Zero-Valent Iron on Mars:
An Alternative Energy Source for Methanogens

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Methanogens – Good Model for Possible Subsurface Life on Mars

• Can grow in temperatures below 0 C (Reid et al., 2006)

• Can tolerate exposure to extremely low pressures (Altheide and Kral, 2008)

• Phylogenetically primitive

*Mars in a laboratory!
Fe$^0$ on Mars

- Several large iron meteorites composed primarily of Fe$^0$ found on Mars’ surface. *(Schroder et al., 2008)*

- Stony-irons containing substantial Fe$^0$ also found in what might be a strewn field. *(Schroder et al., 2008)*

Courtesy: NASA/CORNELL
Micrometeorite Delivery

• Just like Earth, Mars is bombarded with meteoritic debris, much of it Fe\(^0\).
  – Substantially thinner atmosphere increases the amount reaching the surface

• Flynn and McKay (1990) estimate as much as 29% of Martian soil from meteorites.
  – Up to 59,000 tons per year delivered to the surface
Shock-reduction from Impacts

• Impacts can lead to shock-reduction of iron-bearing minerals resulting in nanophase Fe$^0$.

• Numerous studies confirm Fe$^0$ in SNC meteorites. (e.g. Kurihara et al., 2009)

• This has been mimicked in the laboratory using JSC Mars-1 regolith simulant. (Moroz et al., 2009)

1) TEM image of NWA 2737 olivine. Small, dark (electron-dense) spherules are consistent with α-iron kamacite [after Treiman et al., 2007] (Pieters et al., 2008)
Fe$^0$ Source Summary

- Large meteorites deliver exogenous Fe$^0$
- Micrometeorites deliver exogenous Fe$^0$
- Large impactors generate and spread nanophase Fe$^0$ due to shock-reduction of iron-bearing minerals
- May lead to substantial buildup of Fe$^0$ over time
**Fe⁰ Relationship to Methanogens**

- Protons in solution can react with Fe⁰ to produce H₂, but the reaction is not thermodynamically favorable.
  \[ 4\text{Fe}⁰ + 8\text{H}^+ \rightarrow 4\text{Fe}^{2+} + 4\text{H}_2 \]
  \[ \Delta G°^r = +3.5 \text{ kJ} \]
- However, a sink for H₂ can drive the reaction.
- Daniels *et al.* (1987) show that methanogens in nutritive medium can utilize the H₂.

Daniels *et al.* (1987)
This Study:

• Fe⁰/any H⁺ in solution (energy)
• Bicarbonate buffer/CO₂ (carbon/water)
• Montmorillonite clay (micronutrients)

• Does methanogenic metabolism take place in these Mars-relevant conditions?

*Why montmorillonite?
Montmorillonite clay can supply the micronutrient requirements of methanogens.
Results: Fe\(^0\) vs. no H\(_2\)
Obvious oxidation to $\text{Fe}^{3+}$

*Is the darker color of the montmorillonite an indication of $\text{Fe(OH)}_2$?
Comparison to Previous Work

- Initial study before transfer
- Initial study after transfer
- Fe⁰-included

Methane Concentration (% vol.)

Time (days)
Concluding Remarks

• $\text{Fe}^0$ is available on Mars
• $\text{CO}_2$ is available on Mars
• Montmorillonite-like clays are available on Mars
• Given the right environmental conditions, these three materials can support methanogenic metabolism
• The temperature was not exactly Mars-relevant, BUT…