The Cosmos

Planets & Life

PHYS 214

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Please start all class related emails with "214:"

Assignment 3 due Wednesday

- TYPO! in assignment 3 Q3(a) - the equation should be derived in terms of M_1,M_2,a_2 and not a_1 as originally listed. The online assignment has been updated.
- Assignment 2's (finally!) marked will hand back on Wed

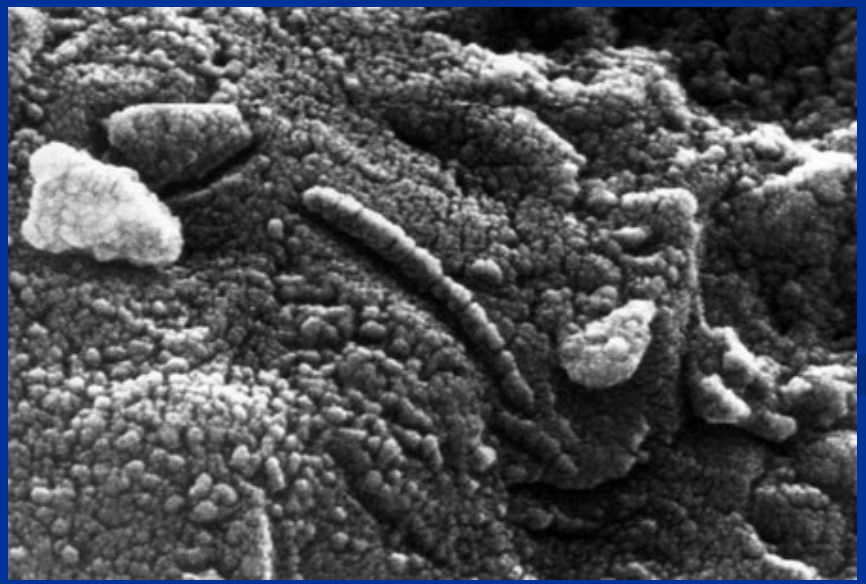
Check out Google mars: http://www.google.com/mars/

Today's Lecture

- Looking for life on Mars
  - How to look for life
  - Viking landers – what they found
  - Future missions

Flying over Victoria crater

Surface water in the past



Fossilized bacteria brought to Earth from Mars?

Life on Mars

- Mars **now** is **very inhospitable**: cold, little atmosphere, no UV shielding, no(?) liquid water
- But thought to be much different ***in the past***: evidence for lots of **liquid water** on surface, and a **thicker atmosphere** 3- 4 billion years ago.
- Could **life have begun in the past**, within the first ~billion years?
- If life started, could it have survived until the present? Or could we find traces of past life?
- Remember that we see life existing on Earth in **extreme conditions** (e.g. extremophiles)

Martian atmosphere: a genuine puzzle

- Mars is 1/10th the mass of the Earth and ½ the diameter
  - The escape velocity is thus a bit under half that of the Earth (Mars escape velocity ~ 5 km s^{-1})
- Comparison of molecular speeds shows that for N_2 and CO_2 these are both well under the 1/6 of the escape velocity we mentioned (at 300 K speed of N_2 is about 514 m s^{-1})
  - If Mars cooled rapidly though, mass can be lost from the atmosphere by precipitation
- So why does Mars have such a thin atmosphere if liquid water requires a warm high pressure (=thick) atmosphere to survive?
  - Perhaps a thicker atmosphere was lost through other mechanisms – may be impacts producing large amounts of local heating
  - Incomplete outgasing during planetary differentation?

How to look for life: biosignatures

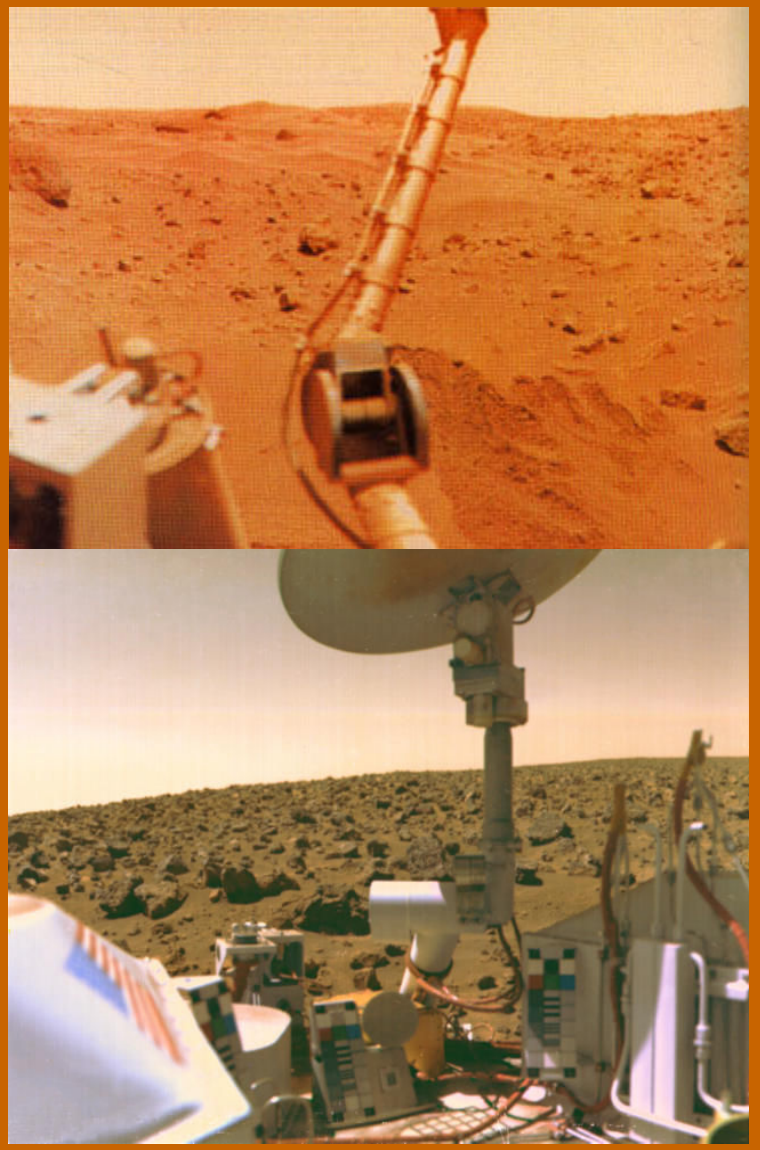
- Chemicals and/or physical characteristics that are derived from life forms are called biosignatures
  - Animal tracks are a trivial example of a physical phenomenon
  - Free O_2 in the atmosphere is often considered a strong biosignature (but doesn't have to be)
- **Best bet: *Microorganisms,* hardier** and **outnumber** larger creatures
  - e.g. microbial life only life on Earth for billions of years
- **Makes sense to look for LAWKI**
  - based on Carbon chemistry
  - fluid solvent (water)
  - study both Martian **atmosphere** and **soil**
- Must avoid contamination: ensure exploration craft are **sterilized**, and that samples can be obtained **unaffected** by spacecraft

Planetary Protection

- Planetary protection is the term given to the practice of protecting solar system bodies from contamination by Earth life
  - Also protects Earth from life forms that may be returned from other solar system bodies
- The International Council of Science Committee on Space Research (COSPAR) sets stringent limits on contamination of other bodies
  - COSPAR indirectly advises the UN
- The US (NASA) generally follows COSPAR guidelines
- Mission design and "cleanliness" of hardware depends upon the mission
  - Fly-by or orbiters usually are allowed a lower level of cleanliness compared to landers and rovers (complete sterilization may be required for landers)
  - Also once cleaned must ensure that hardware does not aquire new biota while still on Earth

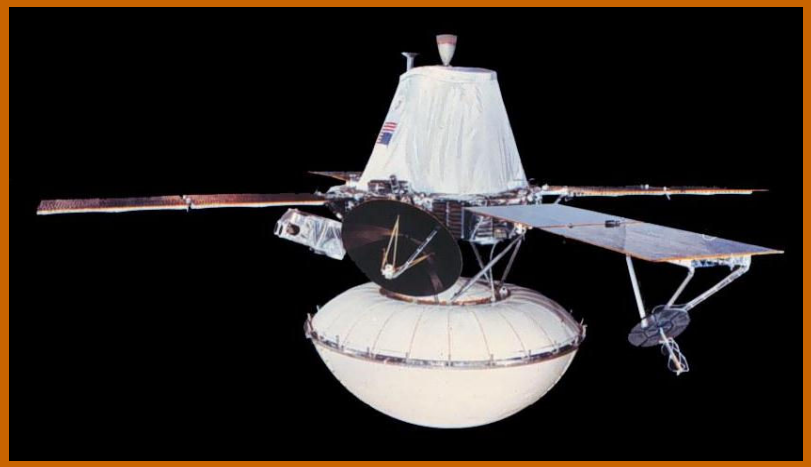
Viking landers

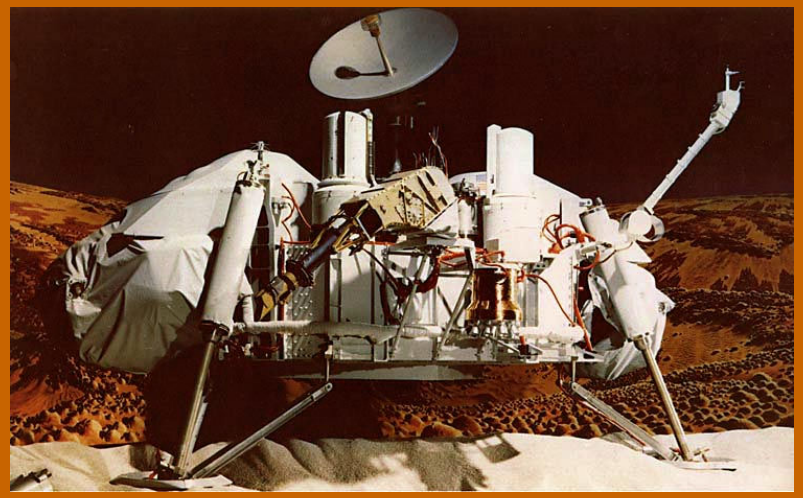
- **Viking 1 and 2:** launched in summer of 1975, and landed in July and September 1976.
- Two sites ~2000 km apart: Chryse Planitia, Utopia Planitia
- **Goals:**
  - obtain high-resolution images of Martian surface
  - study structure, composition of atmosphere and surface
  - search for evidence of life



Combined mission: orbiter & lander

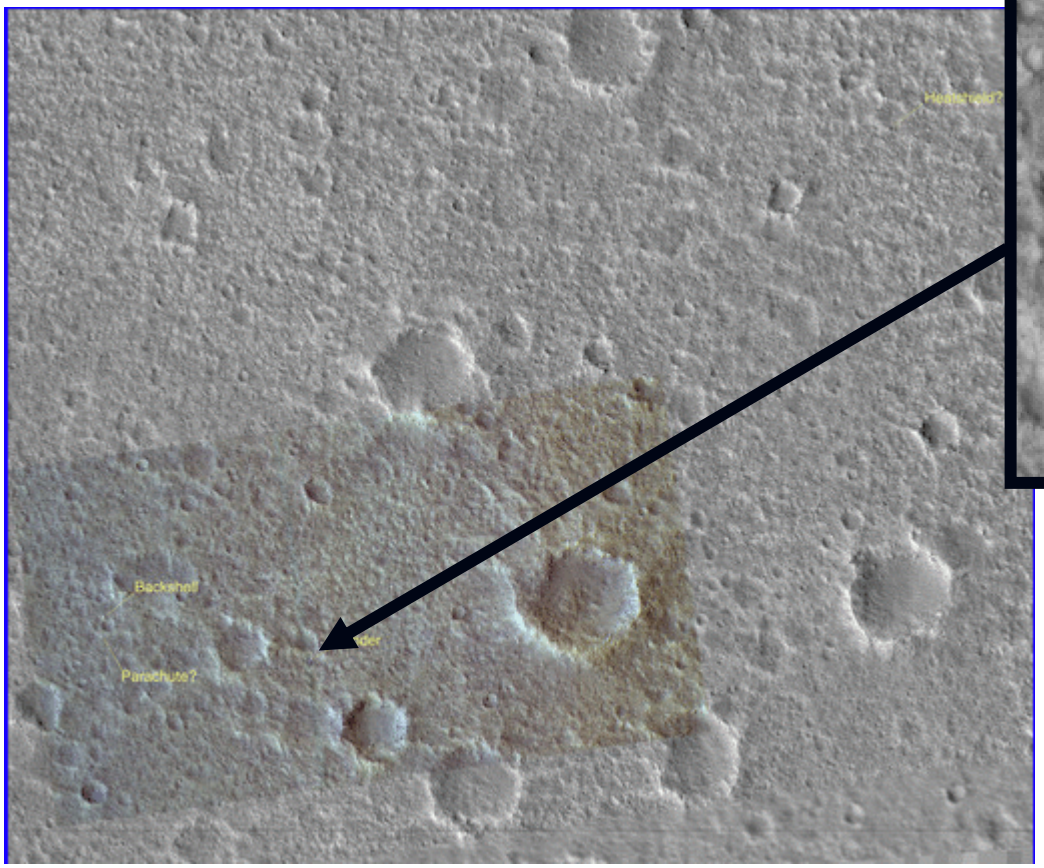
- Orbiter:
  - to map the Martian surface (scout out landing sites) and relay signals
- Lander:
  - to carry out experiments on surface (including 3m long arm to dig soil samples)



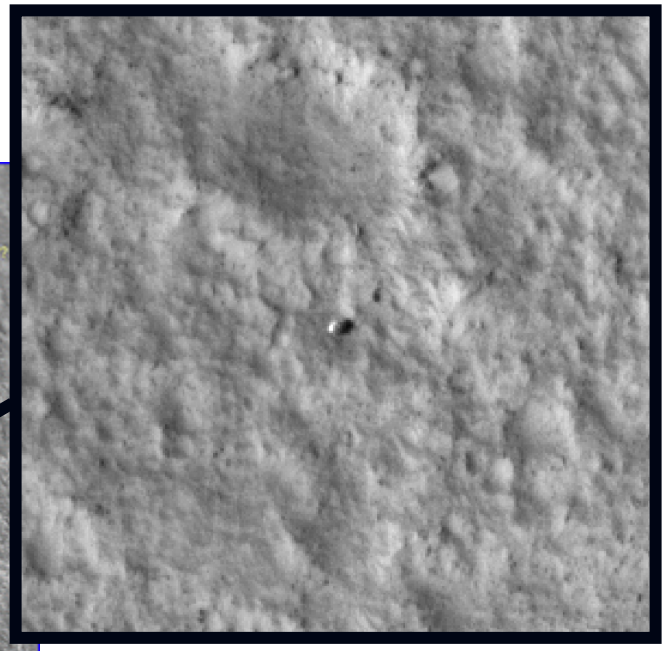


Viking Landers spotted from space!

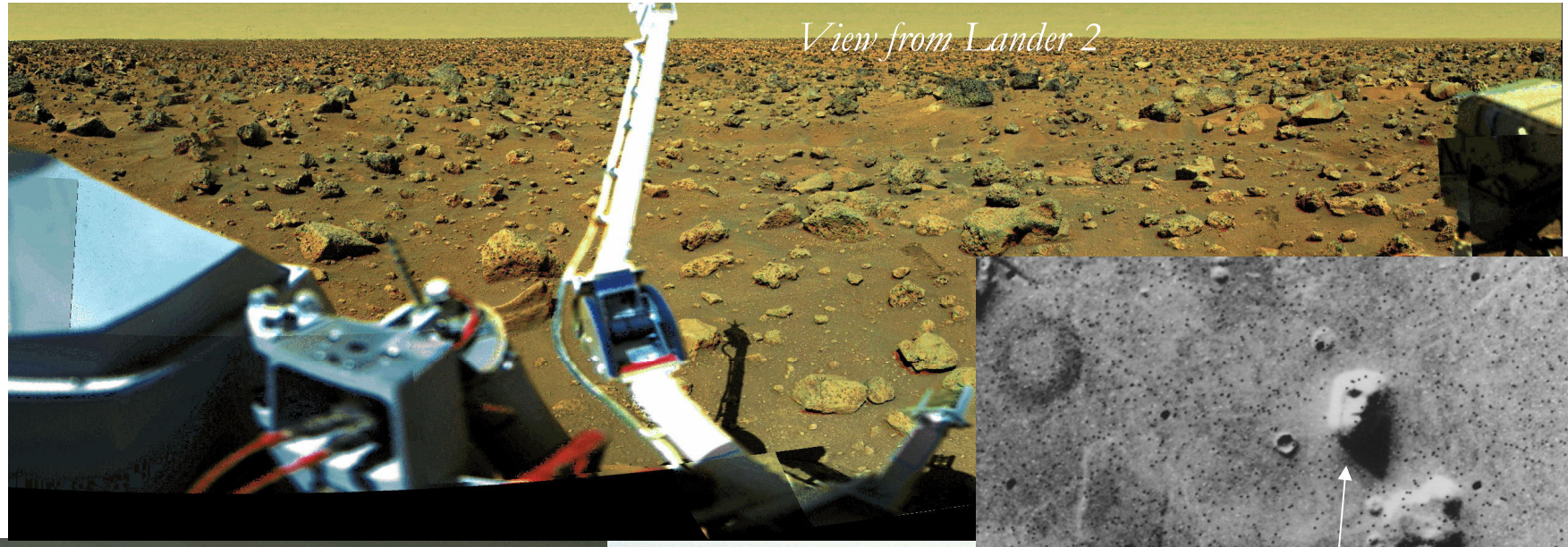
In October 2006 the Mars Reconnaissance Orbiter photographed the regions in which the two orbiters landed

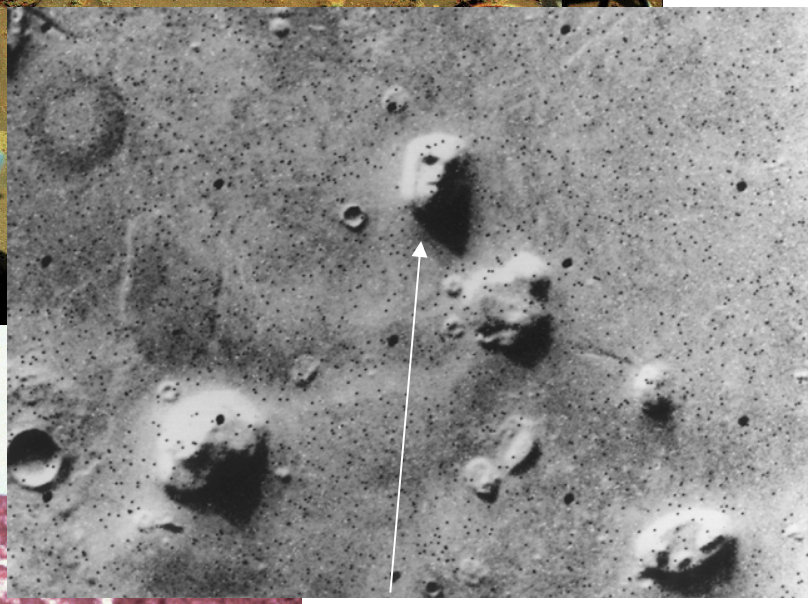


Viking 1

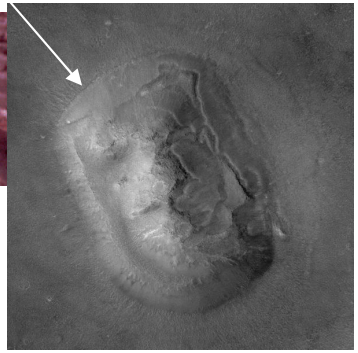


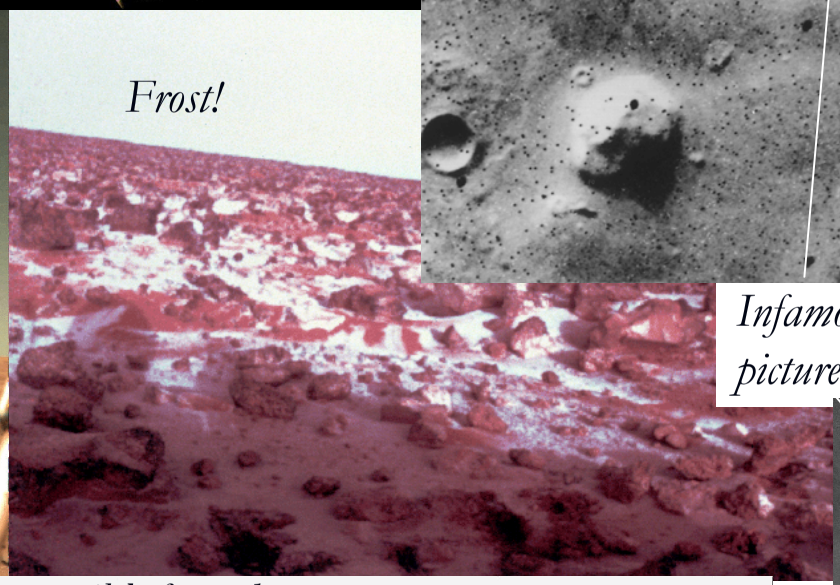
30 years after landing!

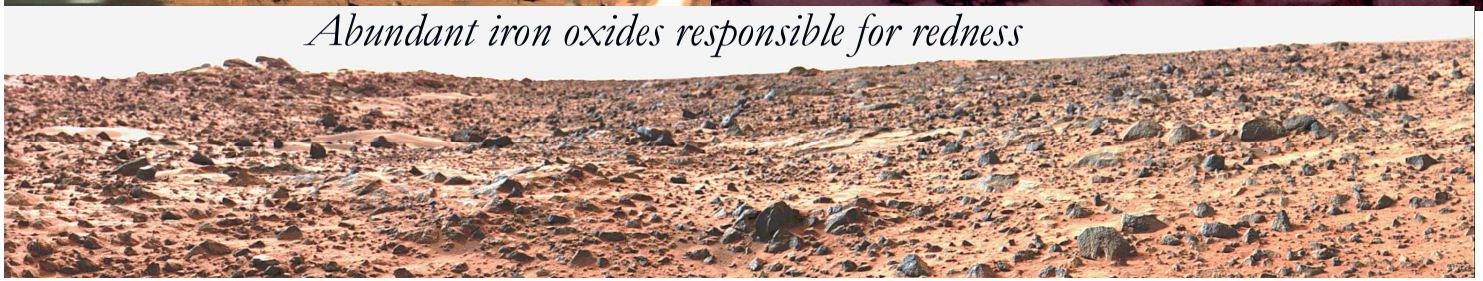




Infamous "face on Mars" picture



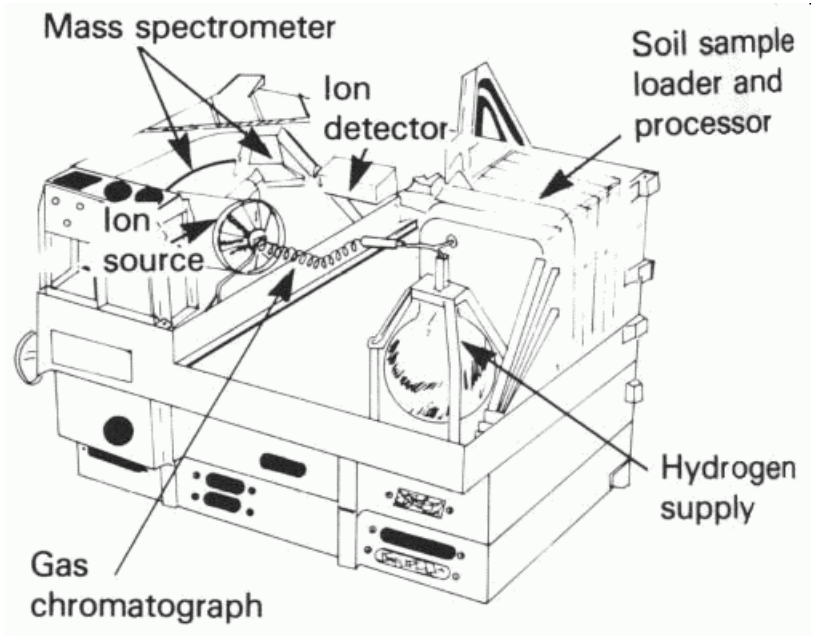




Viking tests for life

- **Images:** no apparent macroscopic signs of life (plants, footprints)
- **Atmosphere:** mass spectrometer showed no O, methane (or silane) that can't be accounted for **abiotically.**

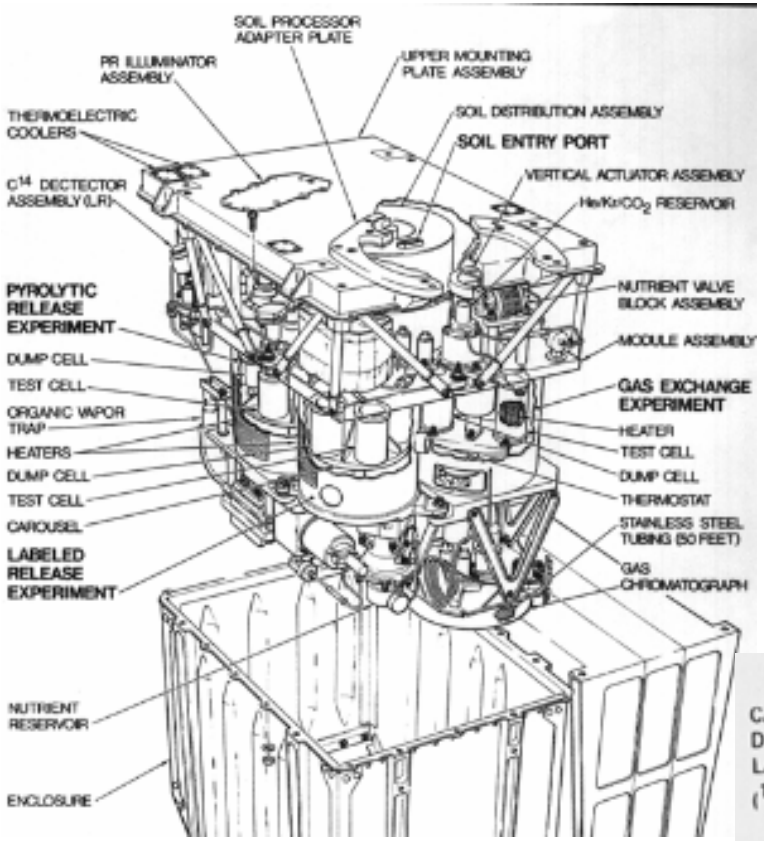
- **Soil: Gas Chromatograph-Mass Spectrometer (GCMS)**
- Two samples from each site
- Bake soil in oven to drive off volatiles, stick to chromatograph
- Chromatograph is heated, and organics leave in sequence
- Determine abundances of any volatiles

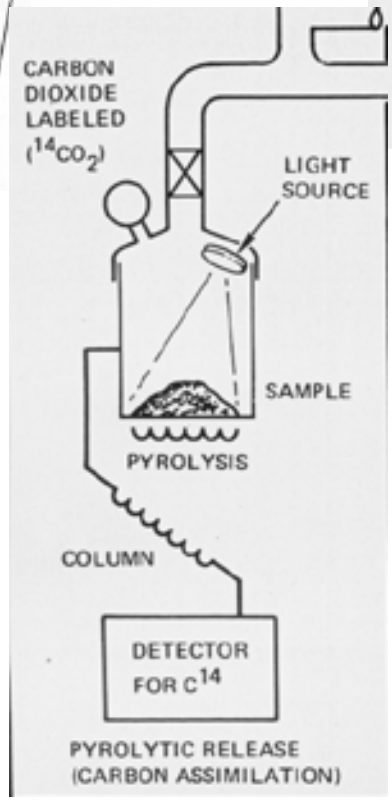


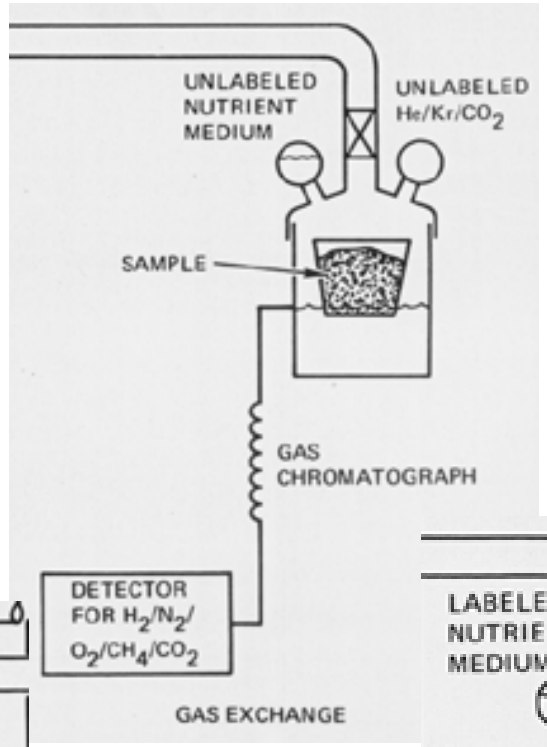
GCMS results for the soil

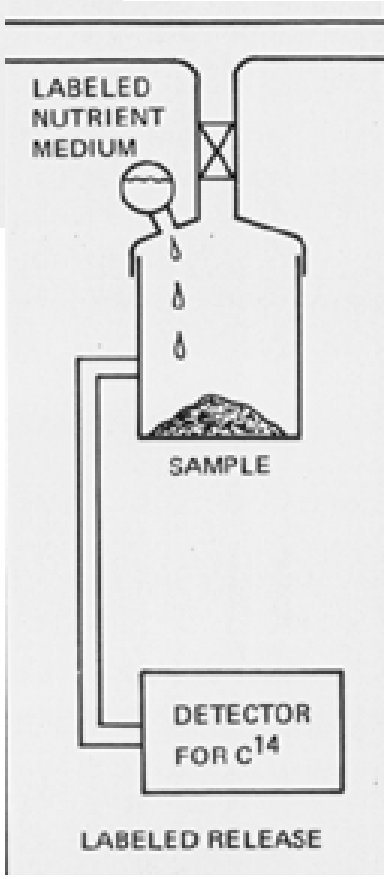
- No organic compounds to few parts/billion
  - less organics than Murchison meteorite – this seems almost too low!
  - Implies < 100 organisms per few gram sample if they are there at all
- Pretty tough in terms of finding life! Life would produce **some** organics.
- Impacts from carbonaceous meteorites would also deliver organics, so something must be destroying them: **peroxides** very quickly turn carbon compounds to CO_2 (see later)

Viking Biology Experiments:



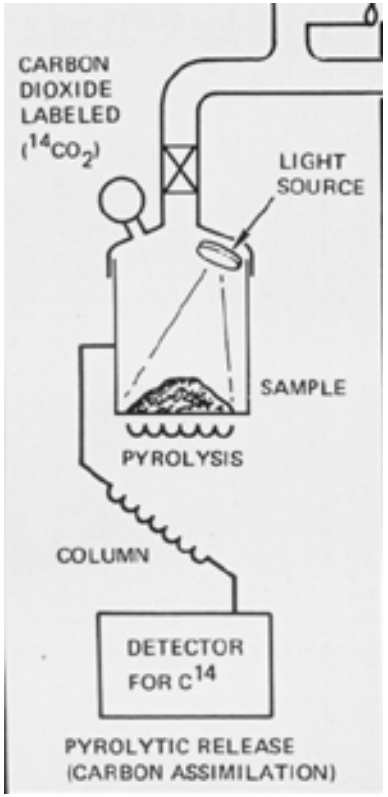






Experiment 1: Carbon Assimilation

- *look for signs of **photosynthesis** – is carbon absorbed into soil in presence of light?*
- Xenon lamp (for "sunlight", UV-filtered)
  - radiotagged CO and CO_2 to differentiate the experiment gas from the Martian atmosphere
- If organisms present, they may absorb CO_2/CO. After 5 days "incubation", gas vented, and soil baked at 750 C. Volatile gases released from heating passed into vapor trap and then measured for radioactivity. If outgassed C14 found: **life/photosynthesis**
- **Again initially positive!** But again dismissed as **inorganic**:
  - e.g. if soil heated to 175 C before test, still positive result
  - perhaps due to ammonia contamination from engines?



Experiment 2: Gas Exchange

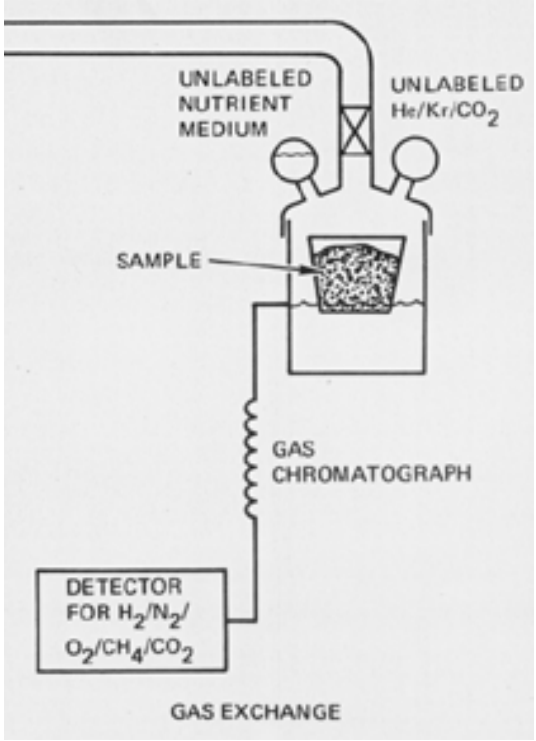
- *look for signs of **metabolism** - look for changes in the gas content of the chamber*

- Water-borne nutrient broth ("***chicken soup***") added to soil sample, and gas chromatograph looked for gases given off by **metabolic processes** (e.g. changes in O, CO_2, NH_3)

- **Positive results!** O found at 15 times normal Martian levels
  - **However,** just exposing the soil to water vapour **(**rather than broth**)** produced a positive result – which is inconsistent with metabolism

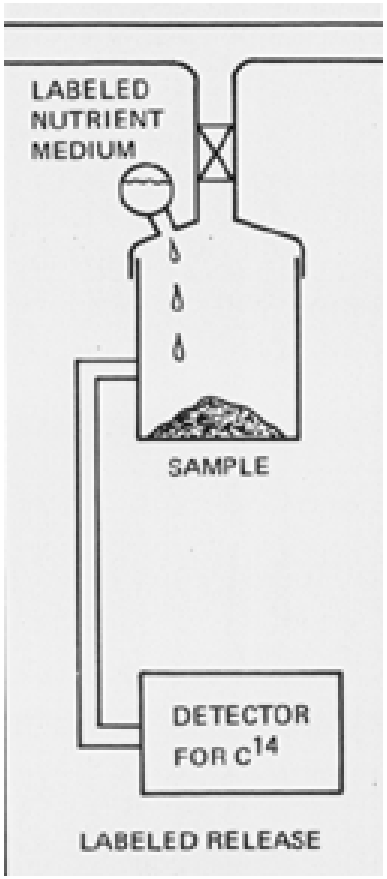
- Thought due to **inorganic** processes: chemical interaction of Martian soil with high pressure of water vapor to produce O. O amounts also **decreased** with time (not expected for life)

- As for 1st experiment same results were found when soil was heated to very high temperatures before testing



Experiment 3: Labeled release

- *look for signs of **respiration** – look for traces of labelled material being breathed out*
- Also used "*chicken soup*", but **radiotagged (labelled)** with (radioactive) C14. If organisms ate nutrients, they would exhale gases with some C14 (e.g. CO_2) from nutrients, which would be detected.
- Also gave **positive results**! Sharp rise in radioactive gases, stronger than seen on Earth.
- But also a **chemical reaction:** organic chemicals in broth reacting with **peroxides**, e.g: $H_2O_2 + HCOOH = 2H_2O + CO_2$
  - can be reproduced on the Earth
  - when more broth added, level of radioactive gases **decreased**



The results from this experiment showed the heating the sample did remove the positive result – whether this is a sign of life is still debated by some, but overall there is not much controversy.

Summary of results from Viking landers

- All three experiments **initially gave positive results**
- But now think positive results **not due to life**, but to contamination, or interactions with Mars soil chemistry (esp. **peroxides**)
- Don't think any microorganisms would have been killed by act of landing, or by experiments themselves
- No evidence of carbon-based life so far on Mars ...

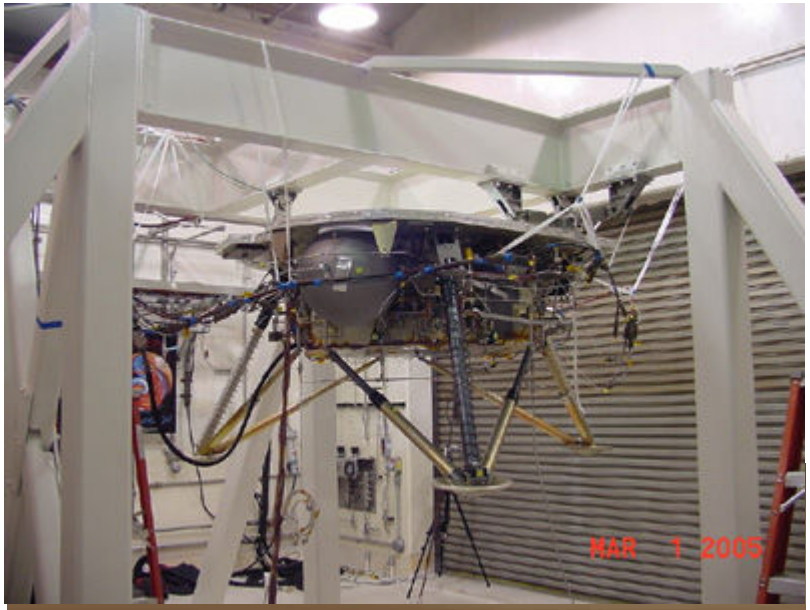
Mars Rovers – what have they contributed?

- Geological oriented missions – no biological tests!
  - Strong focus on engineering solutions as well
- Focus has been on looking closely at rocks for geological evidence of water
  - Included "rock abrasion tool" to examine what lies underneath surface coatings

Mars rovers 3 year summary

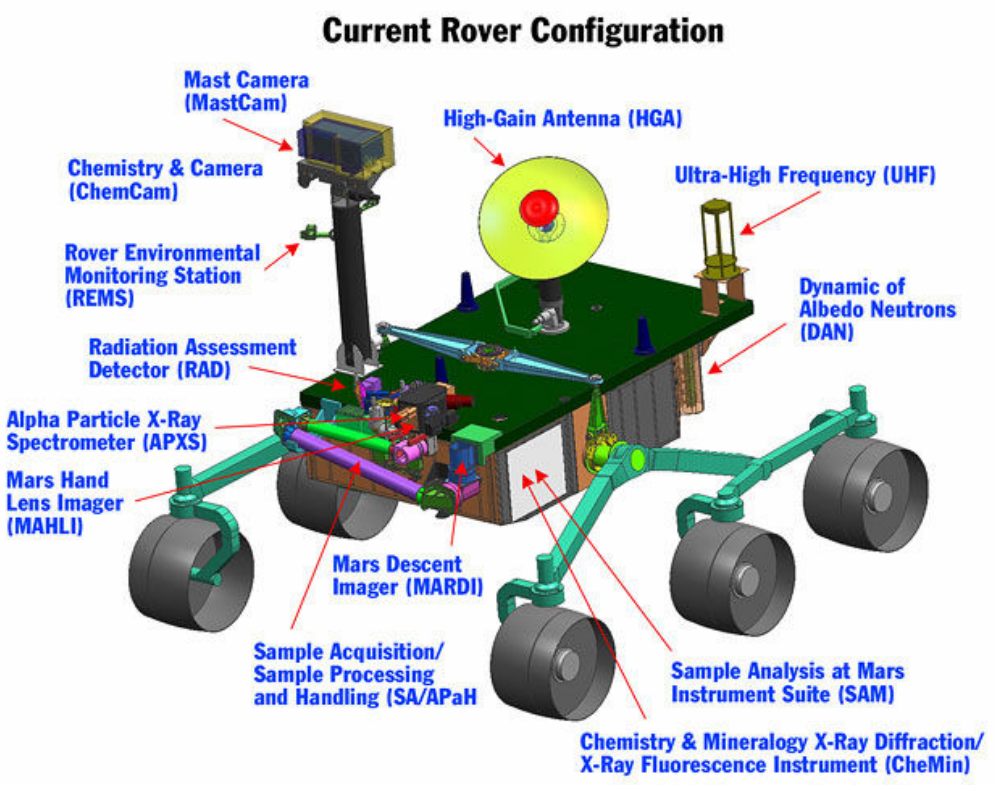
Phoenix mission (scheduled to arrive 2008)

- Canadian involvement - meteorological (MET) package (pressure & temperature sensors)
- Targetting the polar regions where we know there will be subsurface water (in some form)
- Will have robotic arm to extract samples to be placed in a "wet chemistry lab"
  - Will give indications about pH and general biocompatibility of the soil with life



Mars Science Laboratory (scheduled to arrive 2010)

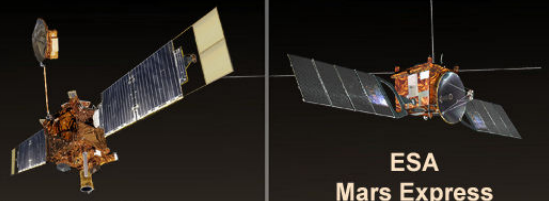
- Strongly multinational collaboration (US, France, Germany)
- At 800 kg, it will be much larger than current rovers
- Will carry a GCMS and spectrometer to measure composition of samples
- Also will carry more equipment for doing analysis external to the rover (laser vaporization and measurement of the resulting emission)
- Radiation data to estimate human exposure risks will be taken



NASA Mars Exploration Program

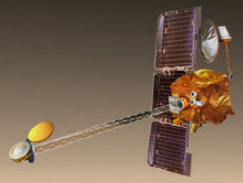
Launch Year

OPERATIONAL



Mars Global Surveyor

ESA
Mars Express



Mars Odyssey

Mars
Reconnaissance
Orbiter
(Italian SHARAD)

2007

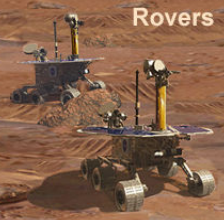
Competed Scout Mission

Phoenix

2009

Mars Telesat

Mars Science
Laboratory



Mars
Exploration
Rovers

...Next Decade

Explore the
Evolution of Mars

Search for
Evidence of Past Life

Science pathways
responsive to discovery

Search for Present Life

Explore
Hydrothermal
Habitats

What about Martian meteorites?

- Most asteroids from asteroid belt, but also from Moon and Mars
- **Martian meteorites:** also called SNC-type, 34 known to date, most found in Antarctica.
- Believed to have been **blasted** from surface of Mars. Numerical models show this can work.
- Most have ages <= 1.3 billion years, and are basaltic

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http://www.cnn.com/TECH/9608/06/mars.life/ Go artian meteorite" 1996

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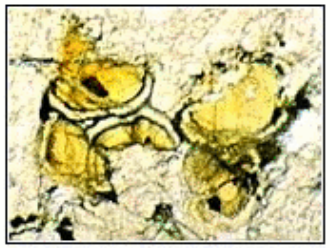
Ancient meteorite may point to life on Mars

'Biggest discovery in the history of science'

August 7, 1996
Web posted at: 1:15 p.m. EDT



A cross section of the meteorite (NASA)

RELATED SITES & STORIES

WASHINGTON (CNN) -- NASA announced Wednesday that a primitive form of microscopic life may have existed on Mars about 4 billion years ago.

The announcement was made in Washington at a news conference to discuss the findings, made by researchers from NASA and various universities.

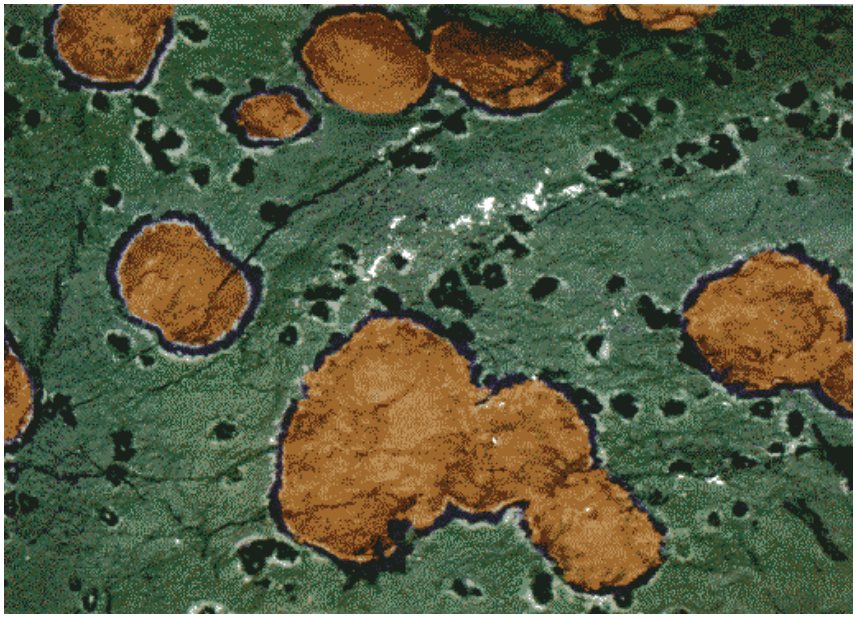
Before the news conference, a source close to the agency told CNN, "I think it's arguably the biggest discovery in the history of science."

This was BIG news in 1996…

ALH84001

- ~2 kg, found in Antarctica in 1984, age ~4.5 billion years
- Ejected from Mars ~16 million years ago
- Landed on Earth ~ 13,000 years ago (carbon dating)
- Took 12 years till looked at for signs of life by McKay, Gibson et al. They announced their results in 1996 ...

Carbonate Globules – where the attention focused



- **Flattened spheres**, 20-250 microns in size covering walls of cracks. No other SNC meteorite has these globules
- Isotope analysis of carbon C12/C13 shows they're **not likely terrestrial**
- Isotopic analysis of O suggests they formed from **water-rich fluid**, but big question is at **what temperature**? Cold/Hot?

Evidence from ALH84001 for Martian Life

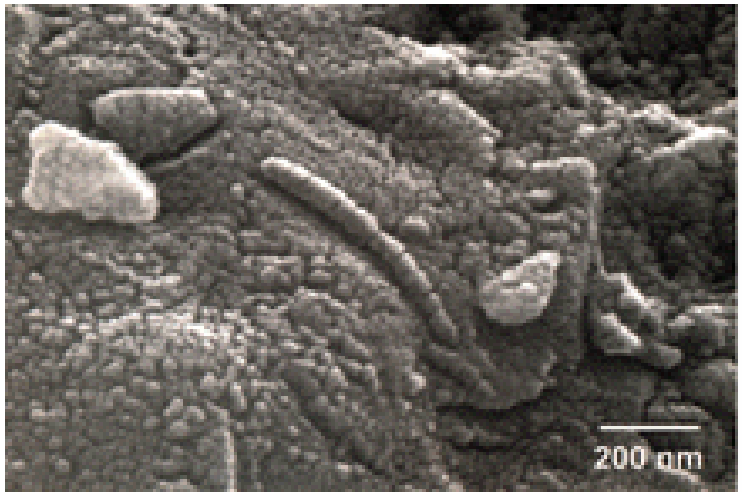
- **(1) Metallic grains** resembling those formed by terrestrial bacteria
  - ALH84001 magnetite (Fe_3O_4) crystals similar to those produced by **anaerobic bacteria** on Earth
  - But found in lifeless places too…

- **(2) Organic molecules** (PAHs) in/on globules
  - PAHs (Polycyclic Aromatic Hydrocarbons) created when terrestrial organisms die and decay
  - PAHs also found in lifeless places too (including space)

- **(3) Unusual structures** looking like Earth **bacteria fossils**
  - This really piqued the interest of the public…

Microfossils

- SEM views show the carbonate globules have **ovoid** and **tube-shaped** bodies similar in shape to terrestrial **deep-earth bacteria**



- Sizes range from 40-80 nm (ovoids), tube-shaped bodies (20-40 x 30-170 nm) and some as large as 700 nm

- These are ~30 times smaller than those on Earth. Too small to contain genetic info and metabolic machinery? (>250 nm)

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Space rock re-opens Mars debate

By Paul Rincon
BBC News science reporter

A carbon-rich substance found filling tiny cracks within a Martian meteorite could boost the idea that life once existed on the Red Planet.

The meteorite fell to Earth in Egypt in 1911
(*Image: Natural History Museum*)

The material resembles that found in fractures, or "veins", apparently etched by microbes in volcanic glass from the Earth's ocean floor.

Details will be presented at the Lunar and Planetary Science Conference in Houston, Texas, next month.

All the processes of life on Earth are based on the element carbon.

Proving carbon in Martian meteorites is indigenous - and not contamination from Earth - is crucial to the question of whether life once arose on the Red Planet.

Initial measurements support the

"We don't exactly know what it

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- 248-dimension maths puzzle solved
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- Lunar dust 'may harm astronauts'

Still no clear evidence that the carbon is biological in origin…

A human mission to Mars?

- Robotic missions can only do so much
  - A robot can't make a sandwich like you or I can!
- Bush presidency announced a "plan" to put humans on Mars by 2030
  - Russia and Europe have also considered missions but have made no official announcement
- A moon base will serve as a staging area to Mars (much will be learnt by having an established moon base)
- Many, many problems to solve:
  - Engineering – vehicle power (nuclear?), energy budget for getting there and back
  - Human exposure – psychology of confined space, radiation exposure during flight looks to be virtual death sentence
  - Politics and science – such a mission is expected to costs over $120 billion over 20 years, does the science case warrant this expenditure?

Summary of lecture 24

- No evidence for **active life** on Mars, at least on **surface**.
- But we haven't looked at many places. Could life be elsewhere on the surface?
  - Martian surface **well-mixed** due to surface turnover and dust storms. Viking did look at two places separated by 2000 km
- Maybe (deep) **underground** or in **polar caps**?
  - Underground bacteria on Earth, also have found extermophiles that live dormant in ice
  - Evidence for past water on surface of Mars, 3-4 bya. Blue-green bacteria on Earth were thriving at that time
  - Need to send missions to look at these sites
- **Any** finding of life (past or present) on Mars hugely exciting!!!

Next lecture

- Titan