reaction network developing over time in separate streams and pools...[and] the various products would be synthesized by subtle variations in the flow-chemistry history of the streams and pools.”

Patel, B.H.; Percivalle, C.; Ritson, D.J.; Duffy, C.D.; Sutherland, J.D.; Nature Chemistry, 2015, 7, 301-307
Deep Fractures: Subsurface Habitability
Conclusions

- Gale crater contained a long-lived ancient lake fed by surface waters derived from low-elevation highlands, and also groundwater.
- Mineral compositions show unexpected and surprising diversity in Murray formation, representing environmental differentiation over geologically brief time scales.
- High silica compositions inconsistent with acid weathering, via minerals, major/minor elements.
- Opaline silica may have precipitated as early diagenetic sediment, or directly from water column to form finely laminated mudstone.
- These rocks provide compelling evidence for habitability, and remarkably Earth-like analogs for biosignature preservation.
- Boutique missions – look for borates, cyanide salts, etc.
Clinoform Sandstone (View to West)

Toplap surface

10 m
Pliocene Deltas, Caspian Sea, Azerbaijan
Gale is on the Dichotomy Boundary
Mineralogy-based Chronostratigraphy for Mars

Bibring et al., 2006

- Major Step Forward
- Based on physical properties that show apparent temporal evolution
- Testable based on *in situ* measurements
- *But like all time scales is now in need of revision*
Toward a Global Stratigraphy For Mars

(Grotzinger and Milliken, SEPM, 2012)