Mars Habitability for MSL

Dawn Y. Sumner
Geology, UCDavis

Photo Credit: NASA/JPL
Looking for Life on Earth

- **Morphological Fossils**
  - Microbial Communities
    - Stromatolites & Microbialites
  - Microfossils
    - Too small for MSL to see

- **Most Common Where Minerals Precipitate**

Photo Credit: Sumner
Looking for Life on Earth

- **Organic Molecules**
  - Isomers
    - Chirality
    - Diastereomers
    - Structural
  - Subunit Building Blocks
  - Patterned Distributions
  - Specific Compounds
- **Often Associated with Clay Minerals**

Image Credit: Waldbauer et al., in review, Precambrian Research (NRC, 2007, An Astrobiology Strategy for the Exploration of Mars)
Chemical Activity of Water

• **Life needs a certain water activity to reproduce.**
  - “Based on current knowledge, terrestrial organisms are not known to be able to reproduce at an activity of water below 0.62.” (These are fungi and yeast in the lab.)

• **Solutes reduce water activity.**
  - NaCl saturation: $a_w = 0.75$
  - CaCl$_2$ saturation: $a_w = 0.29$

• **Lower solute limits not characterized for bacteria or archaea.**

(MEPAG Special Regions Science Analysis Group, 2006, Astrobiology)
Chemical Activity of Water

• **Thin Film or Matrix Effects**
  
  \( a_w = 0.999 \): Microbial motility ceases in porous media
  
  \( a_w = 0.97 – 0.95 \): Lower limit for growth of *Bacillus spp.*
  
  \( a_w = 0.88 \): Lower limit for growth of *Arthrobacter spp.*
  
  \( a_w = 0.93 – 0.86 \): Microbial soil respiration ceases

• **Average Water Film Thickness and \( a_w \):**
  
  500 nm \( a_w = 0.996 \)
  
  3 nm \( a_w = 0.99 \)
  
  \(<3 \) nm \( a_w = 0.97 \) (<10 \( H_2O \) Molecules Thick)
  
  \(<1.5 \) nm \( a_w = 0.93 \) (< 5 \( H_2O \) Molecules Thick)
  
  \(<0.9 \) nm \( a_w = 0.75 \) (< 3 \( H_2O \) Molecules Thick)

(MEPAG Special Regions Science Analysis Group, 2006, Astrobiology)
Mars - Bad for MSL

- **Regolith & Dust**
  - Too Oxidizing for Organics
  - No Textural Preservation

- **Unaltered Igneous & Metamorphic Rocks**
  - High Temperature Origin

Photo Credit: NASA/JPL Pathfinder
Mars - Poor ↓ to Okay ↑ for MSL

- **Weathered Outcrops**
  - Degradational Environment (↓)
  - Long Surface Exposure Time (↓)
  - Oxidative, Dry Surface Now (↓)
  - Local Life Required (↓)

- **Hydrothermal Systems**
  - Accretionary (↑)
  - Mineral Precipitation (↑)
  - High Water Activity (↑)
  - High Temperature (↓)

Photo Credit: Mars Express/OMEGA and HRSC teams

Mawrth Valles
Blue = Clays
Mars - Sedimentary Rocks

- **Better Syn-Sedimentary Properties**
  - More Water Exposure
  - Lower Oxidation State
  - Finer Grained

- **Better Post Depositional Properties**
  - Less Water Exposure
  - Deflating or Eroding Topography

~1 km wide

Photo Credit: NASA/JPL/MSSS MOC
Mineralogy - Hematite & Fe(III)

- In Sediments
- Suggests Aqueous Activity
- Exciting Discoveries

But ...

Aram Chaos
Hematite Abundance

(Glotch and Arvidson, 2007, JGR)
Mineralogy - Hematite & Fe(III)

- Not Stable with Organics
- Kinetics of Fe(III) Reduction and Organic Oxidation is Rapid (on geologic timescales)

(Sumner, 2004, JGR)
Mineralogy - Hematite & Fe(III)

- Only Studies I Know from Earth:
  - 2 Ma Rio Tinto terrace
    - Goethite and Recalcitrant Organics Only
      (Fernandez Remolar and Knoll, in review)
  - Jurassic Navajo Sandstone
    - Hematite Concretions Lack Organics
      (Souza-Egipsy et al., 2006)
  - 1.88 Ga Gunflint Iron Formation
    - Hematite and Graphite Inclusions in Chert
      (Tazaki et al., 1992)
    - Pressure may stabilize graphite
Mineralogy - Sulfates

- Require Substantial Water-Rock Interaction
- Precipitation can Encapsulate Organics

(Griffes, et al., 2007, JGR)
Mineralogy - Sulfates

- Not Stable with Organics
- Kinetics of S(VI) Reduction to S(-II) and Organic Oxidation can be Very Slow
  \[ \text{SO}_4^{2-} \text{ Metastable for 1-10 billion years at pH 4-7} \]
  \[ \text{SO}_4^{2-} \text{ Metastable for 5,000 years at pH 2} \]
  (Ohmoto and Lasaga, 1982)

- I know of no studies on Earth showing organics in ancient sulfates
  - Microbial sulfate reduction may oxidize organics
Mineralogy - Clay Minerals

- Not all Phyllosilicates are Clay Minerals
  - Smectites good
  - Micas irrelevant

- When in Deposited Layers:
  - Regional Signatures Integrated
  - Good Preservation Potential

Nilli Fossi
Greener = “Phyllosilicates”

Silicate mineral spectral map

10 kilometers

Mineralogy - Clay Minerals

- Bind Organics in Interlayers
- Low Redox Potential
- Low Post-Depositional Permeability

MSL Landing Sites

- **Mineral Summary**
  - Hematite - Bad for Organics, Good for Morphology
  - Sulfates - Okay for Organics, Okay for Morphology
  - Clay Minerals - Good for Organics, Bad for Morphology
MSL Landing Sites

- **Good Syn-Depositional Parameters**
  - High Water Activity
  - Accreting Environment
  - Mineral Precipitation
  - Low Oxidation State

- **Good Post-Depositional Parameters**
  - Low Water Activity, Low Permeability
  - Low Temperatures
  - Low Oxidation State
  - Deflating or Eroding Topography