Meteorites and the Story of Mars Meteorite ALH84001

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Searching for Life on Mars: Overview

Criteria for life & What tools are needed

Searching for Mars Life
  - The Mars Viking Experiment
  - History
  - Findings

Meteorites
  - History & formation
  - Falls of note
  - The US Meteorite program
  - Meteorite classification

ALH84001
  - Description
  - Pieces of evidence

Summarize Findings

What would you consider as convincing evidence for life on a planet?

What Tools Would you Need?
Scanning Electron Microscope

- Accessible technology
  - Focused e- interact with sample surface
  - Magnetic fields move the beam over sample
- So good: see new features!
- Works best if sample is coated
  - Vapor coating of carbon, gold, palladium 2-20 nm

What May Cause Concern?

In situ / Physical specimen
- Sample Storage & preparation
- Realistic setting – time / space
- Biological indicators e.g. isotopes
  - Not derived from a habitable zone
  - Funding for Good background research

Accessible technology

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Searching for Life on Mars: Viking experiments

James Lovelock & Mars NASA
Viking (1961)
- Asked to provide advice on life detection – how to recognize it
  - A planet will exhibit an atmosphere which is far from chemical equilibrium if there is life
  - If there is life, it must be pervasive (i.e. there can’t be a little bit of life)
  - Life uses liquids and atmosphere to "communicate" or interact by sharing nutrients, wastes & evolution,
  - Thus the chemistry of the environment should be constantly changing in the presence of life
- Prediction:
  - Life will not be found on Mars – because it exhibits Atmospheric equilibrium chemistry

Viking Mars Mission
- 1968 James Martin asked to lead mission science
- Launch Viking 1 8/20/75; Viking 2 2 mo later
- Viking 1 lands - 20 July 1976
- Viking 2 lands - 3 September 1976
- 2 year program – search for life

Viking Orbiter Images

Viking 1 orbiter image
Candor Chasma (Valles Marineris) 1978
Mars Environment

- Viking temperatures – similar at both landing sites
- Effect of large dust storm is seen in the Temperature profile

Sunset 20 Aug 1976

### Mars Viking Life Experiments

- **Gas Exchange Experiment (GEX)**
  - Changes in the makeup of gases (related to biological activity) in a test chamber

- **Labeled Release Experiment (LR)**
  - Detect the uptake of a radioactively-tagged liquid nutrient by microbes
  - Gases emitted by microbes would show tagging.

- **Pyrolytic Release Experiment (PR)**
  - "Cooking" regolith samples exposed to radioactively-tagged CO₂ to see if the chemical had been used by organisms to make organic compounds.

- **Gas Chromatograph – Mass Spectrometer Experiment (GCMS)**
  - Heated a regolith sample
  - Revealed an unexpected amount of water
  - Failed to detect organic compounds. This absence was so absolute that it seemed there must be some mechanism actually destroying carbon compounds on the surface.

### Viking Life Experiments Press Conference

"Viking not only found no life on Mars, it showed why there is no life there…. the extreme dryness, the pervasive short-wavelength UV radiation…

Viking found that Mars is even dryer than had previously been thought…

The dryness alone would suffice to guarantee a lifeless Mars; combined with the planet’s radiation flux, Mars becomes almost moon-like in its hostility to life."

### Searching for Life on Mars:

**Meteorite background**

- Lead scientist, H. P. Klein said the experiments didn’t rule out life, either
- Gilbert Levin (Mars team) said LR experiment showed life
- Most scientists believe chemicals created a false positive
- Data is available to the public
- The debate continues
- NAI – important to understand the biomarkers – what would be the sign of life.
**Meteorite History**

- Most famous European fall – 17 Nov 1492
- Witnessed (boy) – m-deep hole
- Attracts attention of Emperor Maximilian
- Considered good omen – preserved

**Origin of Meteors / Meteorites**

- Earth passes through dust in comet orbit
  - Burns in Earth atmosphere
  - Larger chunks resulting in meteorite finds come from
    - Moon
    - Mars
    - Asteroid collisions

**Fireballs / Debris**

**The 15 Feb 2013 Fireball**

- Chelyabinsk Russia
  - Largest since 1908
  - Size ~ 17 m (larger than early est)
  - ~ 10^4 tons, v = 18 km/s
  - Energy ~ 500 kilotons TNT
  - Fall found – ordinary chondrite
    - < 10% metallic iron
    - Largest piece likely in lake

**Tagish Lake Meteorite**

- Canadian fall 18 Jan 2000
  - 56 ton meteoroid
  - 4 m diam (500 fragments found)
- Primitive CC (carbonaceous chondrite)
  - 2 diff types mixed (CI, CM)
    - some with carbonates
  - Full of nanodiamonds
  - Low density
  - Form farther out in SS
  - D-type parent: 773 Irmintraud

**US Antarctic Meteorite Program**

- NSF – Funds collection near transantarctic mountains
  - Desert-like conditions
  - Contrast between low albedo meteorites & snow
- NASA – Examines at JSC in Houston
- Smithsonian – Curates
  - 15,000 specimens, 13,000 from Antarctica
  - Oldest – Earth residence 10^6 yrs
  - 1981 – first recognized from Moon
- 2006 Mt. Erebus expedition (UHNAI postdoc)
**Meteorites**

Undifferentiated

- Chondritic Meteorites
  - 3 main types
    - Ordinary
    - Carbonaceous
    - Enstatite
  - 5 main components
    - including the oldest dated material in the Solar System

- Allende (CC)

**Differentiated (Non-chondritic meteorites)**

- ALH 77005 (Mars)

**Stony (including Chondrites)**
- 95% of all meteorites

**Stony-Iron**
- 1% of total finds

**Iron**
- 4% (most often found)
- Pure metal – Ni/Fe alloy
- Form by differentiation then breakup of parent

**Ni-Fe meteorites**
- Widmanstatten pattern
- Crystal size is related to cooling times for magma
  - From differentiation
  - Melt near surface

**Achondrites**
- Angrites
- Aubrites
- Brachinites
- ureilites
- HED (3 types)
- Lunar
- Martian (4 types, SNC)
  - Shergottites
    - Typical of terrestrial basalts
  - Nakhlites
  - Larger Fe-rich olivine/pyroxene
  - Form with aqueous alteration
  - Chassigny
  - 90% olivine, 10% pyroxene
  - Orthopyroxenite (ALH84001)

**Mars Meteorites**
- Mars Origins
  - Large volatile composition
  - parent body has atm
  - Isotopic Fractionation pattern unique: Mars
- Find Locations
  - 50% in Antarctica
  - 1 from Nigeria

Adapted from http://www.mnh.si.edu/earth/text/5_1_4_0.html
Which of the following meteorites is least likely to be a Martian meteorite?

A: Peekskill stony
B: Lunar meteorite
C: Allende (CC)
D: Stony-Iron

Searching for Life on Mars
Case Study: ALH 84001

Physical specimen
- Human history
- Description

Physical evidence e.g. Fossils
- Fossils?
- Remnants of Fe$_3$O$_4$ from bacteria

Realistic setting – time / space
- Meteorite history

Biological indicators e.g. isotopes
- Carbonates
- Presence of organics & Fe$_3$S$_4$

Biological indicators
- e.g. isotopes

Description of the Meteorite

- 95% orthopyroxene
- Crystal structure has many cracks
  - Cracks have glasses (melted rock) from 30 GPa shock pressure ($3 \times 10^{10}$ atm)
  - Cracks have 0.1mm carbonate (CO$_3$) globules flattened (grow in cracks)
- Polycyclic Aromatic Hydrocarbons (PAHs) near carbonates
- Dissolved carbonates → magnetite and iron sulfide (Fe$_3$S$_4$

History – ALH 84001

- Discovered in Antarctica (’84)
- Known from Mars because of atm gases
- Notable
  - Oldest rock from any planet
  - Orthopyroxenite (not SNC)
- Notoriety (’96)
  - NASA: evidence for life on Mars

Life Story of ALH84001

- Impact
  - Brings ALH84001 to the surface
  - Shock deformed impact glasses
  - Pressures exceed 30 GPa

- Mars Ejection
  - Or ejection from parent
  - Cosmic ray exposure age
    - 16-17 x 10$^6$ yrs ago

- Fall to Earth
  - 13,000 years ago
  - 14C dating
Life Story of ALH84001

- Crystalization
- Impact
- Possible wet era
- Possible formation of carbonates
- Mars Ejection
- Fall to Earth

The Fossils

- Tube-shaped → similar to filamentous cyanobacteria
- 20 nm in size
- Apex Chert 3.5 Gy

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Magnetite & Fe₃S₄

- Compelling evidence for life
  - Bacteria use magnetite as a compass to aid in navigation

ALH84001 – Mars Life
Essential Findings

- 6 Aug 1996 Press Conference
  - NASA Administrator W. Huntress & David McKay

  "...in examining the Martian meteorite ALH84001 we have found that the following evidence is compatible with the existence of life on Mars..."

  - Igneous rock penetrated with fluid → mineral formation & biogenic activity
  - SEM images of carbonates → structures similar to microfossils
  - Fe sulfide & magnetite → life process signature
  - Concentrated PAHs

Extraordinary claims require extraordinary evidence – C. Sagan
The Fossils

**Very controversial**
- Too small for life → 100x smaller than terrestrial
- Life requires cellular structure
- Too small to test composition
- Ruled out contamination

Sample Preparation?

- Thick coatings can "crack" → “segmented” features
- Coatings can smooth out features
- Surfaces can be examined w/o coating → lower resolution

Carbonates

- **Low T formation**
  - Aqueous 30-80°C
  - O isotopic ratios
  - Carbonates ↔ life process on Earth (low T)
  - Supported by O isotopic abundances
  - If formed in liquid → should see other hydrated minerals (missing)

- **High T formation**
  - Petrographic analysis suggests this method
  - Elemental abundances
  - Requires assumptions about chemical equilibrium (unverified)

Magnetotactic Bacteria?

- **Inorganic precipitation**
  - Neutral pH
  - Cannot explain Fe₃S₄
- **Simultaneous precipitation**
  - Requires high pH (alkaline)
  - Dissolved CO₃ → low pH (acid)
  - Acid should affect other minerals (not seen)
- **Biogenic disequilibrium**
  - Life process (?) as on Earth
  - Other processes?

Crystal Structure

- Inorganic minerals align when one solid forms on surface of another
- Movie @ left → (Fe,Mg,Ca)CO₃ formed on inclined fracture
- Magnetites in voids → oriented with respect to CO₃
- Magnetite crystals forms inside CO₃ by diffusion of atoms

Presence of Organics

- No organics from Viking
  - Mass spectrum totally flat at zero
- Should have Mars organics
  - Near C-rich asteroids
  - Non-circular craters
  - Only form from very oblique impacts
  - Implies a close source – in orbit
  - Phobos and Deimos are CM type material (organic rich)
- UV destruction in upper regolith layers
Alternate Ideas – Contamination?

<table>
<thead>
<tr>
<th>Compound/Atomic Mass</th>
<th>ALH84001</th>
<th>EET79001</th>
<th>Ice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naphthalene (128)</td>
<td>Not detected</td>
<td>Not detected</td>
<td>Present</td>
</tr>
<tr>
<td>Fluorene (166)</td>
<td>Not detected</td>
<td>Not detected</td>
<td>Present</td>
</tr>
<tr>
<td>Phenanthrene (178)</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
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<tr>
<td>Chrysene (228)</td>
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<tr>
<td>Perylene (252)</td>
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<td>Present</td>
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<tr>
<td>Anthanthrene (276)</td>
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<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Anthanthracene (278)</td>
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<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>Coronene (300)</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
</tr>
</tbody>
</table>

- EET79001 – only L-amino acids found (contaminates)
- Carbonates absorb PAHs from water (L. Becker expt)
  - ALH84001 was sitting on Antarctic ice for 13,000 yr

Presence of Organics

- PAH
  - Groups of benzene rings
  - Present on Earth in decayed organic material (e.g. coal)
- PAH found in ALH84001
  - Not caused by lab contamination
  - Not caused by Antarctic contamination
- Mass spectrum
  - Simpler than any on Earth
  - Different from meteorite mass spectra
  - Possible early life?

Don’t know character of ancient DNA

Consequences of ALH 84001

- Oldest rock from any planet
  - Shows ancient Mars crust very well preserved
- Stimulated an era of bioastronomy
  - Sequence of Mars Missions
  - Renewed vigor for life searches (e.g. President’s 2004 initiative)
- Stimulated new meteoritics research

Science is self correcting. … The goal is to know. 
‘Possibly… perhaps… maybe’ are not firm answers, and feel-good solutions do not count.”
- The Hunt for Life on Mars

“The absence of evidence is not evidence for absence”
- Sagan