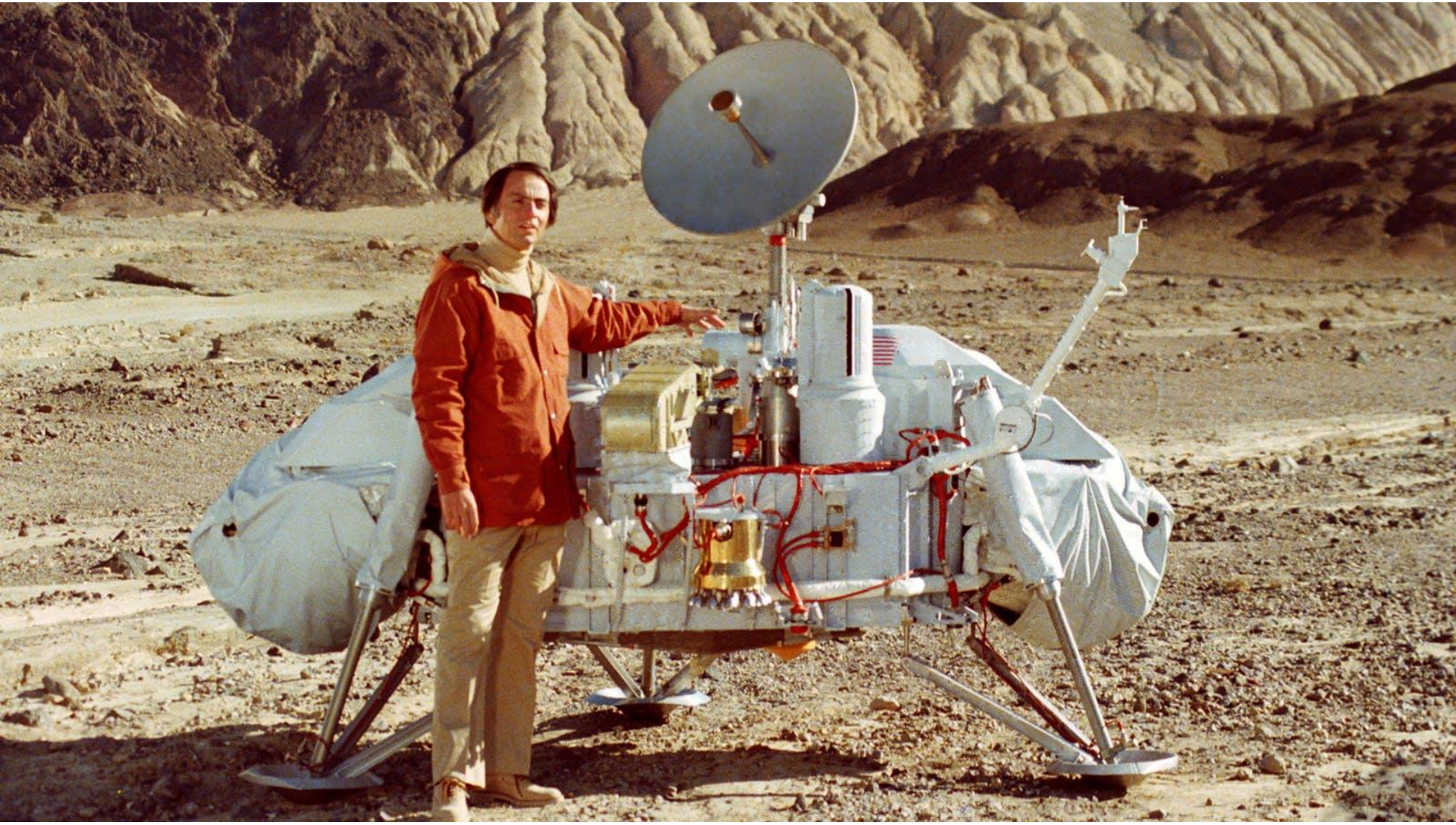
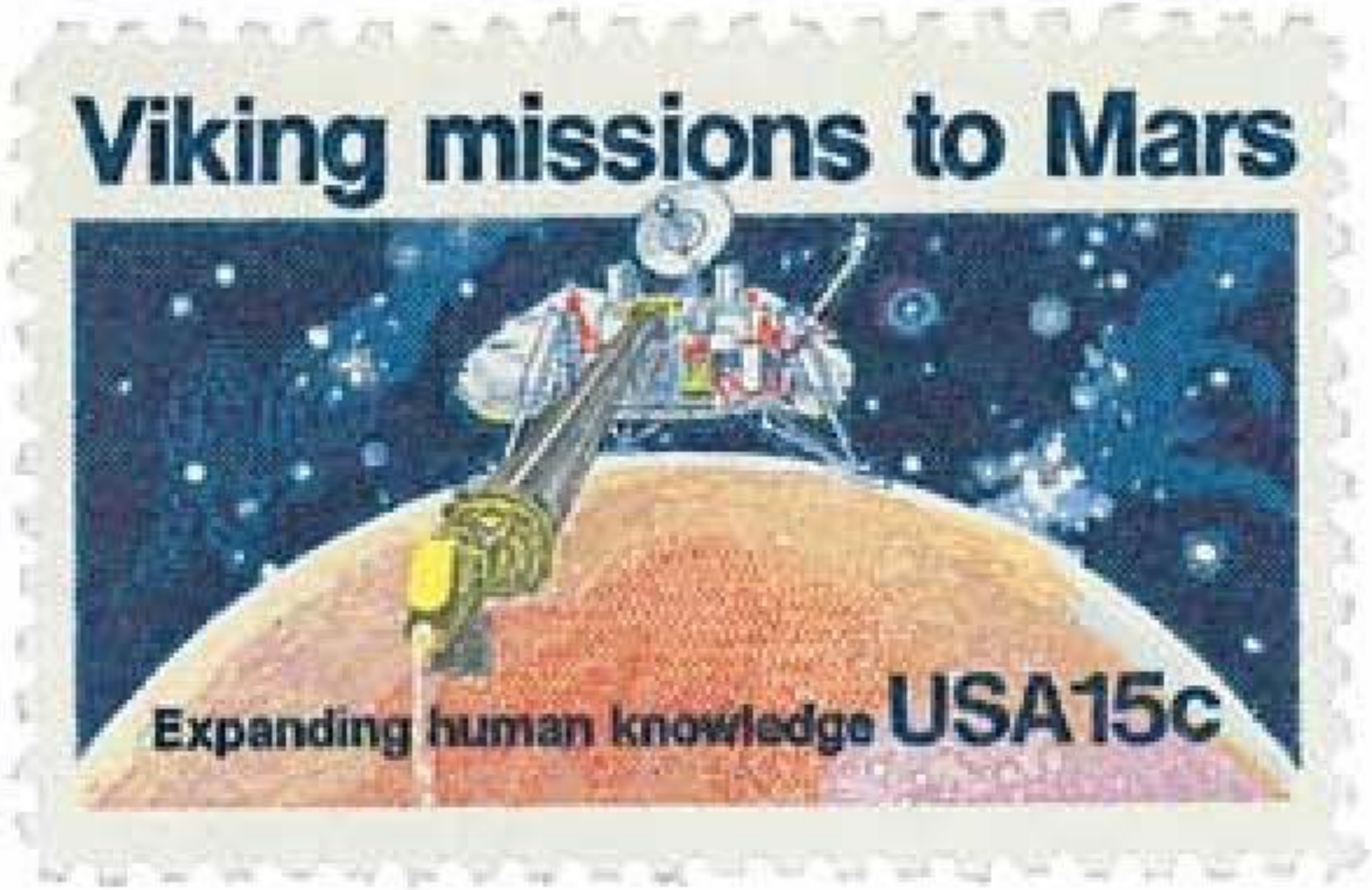
life on mars

what to know before we go

david a. weintraub

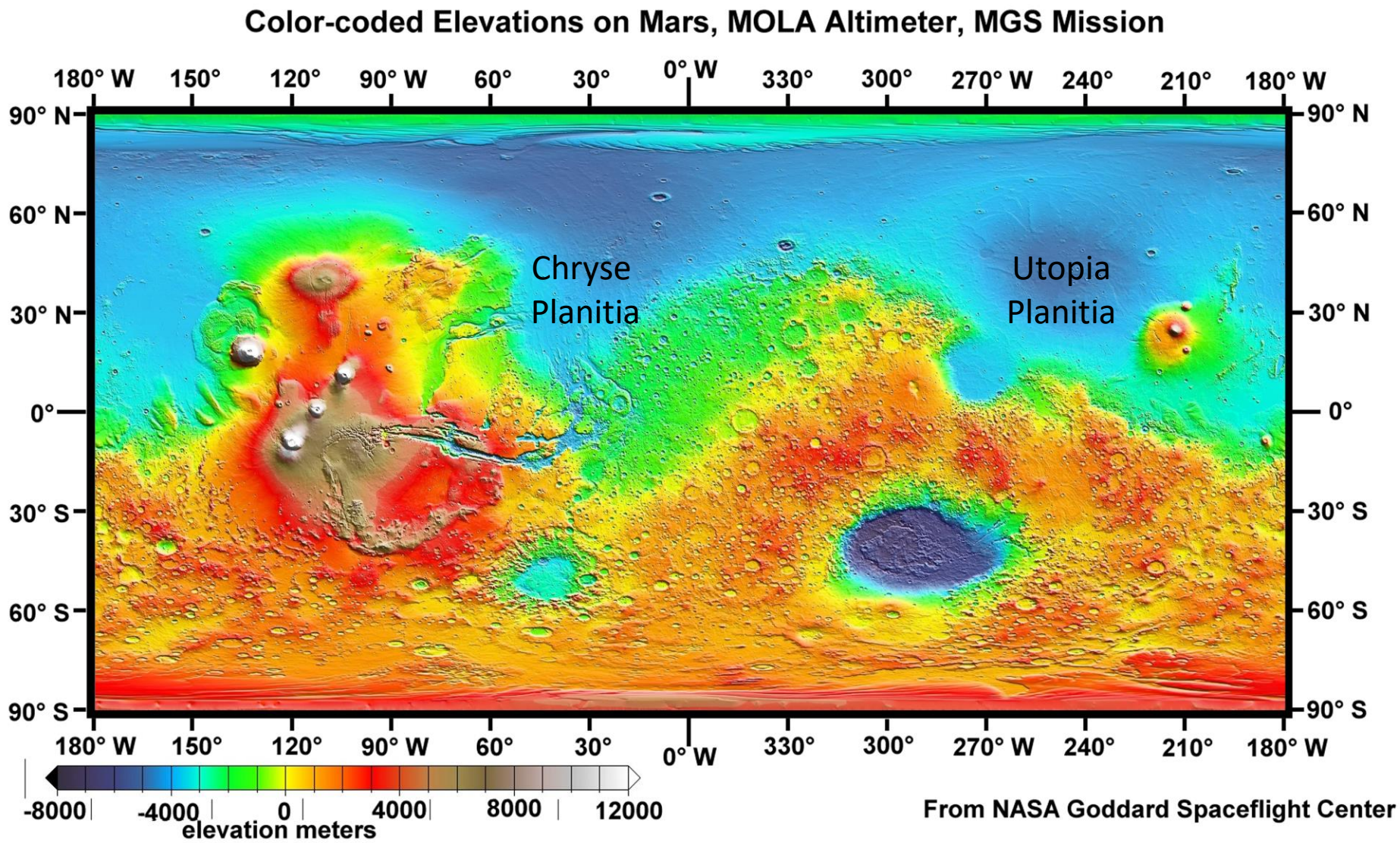


Carl Sagan and Viking Lander (not on Mars!)



July 20, 1976, Viking 1 landed on Chryse Planitia, Mars.
September 3, Viking 2 landed on Utopia Planitia.

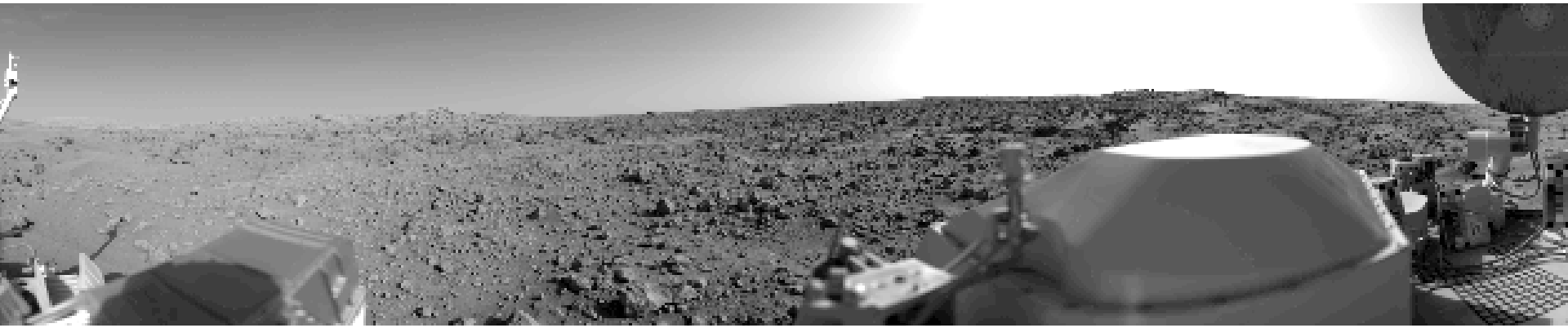
The Viking Orbiters imaged the entire surface of Mars at a resolution of 150 to 300 meters, and selected areas at 8 meters.


Color-coded Elevations on Mars, MOLA Altimeter, MGS Mission
180° W
150°
120°
90° W
60°
30°
0° W
330°
300°
270° W
240°
210°
180° W
90° N
60° N
30° N
0°
30° S
60° S
90° S
Chryse Planitia
Utopia Planitia
-8000
-4000
0
4000
8000
12000
elevation meters
From NASA Goddard Spaceflight Center

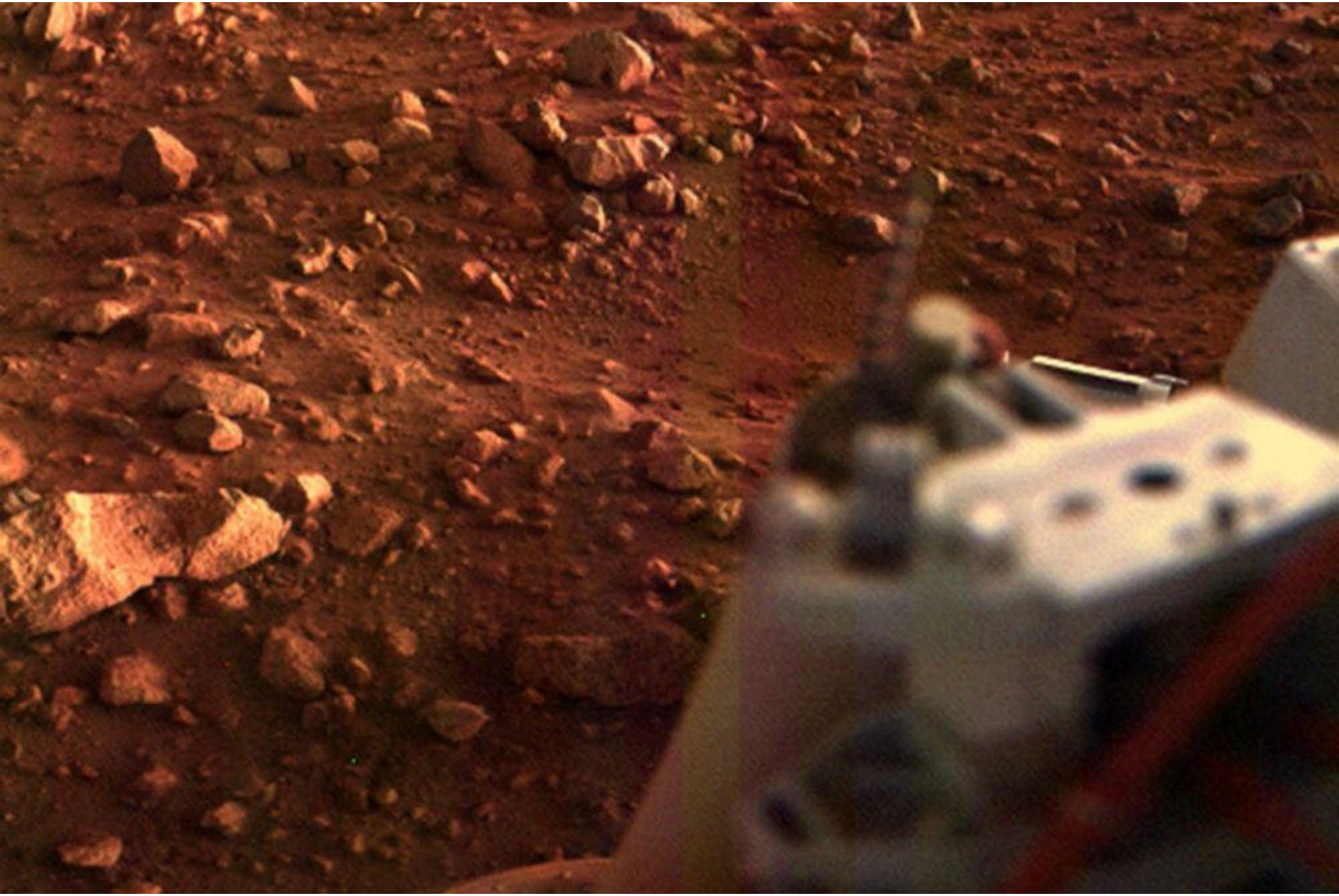
First Task: Look for 'macrobes

***Macrobe: a** life-form visible to the naked eye*
--- Carl Sagan

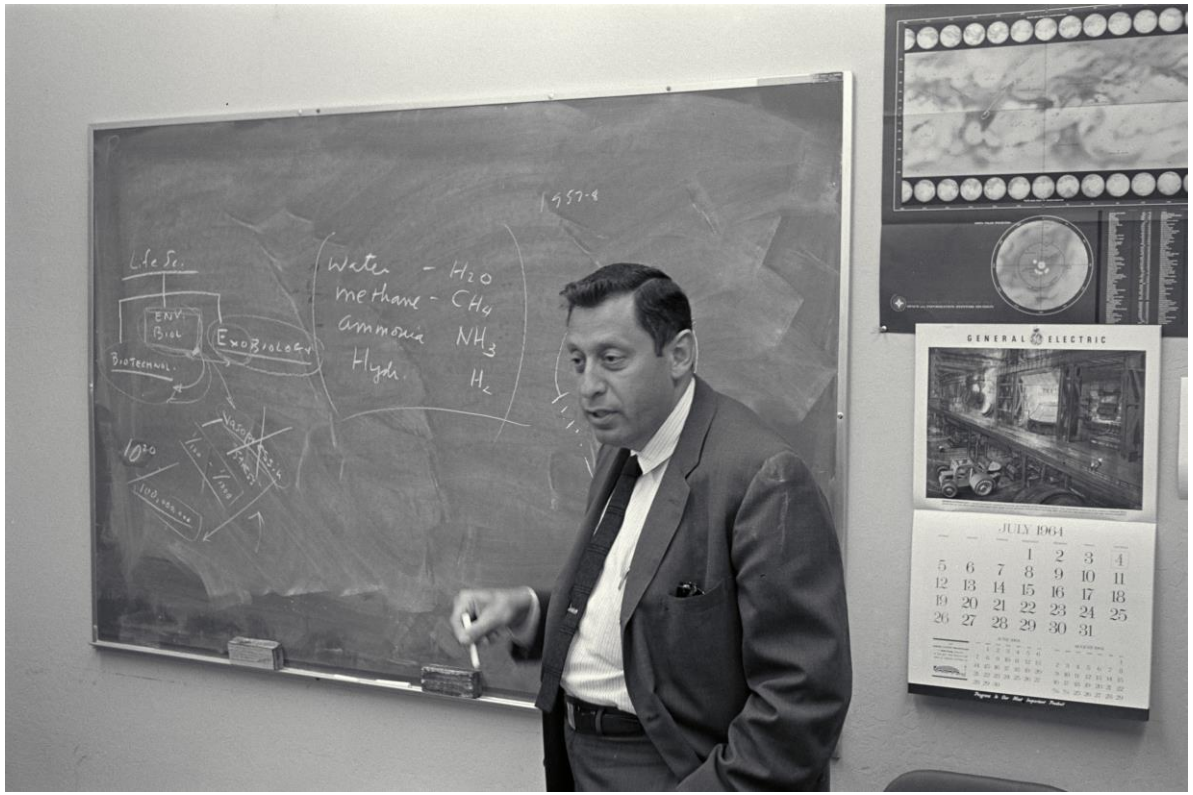
"There is no reason to exclude from Mars organisms ranging in size from ants to polar bears. And there are even reasons why large organisms might do somewhat better than small organisms on Mars." --- Carl Sagan



First Viking lander survey panorama, obtained on the surface of Mars on July 20, 1976, revealing **no macroscopic Martians**.



Next Task:
Biology Experiments



Harold Klein (1921-2001)
PhD, Microbiology (UC Berkeley, 1950)
Biology Team Leader for Viking missions

1. Gas-Exchange Experiment
2. Label-Release Experiment
3. Pyrolytic-Release Experiment
4. Gas Chromatograph Mass Spectrometer Experiment

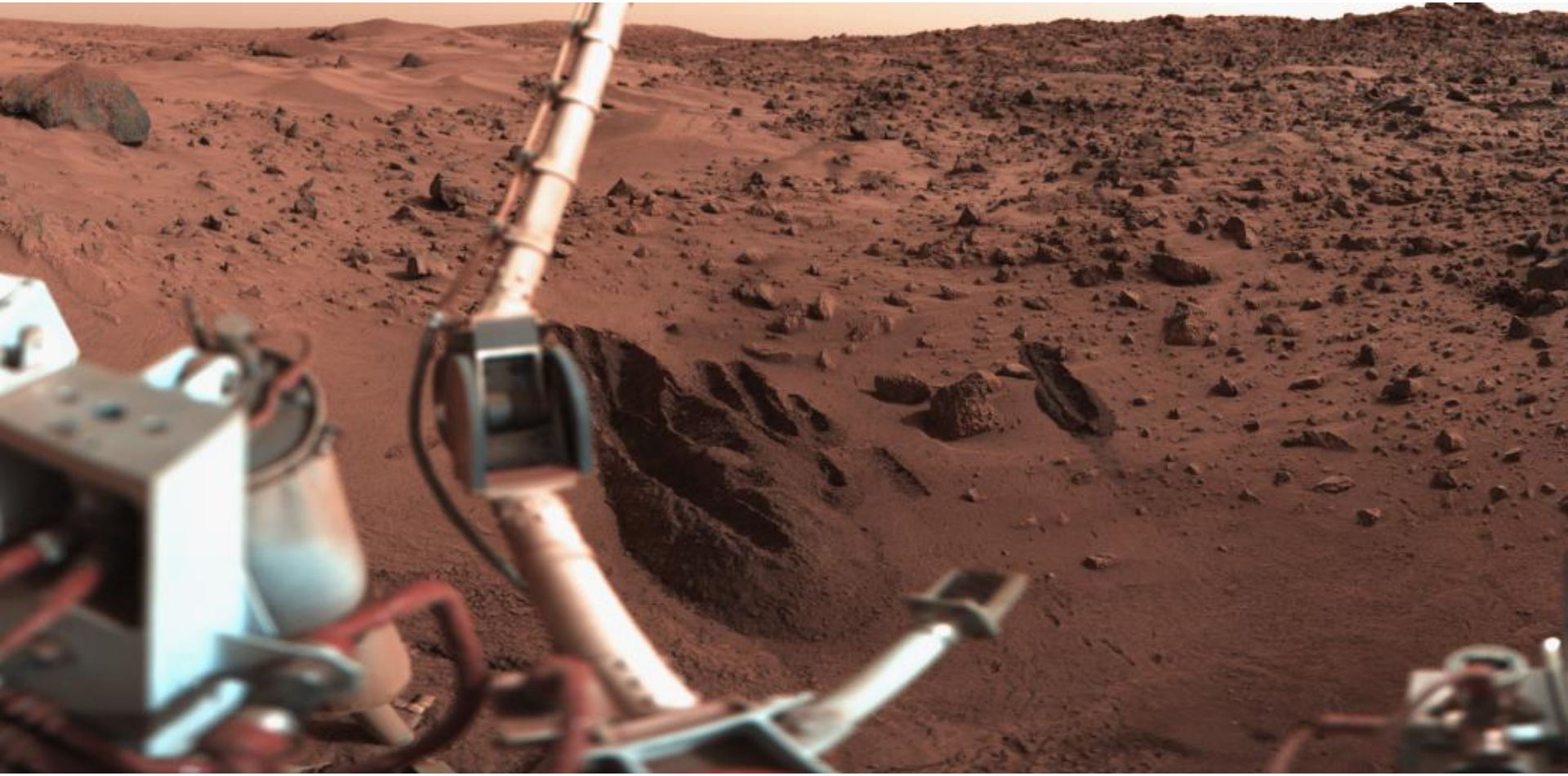
All four fit within one cubic foot of payload space

1. Gas-Exchange Experiment (Vance Oyama)

-- biochemist (1922-1998)
-- chief of life-detection branch at NASA Ames

Gas-Exchange Experiment (Vance Oyama)

Robotic arm reached out from the lander and scraped a small amount of dirt off the surface of Mars, which it then dropped into a chamber inside the lander.



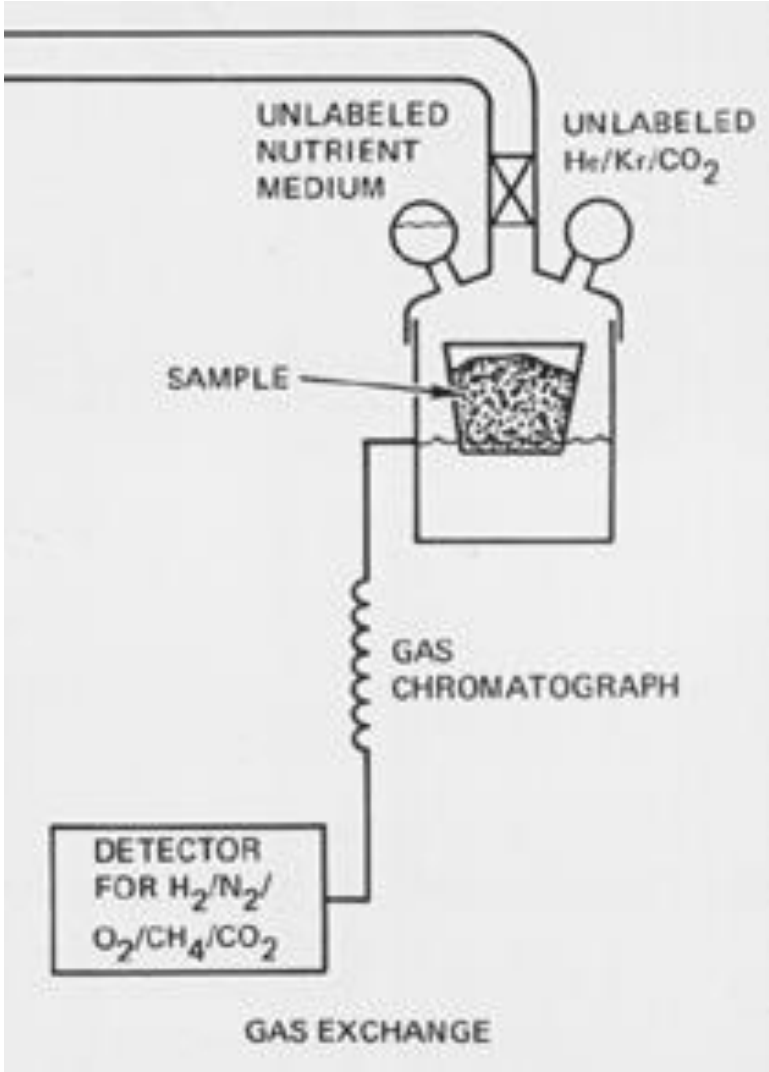
Gas-Exchange Experiment (Vance Oyama)

3 experiments, done in series

1st – dirt tested without adding water

2nd – direct tested in the presence of water (water in a petri disk, below the dirt – not in direct contact with the water)

3rd – 'chicken soup' mixture (19 amino acids) added to the water; moisture absorbed by dirt



Would living things (if present) grow? respire? reproduce?
-- **predicted signature of activity**: intake of organic substances followed by exhalation of carbon monoxide, methane, hydrogen, **oxygen**, nitrous oxide, hydrogen sulfide
-- **2.5 hours into 'chicken soup' phase, soil began to release large quantities of oxygen, in a big burst!!!**

2. Label-Release Experiment (Gil Levin) (1922 -)

PhD, Env Engineering

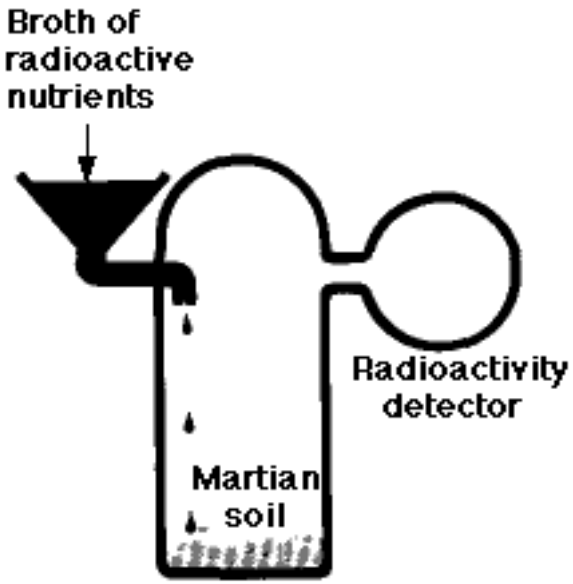
– had invented a device for detecting microbes in polluted water (for his Company Biospherics, Inc., of Maryland; now Spherix)

Label-Release Experiment (Gil Levin)

Same --- Robotic arm reached out from the lander and scraped a small amount of dirt off the surface of Mars, which it then dropped into a chamber inside the lander.

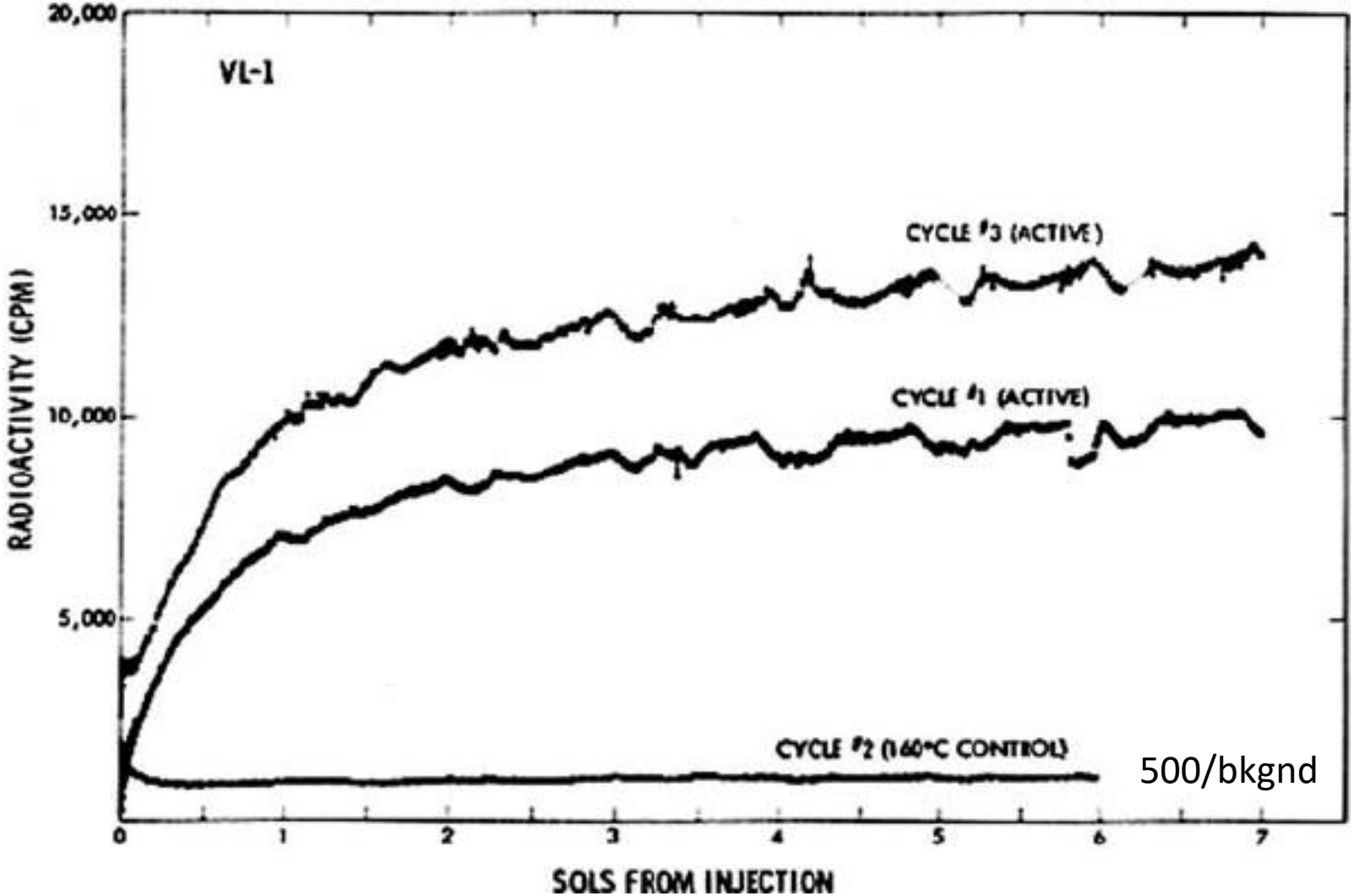
– injected synthesized amino acids and carbohydrates into dirt; all contained radioactive carbon-14 instead of stable carbon-12

- If any biological activity occurred, carbon would be eaten metabolized, then exhaled as radioactive CO_2 gas; geiger counter would detect radioactivity



Labeled Release (LR) experiment

- ‘background’ level of radioactivity: 500 counts per minute
- Immediate results:
    - 4,500 counts per minute after 9 hours
    - 10,000 counts per minute after one day



July 31, 1976, Sol 11
First NASA press conference for Biology Team
-- led by Harold Klein --

One of the two Viking biology experiments, the Gas-Exchange experiment, had already yielded "at least preliminary evidence [release of oxygen] for a very active surface material."

A second experiment, the Label-Release experiment, had generated a response [high levels of radioactive carbon] that looked "very much like a biological signal."

Both results, he cautioned, "must be viewed very carefully. We believe there is something in the surface, some chemical or physical entity, which is affording the surface material a great deal of activity and may in fact mimic—let me emphasize that: mimic—in some respects, **biological activity**."

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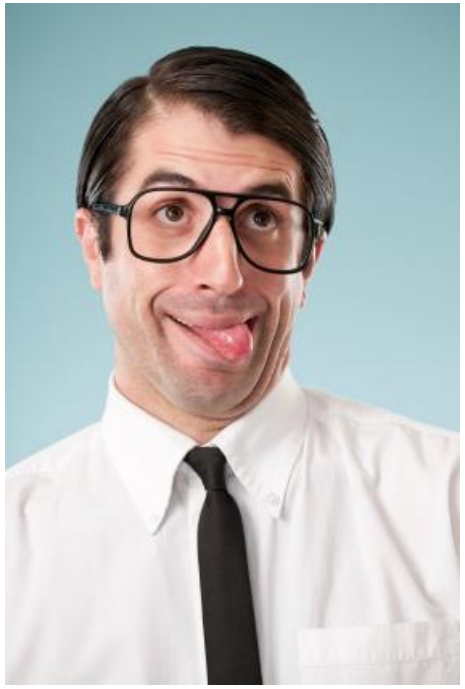
BIOLOGICAL ACTIVITY !!!!!!

Embarrassment?

One reporter asked whether the production of oxygen (in Gas-Exchange experiment) was evidence for photosynthetic activity on Mars.
… But this experiment took place inside the Lander, in the dark ... **Huh?**

Another reporter: Could animals have produced the oxygen. ... **Huh?**



New York Times headline on August 1, page 1
“Scientists Say Data Could Be First Hint of Life on the Planet.”

New York Times headline on August 1, page 1, page 1
“Tests by Viking Strengthens Hint of Life on Mars”

What's going on? **Somebody held a press conference too soon …**

Viking Biology Team conclusion, after further laboratory research on Earth:

The Gas-Exchange and Label-Release experiments "confirmed the presence in the surface of very reactive, oxidizing species"

Interpretation of 'oxydizing species':

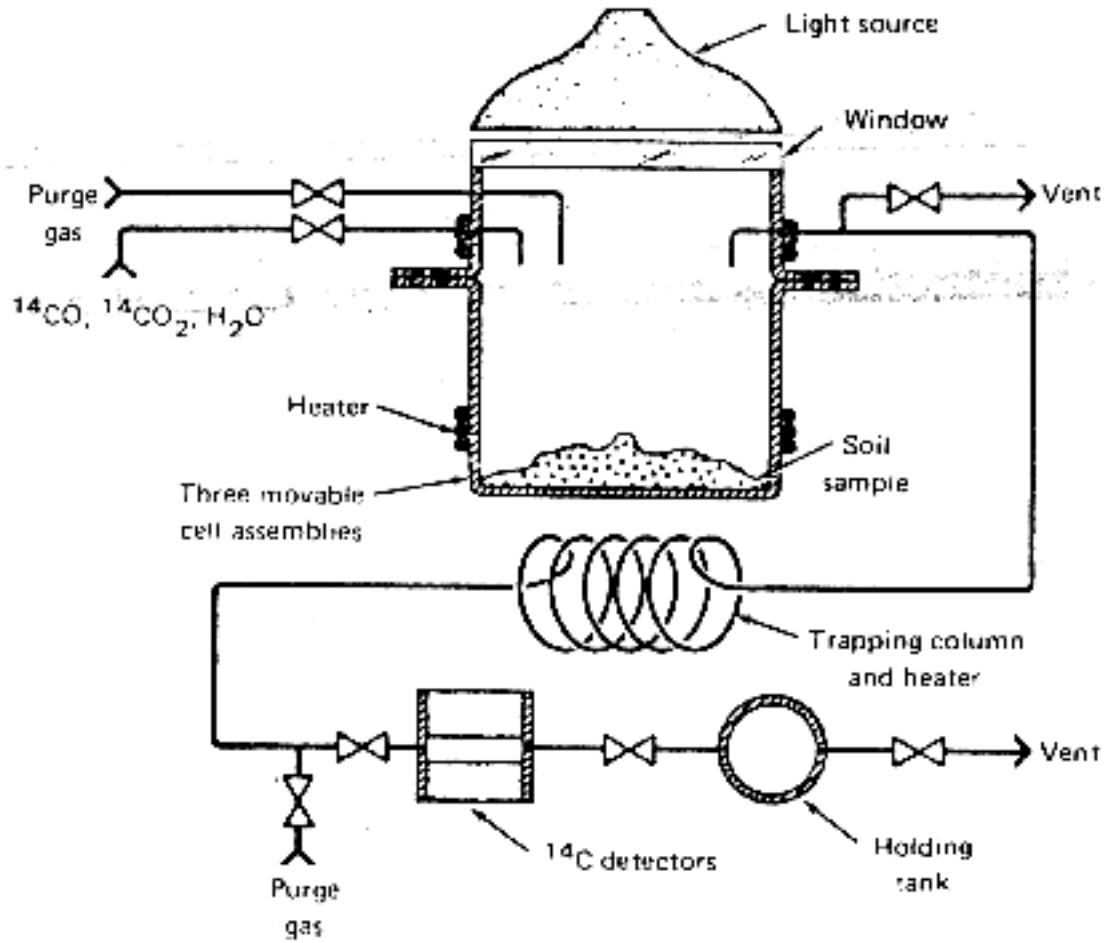
a kind of molecule that produced oxygen when water was put in contact with the soil or that produced carbon dioxide when water containing organic compounds was put in contact with the soil**.**

Neither experiment required biological activity to generate the measured signals.

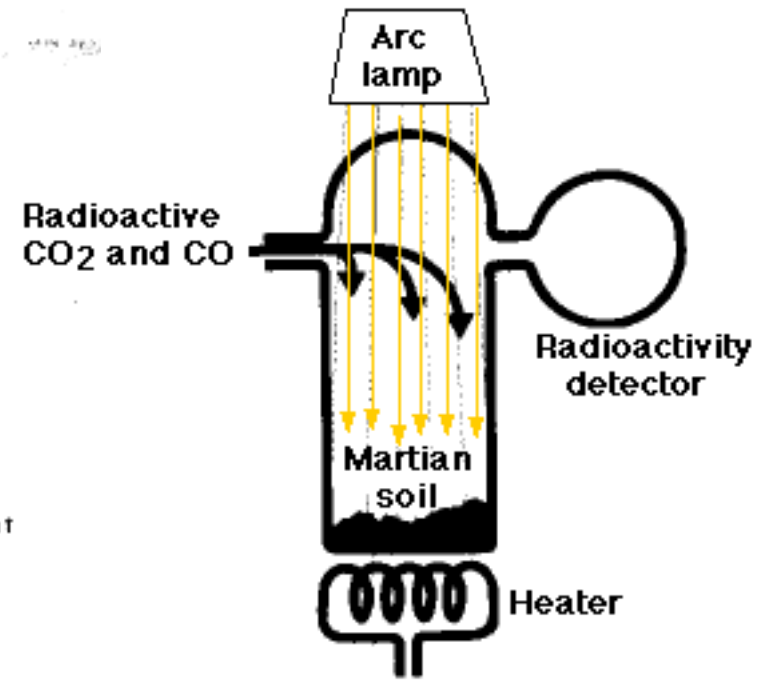
New York Times headline on August 21, page 18

"Experiment Fails to Rule out Possible Biological Processes on Mars"

3. Pyrolytic-Release Experiment (Norman Horowitz) (1915-2005)



The pyrolytic release experiment put radioactively tagged ^{14}CO and $^{14}CO_2$ gases with a sample in artificial sunlight, let it incubate for several days, and then heated it to see if tagged carbon had been incorporated by the sample. It was, and markedly more than in a "sterilized" control sample.



The Pyrolytic Release (PR) experiment

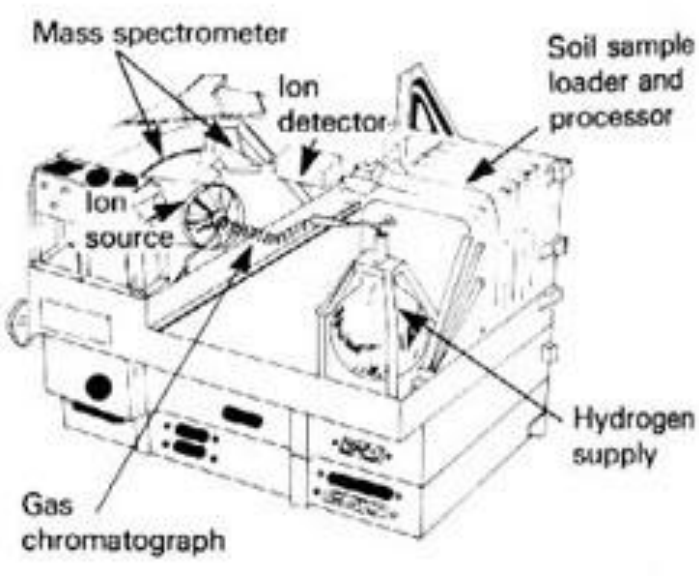
Pyrolytic-Release Experiment (Norman Horowitz)

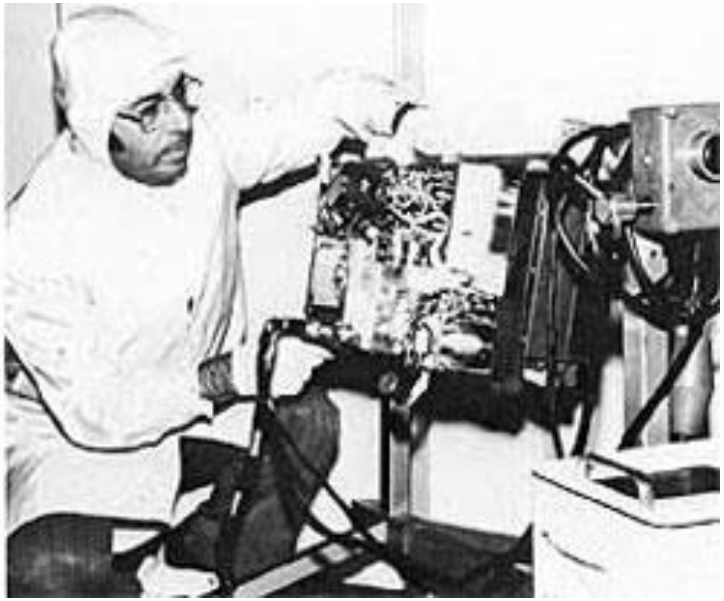
Again - Robotic arm reached out from the lander and scraped a small amount of dirt off the surface of Mars, which it then dropped into a chamber inside the lander.

No water: just like Mars (supposedly)

-- inject martian air into apparatus; add radioactive CO and CO_2
-- look for update of CO_2 into soil
-- heat soil to force gas out of soil to measure uptake
-- soil heated to 1,175 ˚F
-- some CO_2 detected,
-- but also could not be destroyed at high temperatures, **so the process that is producing this signal could not be biological**
-- answer: detected molecules produced by chemical reactions with iron-rich minerals that are naturally abundant in the Martian soil.

4. Gas Chromatograph with a Mass Spectrometer (GCMS) Experiment (Klaus Biemann)





Gas Chromatograph with a Mass Spectrometer (GCMS) Experiment (Klaus Biemann)

Again - Robotic arm reached out from the lander and scraped a small amount of dirt off the surface of Mars, which it then dropped into a chamber inside the lander.

- Heat Martian soil to 50˚C, then to 200˚C, 350˚C, and 500˚C
- Slowly vaporize carbon-containing ('organic') compounds

Search for Organic and Volatile Inorganic Compounds in Two Surface Samples from the Chryse Planitia Region of Mars

Abstract. *Two surface samples collected from the Chryse Planitia region of Mars were heated to temperatures up to 500°C, and the volatiles that they evolved were analyzed with a gas chromatograph–mass spectrometer. Only water and carbon dioxide were detected. This implies that organic compounds have not accumulated to the extent that individual components could be detected at levels of a few parts in 10^9 by weight in our samples. Proposed mechanisms for the accumulation and destruction of organic compounds are discussed in the light of this limit.*

Science, New Series, Vol. 194, No. 4260 (Oct. 1, 1976)

IF THE GCMS EXPERIMENT HAD BEEN DONE FIRST ON A PREVIOUS MISSION TO MARS, THE OTHER THREE BIOLOGY EXPERIMENTS NEVER WOULD HAVE BEEN DONE

1992: post-mortem on Viking Experiments by Klein, Horowitz, and Biemann

"The absence of organic compounds at these two very distant (from each other) sites demonstrated that there is presently neither biological nor abiological synthesis of organic compounds occurring . . . What became clear even during the Viking mission was that if the GCMS results were correct (and there was reason to believe that this was the case) **the three biological experiments had essentially lost their original purpose**. **With no detectable trace of organic matter in the surface material, there was no possibility of finding extant life at the two landing sites**."

"The Viking findings established that there is no life at the two landing sites, Chryse and Utopia. Although the two sites are 25˚ apart in latitude and on opposite sides of the planet, they were found to be very similar in their surface chemistry. This similarity reflects the influence of global forces such as extreme dryness, low atmospheric pressure, short-wavelength ultraviolet flux, and planet-wide dust storms in shaping the Martian environment. **These same forces virtually guarantee that the Martian surface is lifeless everywhere**."

Not convinced: Gil Levin

1979, in *Science*: “despite all hypotheses to the contrary, the distinct possibility remains that biological activity has been observed on Mars.”

1989: A decade has passed since the first labeled-release (LR) Viking biology experiment produced an astonishing positive response on Mars. But that response was deemed unconvincing when no organic compounds was [sic] found. As a result, many attempts have been made to explain the LR data without invoking life. The dominant theory expounded hydrogen peroxide as a chemical agent, suggesting that it reacted with one of the nutrient compounds to mimic a biological response. This theory was tested and essentially disproved on Mars. There is in fact no evidence that it exists on Mars, and even if it formed it would be destroyed by the environment long before it could affect an experiment. **We have carefully tested all of the nonbiology theories and have found none to be scientifically adequate. We also verified that the GCMS organic detection sensitivity may have missed very low densities of organic matter**. It is now our contention that the survival of the LR data, together with other information not previously considered (including Viking Lander image and spectral data that suggest the possible existence of Martian lichen), justifies the conclusion that it **is now more probable than not that the LR experiment did in fact detect life on Mars.**

But maybe …

Viking I and II detected chloromethane and dichloromethane on Mars –
organic molecules!
interpretation: terrestrial contamination:
--- but maybe the interpretation is wrong

Chris McKay (NASA Ames Research Center): “There’s a possibility that some of those organic molecules are in fact biomarkers.”

Reanalysis of the Viking results suggests perchlorate and organics at midlatitudes on Mars

Rafael Navarro-González,[1] Edgar Vargas,[1] José de la Rosa,[1] Alejandro C. Raga,[1] and Christopher P. McKay[2]

Received 17 March 2010; revised 8 August 2010; accepted 19 August 2010; published 15 December 2010.

June 7, 2018: NASA Finds Ancient Organic Material, Mysterious Methane on Mars

To identify organic material in the Martian soil, Curiosity drilled into sedimentary rocks known as mudstone from four areas in Gale Crater. This mudstone gradually formed billions of years ago from silt that accumulated at the bottom of the ancient lake. The rock samples were analyzed by SAM, which uses an oven to heat the samples (in excess of 900 degrees Fahrenheit, or 500 degrees Celsius) to release organic molecules from the powdered rock.

SAM measured small organic molecules that came off the mudstone sample – fragments of larger organic molecules that don't vaporize easily. Some of these fragments contain sulfur, which could have helped preserve them in the same way sulfur is used to make car tires more durable. [Who knew that?]

The results also indicate **organic carbon concentrations on the order of 10 parts per million or more. This is close to the amount observed in Martian meteorites and about 100 times greater than prior detections of organic carbon on Mars' surface. Some of the molecules identified include thiophenes, benzene, toluene, and small carbon chains, such as propane or butene.**

In 2013, SAM detected some organic molecules containing chlorine in rocks at the deepest point in the crater. This new discovery builds on the inventory of molecules detected in the ancient lake sediments on Mars and helps explains why they were preserved.

Dec 27, 1984: Roberta Score and ANSMET team find ALH 84001

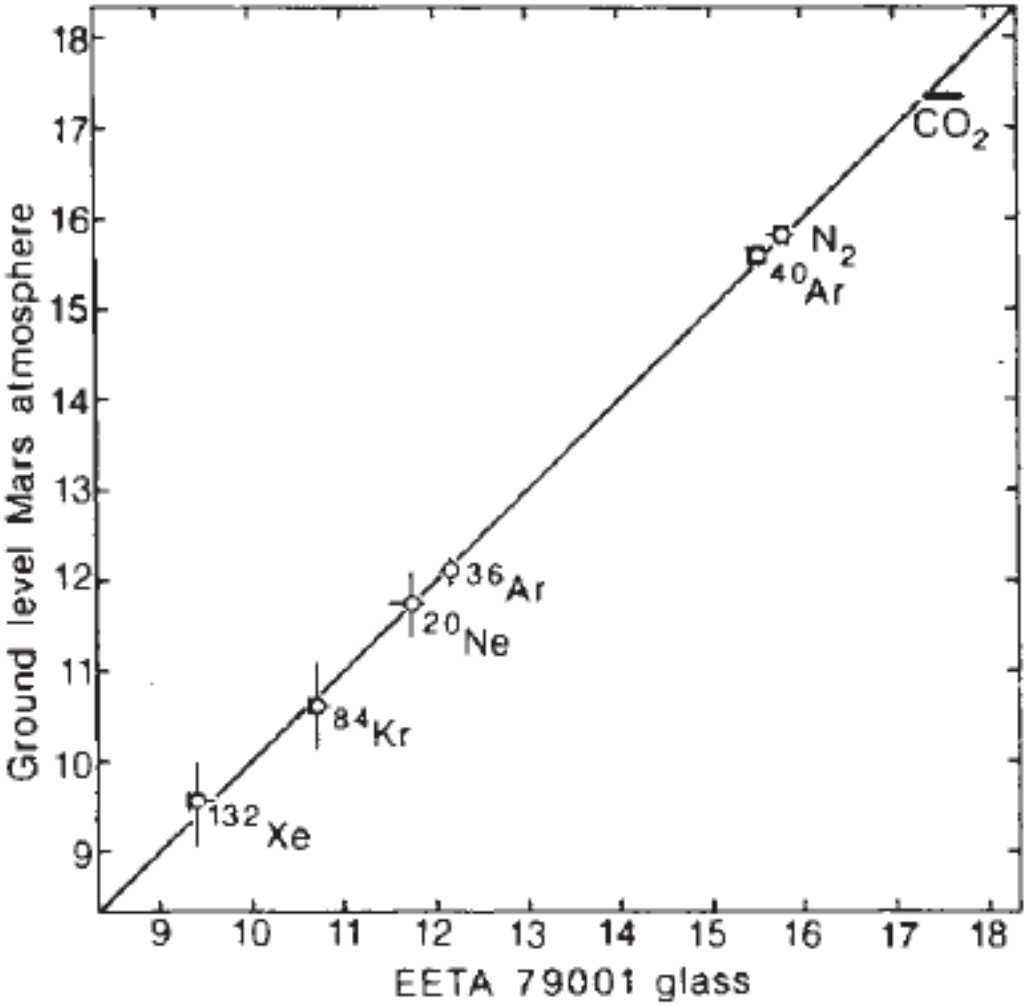
Glenn MacPerson, Smithsonian Museum of Natural History:
classifies it as an **igneous rock, almost certainly from Vesta**

1979: EETA 79001: found in Elephant Moraine region of Antarctica

Jan 18, 1982: ALH 81005 discovered --- soon proven to be first known meteorite from Moon

EETA 79001; Weight: 17.4 pounds

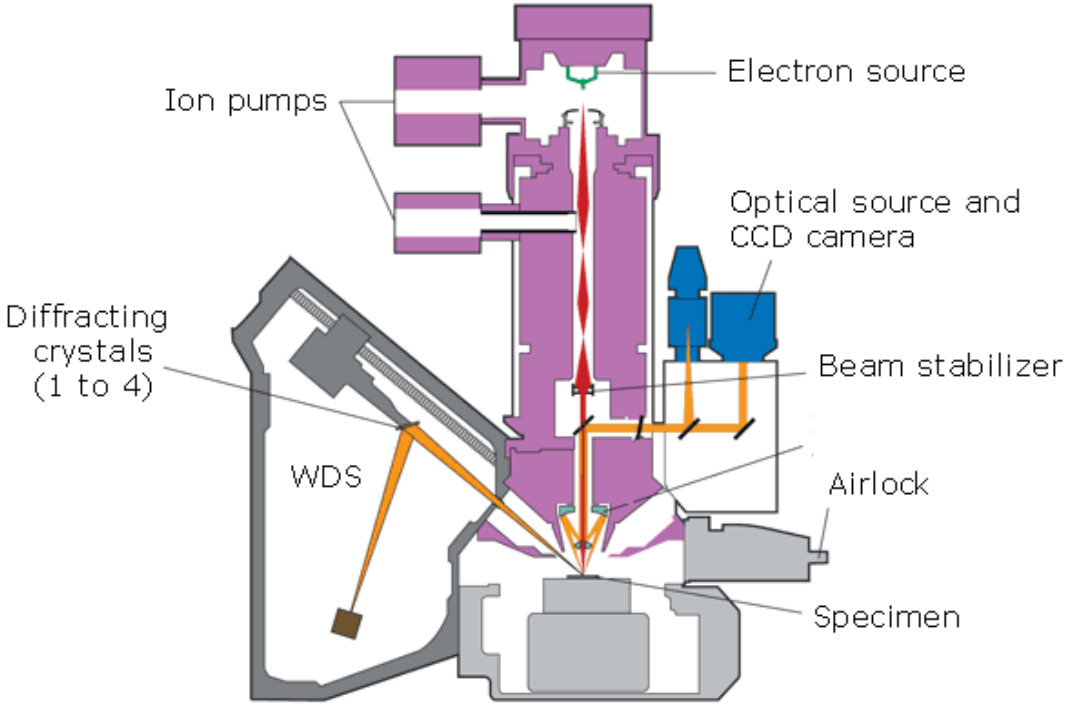
ALH 81005 ; Weight: 1.1 ounces



Comparison of the relative abundances of various gases trapped in EETA 79001 glass with samples of the martian atmosphere taken by the Viking spacecraft. The number of particles per cubic centimetre is shown on a log – log plot.

1985: Robert Pepin shows that EETA 79001 has air trapped inside in bubbles, that contents of air bubbles (amounts of xenon, krypton, argon, neon, N_2, CO_2) are a perfect match to the atmosphere of Mars.

EETA 79001 is from Mars!



David Mittlefehldt

geochemist from Lockheed Engineering

working for NASA in Houston

Used electron microprobe to study reflected X-rays from ALH 84001

should look like all other known meteorites from Vesta (only known source of igneous meteorites). Didn't.

What other solar system body could yield igneous rocks?

X-ray 'fingerprints' of ALH84001 did match those of known martian meteorites (SNCs).

ALH 84001 is from Mars!

Other martian meteorites = SNCs

All SNCs are 'young': 1.3 billion years old and formed from lava on surface of Mars (rocks formed at low pressure).

ALH 84001 formed *inside* Mars 4.091 billion years ago.

RESEARCH ARTICLE

Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001

David S. McKay, Everett K. Gibson Jr.,
Kathie L. Thomas-Keprta, Hojatollah Vali,
Christopher S. Romanek, Simon J. Clemett,
Xavier D. F. Chillier, Claude R. Maechling, Richard N. Zare

SCIENCE • VOL. 273 • 16 AUGUST 1996

August 7, 1996

NASA/*Science*/White House joint press conference

Claim: they had discovered evidence inside ALH 84001 of fossils that strongly suggested that life had existed on Mars in the ancient past.

In examining the martian meteorite ALH84001 we have found that the following evidence is compatible with the existence of past life on Mars: (i) an igneous Mars rock (of unknown geologic context) that was penetrated by a fluid along fractures and pore spaces, which then became the sites of secondary mineral formation and possible biogenic activity; (ii) a formation age for the carbonate globules younger than the age of the igneous rock; (iii) SEM and TEM images of carbonate globules and features resembling terrestrial microorganisms, terrestrial biogenic carbonate structures, or microfossils; (iv) magnetite and iron sulfide particles that could have resulted from oxidation and reduction reactions known to be important in terrestrial microbial systems; and (v) the presence of PAHs associated with surfaces rich in carbonate globules. None of these observations is in itself conclusive for the existence of past life. Although there are alternative explanations for each of these phenomena taken individually, when they are considered collectively, particularly in view of their spatial association, we conclude that they are evidence for primitive life on early Mars.

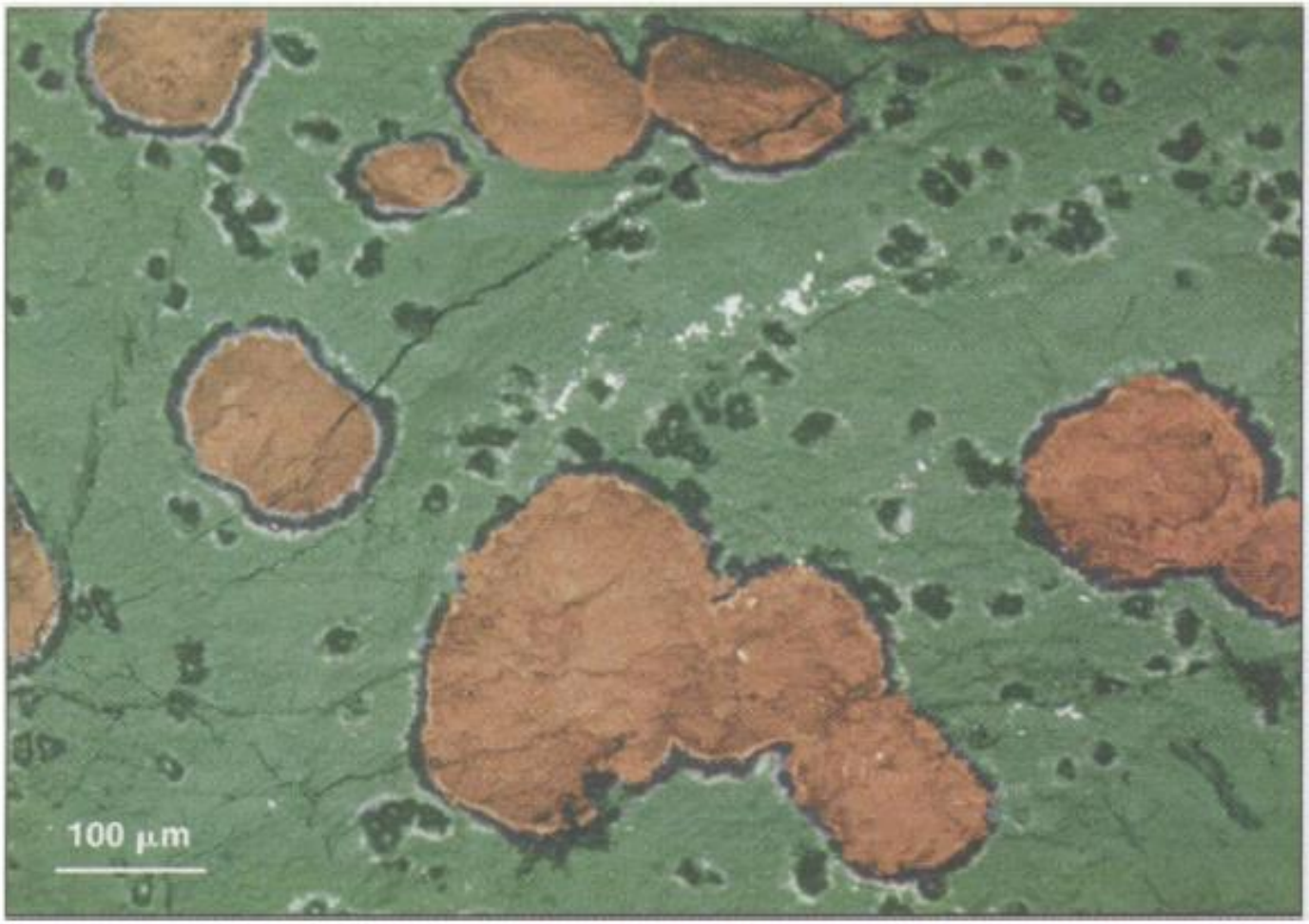
“It is well worth contemplating how we reached this moment of discovery. More than 4 billion years ago this piece of rock was formed as a part of the original crust of Mars. After billions of years it broke from the surface and began a 16-million- year journey through space that would end here on Earth. It arrived in a meteor shower 13,000 years ago. And in 1984 an American scientist on an annual U.S. government mission to search for meteors on Antarctica picked it up and took it to be studied. Appropriately, it was the first rock to be picked up that year—rock ALH 84001. Today, ALH 84001 speaks to us across all those billions of years and millions of miles. It speaks of the possibility of life. If this discovery is confirmed, it will surely be one of the most stunning insights into our universe that science has ever uncovered. Its implications are as far-reaching and awe-inspiring as can be imagined.”

Four lines of evidence:

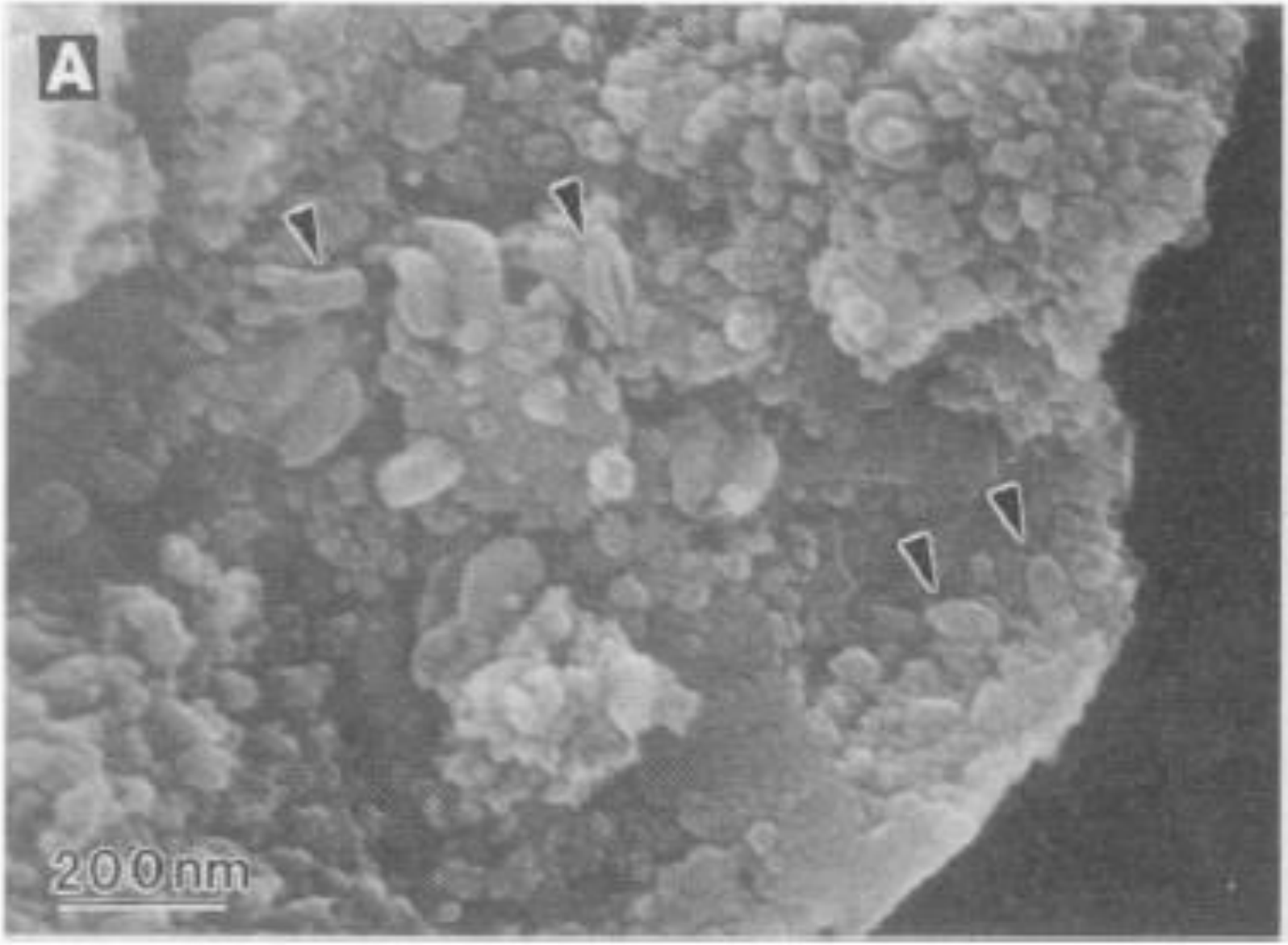
1. Carbonate globules
2. Minerals associated with carbonate globules
3. Elongated, tubelike structures that look like fossil bacteria
4. PAHs (polycyclic aromatic hydrocarbons)

Carbonate globules (orange blobs)

Fig. 2. False-color backscatter electron (BSE) image of fractured surface of a chip from ALH84001 meteorite showing distribution of the carbonate globules. Orthopyroxene is green and the carbonate globules are orange. Surrounding the Mg-carbonate are a black rim (magnesite) and a white, Fe-rich rim. Scale bar is 0.1 mm. [False color produced by C. Schwandt]

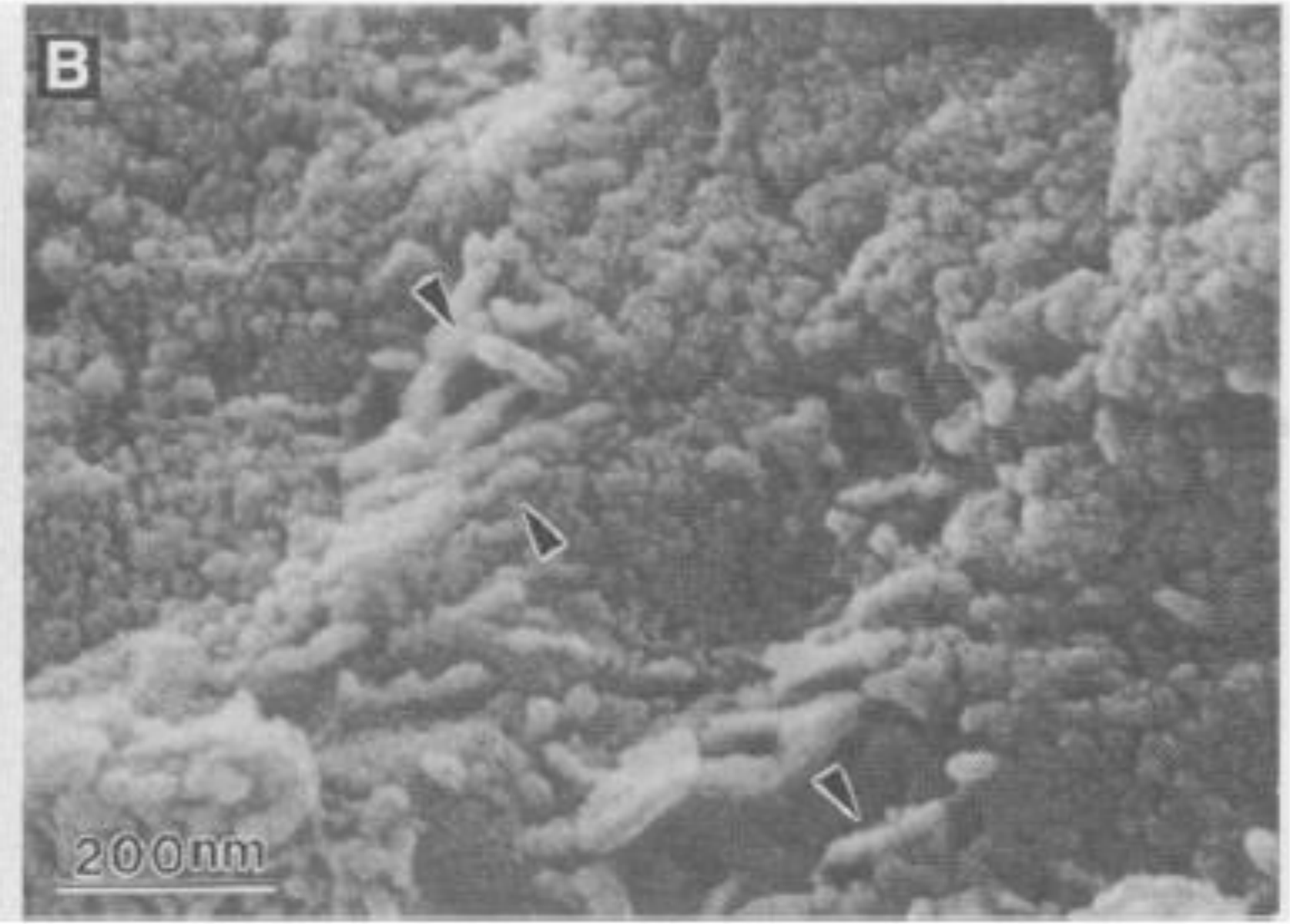


Associated minerals (e.g., magnetite)

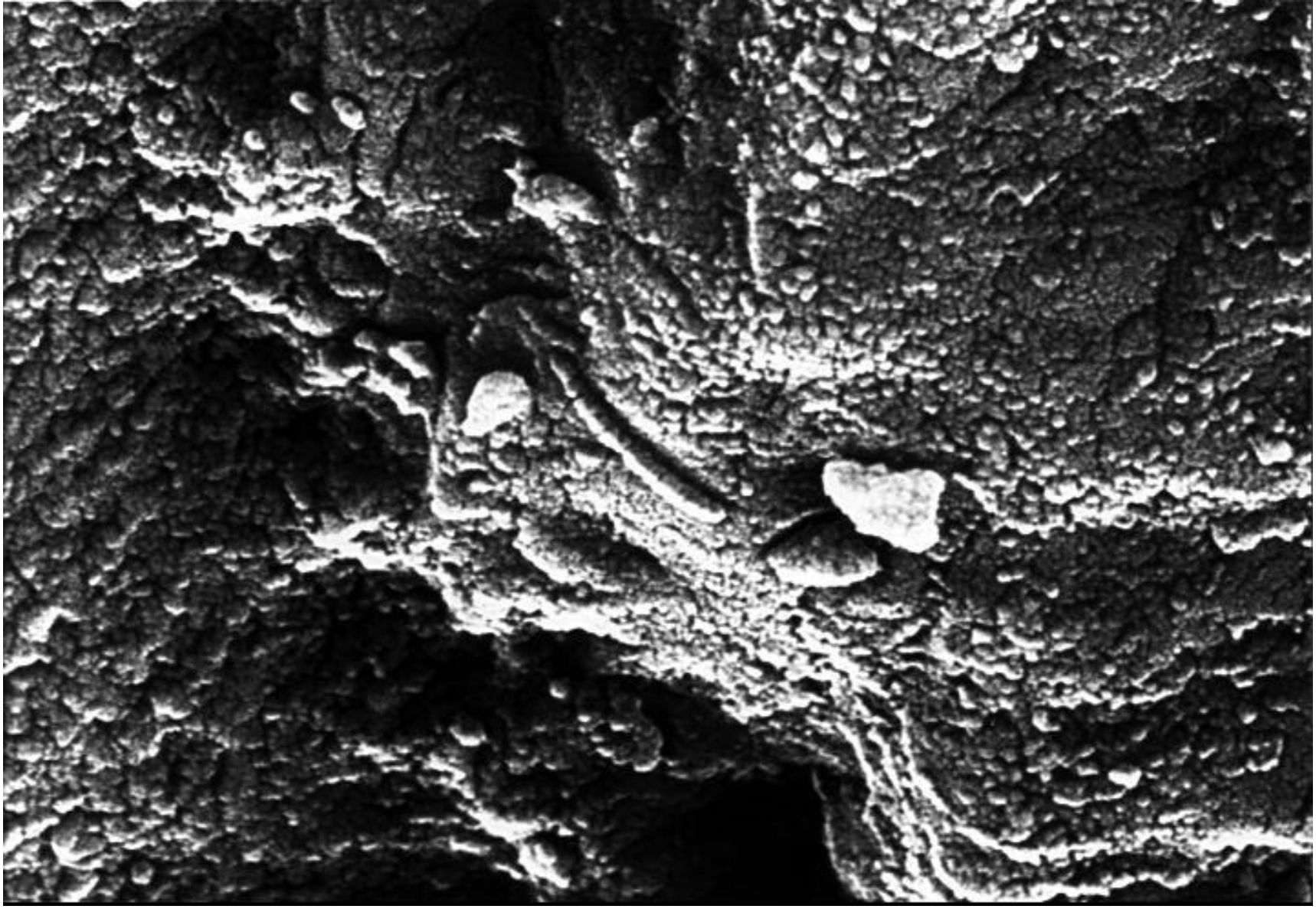


Surface of iron-rich rim area. Numerous ovoids, about 100 nm in diameter, are present (arrow). Tubular shaped bodies are also apparent (arrows). Smaller grains may be magnetite and pyrrhotite.

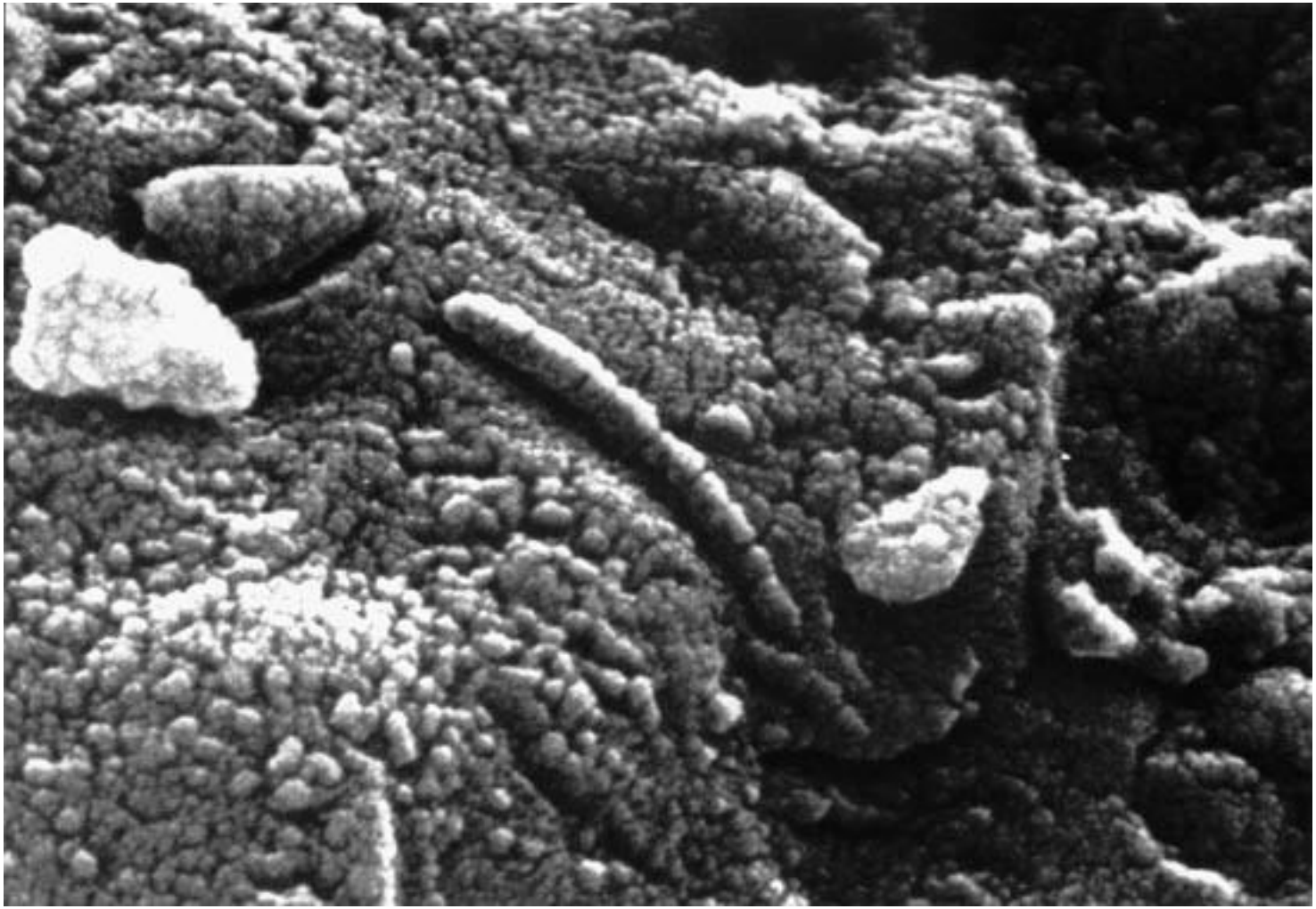
Tubelike structures (fossil bacteria)

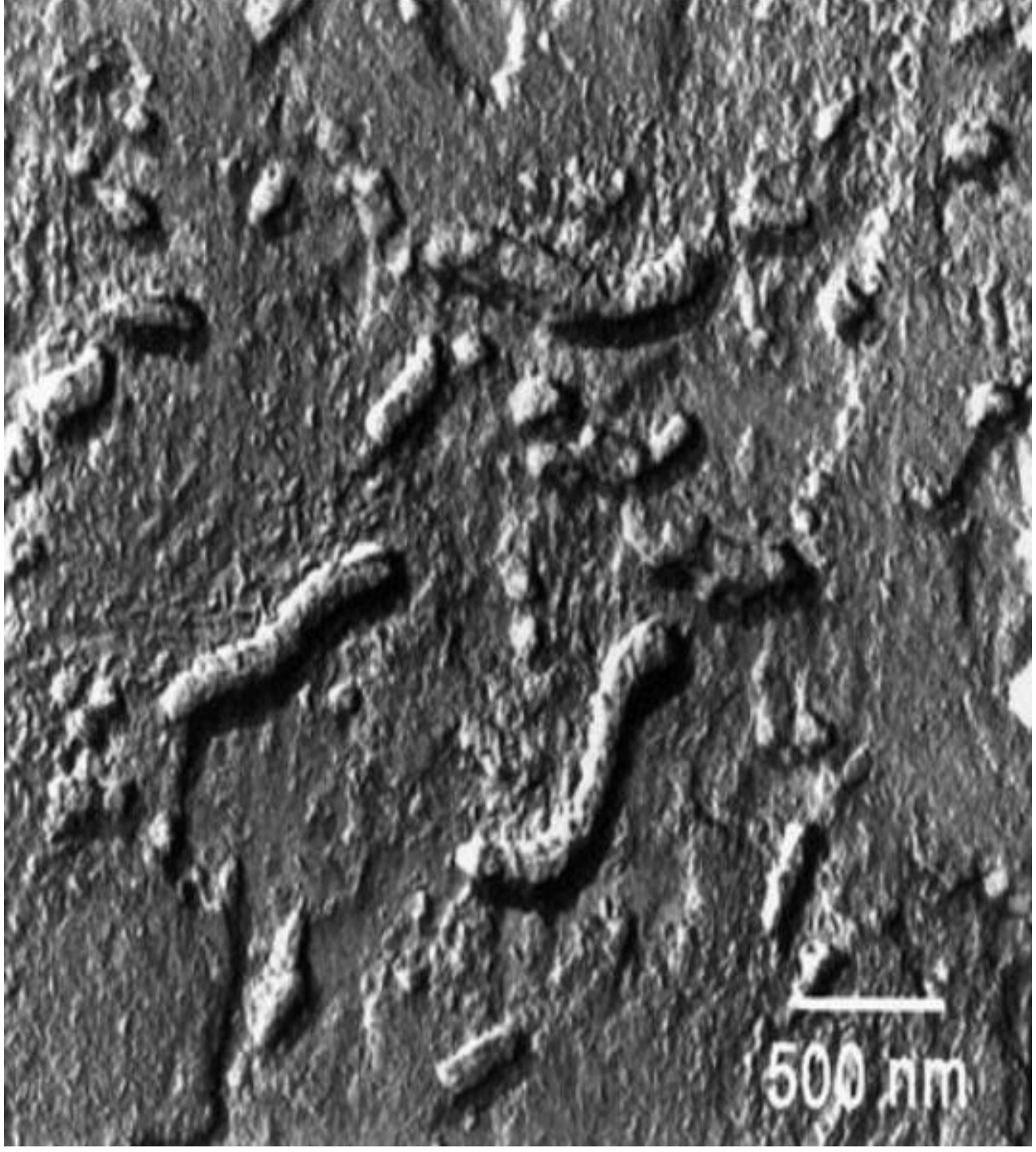


Close view of central region of carbonate showing textured surface and nanometer ovoids and elongated forms (arrows).



At the center of this image is a tube-like structure whose diameter is less than 1/100th that of a human hair and that is located in a carbonate globule inside the meteorite. The scientific team that performed the original investigation of this sample argued that the tube-like structure was a fossil of a bacteria-like life form.




500 nm

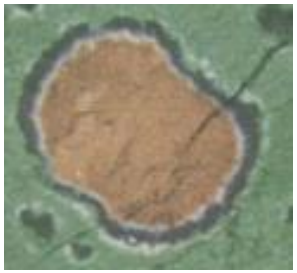
20-40 nm wide, rod-shaped structures composed of carbon-bearing molecules that *resemble* rod-shaped bacteria

Undisputed: tubular, rope-like structures that *look like* certain kinds of terrestrial bacteria

BUT smaller than any known terrestrial bacteria

1998 NAS Panel of experts: “Free-living organisms require a minimum of 250 to 450 proteins along with the genes and ribosomes necessary for their synthesis. A sphere capable of holding this minimal molecular complement would be 250 to 300 nm in diameter, including its bounding membrane.”

VERDICT: almost certainly not bacteria, not fossils of living things



orange-colored, pancake-shaped, carbonate globules; 1% of mass of meteorite

rich in minerals that contain the carbonate ion CO_3^{-2}

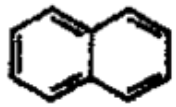
Almost certainly formed in water
(formed when Mars was wet --- 4.1 BY ago!)

In vicinity of mineral grains that looked to be of bacterial origin

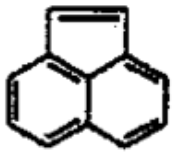
That is, on earth these mineral grains are products of biological activity

Problem: probably formed at high temperatures (T > boiling)

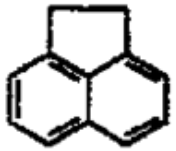
Consensus: formed as “nonbiological precipitation of minerals from supersaturated aqueous solutions”



NAPHTHALENE



ACENAPHTHYLENE



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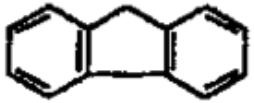
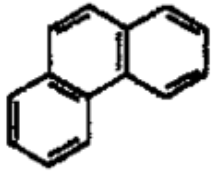


FLUORENE



PHENANTHRENE

PAHs: ring-shaped molecules that contain both hydrogen and carbon atoms

Zare: [It] “very much resembles what you’d expect when you have simple organic matter decay.”

Claim: formed by ‘diagenesis of microorganisms’ [process by which living matter decays into sediment]

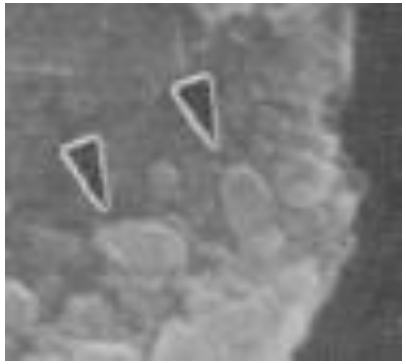
PAHs found everywhere:

- form from the incomplete combustion of organic matter (e.g., cooking meat or burning tobacco, coal, or oil) or from the slow but natural decomposition of dead organisms.
- Formed in non-biological industrial processes
- Found everywhere in the universe (interstellar clouds, red giant stars, planetary nebulae), in meteorites, on surfaces of asteroids, in atmosphere of Titan
- Hard NOT to find them!

CONSENSUS: PAHs real, but almost certainly contamination and not biological in origin

Magnetite Crystals: On Earth, some bacteria build within themselves chains of magnetic crystals that they then use to orient themselves with respect to Earth's magnetic field

magnetic crystals in ALH 84001 were similar to those found in magnetotactic bacteria on Earth



Are crystals similar in their sizes and shapes and crystallography to those found for magnetic crystals in magnetotactic bacteria on Earth?

- McKay et al.: YES

Others: NO. considerable structural, morphological, and crystallographic variability in the magnetite crystals are found in various species of magnetotactic bacteria, suggesting that it is difficult to confirm a biological origin for magnetite particles simply by comparing them with the magnetite crystals observed in terrestrial bacteria

CONSENSUS: the verdict on the presence of biological life on Mars cannot be reached on the basis of this thin line of evidence alone

The Jury is still out