Life Detection: 40 years after Viking

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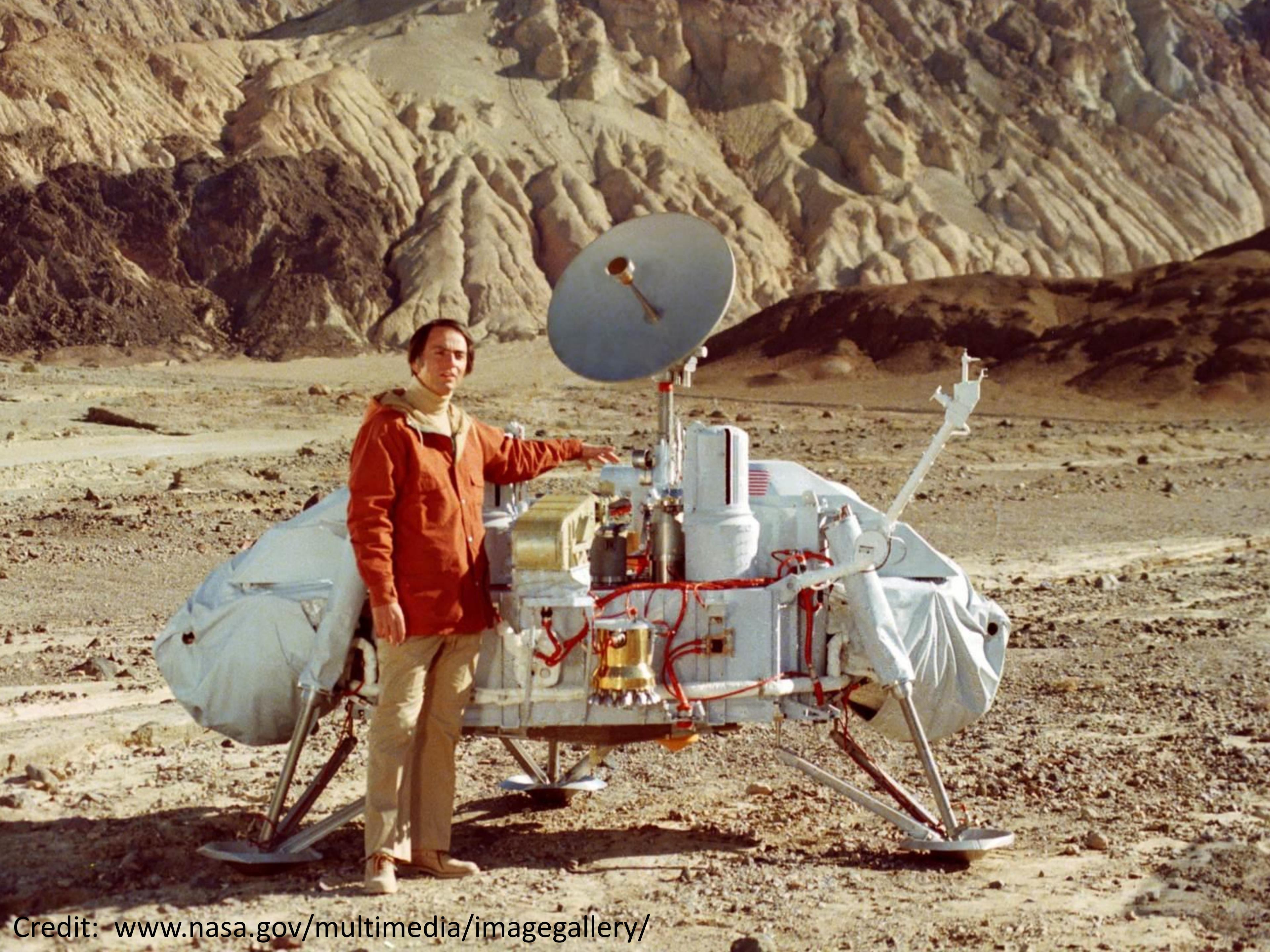
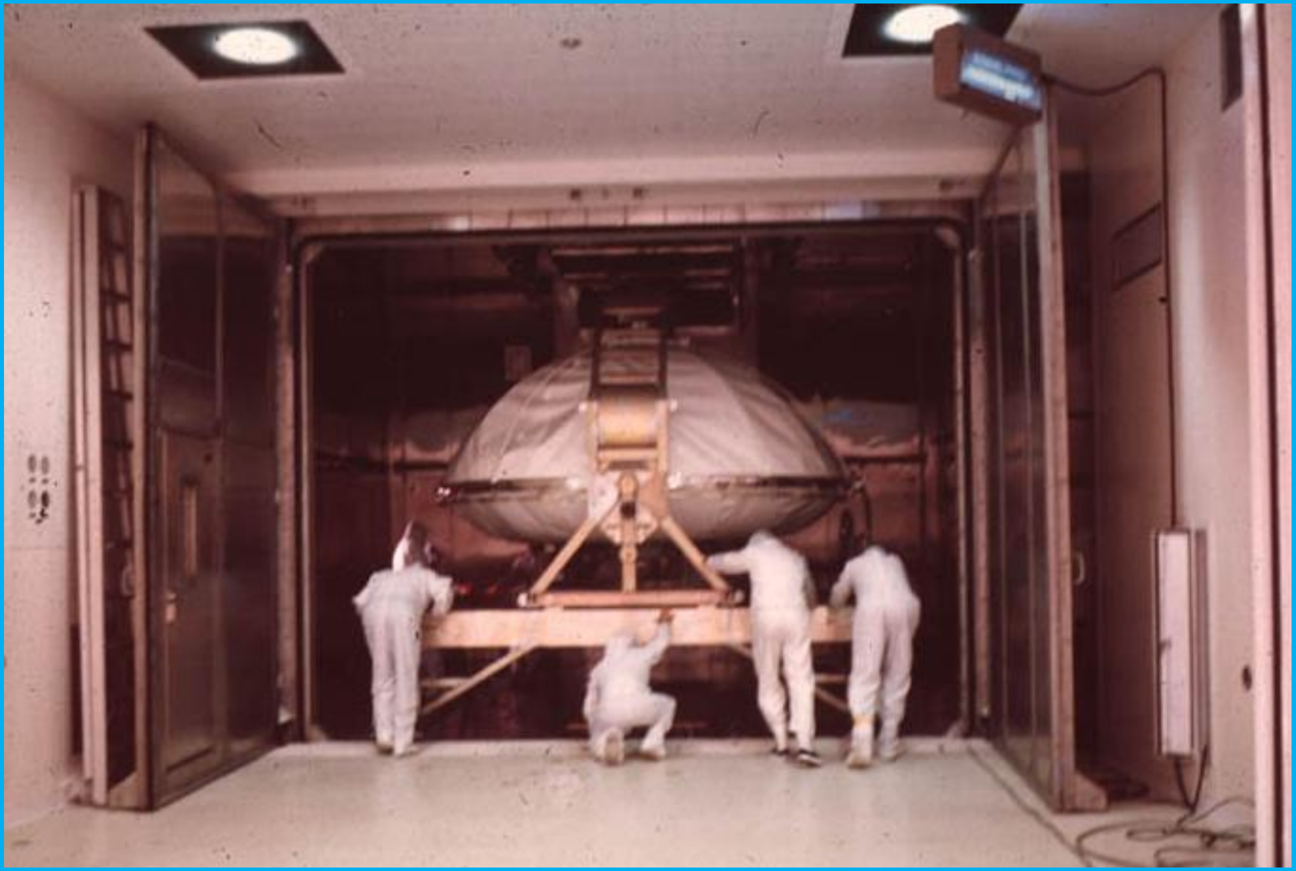
National Academy of Sciences Space Studies Board (NAS / SSB)
Workshop on “Life Across Space & Time”
(Beckman Center; 12-6-2016)



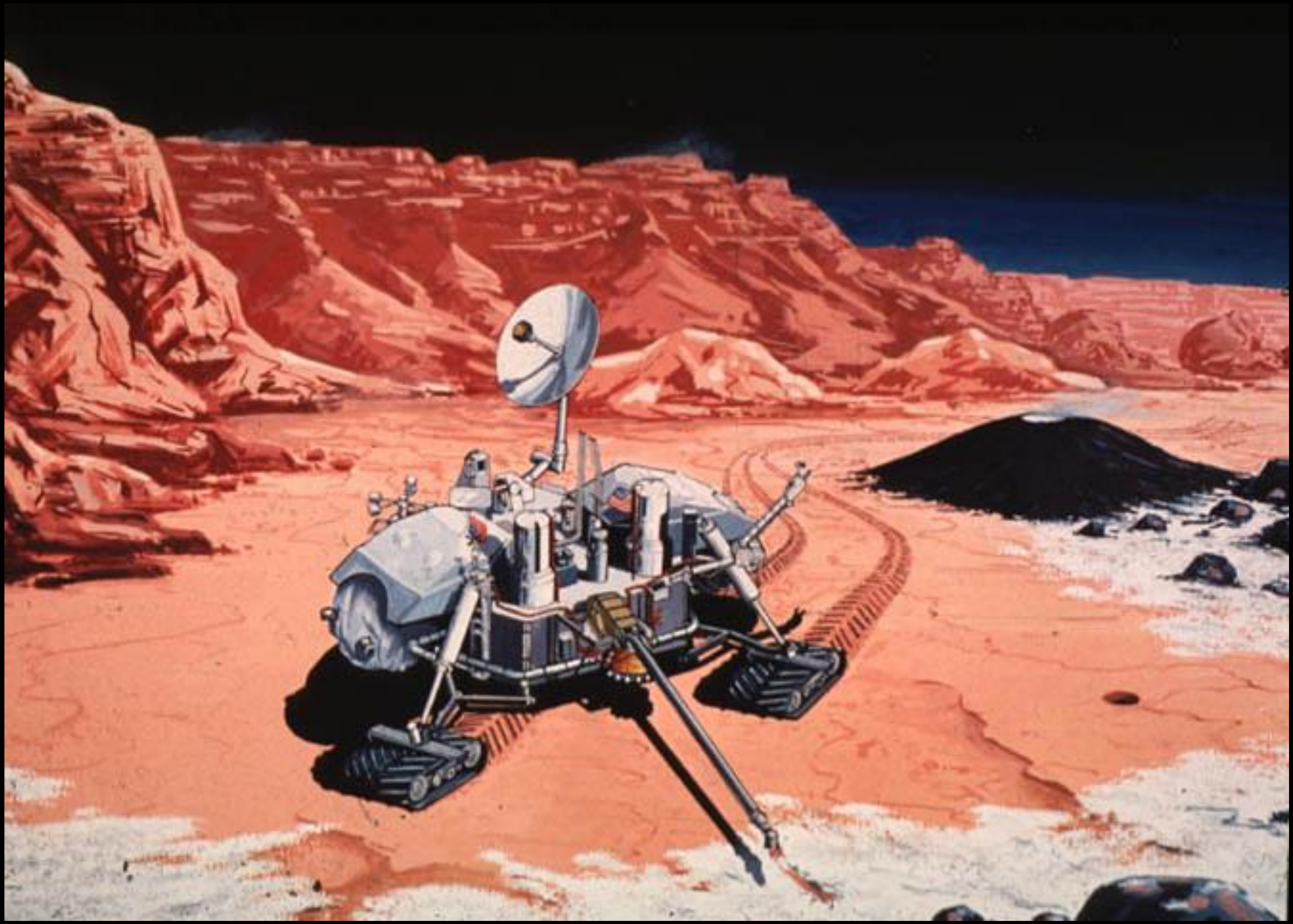
Credit: www.nasa.gov/multimedia/imagegallery/

Viking going into the Sterilization Oven at KSC (PHFS)

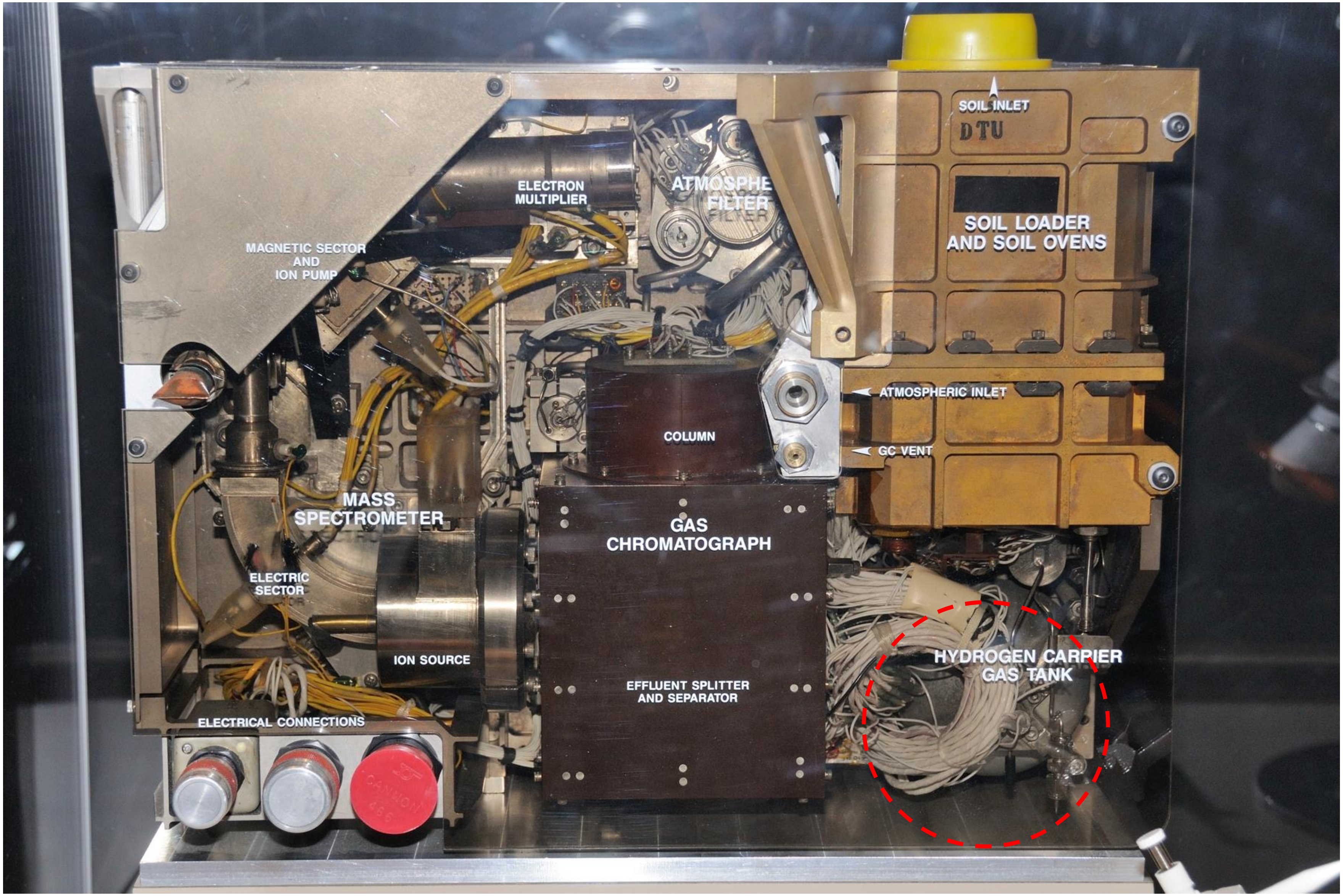


Credit: NASA

Viking Follow-on Rover (1979, ’81, ‘83)



GCMS Instrument



Credit: NASA

Biology experiments were elegantly simple.

Each could be conducted on one lab-bench.

But deceptively difficult to implement for flight.

NASA SP-334
(1975)

FIGURE 41.—Pyrolytic release experiment.

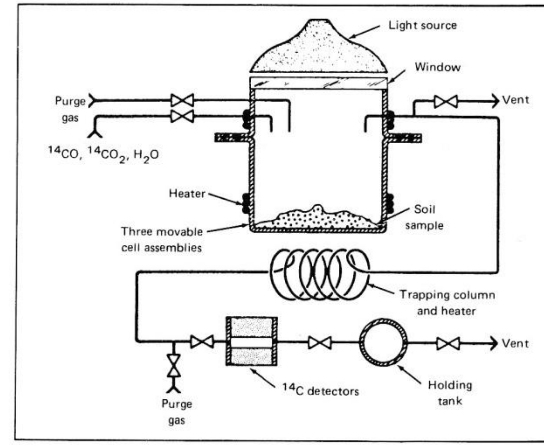


FIGURE 42.—Labeled release experiment.

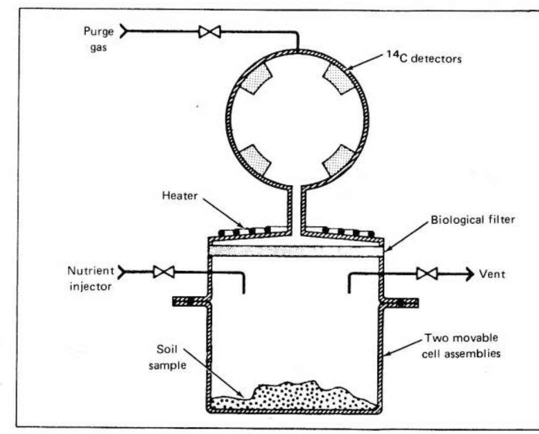
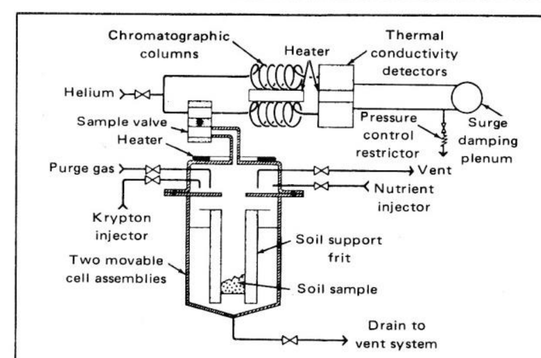
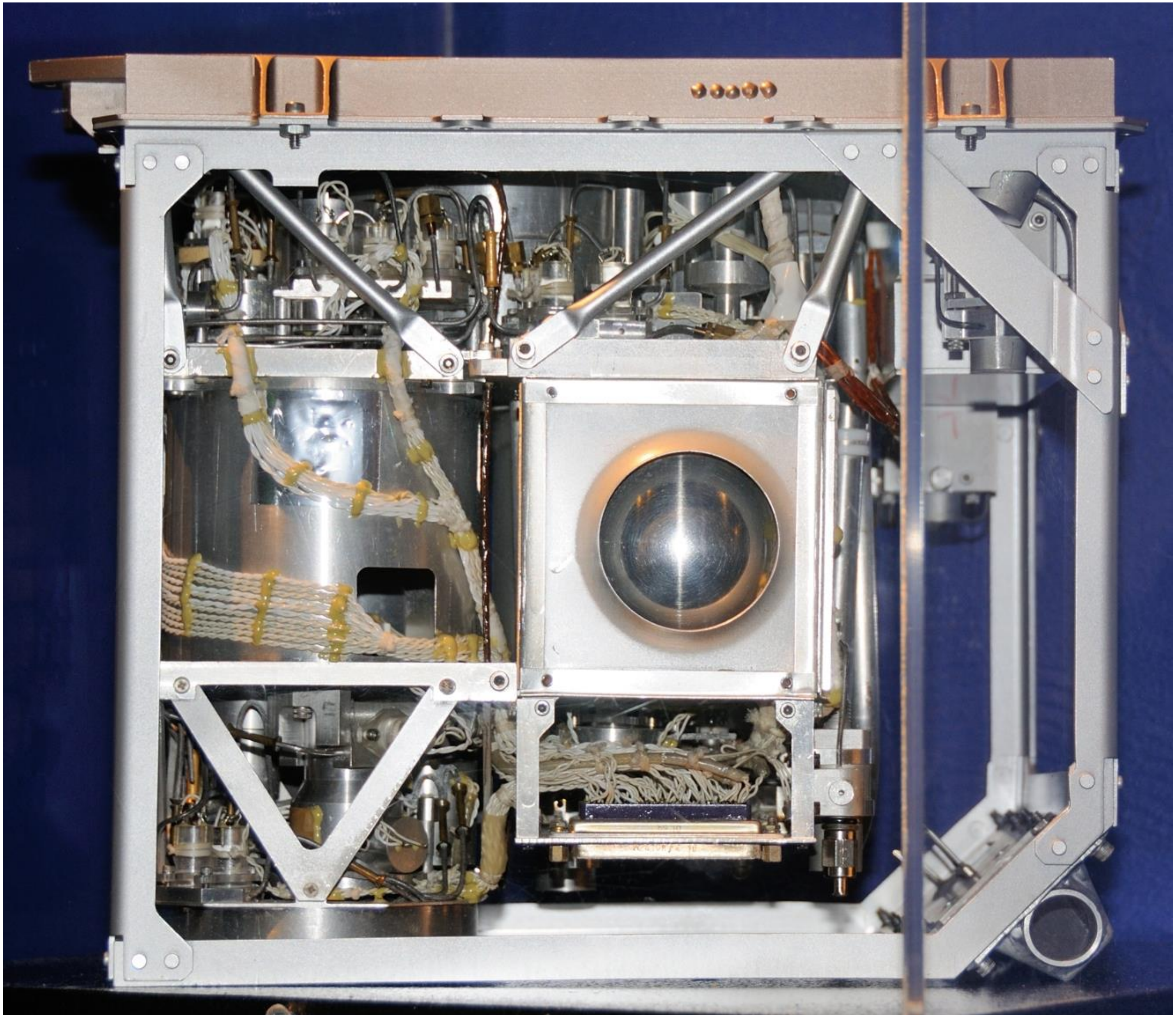


FIGURE 43.—Gas exchange experiment.

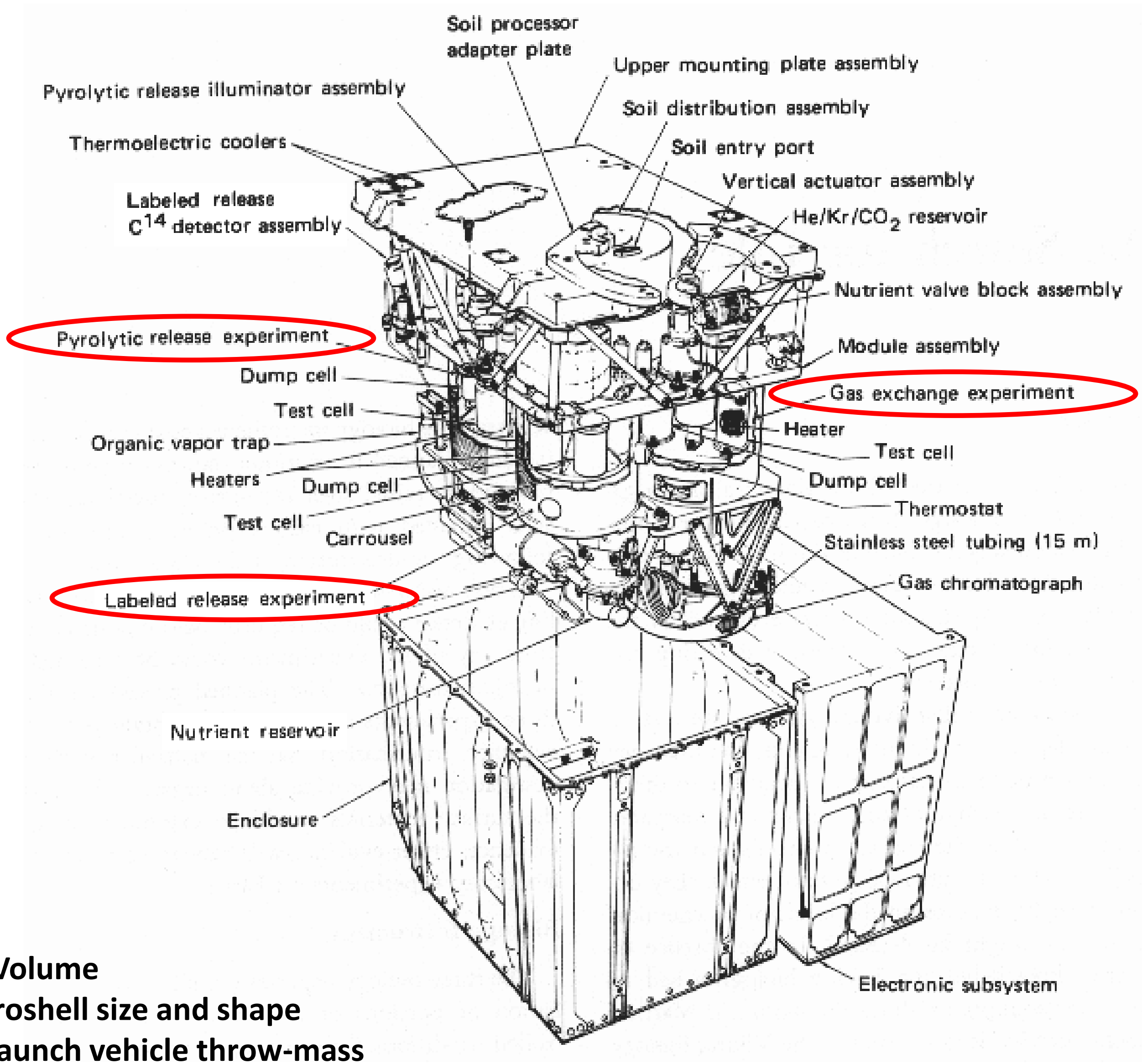


Biology Instrument package



Credit: NASA

The Viking Biology Experiment



Less than 1 ft^3

Limited by Lander Volume

. . . Limited by aeroshell size and shape

. . . Limited by Launch vehicle throw-mass

. . . Limited by non-availability of Saturn V

Credit: NASA

VIKING BIOLOGY EXPERIMENTS

EXPERIMENT	INVESTIGATORS	MONITORS	SUBSTRATES	EXPERIMENTAL OPTIONS
PYROLYTIC RELEASE (PR)	HOROWITZ HUBBARD HOBBY	PHOTOTROPHS (^{14}C INCORPORATION)	$^{14}CO_2$, ^{14}CO (92:8)	DRY OR HUMID; LIGHT OR DARK
LABELED RELEASE (LR)	LEVIN STRAAT	HETEROTROPHS (^{14}C GAS RELEASE)	^{14}C-GLYCINE ^{14}C-DL-LACTATE ^{14}C-DL-ALANINE ^{14}C-FORMATE ^{14}C-GLYCOLATE	MOIST OR WET
GAS EXCHANGE (GEx)	OYAMA	CHANGES IN GAS CONCENTRATION (CO_2, CO, CH_4, O_2, H_2, N_2, N_2O, NO, H_2S	MANY COMPLEX ORGANICS ("CHICKEN SOUP")	DRY, HUMID OR WET

Credit: NASA

Viking Life Detection Results

- GCMS found no organic molecules (<1 ppb)
- PR Experiment was negative for life
  - One anomalous positive.
- GEx Experiment was negative for life
  - But, oxidants in soil, with O_2 released just by humidification
- LR Experiment induced chemical reactions in soils
  - Life? or, Oxidants?

VIKING LIFE DETECTION

INTERPRETATION: Klein, Soffen, Sagan, Young, Lederberg, Ponnamperuma, Kok

EXPERIMENT	INVESTIGATORS	MONITORS	SUBSTRATES	EXPERIMENTAL OPTIONS
PYROLYTIC RELEASE (PR)	HOROWITZ HUBBARD HOBBY HARDY	PHOTOTROPHS (^{14}C INCORPORATION)	$^{14}CO_2$, ^{14}CO (92:8)	DRY OR HUMID; LIGHT OR DARK
LABELED RELEASE (LR)	LEVIN STRAAT	HETEROTROPHS (^{14}C GAS RELEASE)	^{14}C-GLYCINE ^{14}C-DL-LACTATE ^{14}C-DL-ALANINE ^{14}C-FORMATE ^{14}C-GLYCOLATE	MOIST OR WET
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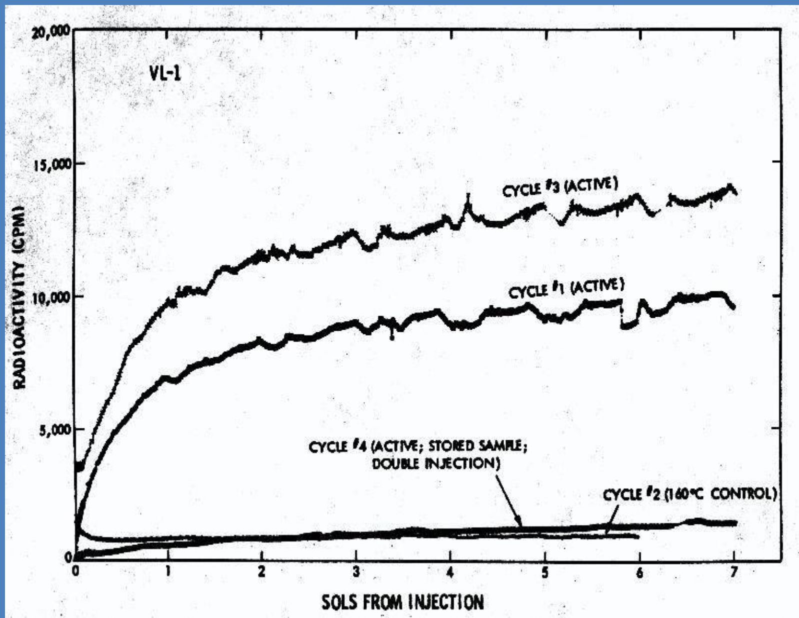
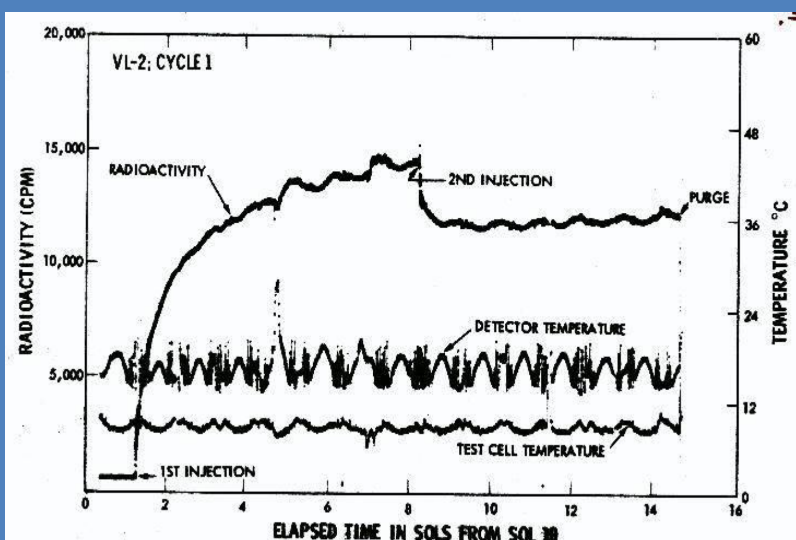
GCMS **BIEMANN**, RUSHNECK, **HUNTEN, ORO**

Labeled Release (LR) Experiment: A Search for Heterotrophs





<u>Experimental Conditions</u>:

1) ^{14}C-labeled compounds: formate, glycolate, glycine, DL-alanine, and DL-lactate.
2) 7 mb Mars atm + He_2 + H_2O = 92 mb with 1st injection.
3) 0.5 g regolith sample; 0.115 ml ^{14}C-labeled nutrient solution per injection. Tests run at ≈ + 10 C.
4) <u>Soil samples</u>: surficial fines, under rocks, long-term on board storage, heat pasteurized (50 C for 3 hrs), and heat-sterilized (160 C for 3hrs).

Response recorded as counts per minute (CPM) of evolved $^{14}CO_2$ gas over many sols.

<u>Conclusions</u>:

1) 1st phase = biology.

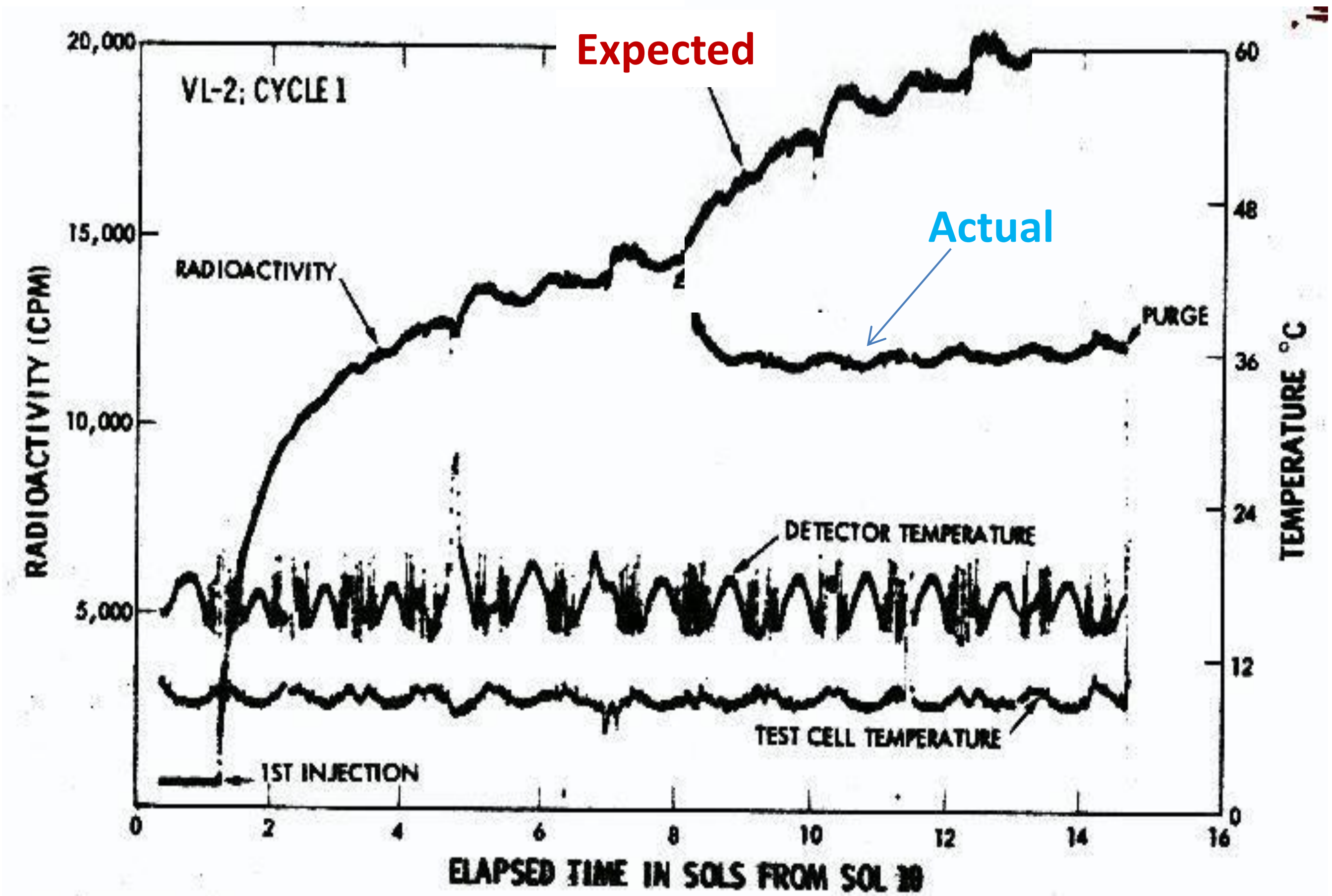
2) 2nd phase = reabsorption of $^{14}CO_2$ by soil chemical equilibria processes.

Levin and Straat, 1976, Science, 194:1322-1329
Levin and Straat, 1977, JGR, 82:4663-4467

Credit: http://www.gillevin.com/

Labeled Release (LR) Experiment: A Search for Heterotrophs

2nd Injection



LR Results – some explanations

- 1st Injection produces strong signal

  Life: just as expected

  Non-life: one or more oxidants in soil (see next slide)

- 2nd Injection

  Life: liquid re-absorbs, or organisms died

  Non-life: oxidant was consumed / destroyed in 1st injection

- Diurnal oscillation of amount of gas in headspace

  Life: circadian rhythm

  Non-life: temperature- dependent uptake in soil (e.g., carbonate)

- Heat sterilization treatments

  Life: aha! Proof positive!

  Non-life: oxidant is heat labile; OR, released H_2O destroys it (Oyama)

H_2O Releases from Martian samples

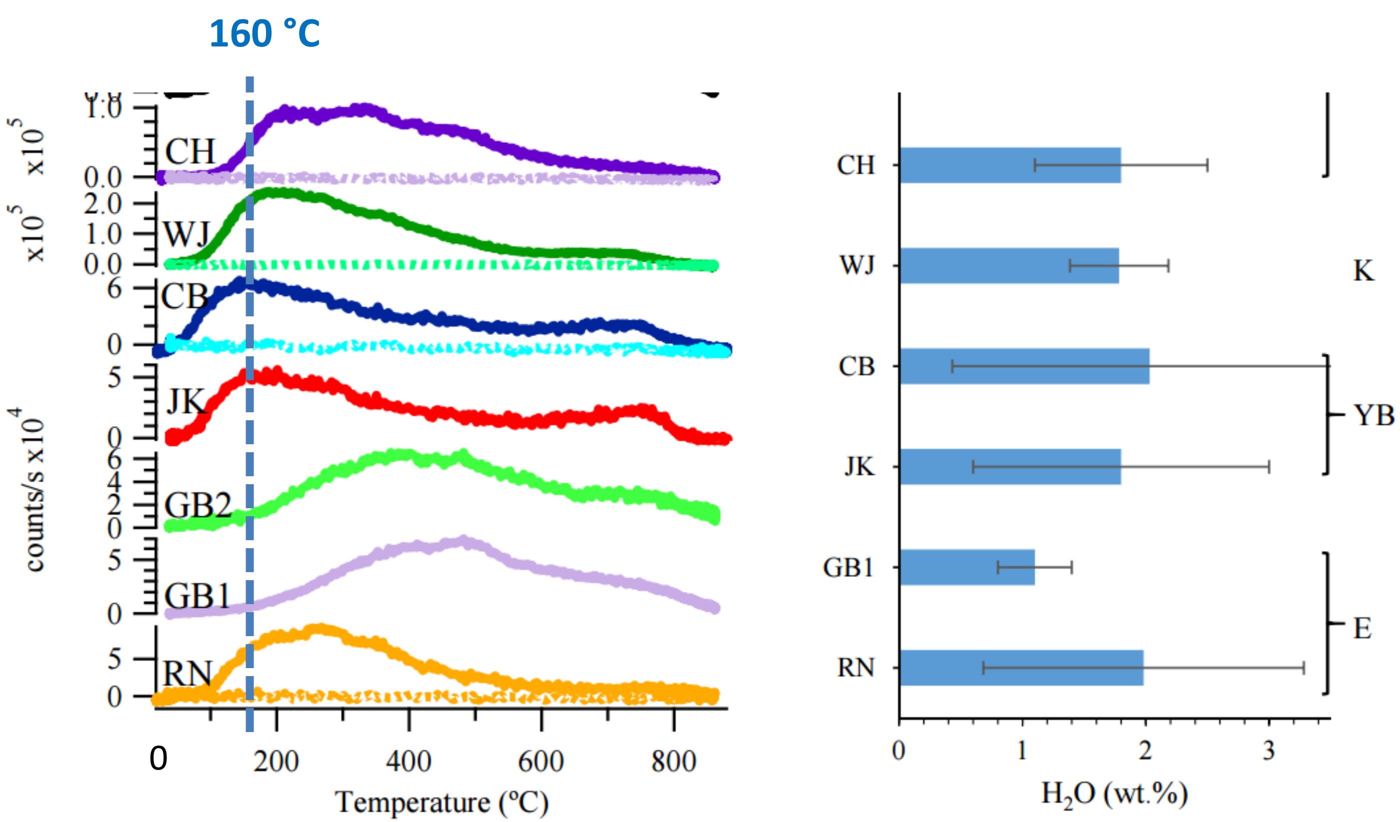


Figure 10. (a) Evolved water (m/z 20) (counts/s) versus temperature as detected by SAM-EGA.

Credit: Sutter, B., et al., submitted for publ., Nov. 2016. (SAM instrument, **Curiosity** MSL Rover)

Viking was a Pioneering Attempt at Detecting Life

A Broad-based Set of Approaches

- First Search for Biomarkers (GCMS)
- First Search for Metabolic Activity*
  - Organic-Based
    - Catabolism (LR, GEx)
    - Anabolism (PR, GEx)
    - Chemoautotrophy(GEx, PR) and Photosynthesis (PR)
  - Inorganic indicators
    - Chemical activity involving gases (GEx)

*Reactivity could even be pre-biotic
(“Metabolism First” origin of life)

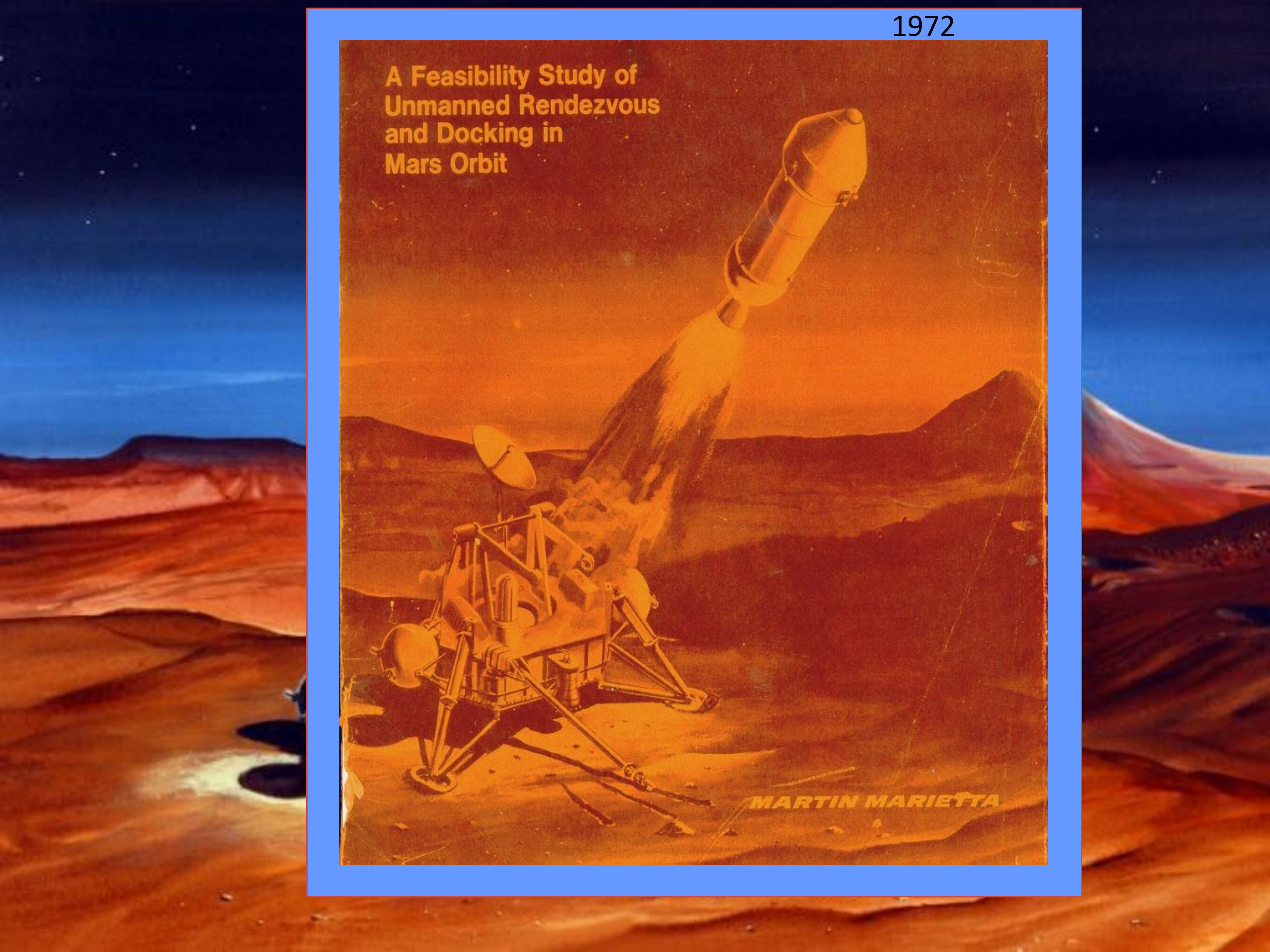
Viking Biology Results and Limitations

- ✓ **No organics detected by GCMS at parts per billion levels of detection**
  but, reactions in pyrolysis ovens. Laser Desorption MS needed.
- ✓ **LR results could be soil chemistry processes, including oxidants (O_3, OH^-, HO_2, H_2O_2, O•, Na_2O_2, UV-NO_x, perchlorates, bromates, peroxonitrites).**

perchlorates + ionizing radiation (GCR/SPE) (Quinn et al., Astrobiol. 13(2013)515)

- **NOT ALL possible metabolites were provided:**
  H_2, H_2S, NO_x, etc. (ABLDI / Kok)
- **Only soils analyzed (under rock, but not inside Badger rock; not in Salt)**
- **GCMS could not detect organics in < 10^3 microbes/cm^3 (equivalent)**

Sample Return is essential to understand inorganic and organic soil chemistry, and continue the search for Life on Mars (cold samples preferred)


1972
A Feasibility Study of
Unmanned Rendezvous
and Docking in
Mars Orbit
MARTIN MARIETTA

A Publication in 2008 stated

"With 30 years' hindsight, . . . The Viking experiments were ill conceived," for 3 reasons:

(i) 99% of organisms cannot be cultured

(ii) Viking experiments were not carried out under martian conditions

(iii) the surface of Mars appears to be inhospitable to life" [the Vikings didn't know the surface environment was harsh]

Lest we Forget . . .

- Dormancy is a common survival strategy of terrestrial life (bacterial endospores, fungal spores, seeds, cysts, nut, lyophilization, cryptobiosis, hibernation)
    - To assess extant vs extinct may require a suitable environment to stimulate activity (germination)

- Abiotic Photochemistry on Mars can provide reactants to drive chemoautotrophy and carbon cycling (without photosynthesis!)

  [Ocean World biospheres do not have this feature]

- Energy Sharing though coupled redox rxns

Orig Life. 1979 Jul/9(3):241-9.
Solar-driven chemical energy source for a Martian biota.

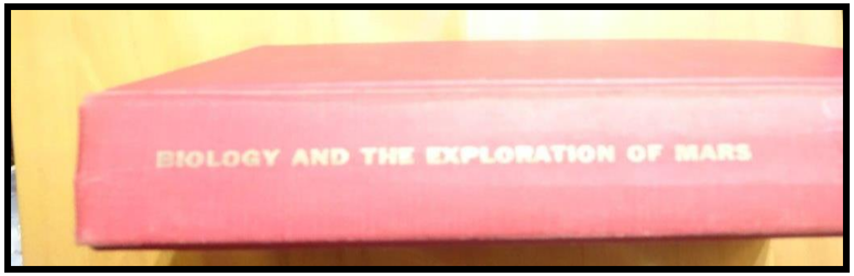
Reply to 2008 Paper's Statements

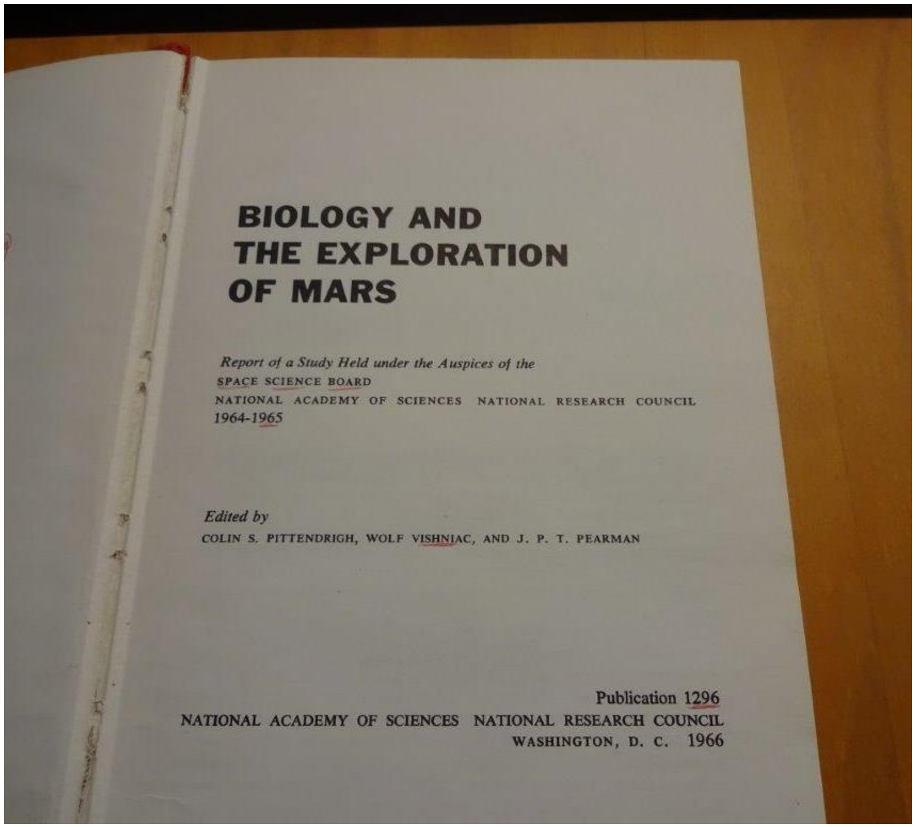
i. There was no attempt to culture any specific type of organism. The Viking tests were positive for any soil on Earth. Three quite different tests for metabolic activities were conducted, including variations of H_2O.

ii. They were conducted at just enough pressure and temperature to prevent boiling of liquid water. Some experiments were conducted with only water vapor.

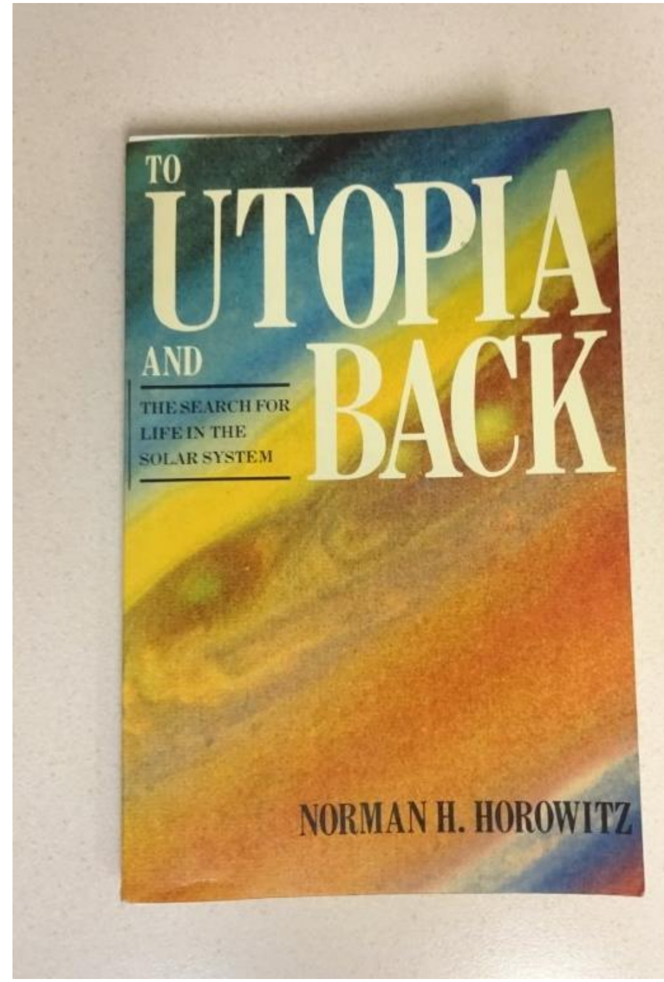
iii. Harsh Environment well-recognized: "Although the environment on Mars differs drastically from that on earth, the difference is not so great that the terrestrial biologist cannot envisage a group of organisms that would not only survive but flourish under Martian conditions" (Vishniac, 1965, p. 229)

Note: If Viking *had* measured high concentrations of interesting organics in the soil, but had brought along no experiments to detect metabolic activity, it would have been criticized for being short-sighted.





NRC Publ. 1296 (1965)



To Utopia and Back: The Search for Life in the Solar System (1986)

Some History of the Viking Search for Life

From “Biology and the Exploration of Mars” SSB Report 1296 (October, 1965)

1. **UV Flux**
   a. “UV flux on Mars may be, in the absence of ozone” such that “most exposed organisms would receive lethal doses in hours” (Sagan, p. 100)
   b. “subsurface or shielded organisms . . for protection from UV” (Vishniac, p. 240)

2. **Other Environmental Factors** (Sagan, Table 2, p. 97)
   a. Surface temperature
      “Mean daytime: -33 C; Warmest: +17 C”
   b. Pressure: “uncertain, 15-85 mbar” (Vishniac says 10-60 mbar)
   c. H_2O: “1.4 to 20 mg/cm^2” (14 to 200 pr μm)
   d. “Depending on the salts, the freezing point may be depressed to -50 deg C.” (Vishniac, p. 238)

From “Biology and the Exploration of Mars” SSB Report 1296 (October, 1965)

3. Extremophiles

Chapter on “A Model of Martian Ecology” (Vishniac, p. 229)

(Wolf Vishniac died in a tragic fall to his death while exploring for life in Antarctica, in 1973)

4. Cultureable Organisms

“Mars, like Earth, cannot be populated by any single type of organism . . . a community of organisms compensate for each other’s activities” (Vishniac, p. 229)

5. Organics

“A negative assay for organic materials would preclude biology”
(Lederberg, p. 129)

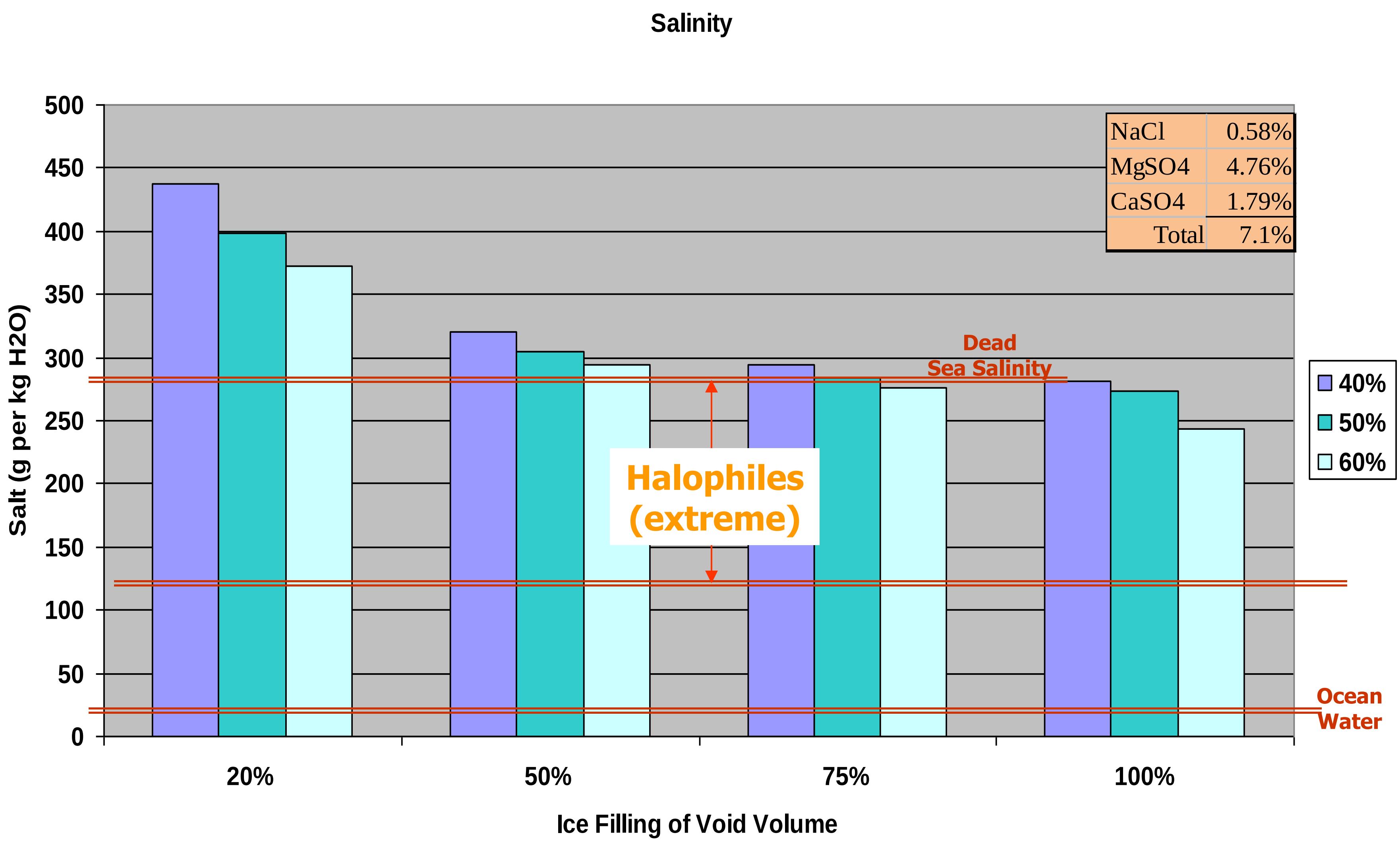
Organics on the moon were nil, as was life (Apollo finding)

XRFS Instrument Findings

- High Fe (iron); usual other elements
- Very high S and Cl in soils
  - Sulfates, chlorides
  - [meanwhile: perchlorates and chlorates (Phoenix)]
- Soils were the same at both Viking sites

  (on opposite sides of the planet)
  - Global soil unit, distributed by dust storms

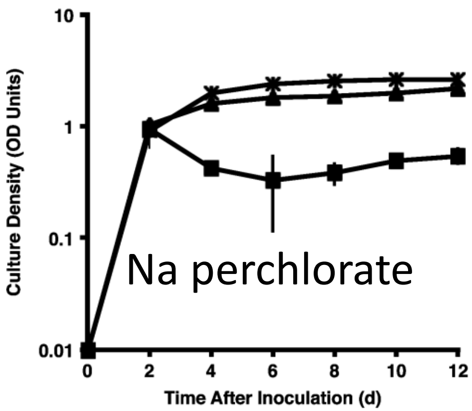
Salt-Rich Regolith:
Salinity of Melting of Ice-laden Soil

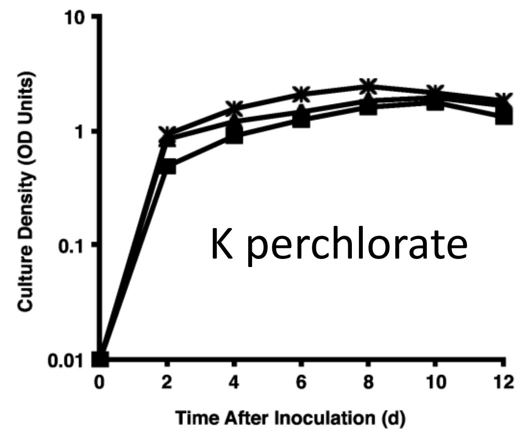


Perchlorate Tolerance in Salinotolerant Microbes (Fei Chen, P.I.)

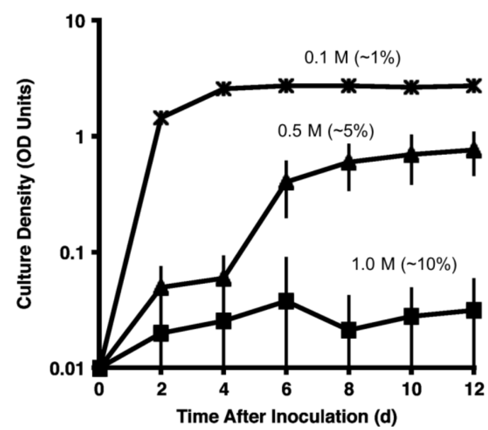
Work from the lab of Mark Schneegurt at Wichita State Univ.

Al Soudi et al. (2016), "Bacterial growth tolerance to concentrations of chlorate and perchlorate relevant to Mars", Intl. J. Astrobiology, in press.





1% $Mg(ClO_4)_2$: Nearly all HL and GSP isolates grow
5% $Mg(ClO_4)_2$: Half of isolates grow
10% $Mg(ClO_4)_2$: No consistent growth



Mg perchlorate

HL = Hot Lake, WA ($MgSO_4$)
GSP = Great salt Plains, OK (NaCl)

With what we Know Now . . .
Life *should* have begun on Early Mars:

Multiple favorable conditions

Obliquity Cycling was unsuspected at the time of Viking.

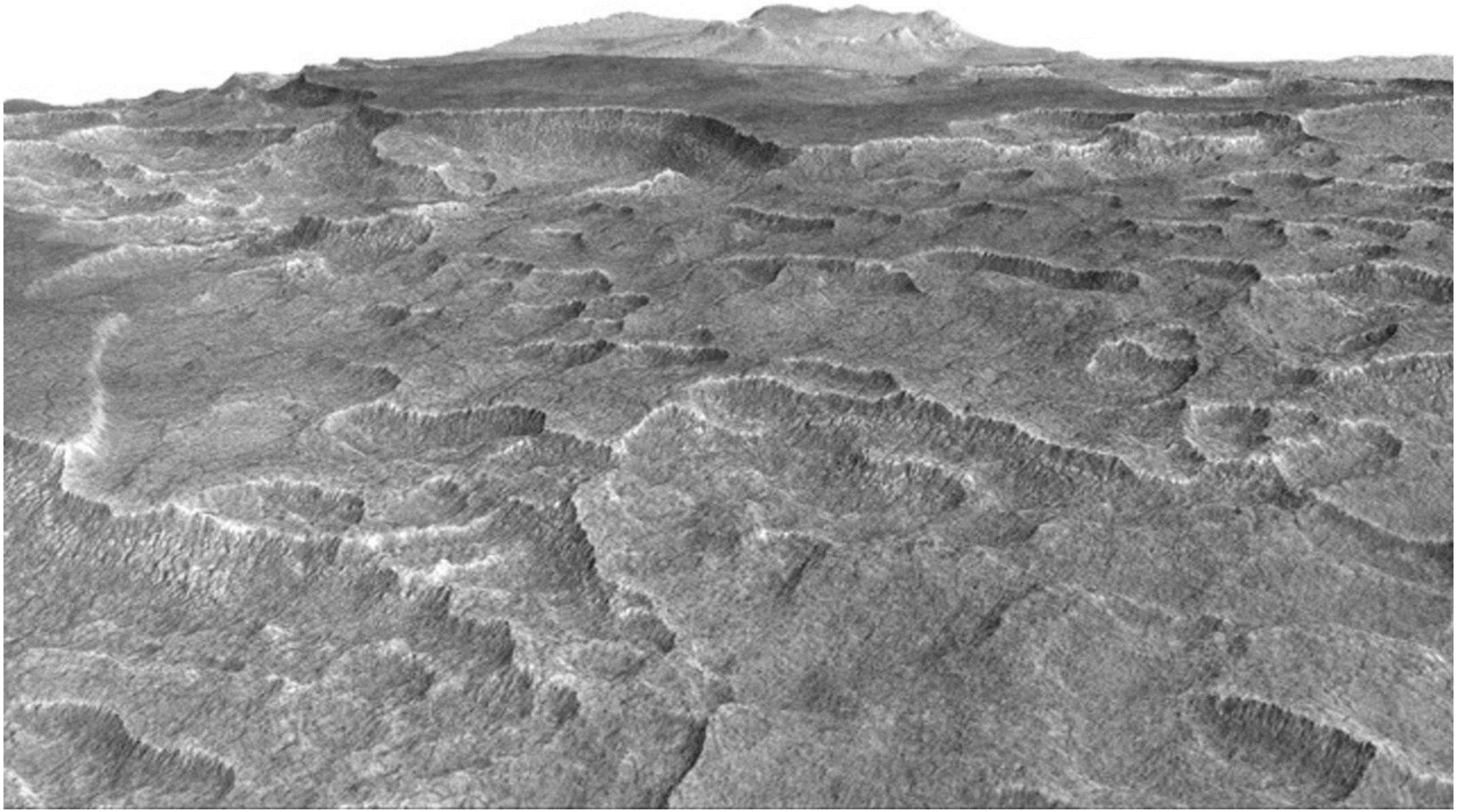
Near-surface Ice at Phoenix Landing Site (68° N)

"Holy Cow" Mosaic Credit: Marco Di Lorenzo, Kenneth Kremer NASA/JPL/UA/Max Planck Institute/Spaceflight

Credit: NASA

Frost at VL-2 (Utopia Planitia)

Extensive Shallow Permafrost Ice in Utopia Planitia (VL-2 Landing Site)



Credit: NASA/JPL. Latitude band: 39-49° N; surface overburden 1-10 m; 50-80% ice/soil; 80-150 m thick; vertical exag =5x. SHARAD radar discovery, announced 11/22/2016; Publ in GRL.

Ergo, the Soffen Memorial Station (VL-2) is at times enveloped by H_2O ice, both above and below the nominal regolith surface.

Conditions were Ideal on Noachian Mars for OoL

- **Denser atmosphere; More Liquid H_2O**
  - Stabilizes liquid H_2O; Access to small, volatile molecules; Waste disposal
  - Not too much water (avoids dilutions, cf. to Earth or ocean worlds)

- **Energy sources**
  - **Abundant H_2 (Kasting et al.; Wordsworth et al., 2016)**

    See next chart

  - **Abundant CO**

    Anaerobic fermentation (hydrogenogenesis, methanogenesis, and acetogenesis)

  - **Organics (same sources as Earth?)**
    - Accretion of carbonaceous meteorites and IDP's
      - » Mars closer to outer asteroid belt, and JFC and KBO comets
    - No ozone layer to inhibit UV photochemical synthesis of organics

  - **Sunlight (43%of Earth)**

Cont'd

Hydrogen Metabolism Examples

- "99% of organisms can utilize H_2" [true?]
- Chemoautotrophy: example energy sources

Methanogenesis	$H_2 + CO_2$	$\rightarrow$	CH_4 or acetate
Sulfate reduction	$H_2 + SO_4^{2-}$	$\rightarrow$	H_2S
Sulfur reduction	$H_2 + S^o$	$\rightarrow$	H_2S
Fe reduction	$H_2 + Fe^{3+}$	$\rightarrow$	Fe^{2+}
Manganese reduct.	$H_2 + Mn^{4+}$	$\rightarrow$	Mn^{2+}

- Anoxygenic photosynthesis:

$$CO_2 + 2\,H_2S + h\nu \rightarrow C(H_2O) + 2\,S^o + H_2O$$

(purple and green sulfur bacteria)

Manganese on Mars

Pinnacle Island (MER-B)
[“jelly-donut rock”]

Windjana (drill); Stephen rock (MSL)

Credit: NASA

Conditions were Ideal on Noachian Mars – cont'd

- **Geomagnetic Shield and Less Obliquity Chaos**
  - Less atmospheric escape; lower radiation dose

- **Bioavailable ~~CHNOPS~~ SPONCH** (air, liquid, and/or soil)

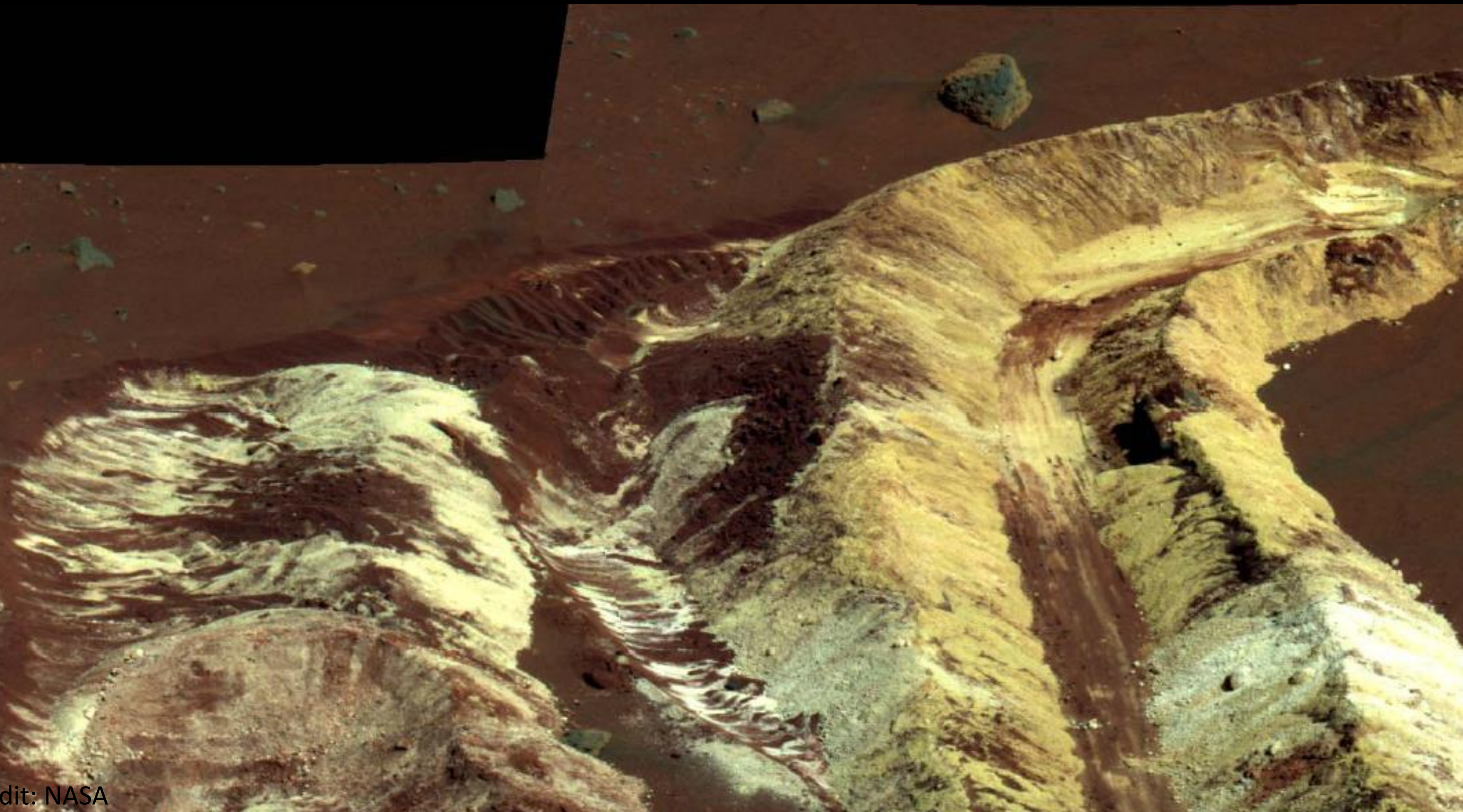
  Probable H_2S, Cu, HCN? (Sutherland cyanosulfidic scenario for protometabolism)

- **Abundant mobile Fe, S, Ni, Zn, Cu, Mn, and P**
  - Hydrogenases are metalloenzymes, with [Fe], [Fe-Fe], or [Fe-Ni], typically w/multiple [Fe-S]
  - Ferrodoxins are [Fe-S] proteins for e-transfer: photosynthesis, N_2 fixation, redox Rxn chains
  - Fe-S Reaction Centers in Photosystem I
  - "Iron-sulfur World" hypothesis (Wächtershäuser)
  - Zn is second most used transition metal (after Fe), in hundreds of proteins
  - Soluble phosphorus for nucleic acid backbone; ATP; phospholipids; etc.

- **Hydrothermal activity**
  - Long-lived shield volcanoes (e.g., O. Mons)
  - Impact-induced hydrothermal networks
  - Home Plate and other examples

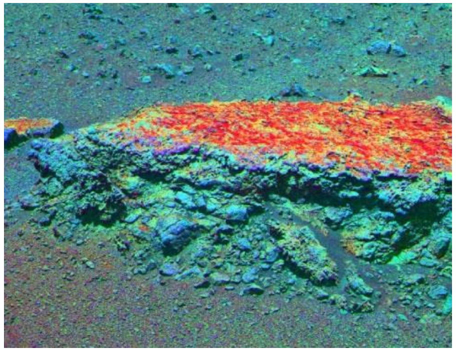
Other than the dearth of organics, Mars is More Favorable than an Ocean World

Ferric Sulfate Salts (Tyrone site, on Husband Hill)

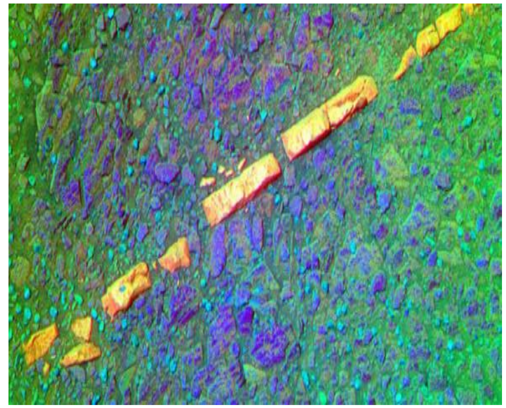


Mars Geochemical Diversity (Opportunity Rover)

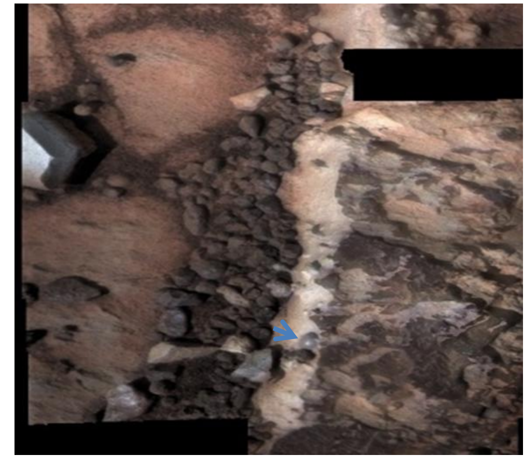
(most within 10's of meters of one another)



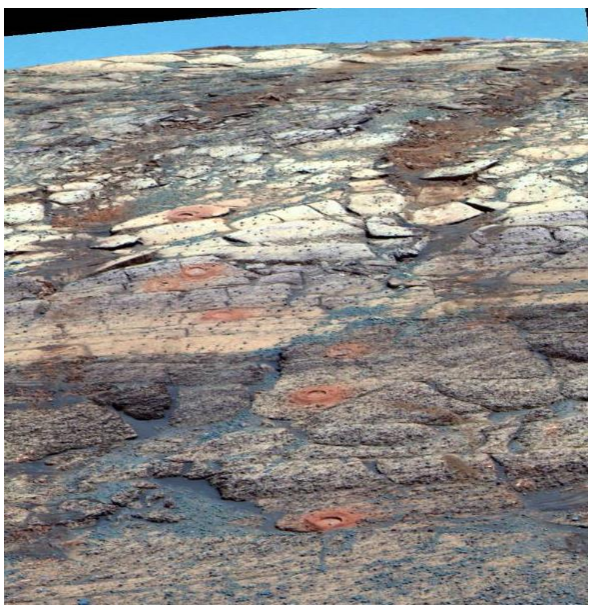
Tisdale: Zn (6000 ppm); P, Ni



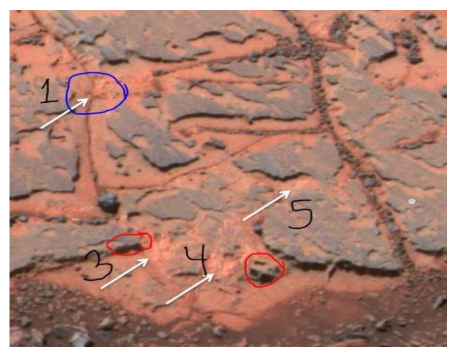
Large Gypsum Veins (Homestake, Ootsark)



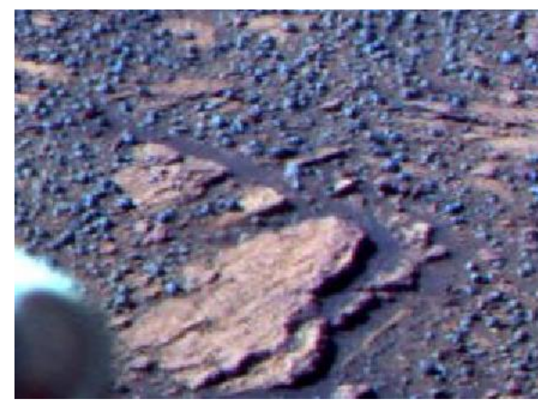
Esperance Boxwork (montmorillonite; coating)



Burns Formation Sediments



Whitewater Lake, Azilda Sandcherry Coatings

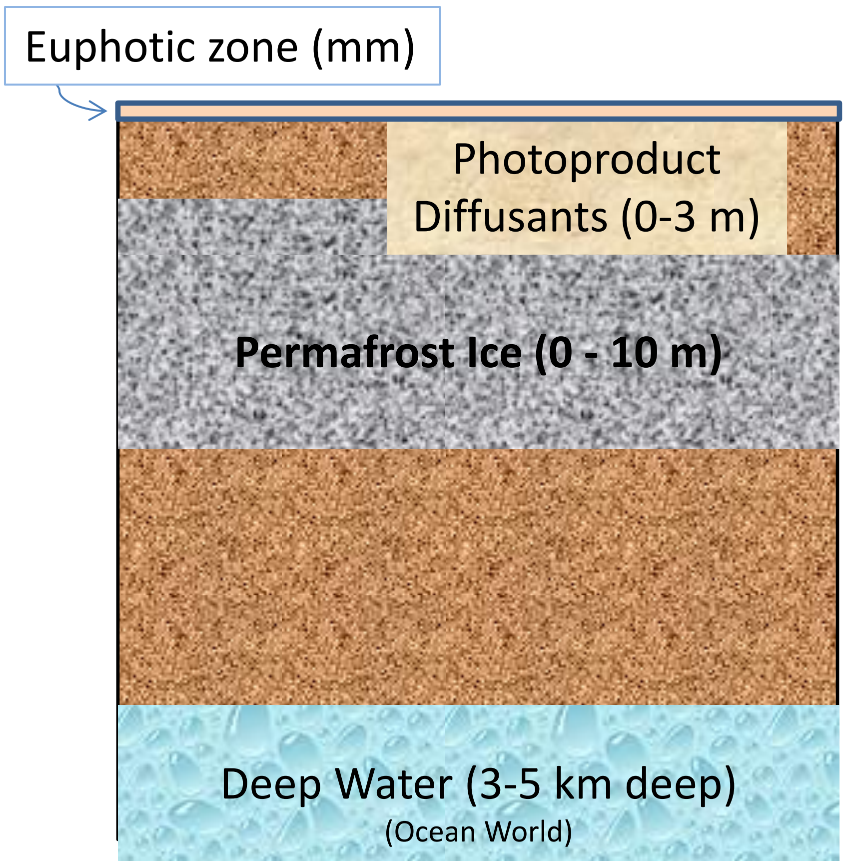


Hematite-Ni Blueberries

Credit: NASA

Where to Search for Life . . . On Mars

Go Vertical



Go Horizontal

- Salts: veins, duricrust, beds, evaporites, cements
- Smectites, other clays
- Silica-rich materials
- Amorphous components
- Trace element enrichments
- Alteration halo's
- Iron meteorites (Fe^0)
- Rock coatings
- Endolithic rock candidates
- Organic-rich sediments

But just Go!

Warning: Mars Fools Us

- Polar caps are H_2O ice; no, CO_2 ice; no, they are both
- Atmosphere is not 85 mbar; is not 40% Ar
- Rocky Flats is not rocks, just peds; Bonneville is not salty
- Canals. no, craters (Mariner IV). no, channels
- Mare are not seas. Well, maybe Ocean in N. Plains
- Intelligent Life. No, just microbes. Oops, no metabolism and no organics
- No organics. Not exactly – rxns in pyrolysis cells
- Wave of Darkening. No, not vegetation
- Missing clays. Yes, but present in certain locations; yes, missing in Gale
- Cl is NaCl. Not exactly – also perchlorates; chlorates; chlorites?
- Limonite-rich regolith. No, basalt plus amorphous
- Gusev Lake Bed evaporites. No, volcanic plains
- Solar arrays: 90 sols max; no, 13+ years (Opportunity)
- Methane: yes; no; maybe local
- Meridiani Hematite. YES! But as Ni-rich concretions

Cont'd

Mars Fools Us - cont'd

- Olivine nowhere to be found; no, many places incl. global soil!
- Soil is smectites; no, but smectite deposits
- VL-2 Landing Site: sand; no, very rocky
- PHX Landing Site-1: smooth, boring; no, boulder field
- SNCs: asteroidal; no, planetary; not Mars; yes, Mars
- Life: "If Anywhere, then Everywhere"; no, must be in oases
- Cannot land in dust storms; yes, can
- Geochemistry: globally same and blah; no, diverse and fascinating
- Soil strength: low (Congressional inquiry); high; both (and nearby)
- Composition w/depth: variable; no (VL); yes (MER-A)
- Erosion rate: high (latex paint); low (MER); High in sediments (MSL)
- Magnetic field: no, missing radiation belts; yes, ancient (remanent mag)
- HCN Polymers for a.a. formation: skepticism (Matthews); yes

- OoL: unique; no, spont. Gen.; widespread in Universe; Fermi paradox

Viking Lessons Learned

- Experiments which are simple in the Lab can be difficult to implement, and expensive to fly, with perplexing results
- The environment, solid-liquid-gaseous, needs to be well-understood
- Understanding martian soil requires sample return (including precautions to preserve oxidants and putative microbes)
- Mars fools us, most of the time.
- "If Life is Anywhere, Life is Everywhere" may not apply
- What If? -- Viking had
  - tried more metabolites (e.g., H_2)
  - dug down to ice, or
  - sought oases, or endolithics, or . . .

Ende

BAK

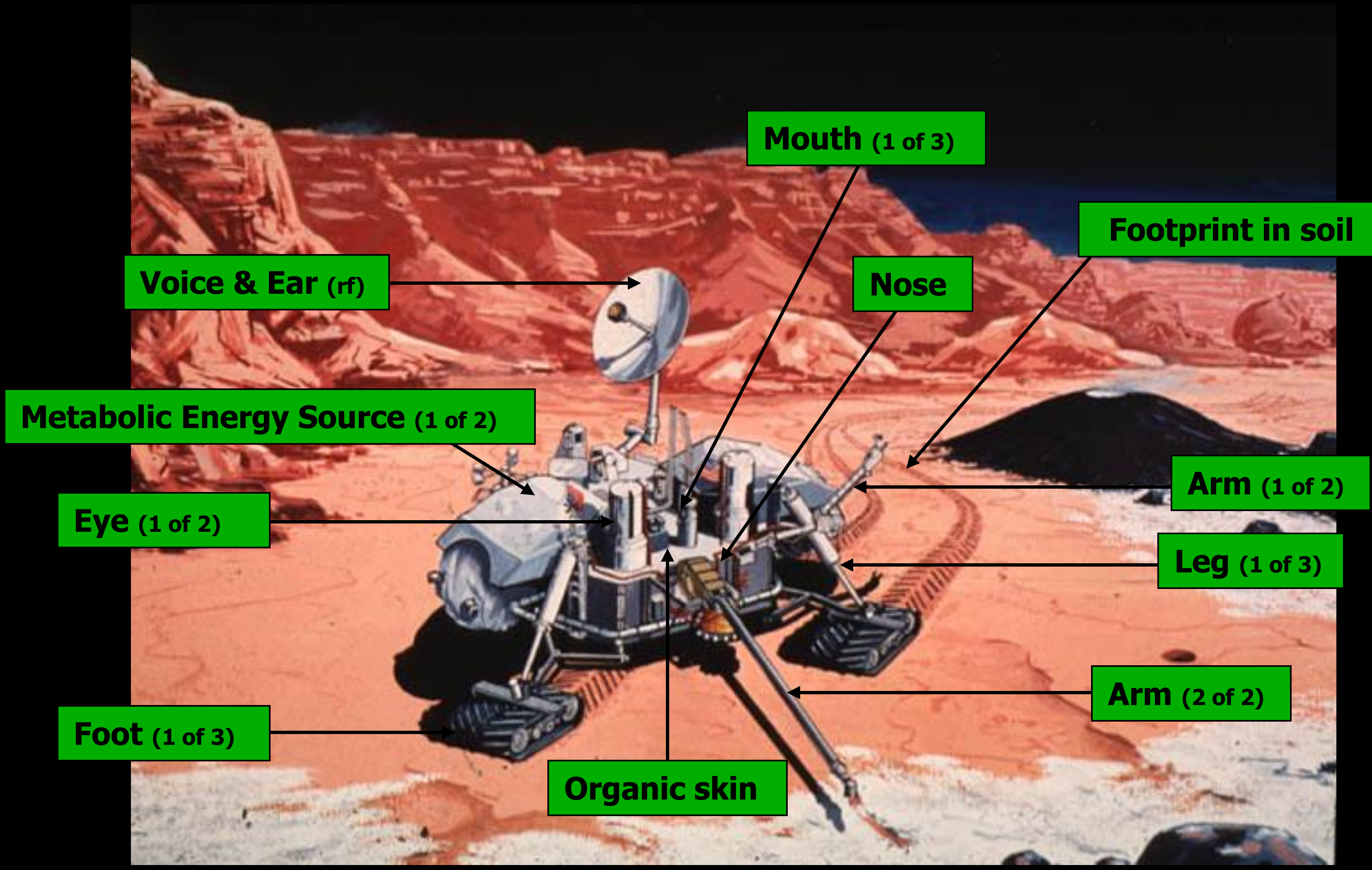
New Since Viking

- Deep sea hydrothermal vent communities (1976)
- Strong Obliquity cycling of Mars
- Vast majority of microorganisms have not been cultivated
- Endolithic communities in desert rocks
- Buried ice on Mars at VL-2 latitudes
  - Phoenix site; Utopia Planitia
- Iron-sulfur world hypothesis (1988-1992)
- Oxychlorines (not just chlorides)
- RNA World hypothesis (1962, ‘67, ‘72, ’76)

  [Rich, Crick, Orgel, Woese, Kuhn, Gilbert]

Earthlings Roaming Mars

How do the martians know it is not alive?



Sources of Cl and S

- Accumulation
  - Magmatic release

    Cl_2, HCl , ClO_x; S, H_2S, SO_2, SO_3, H_2SO_4

  - IDPs, asteroids, comets

    FeS_x, organic S, $MgSO_4$

- Conversion
  - UV photolysis and oxidative reactions

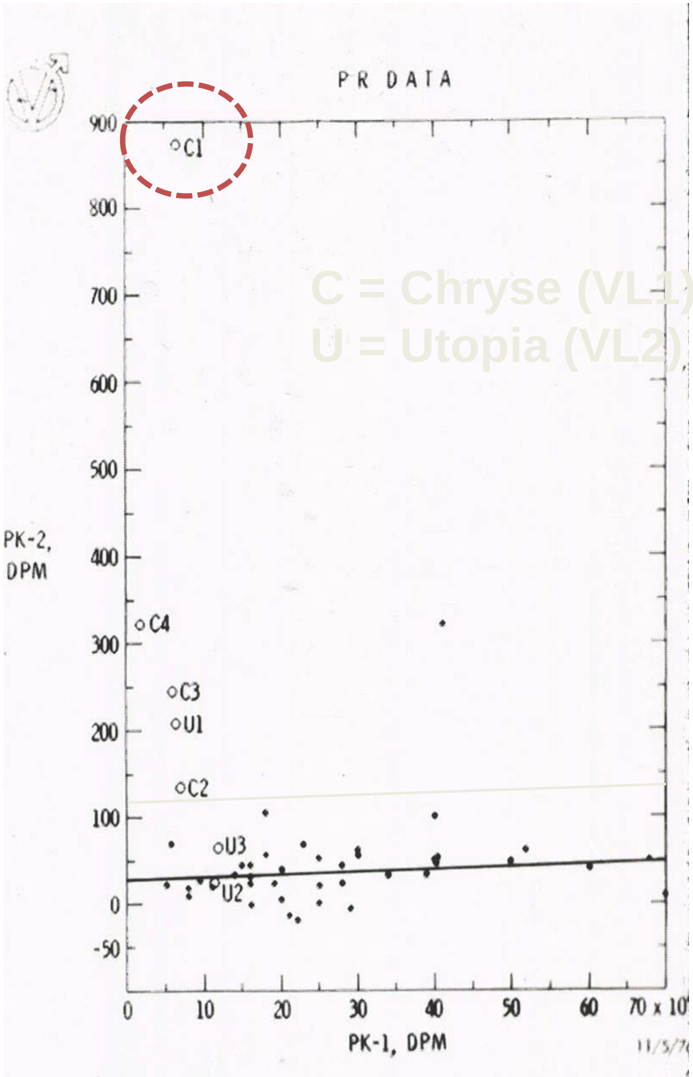
    $H_2S \rightarrow SO_2 \rightarrow SO_3 \rightarrow H_2SO_4 \rightarrow MgSO_4$

Earth-Mars Lithopanspermia*

- More difficult for Earth→ Mars, than vice-versa (escape velocity; thick atmos.; orbital mechanics)
- Short trip times are a low probability event
  - GCR and SPE radiation will sterilize meters-deep
  - Large, self-shielding meteorites are rare
- Sediments probably not be launchable
  - Melosh Mechanism requires strong material
  - All martian meteorites are competent rock

*Clark, 1985; Horneck et al., 1985; Melosh, 1988; Mileikowsky et al., 2000

Pyrolytic Release (PR) Experiment: A Search for Phototrophs



Experimental Conditions:

1) 0.25 cc of Mars soil enclosed in a 4 cc test chamber. 6 W/m^2 xenon bulb yielded ≈ 8 mW/cm^2. 7.6 mb Mars atm + 20 µl of $^{14}CO_2$ and ^{14}CO gases.
2) Total pressure = 10 mb. Temp = +8 to + 26 C.
3) Soil samples incubated 120 hrs in the dark or light.
4) After incubation, a series of gas purge cycles to separated fixed carbon from residual gases.

Peak 1 = residual $^{14}CO_2$ and ^{14}CO gases in purge cycle.

Peak 2 = oxidation of fixed ^{14}C-labeled compounds by heating CuO doped separation column to 640 C.

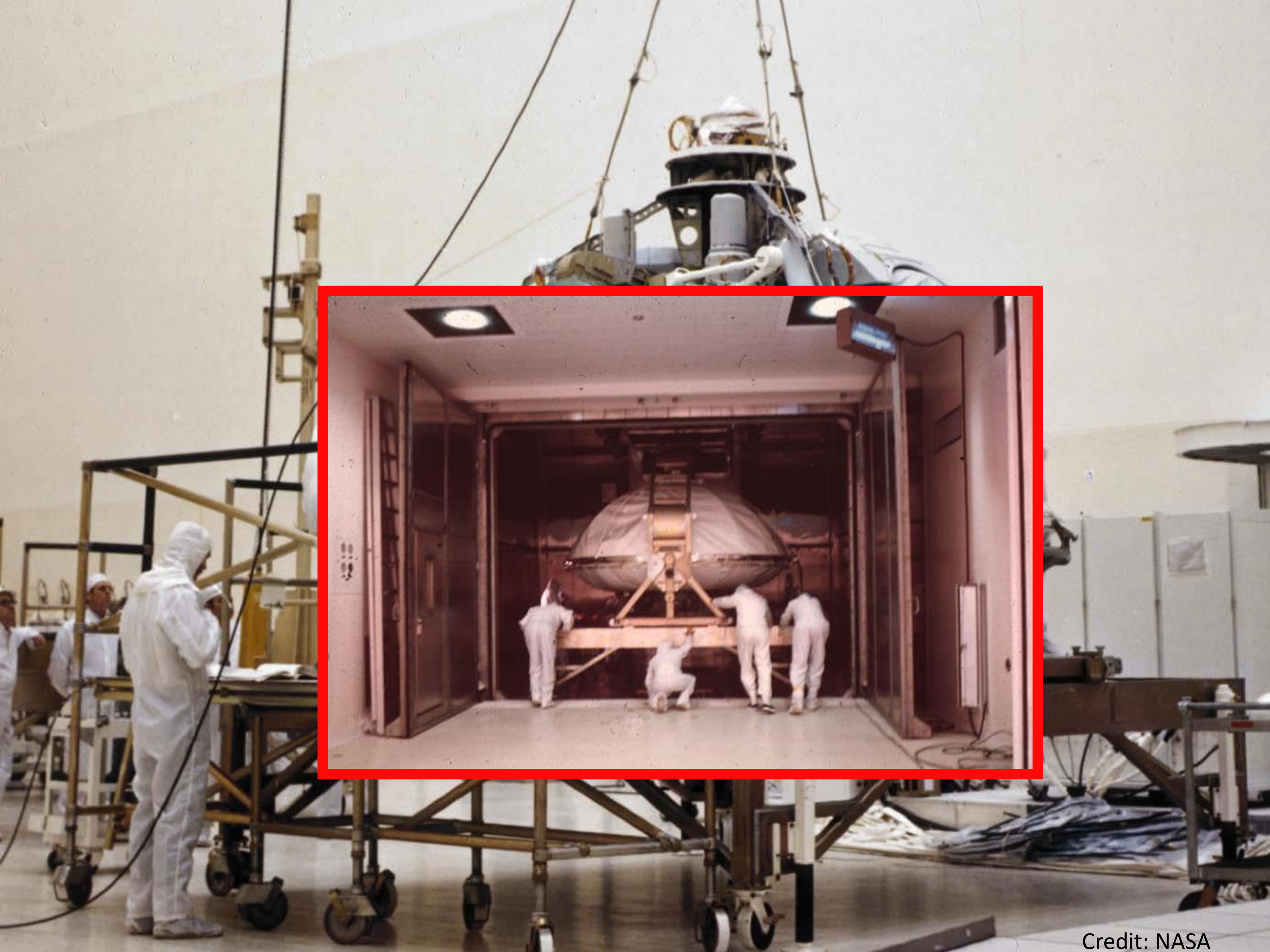
Conclusions:

1) $^{14}CO_2$ or ^{14}CO gases were fixed at very low, but significant, rates.
2) The Rx were not affected by the addition of water vapor but were enhanced by light illumination.
3) Heating samples to 90 C had no effect on the Rx, but heating to 175 C reduced the Rx.

Horowitz and Hobby, 1977, JGR, 82, 4659-4662

104 Common Attributes of Life

Acquire and Process	Digestion	Materials Intake	Plan, Growth
Adaptation, Facultative	Disequilibrium	Meiosis	Plan, Reproduction
Adaptation, Genetic	DNA and/or RNA	Metabolism	Predation
Aggressive expansion	Electrical activity	Micelles	Prey
Anabolism	Energy Capture	Mitochondria	Products, Secrete
Apoptosis (PCD)	Energy Storage	Morphogenesis	Products, Waste
Assimilation	Energy Transduction	Morphology, External	Progeny
Autopoiesis	Evolution	Morphology, Internal	Proteins, a.a.'s
Autotrophy	Excitability	Motion	Quality Control
Biomarkers	Excretion	Movement, Configuration	Quality Control, Growth
Catabolism	Finite size, bounded	Movement, Internal	Quality Control, Repro
Catalysis	Gas exchange	Movement, Locomotion	Reasoning
Cell	Gradients	Multiply	Recycle
Chemistry-unique	Growth & Maintenance	Mutation	Regulate
Chemotrophy	Heat generation	Necrosis	Replication
Chloroplasts	Homeostasis	Negentropy	Reproduction
Color spectral reflectance	Independence	Nutrient uptake	Respiration
Communication	Information	Optical Activity	Respond to Stimuli
Compartmentalization	Ingestion	Organelles	Ribosomes
Competitor	Innovation	Organics-based	Selection
Complexity	Instructions, Activities	Organization, Functional	Self-Repair
Comprehension	Instructions, Repro. Plans	Organization, Structural	Sensory capabilities
Conductivity	Insulate	Parasitisation	Signaling, cell
Death Transformation	Intelligence	Phagocytosis	Specialization
Development	Ion Pumps	Phototrophy	Taxis
Differentiation	Manufacture	Physics-unique	Water dependency



Credit: NASA

At the time of planning for Viking

- Everyone on the project expected life on Mars
- We knew almost nothing about extremophiles
- We didn’t consider the possibility of no organics
- We didn’t expect EUV at the surface of Mars
- We didn’t realize sub-freezing temperatures
- We didn’t realize extreme dryness
- We didn’t realize low pressure
- We didn’t consider salts
- We didn’t consider freezing-point depression
- At least we knew composition of martian meteorites

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Common Misconceptions

Personality Tid-Bits

- Chuck Klein to Clark (pre-launch): ‘I argued to NASA, unsuccessfully, that we needed a mission first to characterize the surface of Mars’
- Pimentel withdrew, unpleasantly, from GCMS
- Ponnamperuma (prominent Exobiologist, not on any Viking team) quickly published a paper in Science on lab experiments explaining LR and GEx results with oxidants
- Levin and Hurowitz were totally at odds in interpreting the final results, even though . . .
  - They had worked together, initially, in developing “Gulliver” (which became LR)
- Sagan-to-Clark, post-Viking: no, you cannot drop the Life-issue from future missions to Mars

Soil Simulants Tests

- Pre-Landing: Aiken Soil model

  TYPE LOCATION: 13 miles east of Fiddletown, CA

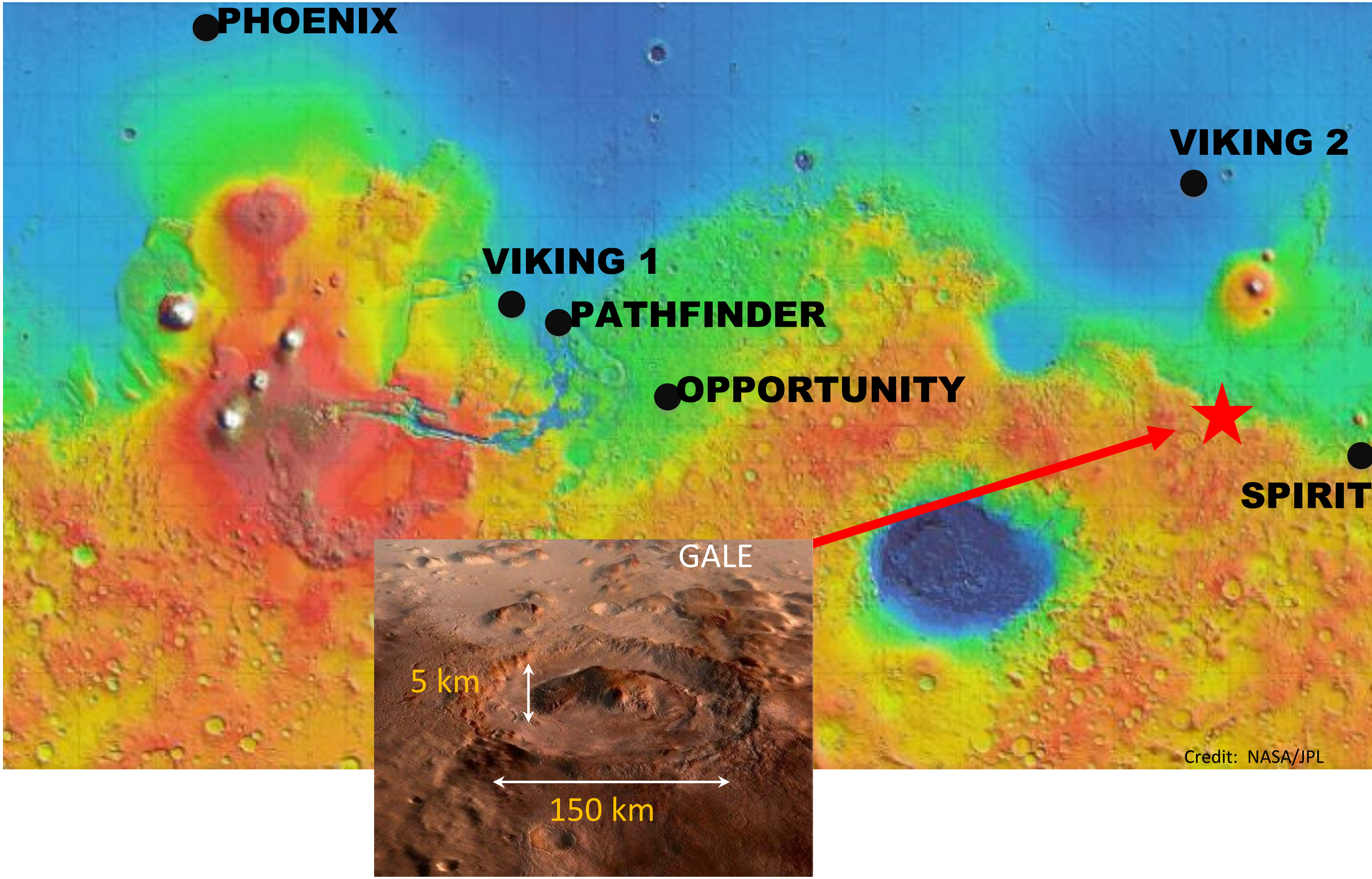
  The Aiken series consists of very deep, well drained soils formed in material weathered from basic volcanic rocks.

  Mean annual precipitation is about 47 inches and mean annual temperature is 55 degrees F.

- Post-landing: Riverside Nontronite
  - Based on an early, incorrect interpretation of Fe-smectite clay in global soil

Note1: No soil on Earth that matches martian soil.

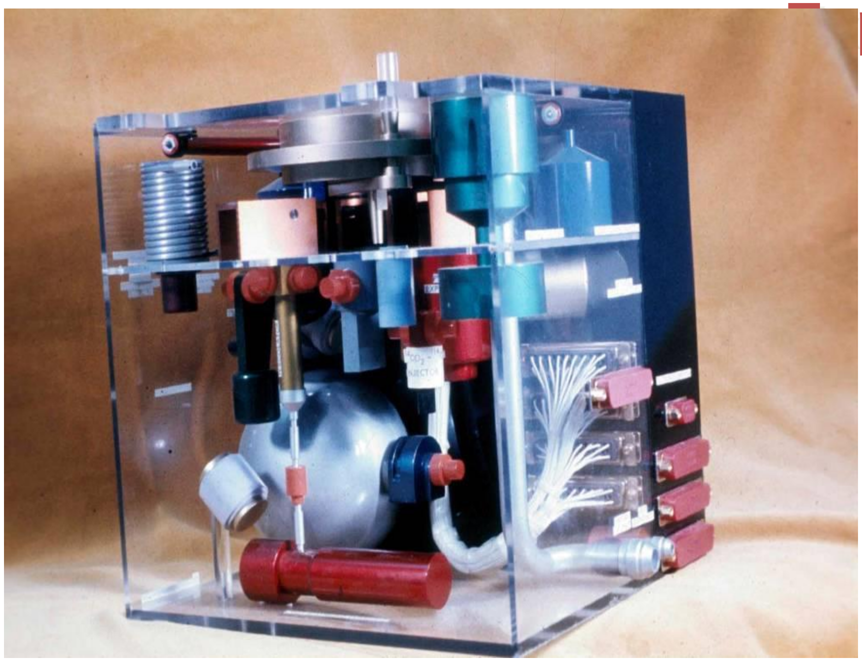
Note2: Clark's later experiment to test for evolved heat-of-wetting using GEx lab unit revealed that the $MgSO_4$ – clay simulant plugged the frit and prevented rapid wetting (lab tests by B. Berdahl).

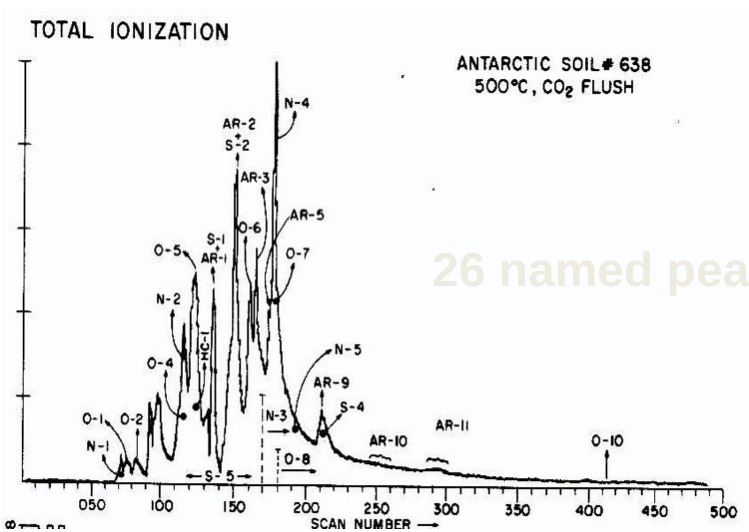


Curiosity Destination : Gale Crater

Credit: NASA

Gas-Chromatography-Mass Spec (GCMS) Experiment





26 named peaks

Credit: NASA

Biemann et al., 1977, JGR, 82:4641-4658

Experimental Conditions:

1) Four pyrolytic ovens that could heat soils for 30 sec at 200, 350, or 500 C.
2) Volatilized organics are captured with a $^{13}CO_2$ gas stream followed by a H_2 gas stream.
3) GC column was maintained at 50 C for 10 min, and then linearly increased to 200 C for up to 54 min.
4) Carrier gas is removed by passage through a palladium separator.
5) And the eluting volatiles enter the Mass-Spec.

Conclusions:

1) Only H_2O and CO_2 were detected.
2) No organics down to a detection limit of a few parts per billion (10^9) by weight in the soils.

Credit: NASA

S in Autotrophic Energetics

Chemoautotrophy (Sulfur Oxidizers)

$$H_2S + 2O_2 \longrightarrow H_2SO_4 \qquad \text{Thiobacillus}$$

Mixotrophy (Sulfate Reducers)

$$Na_2SO_4 + 4H_2 \longrightarrow Na_2S + 4H_2O \qquad \text{Desulfovibrio}$$

Photoautotrophy (Purple and Green Sulfur Bacteria)

$$H_2S + 2CO_2 + 2H_2O \xrightarrow{h\nu} 2(CH_2O) + H_2SO_4 \qquad \text{Chromatium}$$

$$2H_2S + CO_2 \xrightarrow{h\nu} (CH_2O) + 2S + 2H_2O \qquad \text{Chlorobium}$$