Atmospheric Signatures of Habitability and Habitancy

Mark Allen, Jet Propulsion Laboratory, California Institute of Technology

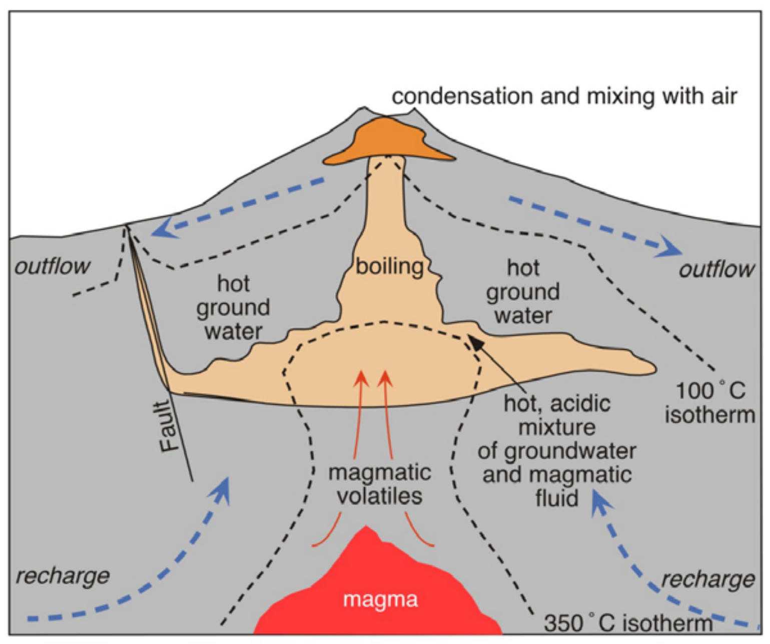
John Eiler, California Institute of Technology

David Des Marais, NASA/Ames Research Center

Barbara Sherwood Lollar, University of Toronto

Is Mars alive?

- Geologically?
  - Observational evidence for surface volcanic flows as young as only several million years
  - As good as today in the geological timeframe
  - Alternative geologic sources include lower temperature water-rock reactions



- Biologically?
  - Life very persistent if conditions are at all hospitable to the existence of life
  - If Mars ever supported life, oases may still exist, albeit below the surface, that are habitable and inhabited.

Life detection via atmospheric composition analysis

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Life Detection by Atmospheric Analysis

DIAN R. HITCHCOCK
Hamilton Standard, Windsor Locks, Connecticut

AND

JAMES E. LOVELOCK
Bio-Science Section, Jet Propulsion Laboratory, Pasadena, California

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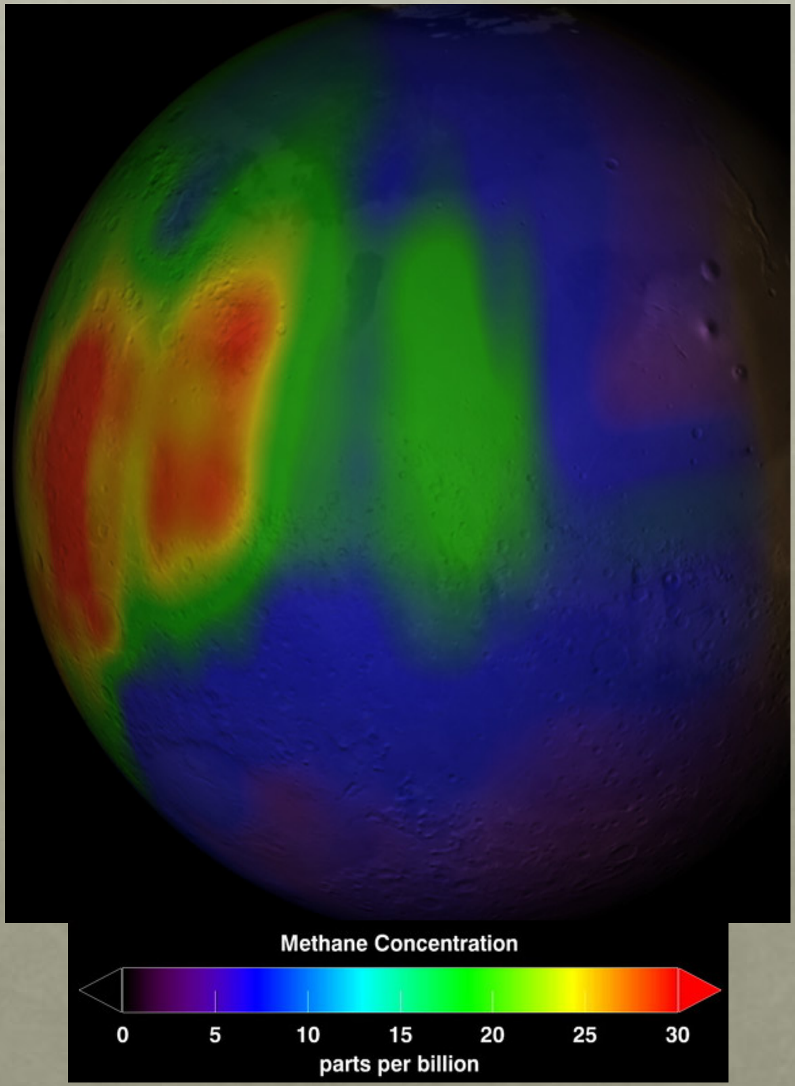
Living systems maintain themselves in a state of relatively low entropy at the expense of their nonliving environments. We may assume that this general property is common to all life in the solar system. On this assumption, evidence of a large chemical free energy gradient between surface matter and the atmosphere in contact with it is evidence of life. Furthermore, any planetary biota which interacts with its atmosphere will drive that atmosphere to a state of disequilibrium which, if recognized, would also constitute direct evidence of life, provided the extent of the disequilibrium is significantly greater than abiological processes would permit. It is shown that the existence of life on Earth can be inferred from knowledge of the major and trace components of the atmosphere, even in the absence of any knowledge of the nature or extent of the dominant life forms. Knowledge of the composition of the Martian atmosphere may similarly reveal the presence of life there.

Remote detection of life on another planet was considered over 40 years ago (at JPL in fact) and focused on the analysis of atmospheric composition. Methane was suggested to be a useful atmospheric marker of extant biology.

Modern atmospheric analysis



- Reported detection of methane by Mumma et al. (2009) raises the question of extant active subsurface processes on Mars, heretofore assumed not to be present
- Question: What biologically relevant subsurface processes might be active today?

Signatures of geological activity

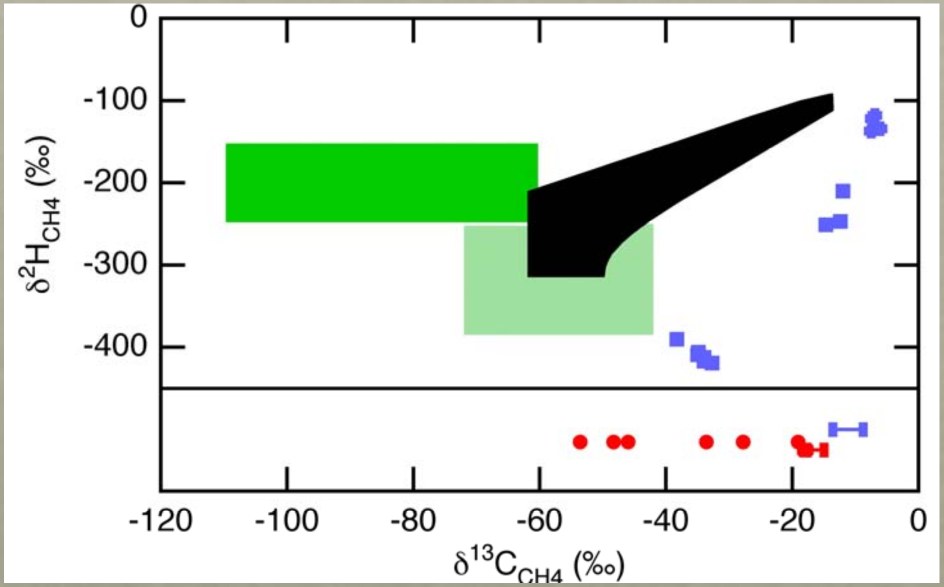
- Similar to terrestrial counterparts, Martian magmas expected to contain dissolved volatiles that become supersaturated during eruption or emplacement in the shallow crust. Volatiles can enter the atmosphere through several processes:
  - direct degassing
  - degassing into shallow hydrothermal systems
  - interaction of rocks with hydrothermal solutions or ground waters
- Molecular composition of volatiles released from Martian magmas likely differs from terrestrial magmas and will depend on several variables
  - temperature of equilibration
    - high temperature: H_2O, CO_2, SO_2, CO, H_2,and N_2,
    - low temperature: H_2O, CO_2, H_2S, S_2, CH_4, NH_3
  - pressure of degassing
  - oxidation state
    - e.g.: SO_2 vs H_2S

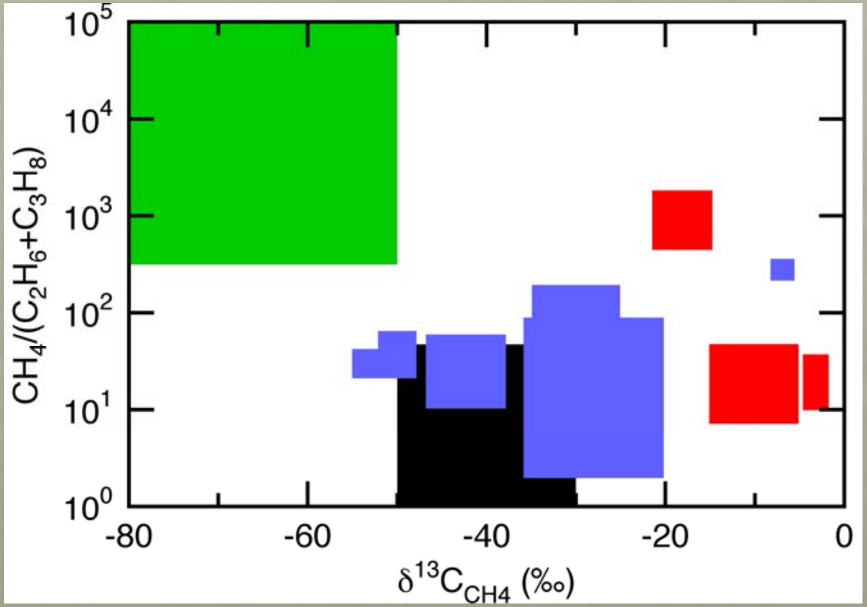
Signatures of biological activity

- **Terrestrial microorganisms produce wide variety of gases as products of energy-yielding oxidation-reduction (redox) reactions and synthesis & decomposition of organic matter**
  - fermentation and anaerobic respiration under strongly reducing conditions: hydrogen-rich compounds, e.g., CH_4, NH_3, H_2S, volatile hydrocarbons, alkylated amines and sulfides
  - nitrogen redox reactions: nitrogen oxides (NO, NO_2, and N_2O)
  - thermal decomposition of biogenic sedimentary organic matter: light hydrocarbons and sulfides
  - microbially-mediated decomposition of sedimentary organic matter using sulfate as an oxidant: H_2S and potentially other reduced sulfur gases

Is methane biogenic or abiogenic?

- Ratios of isotopologues can be ambiguous as sole criteria as more data is collected
- Ratios of chemical species maybe more definitive





Microbial CO_2 reduction (dark green); Microbial fermentation (light green); Thermogenic (black); Hot water-rock (red); Cold water-rock (blue) circa Allen et al. (2006). Larger ranges and increasing overlap of isotopic signatures demonstrated for both biogenic (Takai et al. 2008; Tazaz et al., 2009) and abiogenic processes (McCollom et al., 2010; Taran et al., 2010)

* **Evaluating isotope ratios AND abundance ratios is MOST definitive !**

ExoMars Trace Gas Orbiter

- Joint ESA/NASA mission
- Launch 2016 (proposed)
- Payload instruments: 4 NASA-funded, 1 Belgian-funded
- Measurements
  - Atmospheric composition at parts per trillion sensitivities
  - Spatial & temporal variation
  - Localization of source/sink regions
  - Imaging of potential source/sink surface locations