The Search for Life on Mars

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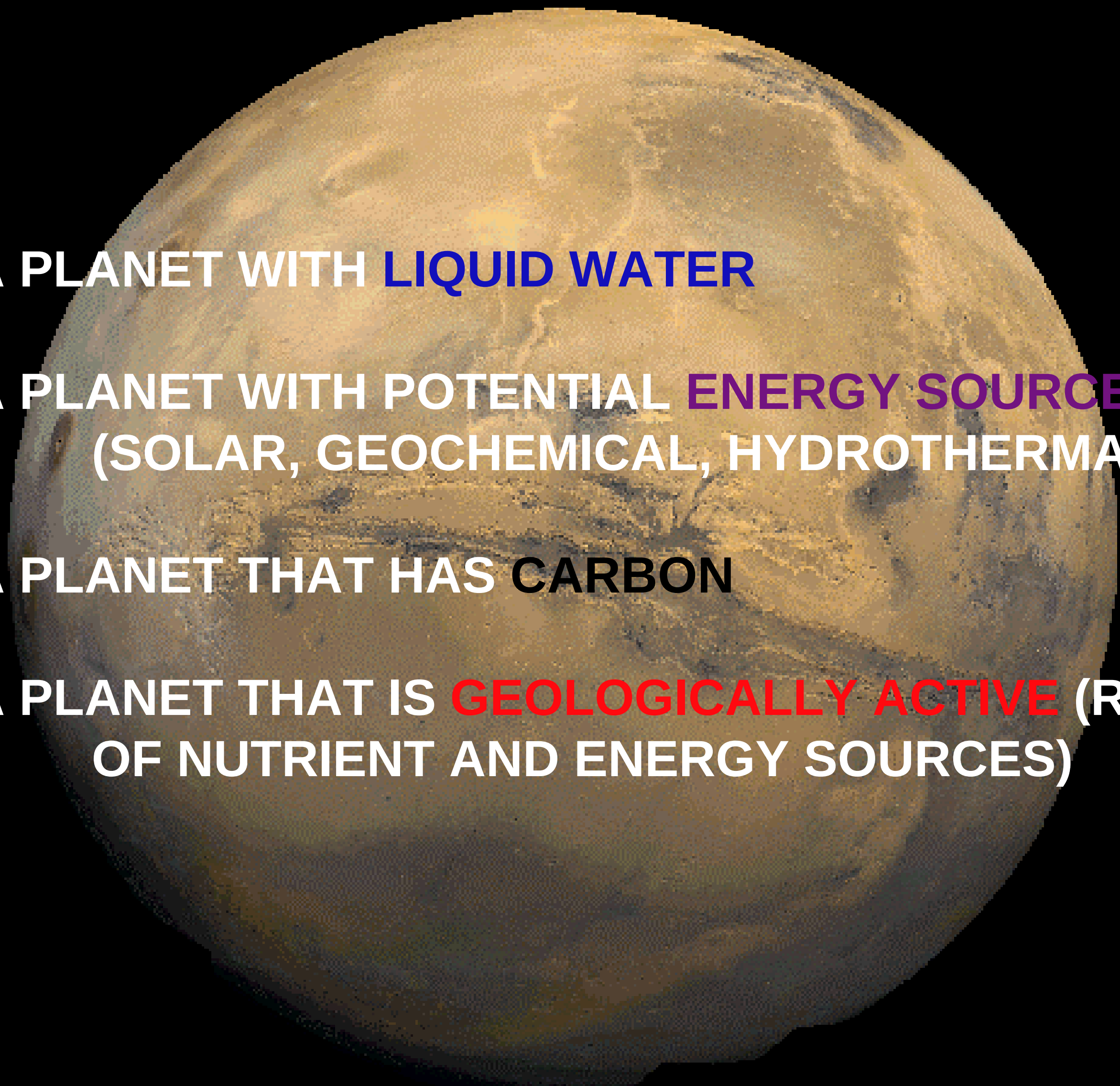
NASA Johnson Space Center

1st Mars Express Science Conf. 2/24/2005

WHAT IS A HABITABLE PLANET?



- A PLANET WITH LIQUID WATER
- A PLANET WITH POTENTIAL ENERGY SOURCES (SOLAR, GEOCHEMICAL, HYDROTHERMAL, …)
- A PLANET THAT HAS CARBON
- A PLANET THAT IS GEOLOGICALLY ACTIVE (RENEWAL OF NUTRIENT AND ENERGY SOURCES)

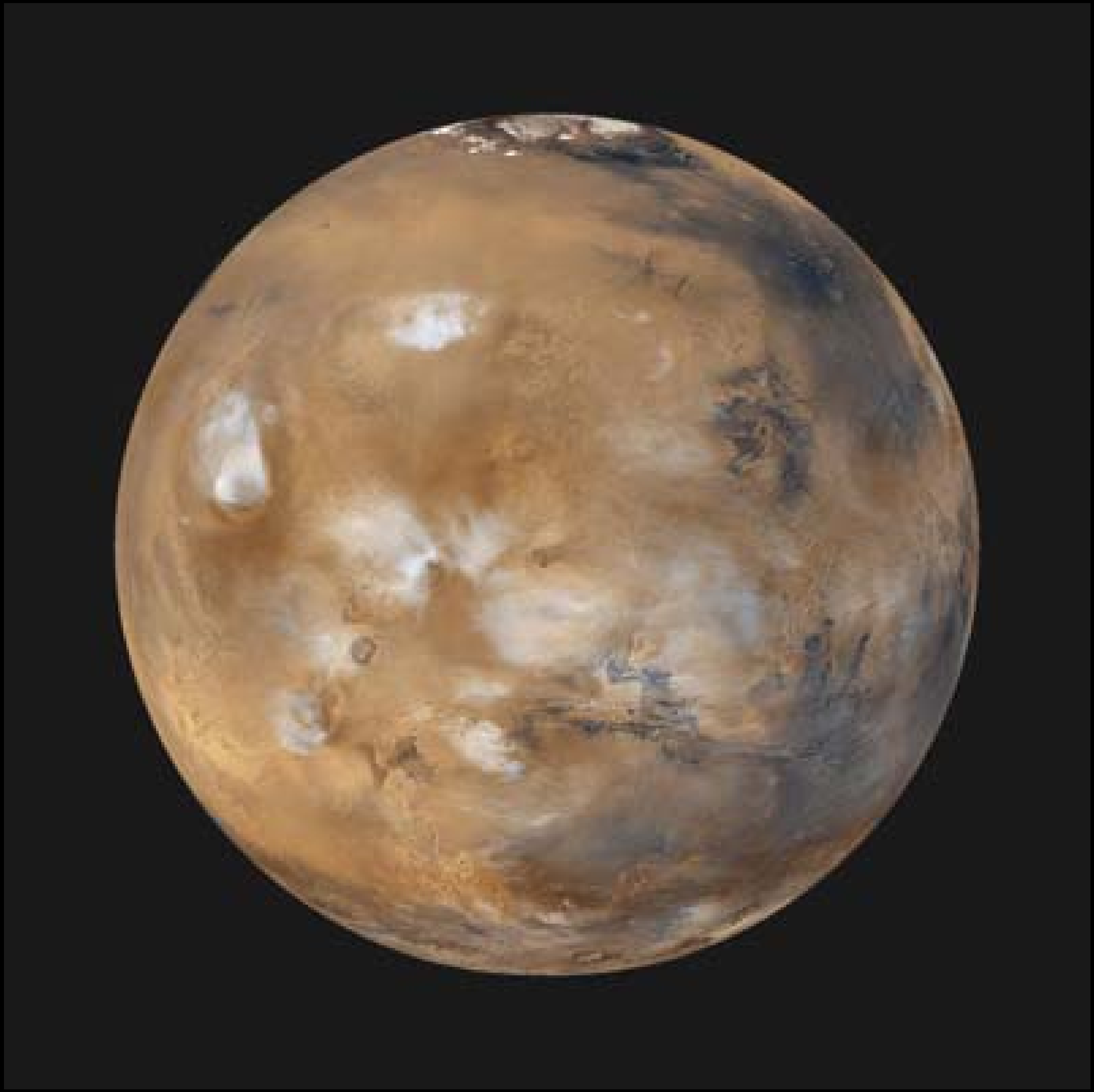
[AFTER WESTALL 2004]

- The habitability of a planet is not a static phenomenon

- It changes with time as a function of:
  1. The position of the planet in the (changing) habitable zone of the Solar System
  2. The geological evolution of the planet in question
  3. The co-evolution of life and a geologically active planet

(Westall, 2004)

The Red Planet Mars



MISSIONS TO MARS

TOTAL OF 36 MISSIONS - ONLY 11.5 SUCCESSFUL

MARS 1960A **First Launch - USSR Oct 10, 1960**

MARINER 4, 6, 7 **- USA Nov. 1964-69- First flybys**

Dry, Volcanic, Cratered, Dusty, Dead Planet

MARS 3 **- USSR - First lander May 28, ‘71**

Only Radio Signal for 20 seconds- Little Data

MARINER 9 **- USA First Mars Orbiter Nov. 14, ‘71**

Mars active planet, volcanoes, channels,

poles, “alive”, 7,000 photographs

VIKING 1 and 2 **USA, July 20 & Sept. 3, 1976 First**

Science Landers & Orbiters

PHOBOS-2 **USSR 1989 -Minimal data before contact lost**

MARS PATHFINDER **- USA Rover July 4, 1997**

***MARS GLOBAL SURVEYOR** **- USA Orbiter**

Sept. 11, 1997

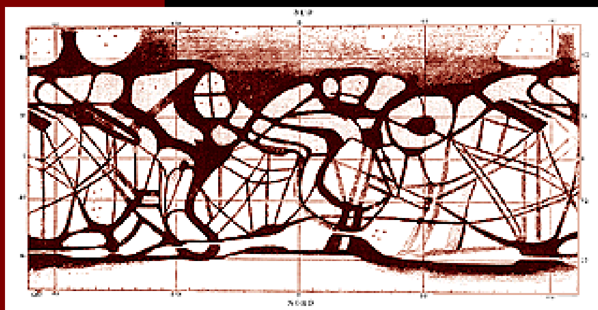
***MARS ODYSSEY** **- USA Orbiter Oct. 23, 2001**

***MARS EXPRESS** **- ESA Orbiter Dec. 2003 (Beagle 2)**

****MARS EXPLORATION ROVERS** **- USA Jan, Feb ‘04**

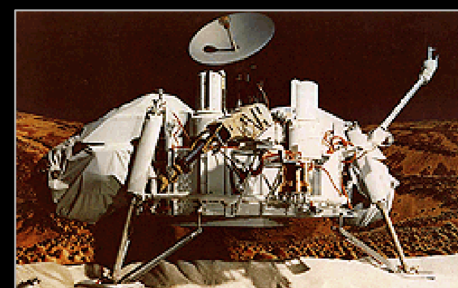
What we have learned...

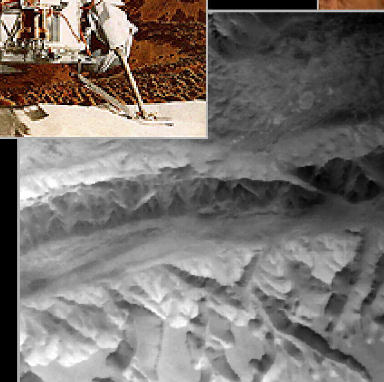
Schiaparelli's observations, 1877

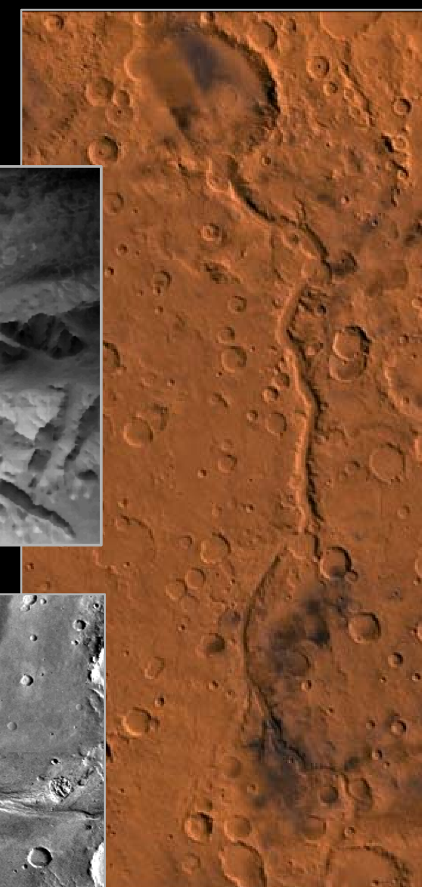


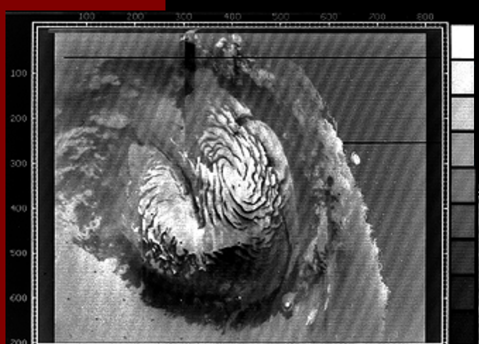
Schiaparelli's map of the Martian surface

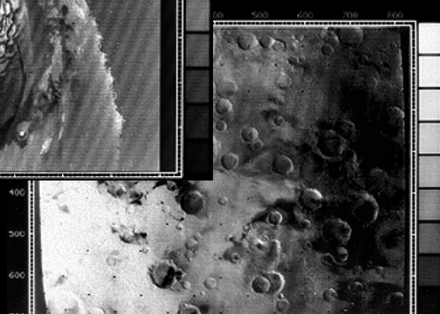
Viking discovered water vapor present in the atmosphere; determined polar ice caps are carbon dioxide and water; found landing site surface was highly-oxidized, iron-rich clay









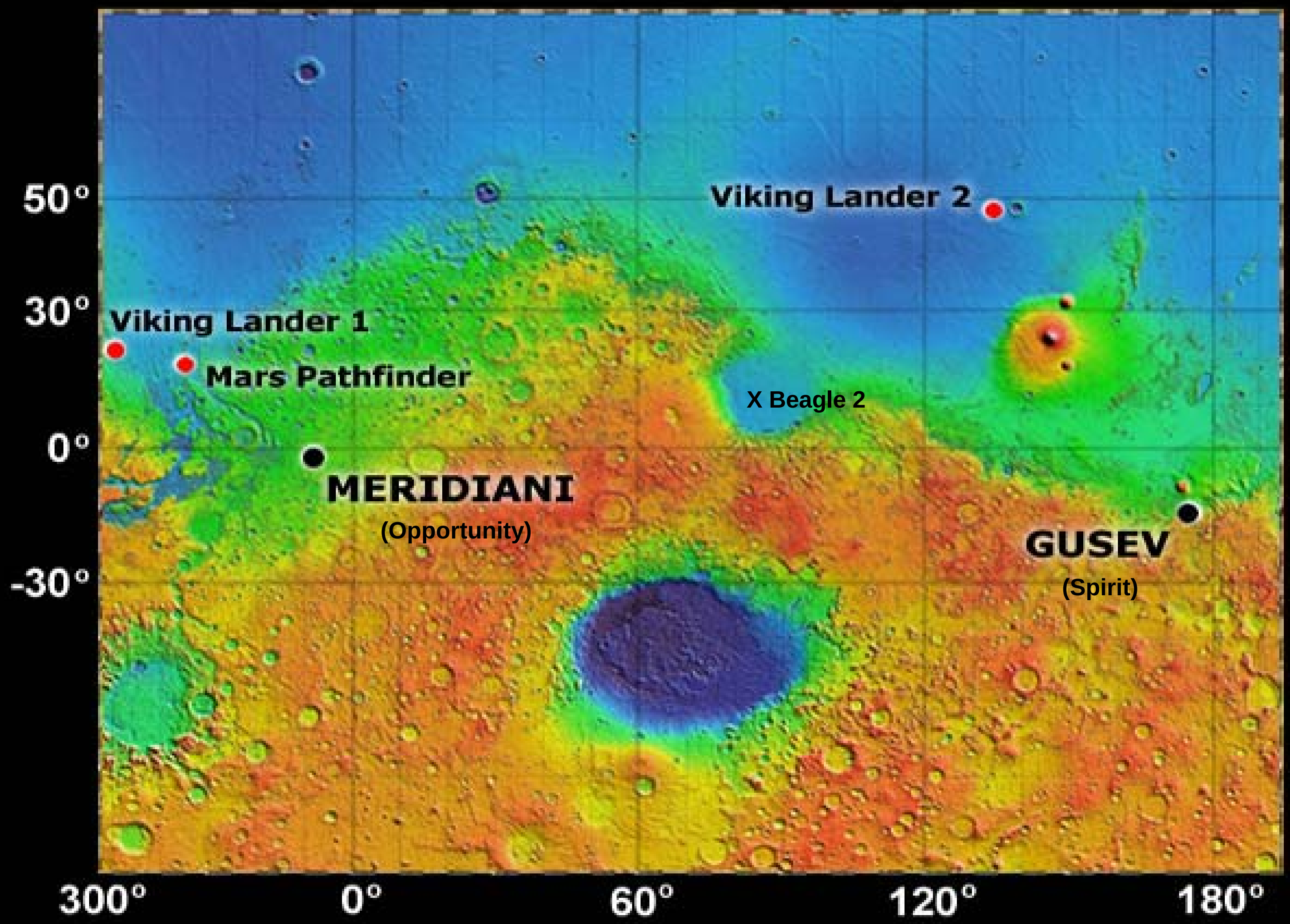


MARS I, II, III*

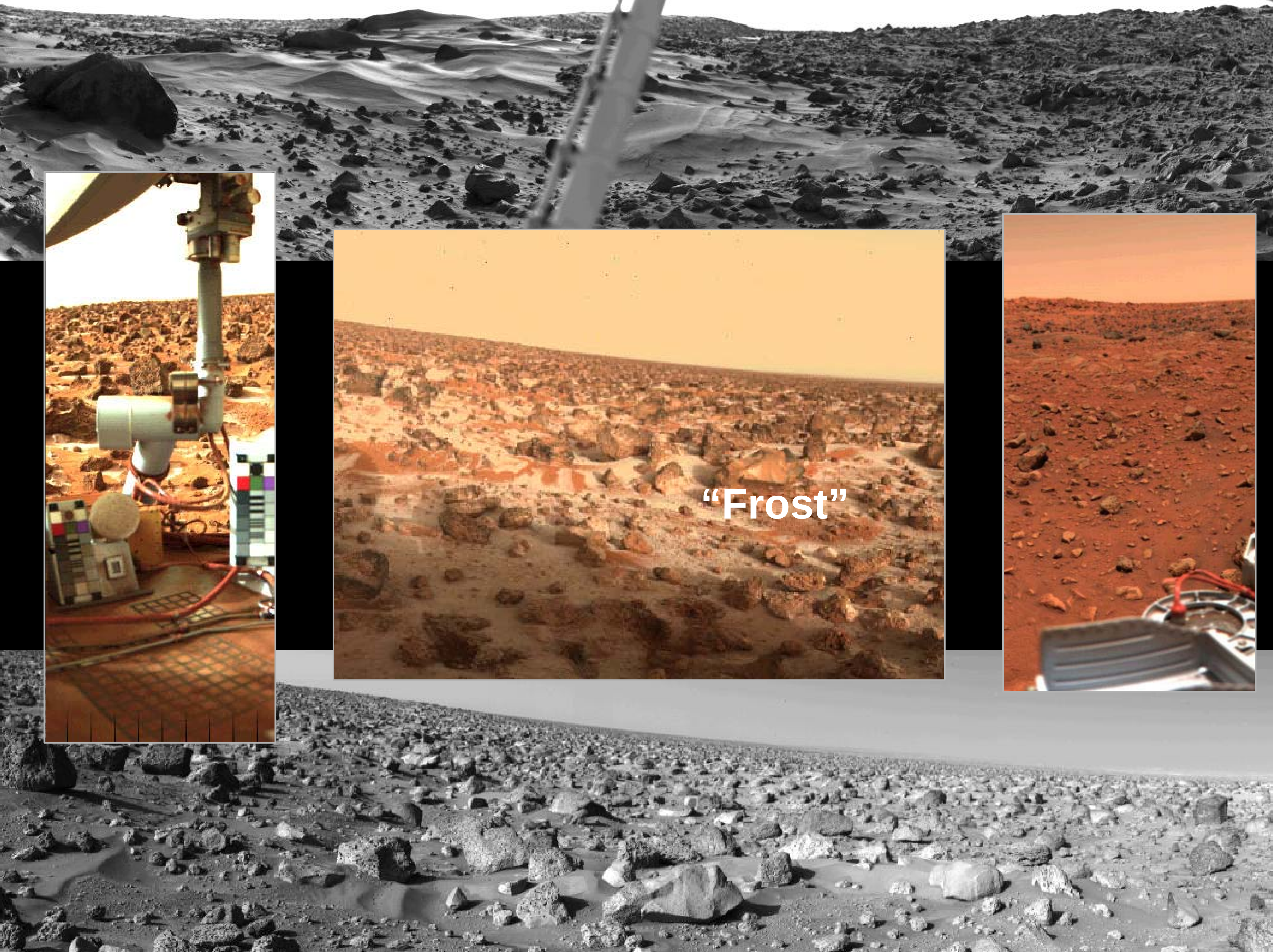
Mariner 4
Mariner 6
Mariner 7
Mariner 9*

Mariner 9 analyzed the atmosphere and revealed giant volcanoes and remnants of ancient riverbeds

Where we have been .....



Viking


“Frost”

Our Farthest Search for Life Beyond Earth

Trench excavated by Viking 1 lander surface sampler

VIKING LANDER HAD FIVE EXPERIMENTS SEEKING LIFE

1. **Camera** - Seeking movements on surface

2. **Gas Chromatograph-Mass Spectrometer**
   - Seeking carbon components - 1 ppm detection.
     NO carbon compounds found - [Note: May have operated instrument incorrectly for C detection]

THREE DEDICATED LIFE DETECTION EXPERIMENTS

3. **Gas Exchange** - seeking oxygen released after metabolism NEGATIVE
4. **Pyrolytic Release** - photosynthesis via isotopically labelled $^{14}CO_2$ followed by pyrolysis seeking ^{14}C NEGATIVE
5. **Labelled Release** - "nutrients" added to sample. Possible positive signature obtained BUT because of NO carbon detected via GC-MS - INCONCLUSIVE.

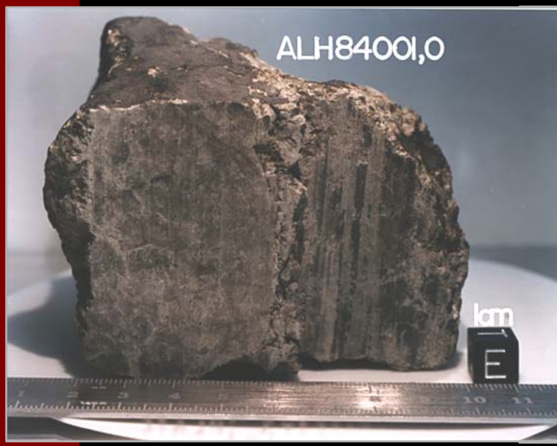
Viking 1 and 2 Label Release Experiment

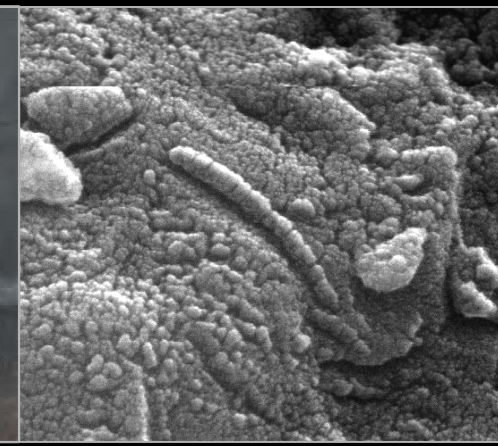
Evolution of $^{14}CO_2$ behaved as if metabolic activity was going on BUT Viking Team noted signals may be an *artifact* of "active" Martian soil - INCONCLUSIVE ? Experiment needs to be repeated.

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

AFTER: Levin and Straat, 1986

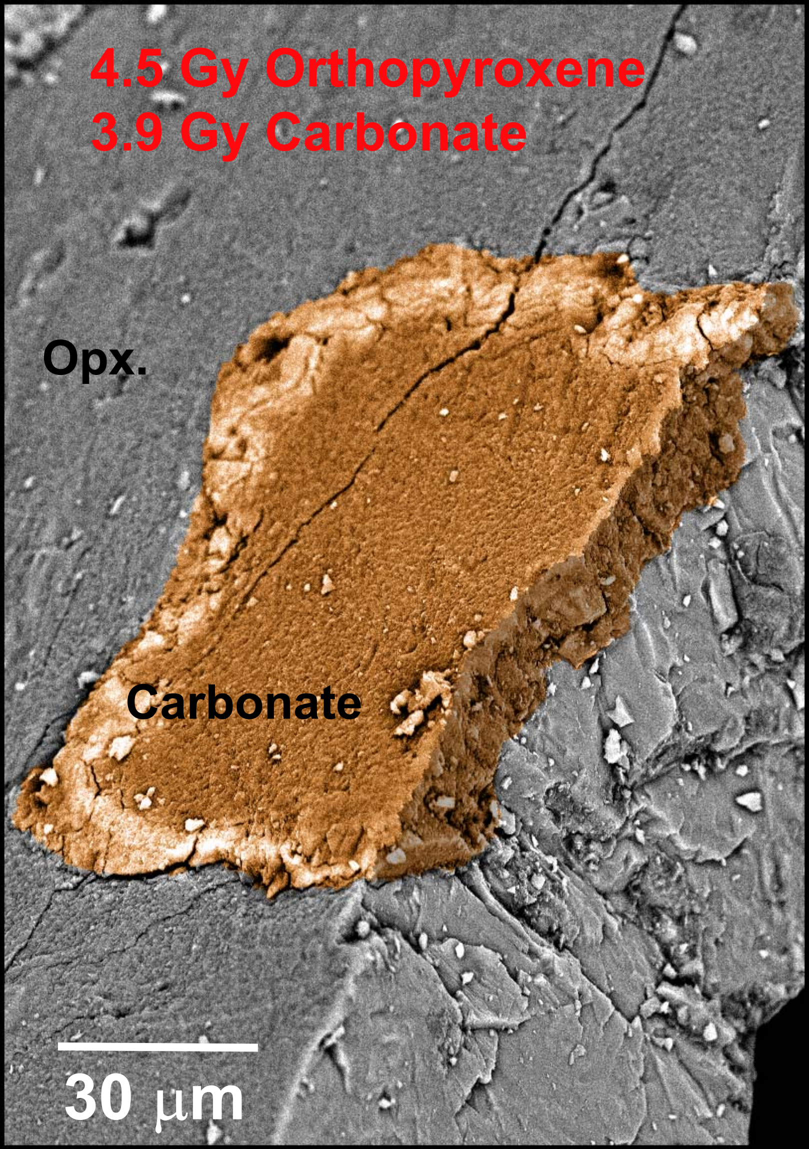
1983 - 1996 - PRESENT Martian Meteorites

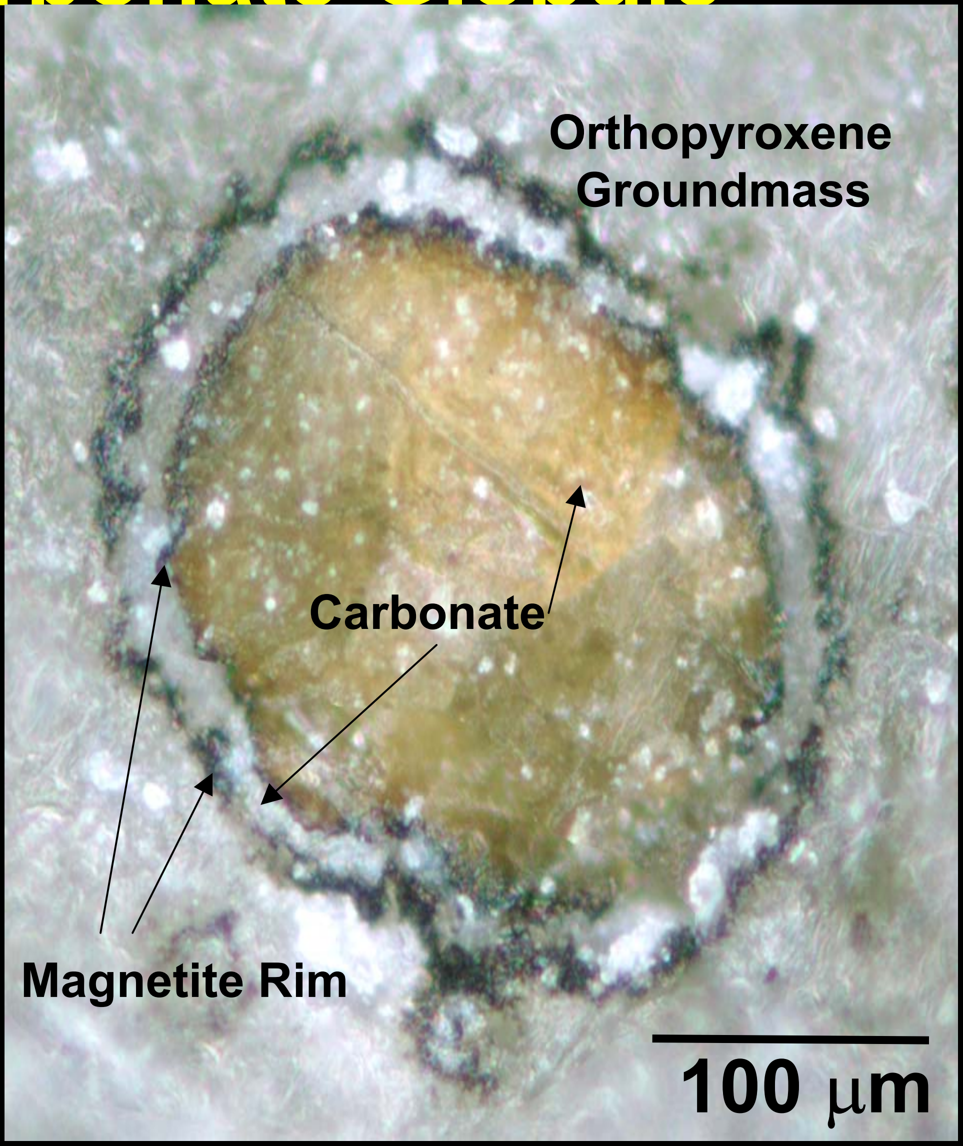




- Martian meteorites strongly suggest that they were "processed" in a wet environment, therefore suggesting that water played a relatively large and important role in the planetÕs crustal history.
- Meteorite (ALHA84001) is almost as old as the solar system, and contains preserved carbonates.
- Mars (unlike Earth) has preserved samples of its earliest rocks (and hence environments) and therefore may harbor clues to how LIFE gets started on any planet in our Solar System.

ALH84001 Carbonate Globule





Four Lines of Evidence Presented in 1996

Carbonates formed at Low-Temperatures,
Indigenous Organic Compounds Present,
Magnetites (Fe_3O_4) of possible biogenic origin,
Unusual Morphologies of “fossilized features”

HYPOTHESIS:
ŅSIGNATURES OF BIOGENIC ACTIVITYÓ

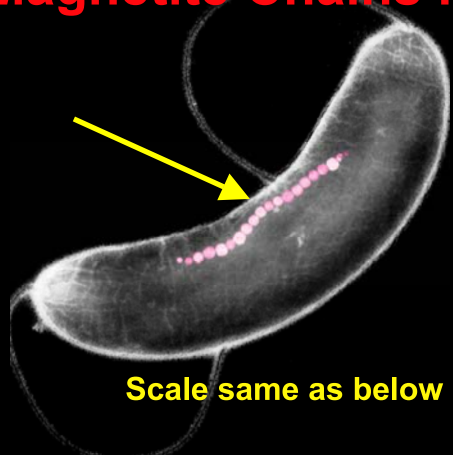
After Eight Years of Extensive Research

All Four Lines of Evidence Still Stand

Magnetite Continues to be our Strongest Evidence

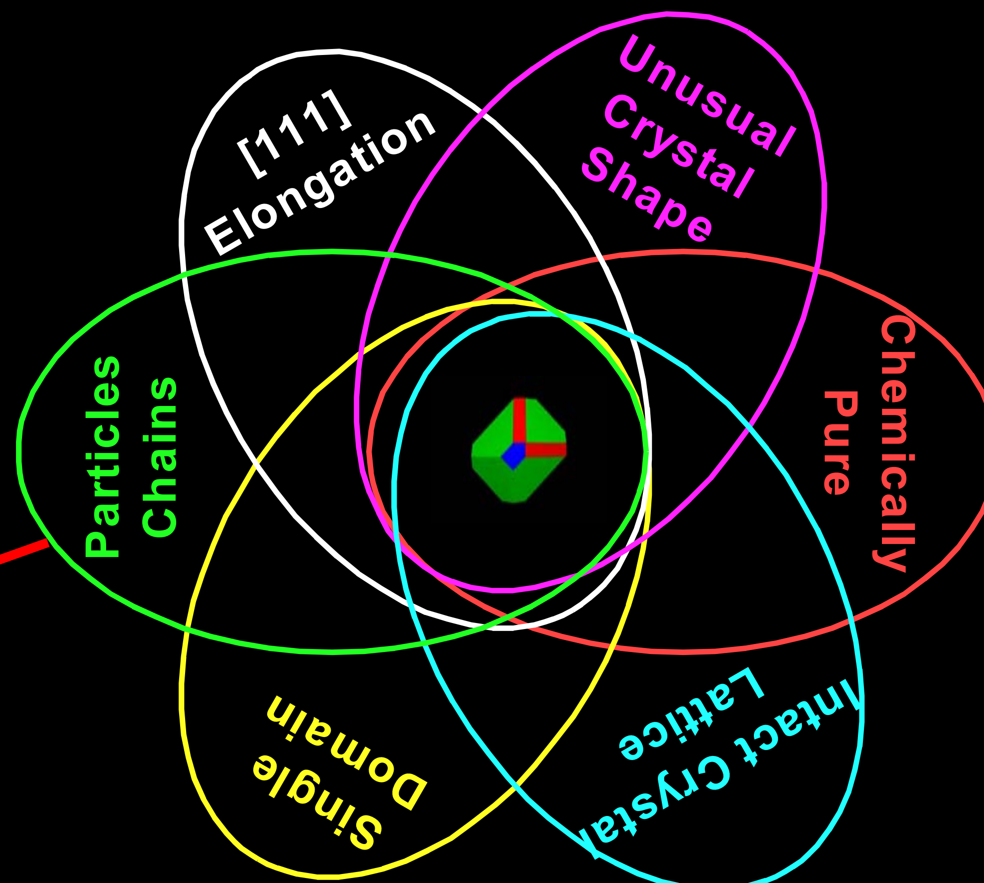
MAGNETITES AS SIGNATURES OF LIFE

MAGNETOTACTIC BACTERIA
Magnetite Chains in MV-1

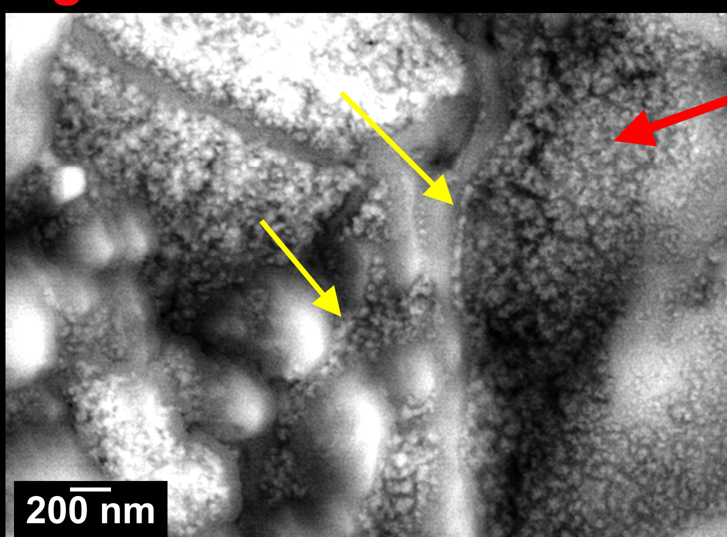


Scale same as below

Six Properties of Biogenic Magnetite



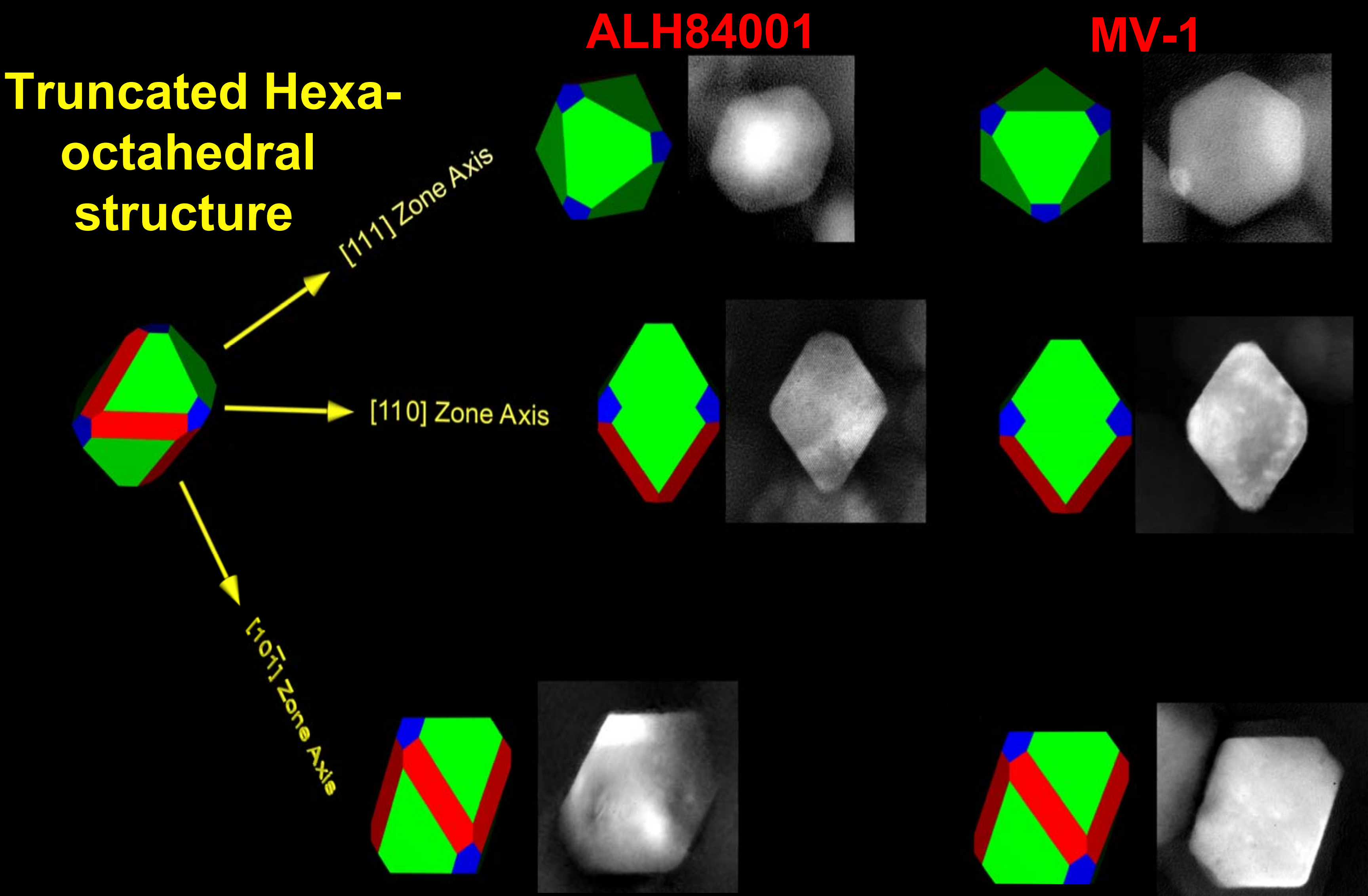
Magnetite Chains in ALH84001



Friedmann et al. PNAS (2001)

Thomas-Keprta et al. 2000, 2001, 2002; Kirschvink, AGU 2003

Morphology of Biogenic and Martian Magnetites



Thomas-Keprta et al. 2000, 2001, 2002; Kirschvink, AGU 2003

MAGNETITES IN MARTIAN CARBONATES

- Unique Magnetite morphologies in ALH84001 Carbonates
  - Identical to Magnetites from MV-1
  - Six Properties which are unique.

Chains of Magnetites in 84001 carbonates (Friedmann et al., PNAS, 2001)

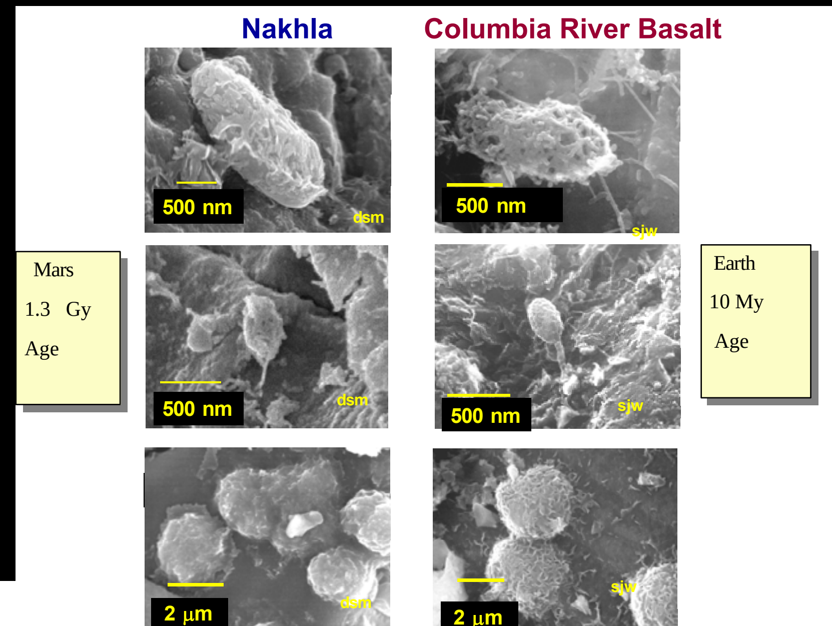
Synthetic Magnetites of Golden et al. are NOT identical to magnetites in 84001 carbonates-Violate several unique properties of Martian magnetites (i.e. compositions, thermal histories, trace elements, etc.)

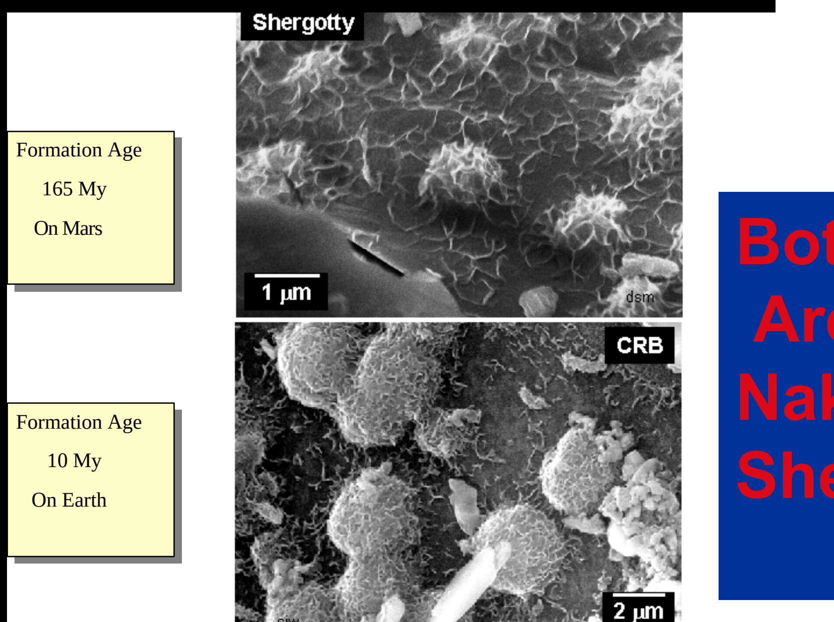
QUESTION: The properties of magnetite have been used to identify signatures of biogenic activity in terrestrial samples for thirty years. When the same signatures exist in Martian carbonates, why do the identification rules not apply?

To be Biology: Duplicates must exist.
Features Found in Two Younger Martian Meteorites of different ages!

Unique Morphologies In two Younger Martian Meteorites Compared to Recognized Terrestrial Fossilized Bacteria in Columbia River Basalt

(Basalt age = 10 my)



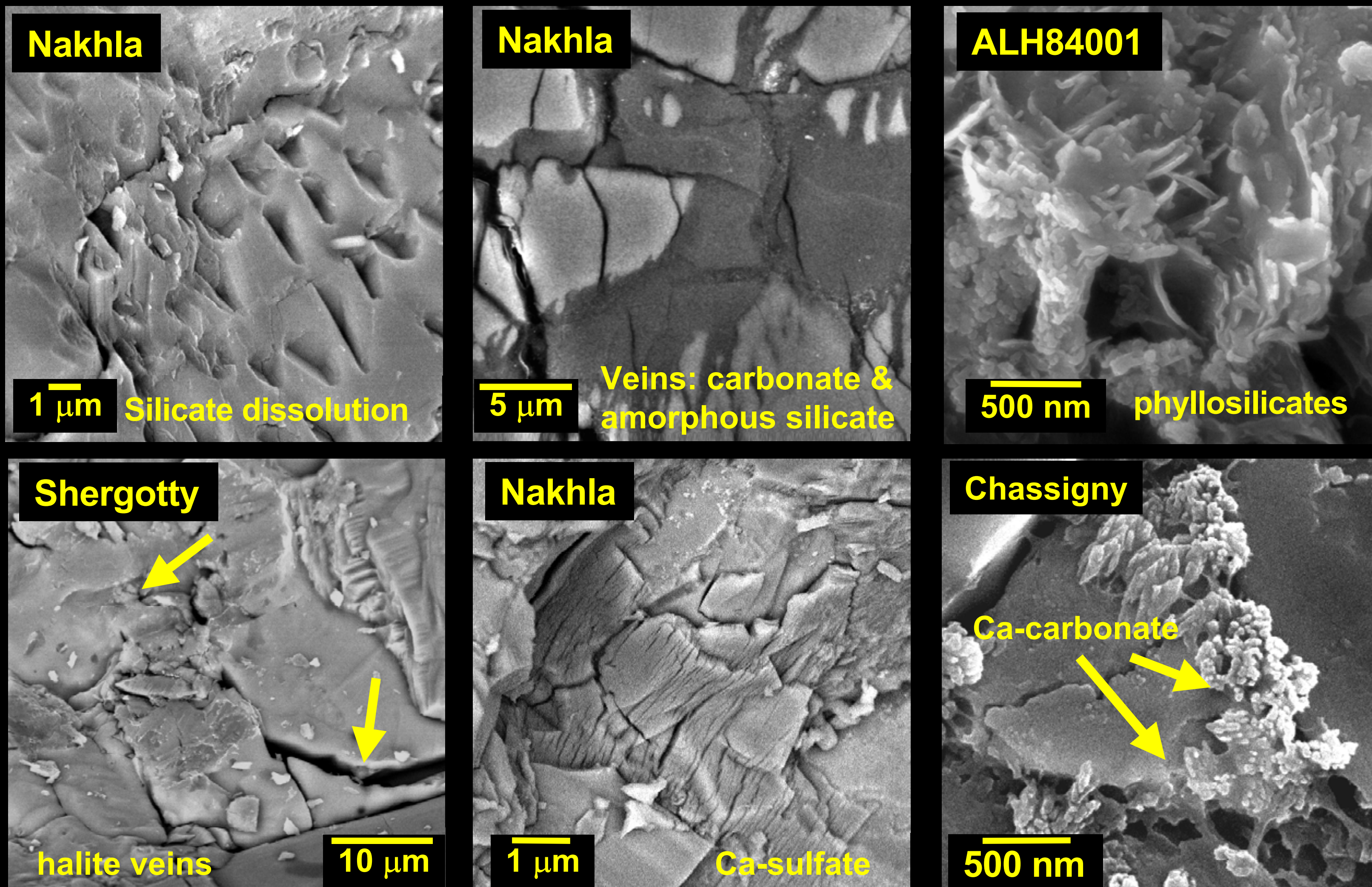


Both Martian Meteorites Are Fresh Falls

NakhlaĜs Fm. Age 1.3 Gy

Shergotty Fm. Age 165 my

Water on Mars? --you bet!!



(Notes: all meteorites shown here except for ALH84001 were <u>observed falls</u>; all examples here are from interiors of the meteorites)

Wentworth et al., Icarus (2005)

CARBON IN MARTIAN METEORITES

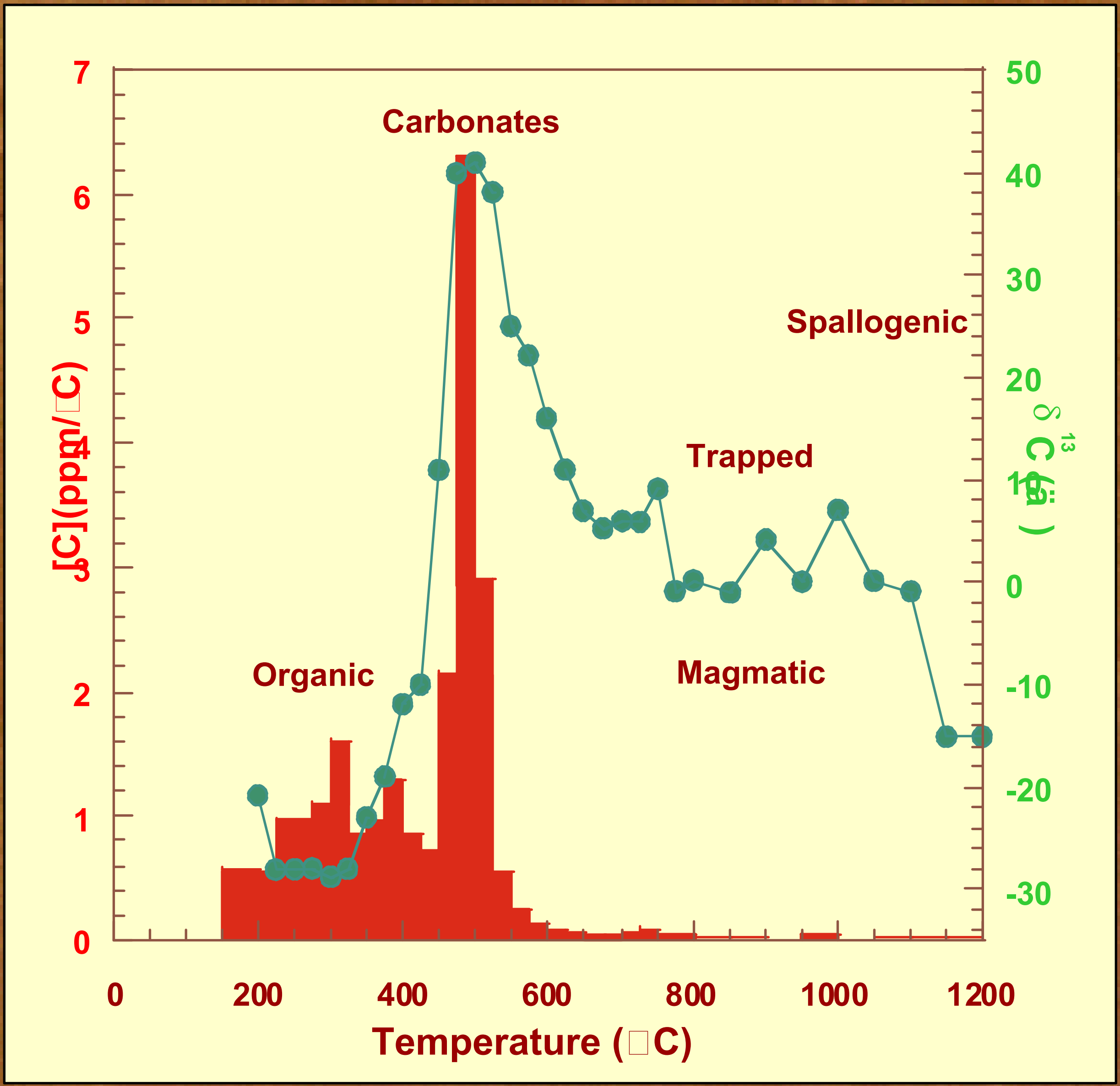
- **<u>Lithosphere</u>**
  Primary Magmatic silicates

- **<u>Hydrosphere and Atmosphere</u>**
  Secondary Carbonates

- **<u>Biosphere (?)</u>**
  Reduced organic carbon components

MARTIAN SAMPLE

ALH84001

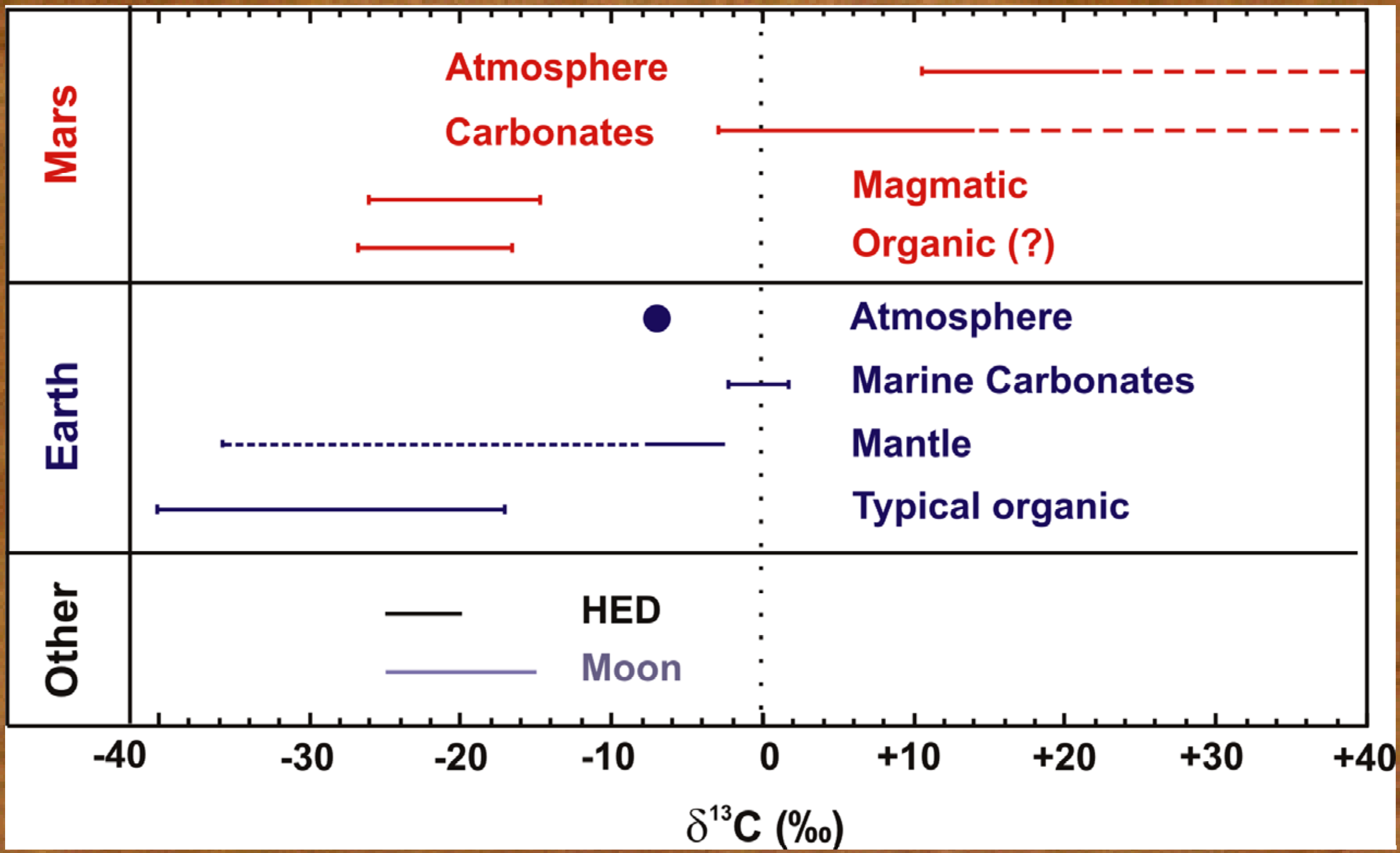


CARBON COMPONENTS

Data from stepped combustion

From Grady et al, 1997

Carbon Isotopic Compositions



After Grady and Wright, 2004

REVIEW OF CARBON COMPONENTS

⇒ **PRIMARY CARBON**

Present as reduced, well crystalline carbon
$\delta^{13}C$ of -20 ± 4‰ (lighter than terrestrial basalts of ~ -5‰)

⇒**EITHER:**

- **δ^{13} C of Mars is different from Earth**
- **Martian meteorites contain reduced carbon with $\delta^{13}C$ established by isotopic fractionation during emplacement (loss of heavy component during degassing)**
- **Secondary Carbonates have $\delta^{13}C$ of ~ +24 to +40‰**
- **Martian meteorites contain a recycled component that could, in principle, reflect a Martian biological signature (range of ~ -18‰ to -60‰)**

[After Grady and Wright, 2004]

MARTIAN METEORITES' REDUCED CARBON COMPONENTS

Indigenous reduced carbon identified in Martian Meteorites:
EET79001 by Wright et al. (Nature, 1989)

^{14}C Signatures in Martian meteorites suggest indigenous reduced carbon component present:
ALH84001 15 to 20 % is indigenous and not terrestrial
Nakhla 75 to 80 % is indigenous (Jull et al.)

Amino Acid's presence in Martian meteorites is inconclusive
ALH84001 has amino acids BUT identified to be contaminants from Antarctic environment.

Nakhla contains amino acids -possible mixture of terrestrial and extraterrestrial amino acids.

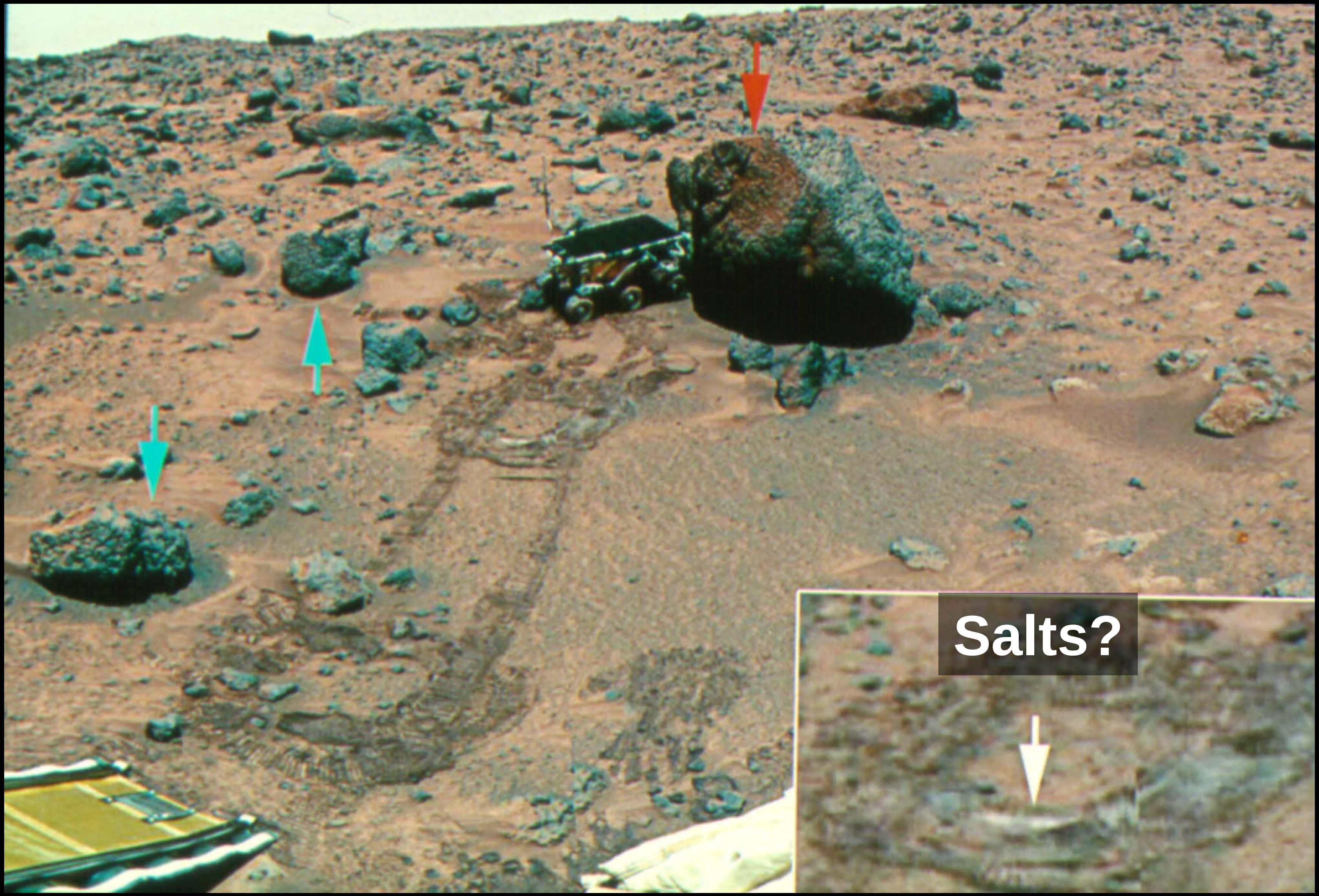
Biofilms identified in Martian meteorites: ALH84001, Nakhla and Shergotty (Gibson et al., Precambrian Research, 2001: Westall et al., 2001,2002)

Mars Pathfinder

1997

- Successfully demonstrated surface mobility and robust entry & landing system
- Stereoscopic imager and elemental analyses of rocks enhanced surface geology

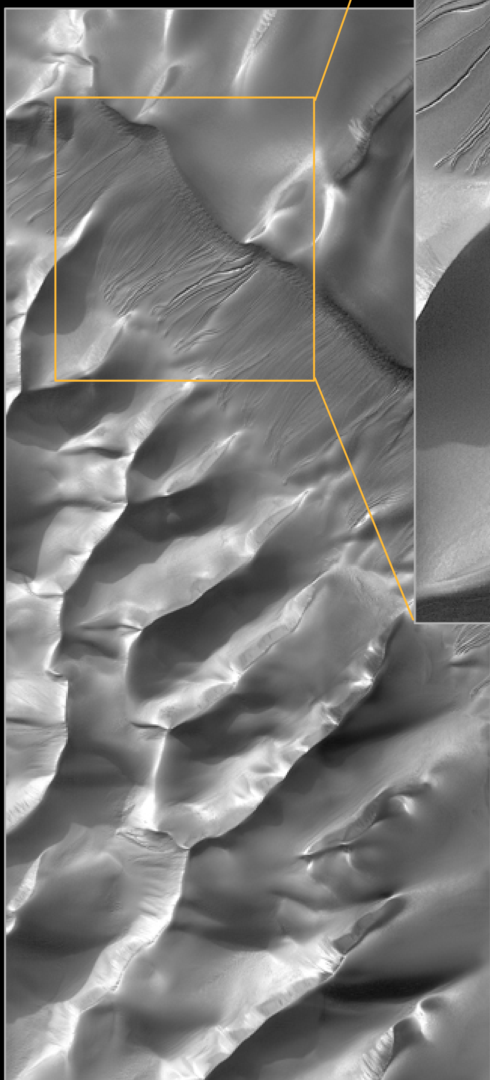
Pathfinder - Mars 1997

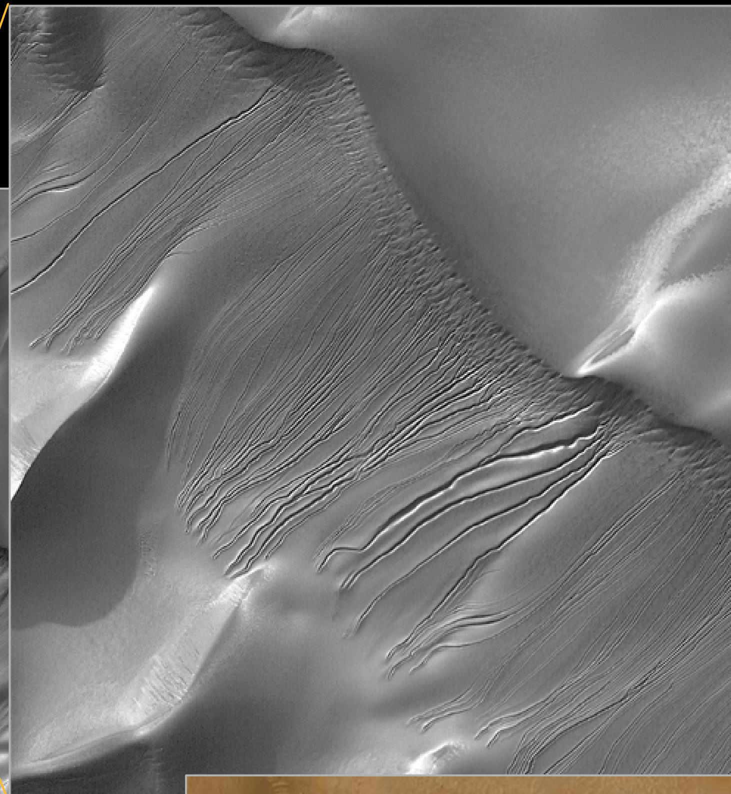


MARS
GLOBAL
SURVEYOR

1999 To
Present

Martian Gullies: *Watersigns*

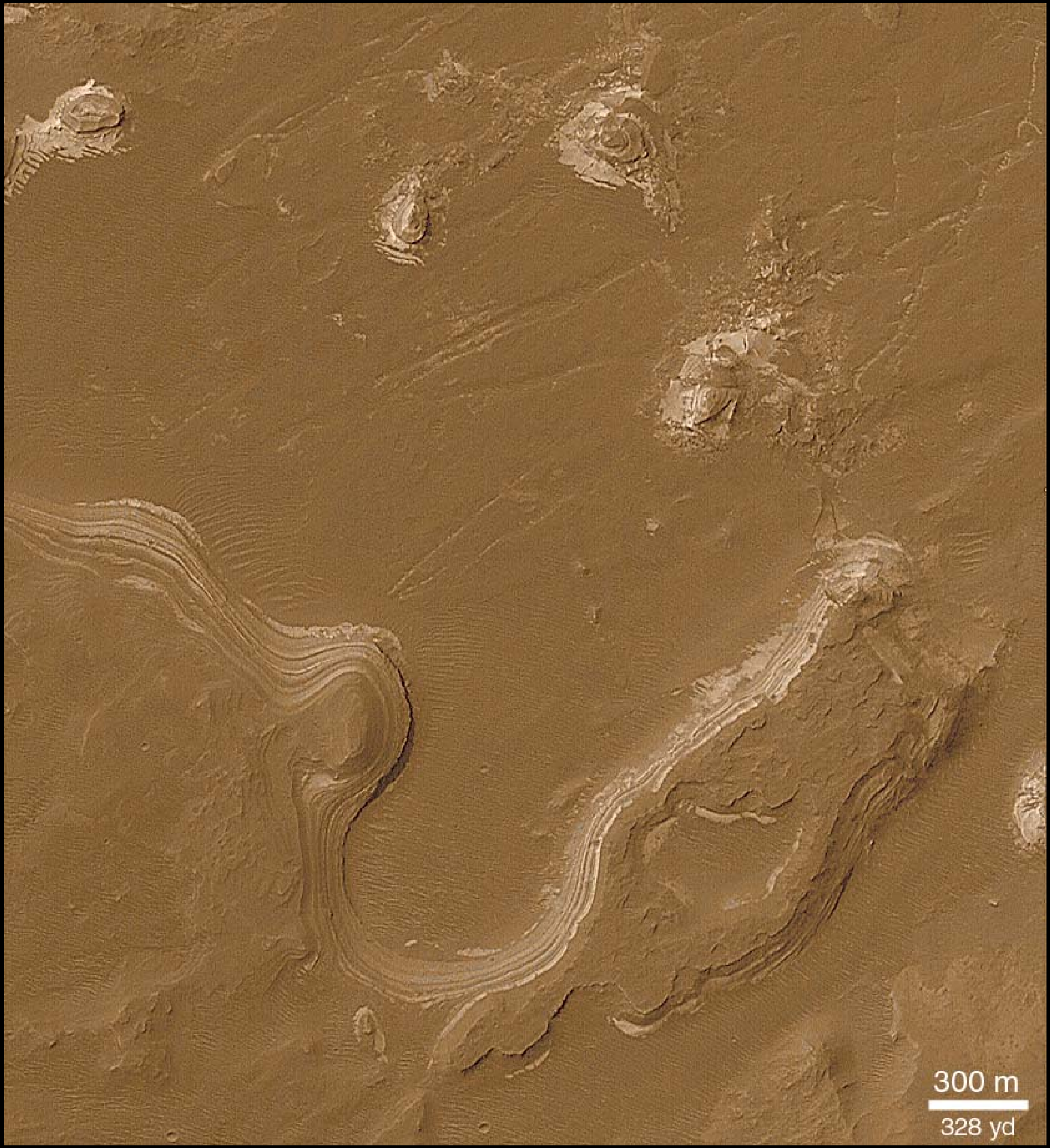


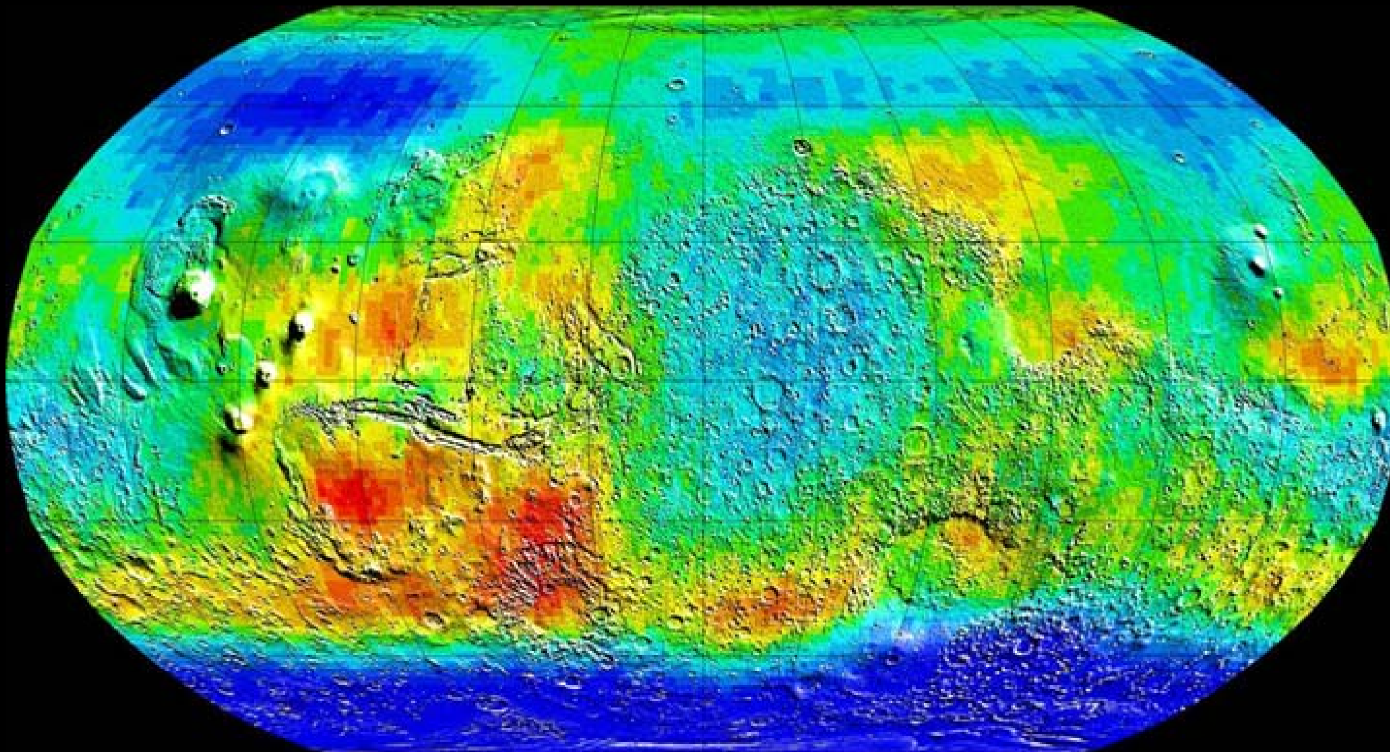


MARS GLOBAL SURVEYOR

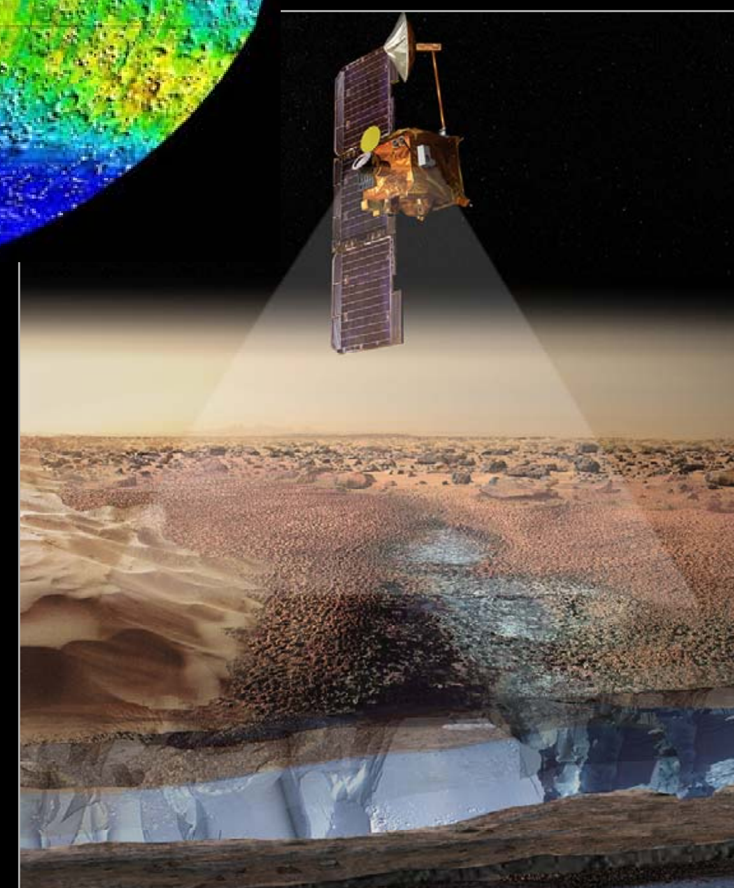
MASSIVE SEDIMENTS

Deposition by:
Wind?
Water?





More Hydrogen Less



Mars Odyssey has revealed abundant water ice in the upper few feet at high latitudes

2001 to Present

Mars and Earth both formed 4.5 billion years ago. Did Mars once have a warm, wet environment for life?

Evidence suggests wet planet

Mars Express with Beagle 2 Approaching Mars


Beagle 2 on Surface
(Artist Impression)
December 25, 2003 ??

MAJOR SCIENCE GOALS

- **Orbiter:**

  Global high-resolution & selected super-resolution photogeology

  Global mineralogical mapping

  Subsurface structure (few km)

  Global atmospheric circulation and chemical composition

  Water/ice reservoirs and cycle

  Surface-atmosphere interaction

  Interaction of upper atmosphere with solar wind

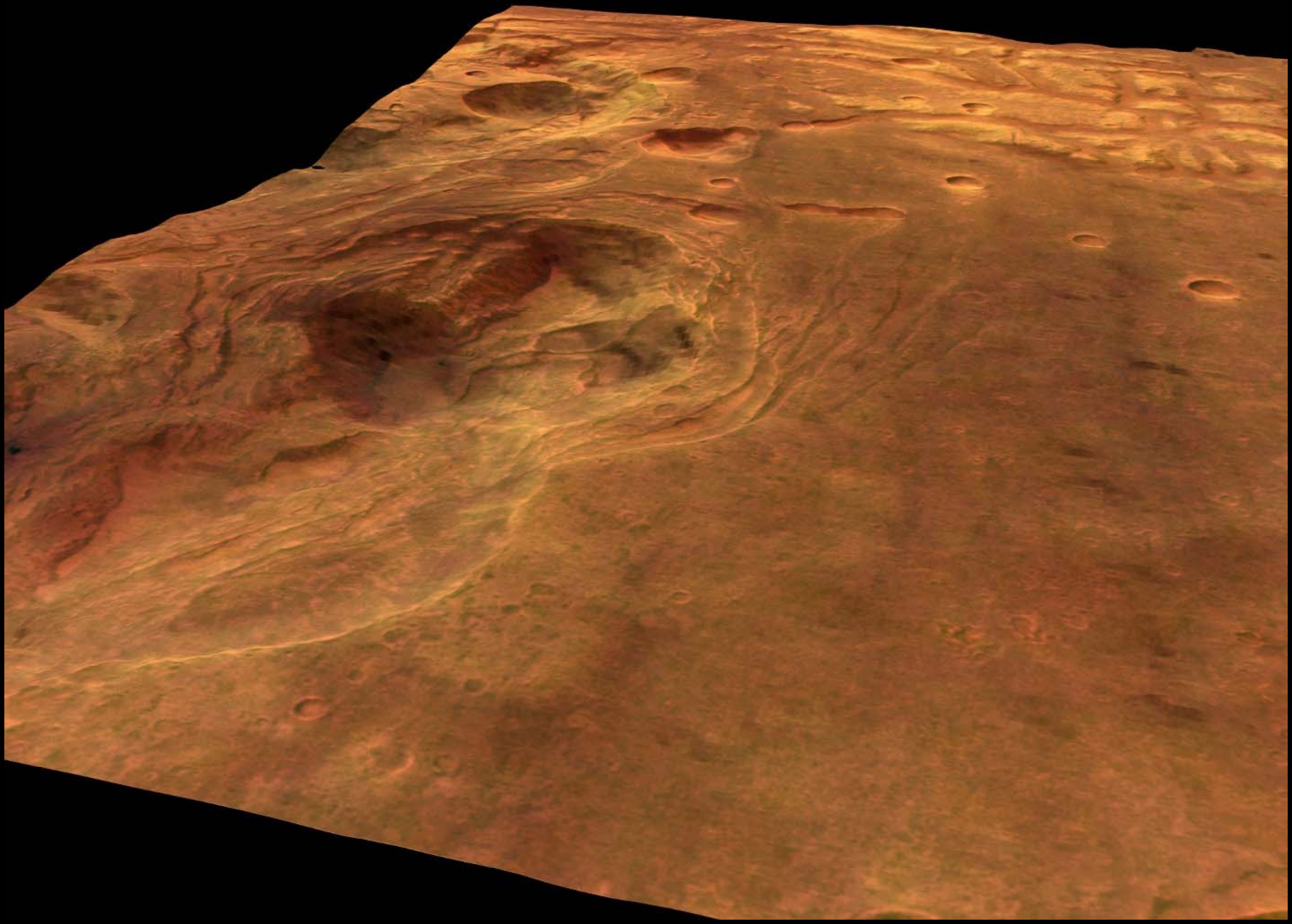
- **Lander:**

  Geology & mineralogy of landing site

  Organic, mineral, isotopic chemistry

  Exobiology (i.e. life signatures)

  Meteorology and climatology



Karst-like

Structure

Water Beneath Surface ?

Mars Express Planetary Fourier Spectrometer Spectra of Methane in Mars’ Atmosphere

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Methane in Mars Atmosphere

SUGGESTIONS OF REGIONAL VARIATIONS IN CH_4 SOURCES

Water in Martian Atmosphere

Methane concentrations increase over three basins suggesting correlation with water/ice.

Water/Ice + Methane = Suggestion of Life??

V. Formisano et al. Science 306, 1758 (2004)

Methane in the Martian Atmosphere: Evidence for Life?

Krasnopolsky, Maillard and Owen, ICARUS (in press, 2004)

¾ Telescopic measurements of CH_4 in Martian atmosphere using Fourier Transform Spectrometer at Canada-France-Hawaii Telescope.

¾ Measured 15 strongest Doppler-shifted lines for CH_4 in Martian atmosphere.

¾ Observed CH_4 mixing ratio is 10 $\pm$ 3 ppb with total photochemical loss of CH_4 in Martian atmosphere is equal to 2.2 x 10^5 $cm^{-2}s^{-1}$.

¾ CH_4 lifetime is 340 years in the Martian atmosphere.

¾ No processes for CH_4 production in atmosphere, so photochemical loss must be balanced by abiotic and/or biogenic sources.

¾ Possible sources of CH_4 in Mars atmosphere:

No recent Volcanism in past 10 MY, NO thermal emissons or hot spots
No current hydrothermal systems on Mars - little CH_4 production if any
Cometary impacts deliver < 2% CH_4 and Meteoritic and Interplanetary Dust delivery does not exceed 4%
METHANOGENESIS by living subterranean organisms (i.e. bacteria) is a plausible explanation for the levels of CH_4 in Martian atmosphere.

METHANE IN MARS ATMOSPHERE

- **Mumma et al. 2003 (DPS)** **10 to 20 ppbV**
- **Krasnopolsky et al. (2004)** **11 $\pm$ 4 ppbV**
- **PFS-MEX Formisano et al. (2004)** **10 + 5 ppbV**
  Plus regional differences
  above selected basins
  with concentrations up to 30 ppbV

Sources for Martian Methane

- o. **Abiotic Sources:**

  Volcanic or Hydrothermal

  No thermal anomalies detection by TES in orbit

  Cometary Infall - Only 2% Contribution - Too Low

  Meteorite/Dust Infall - Only 4% Contribution - Too Low

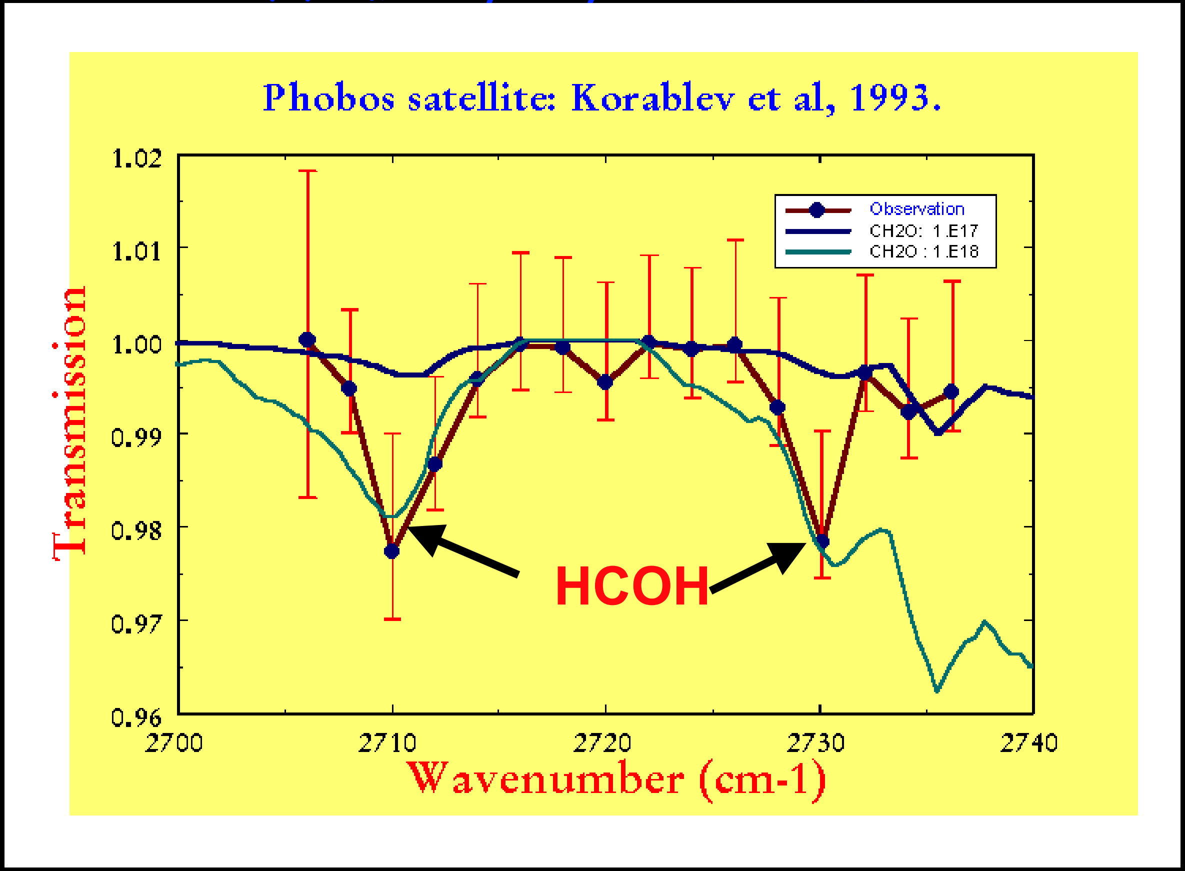
- o. **Biogenic Sources**

  Supported by:

  - o Methane in Martian atmosphere - Methanogenic Bacteria?
  - o Abundance of Martian water - "life requires water"
  - o Indigenous reduced carbon in Martian meteorites
  - o Isotopic composition of reduced carbon- -15 to -18 ‰

  - o Biogenic-like magnetite in Martian Meteorites
  - o Label Release Experiment-Viking ??

1989: observation of formaldehyde by the Russian PHOBOS satellite

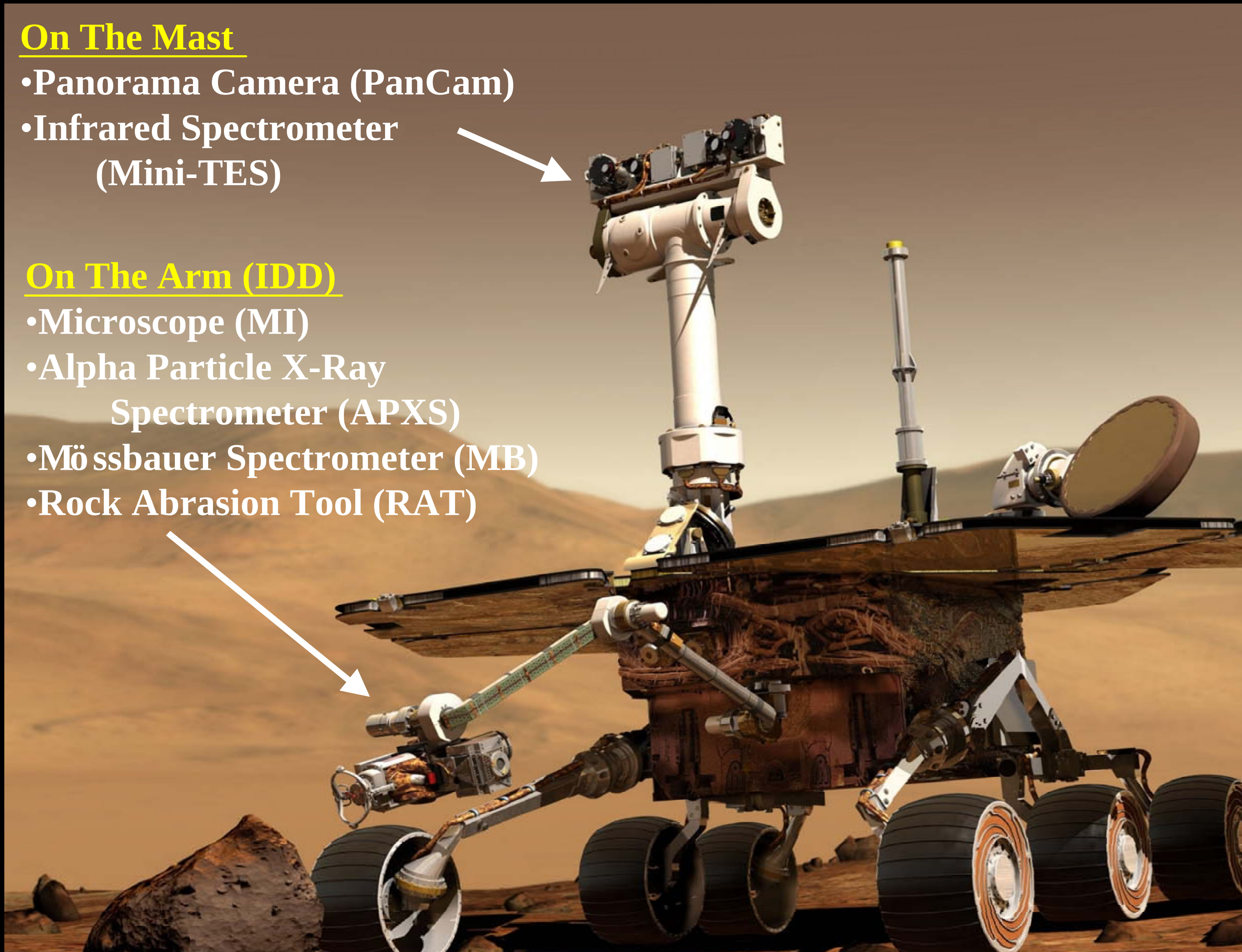


[After Muller et al.EANA, 2004]

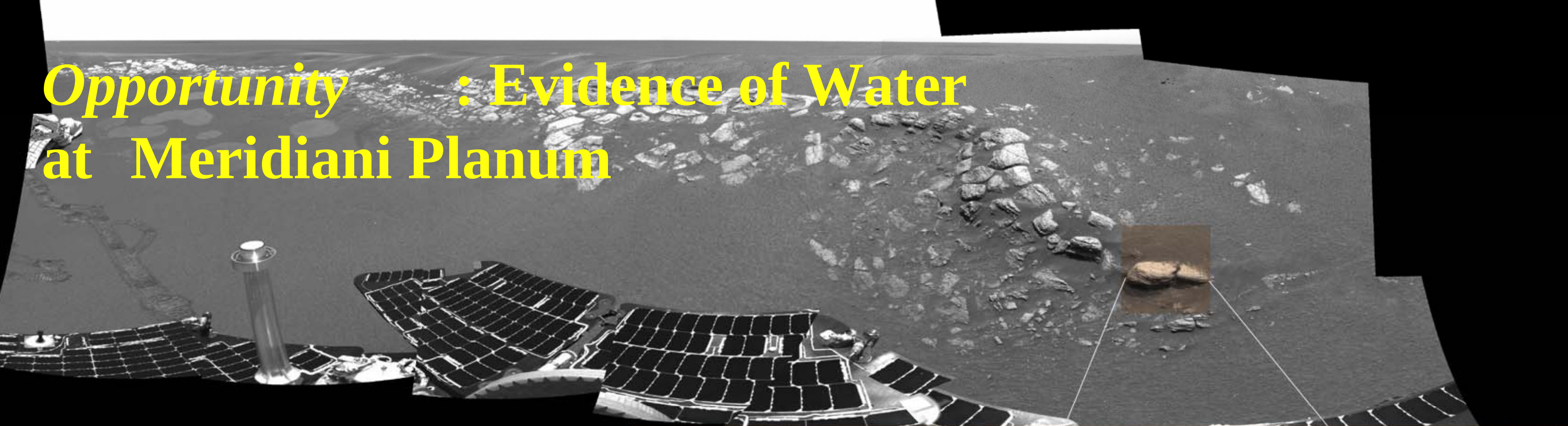
SPICAM
And PFS
this
Meeting
NEW
RESULTS

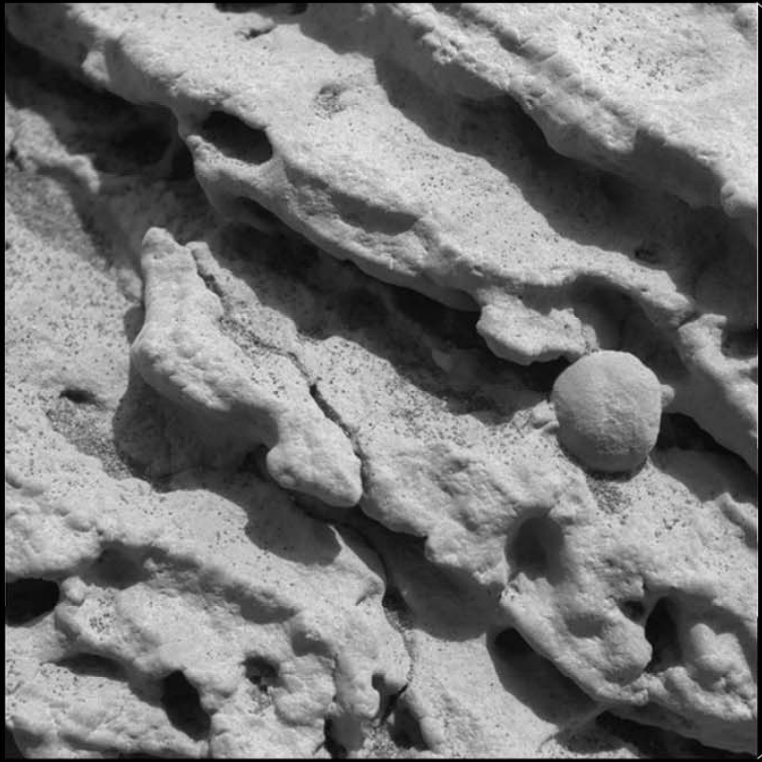
Horowitz et al., PNAS (1971) showed formaldehyde, acetaldehyde, and glycolic adid should be present in Mars atmosphere because of photochemistry. In Lab: $CH_4 + H_2O + uv = HCOH$ (this meeting)
Therefore, formaldehyde's presence is not totally unexpected.

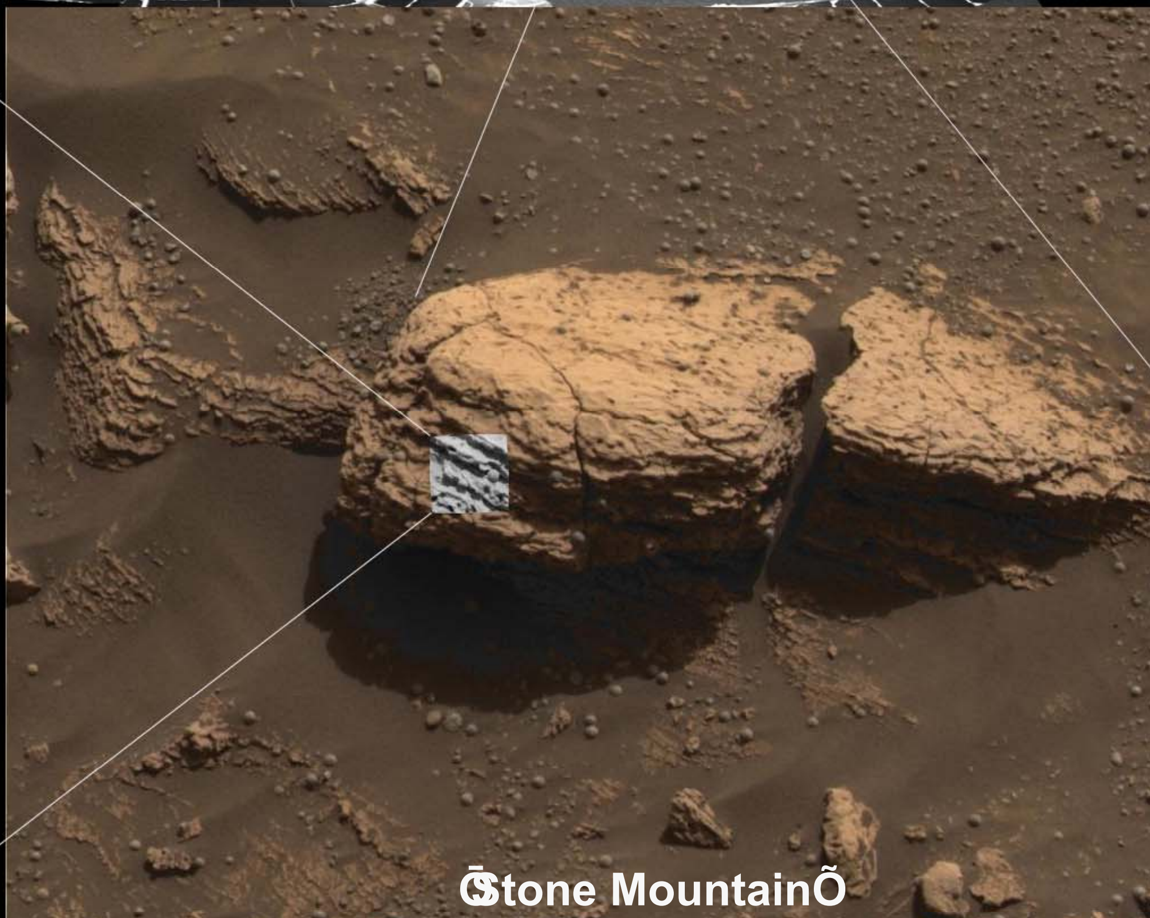
Spirit and Opportunity-Robot Geologists



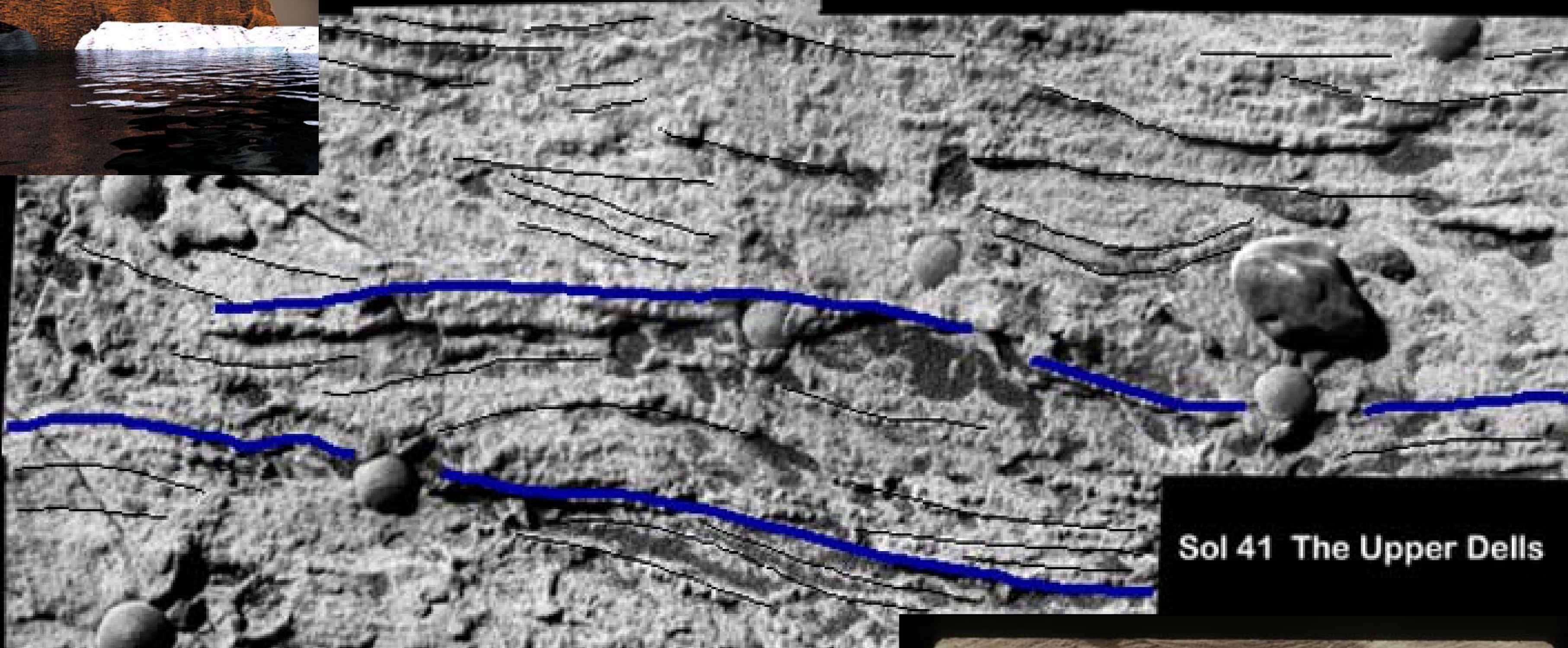
Opportunity: Evidence of Water at Meridiani Planum







Opportunity Discovers Evidence of Rocks Deposited in a Body of Water!



Sol 41 The Upper Dells

Last Chance

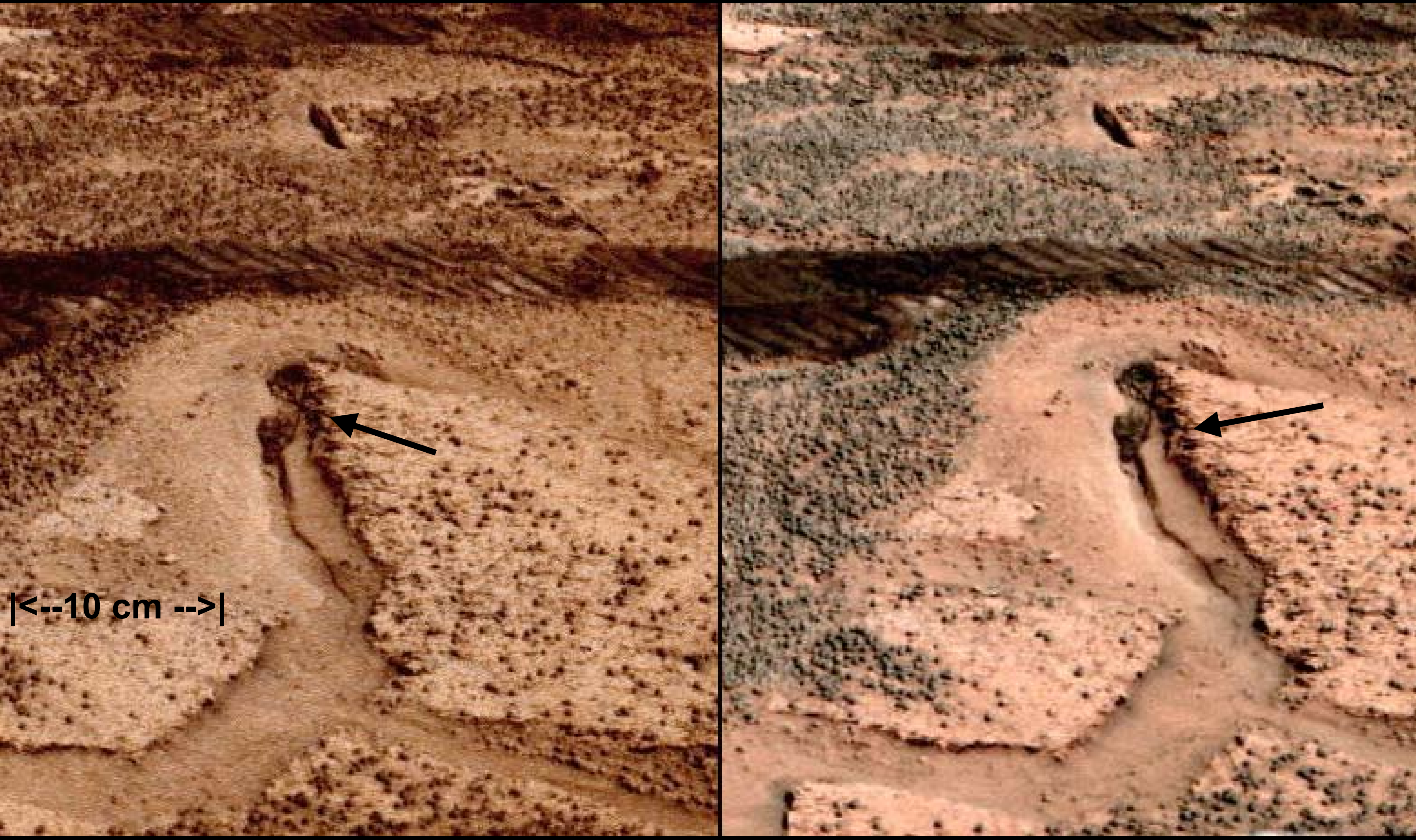
ENDURANCE CRATER

“Geyser” or “Fluid Vent”

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

|<-- ~ 10 cm -->|

Opportunity - Endurance Crater "Geyser Site"

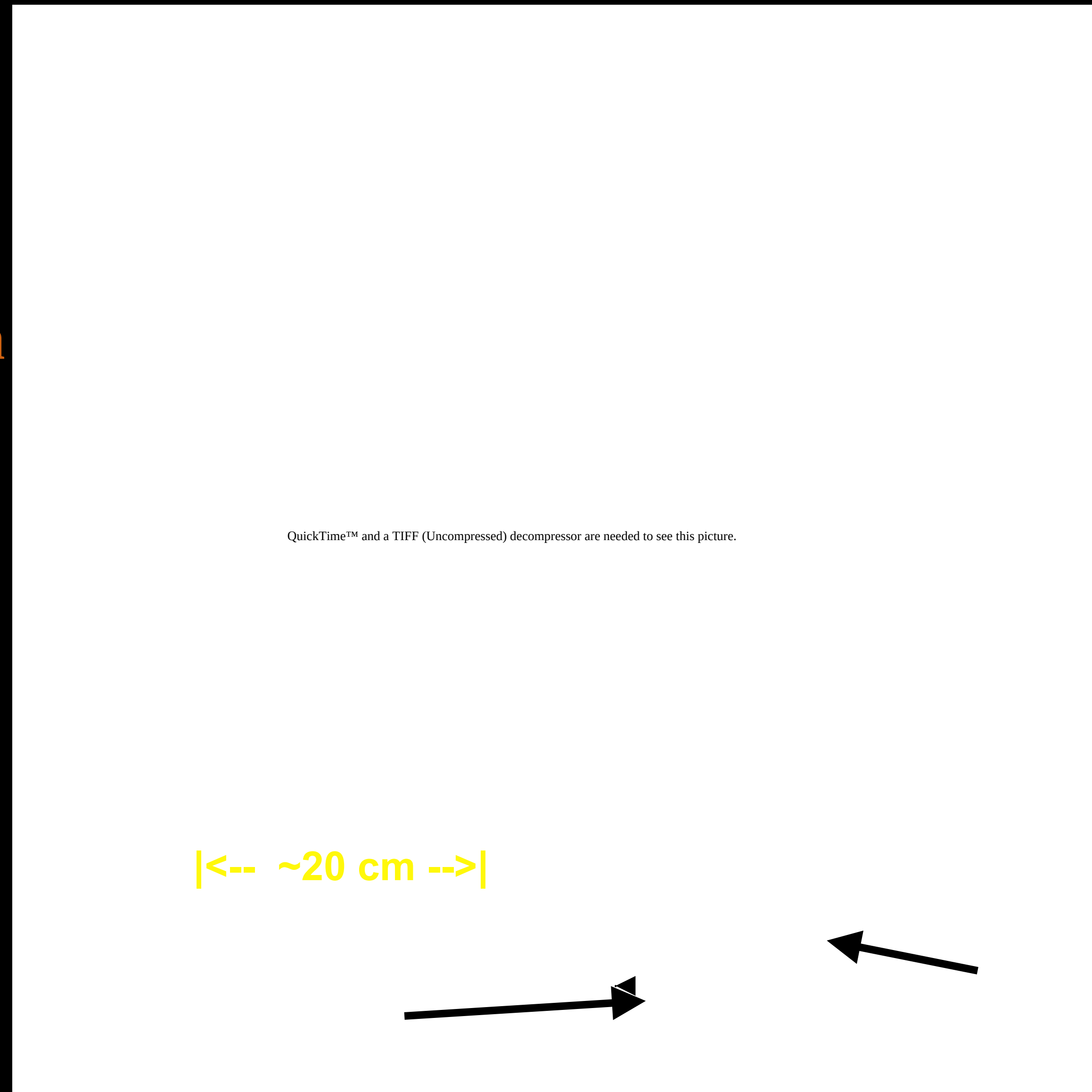


Sol 122

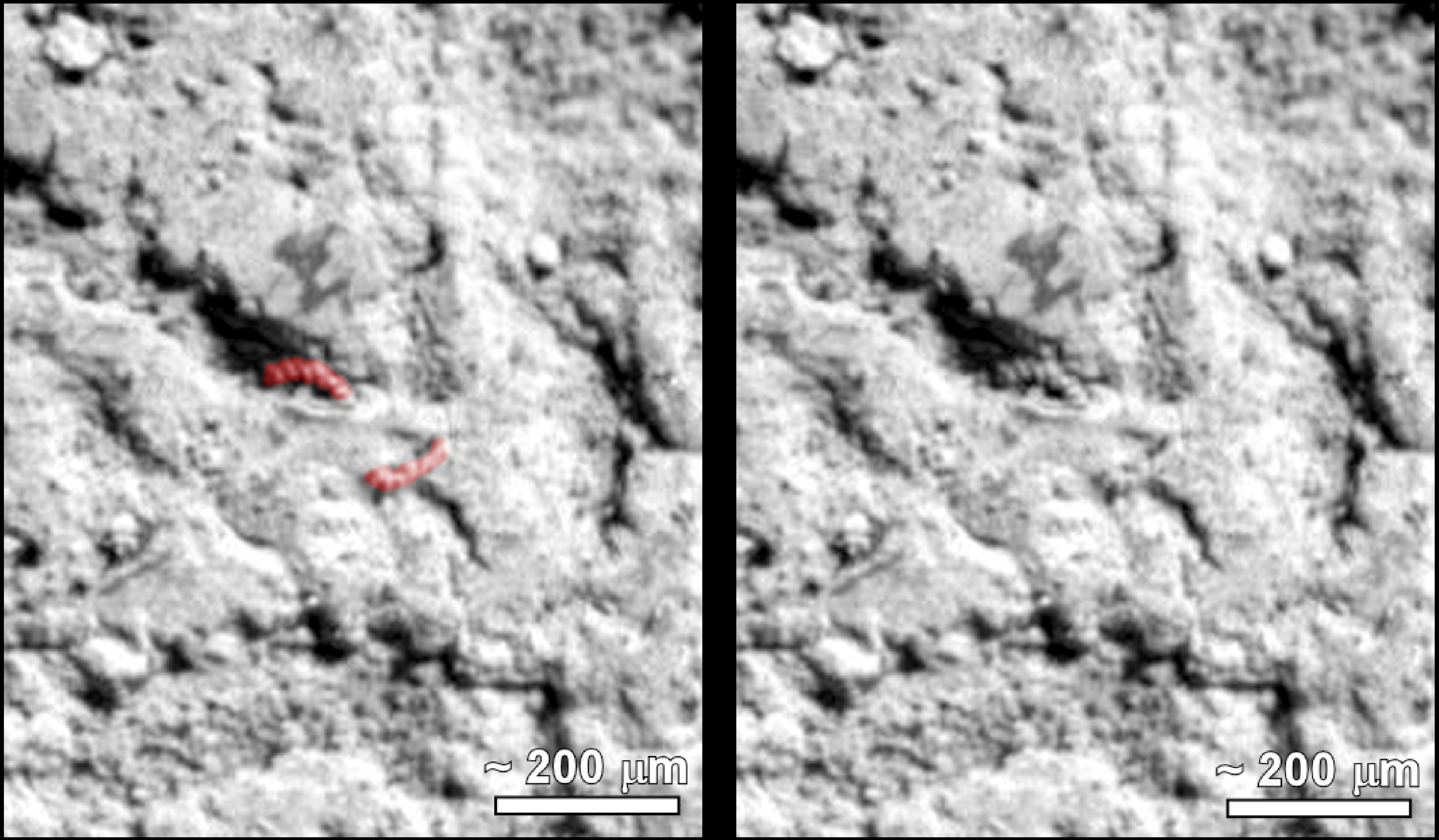
Water Leaking from Beneath the surface in Bonneville Crater

Tufas

Evaporite Deposits ?



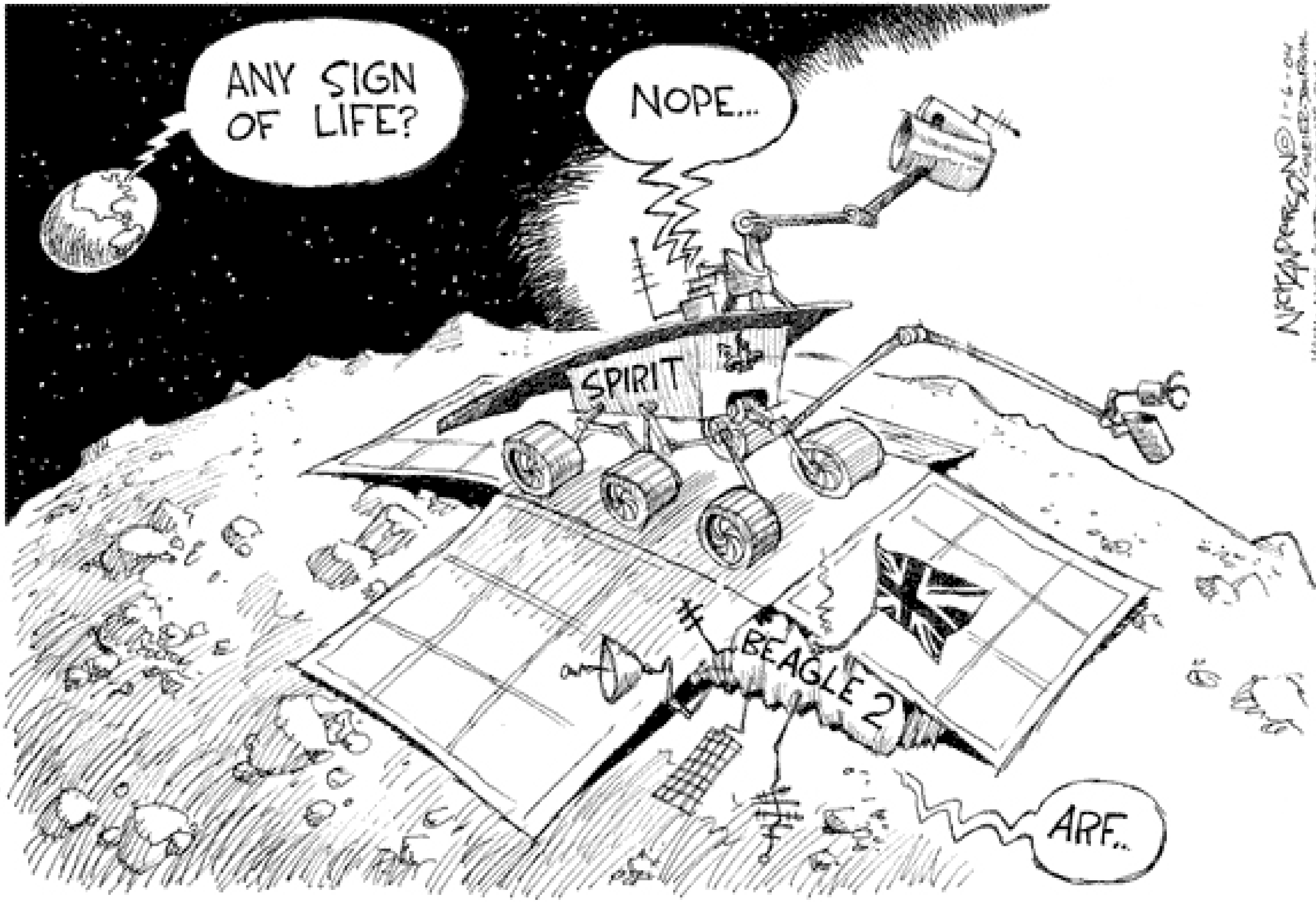
UNUSUAL MORPHOLOGICAL FEATURE:
MICROFOSSIL - ??
ARTIFACT OF "RAT" ABRASION TOOL??



File: 1M130859941EFF0454P2949M1M1; Opportunity, Sol 30

⇒ Presence of sulfates suggest very acidic fluids (pH 2-6)

⇒ Remember: Most living systems prefer slightly alkaline fluids.
However, there are exceptions.


ANY SIGN OF LIFE?
NOPE...
SPIRIT
BEAGLE 2
ARF..

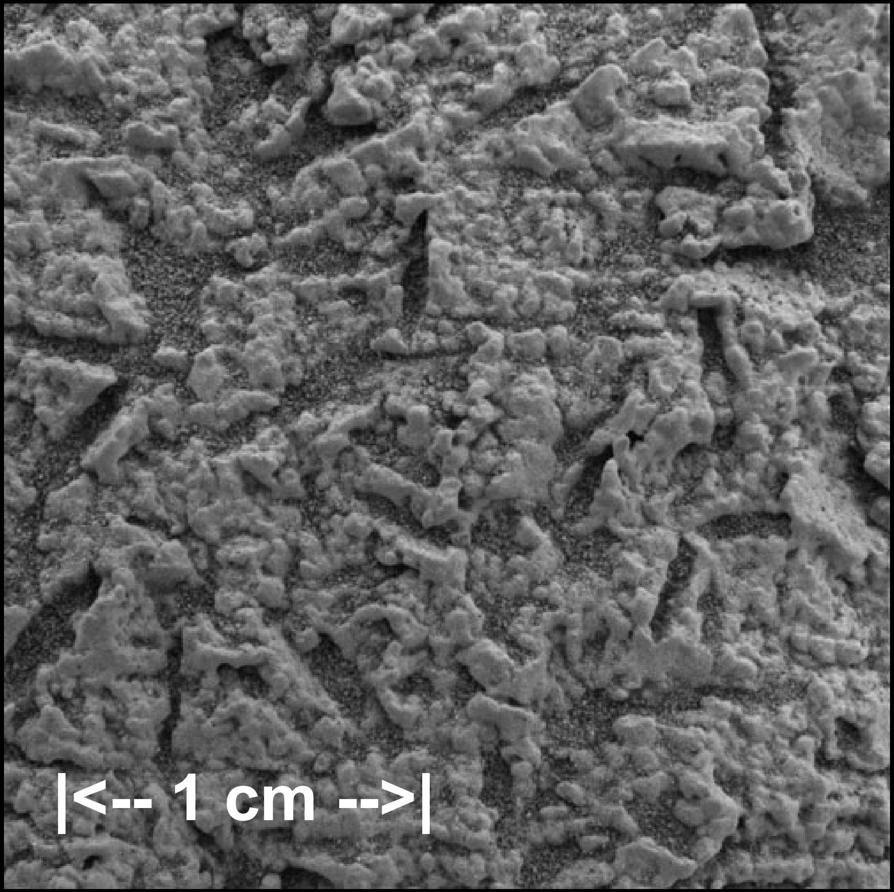
LOST OPPORTUNITIES FOR BIO/GEOSCIENCES

- ANOTHER LOCATION ON MARS
- UV FLUX AT SURFACE - SURVIVAL OF ORGANICS
- ISOTOPIC MEASUREMENTS OF MARTIAN H, C, N, AND O
  In Situ for BIOGENIC ELEMENTS VIA STEPPED COMBUSTION
- METHANE'S ISOTOPIC COMPOSITION AND ABUNDANCE IN
  ATMOSPHERE - DETERMINE IF BIOTIC OR ABIOTIC ORIGIN
- GROUND TRUTH FOR HYDROGEN ABUNDANCES - SUPPORTS
  MARS ODYSSEY MISSION
- SUBSURFACE AND CORE SAMPLES FOR GAS ANALYSIS AND
  COMPOSITIONAL STUDIES
- COMPOSITIONAL ANALYSIS OF WEATHERING SURFACES
- AGE DATING SURFACE MATERIALS - CALIBRATION OF
  CRATERING RATES

Evaporites and Salts at Meridiani Site

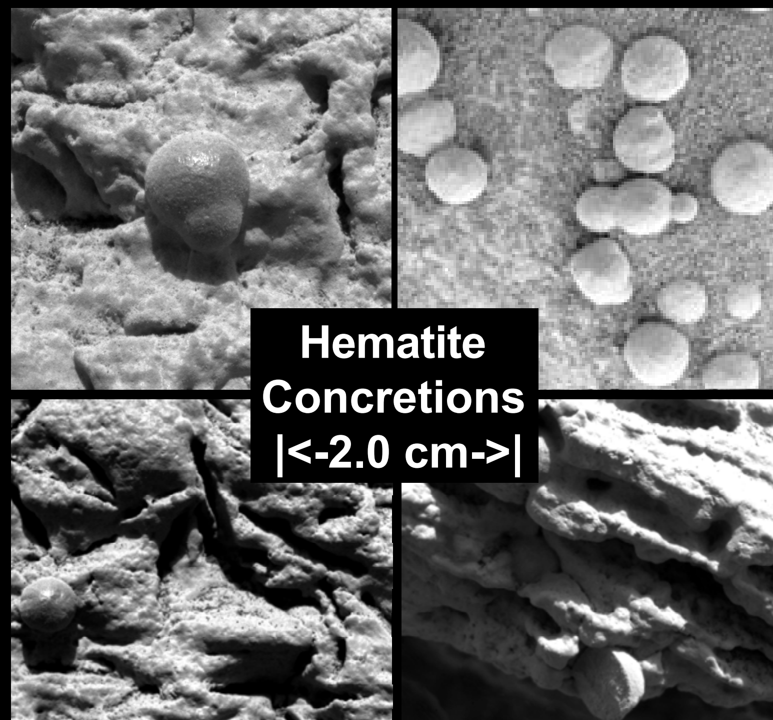
Gypsum ŅMoldsÓ?

A Beagle 2 Instrument Suite could provide information on unanswered questions

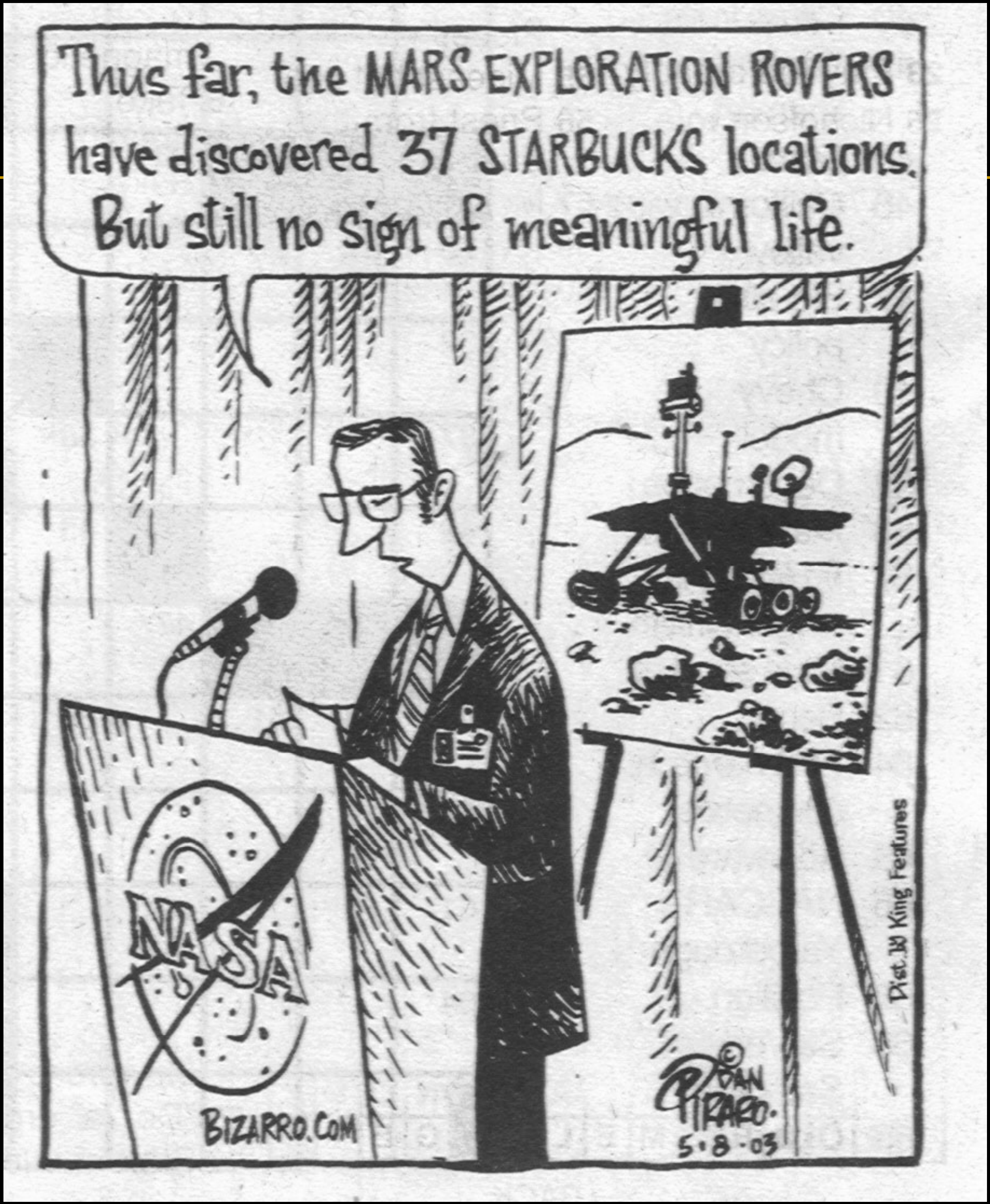


GAP has capability to distinguish between hydrates, carbonates, sulfates, etc. along with measuring isotopic compositions which would have assisted in identifying origins of evaporites

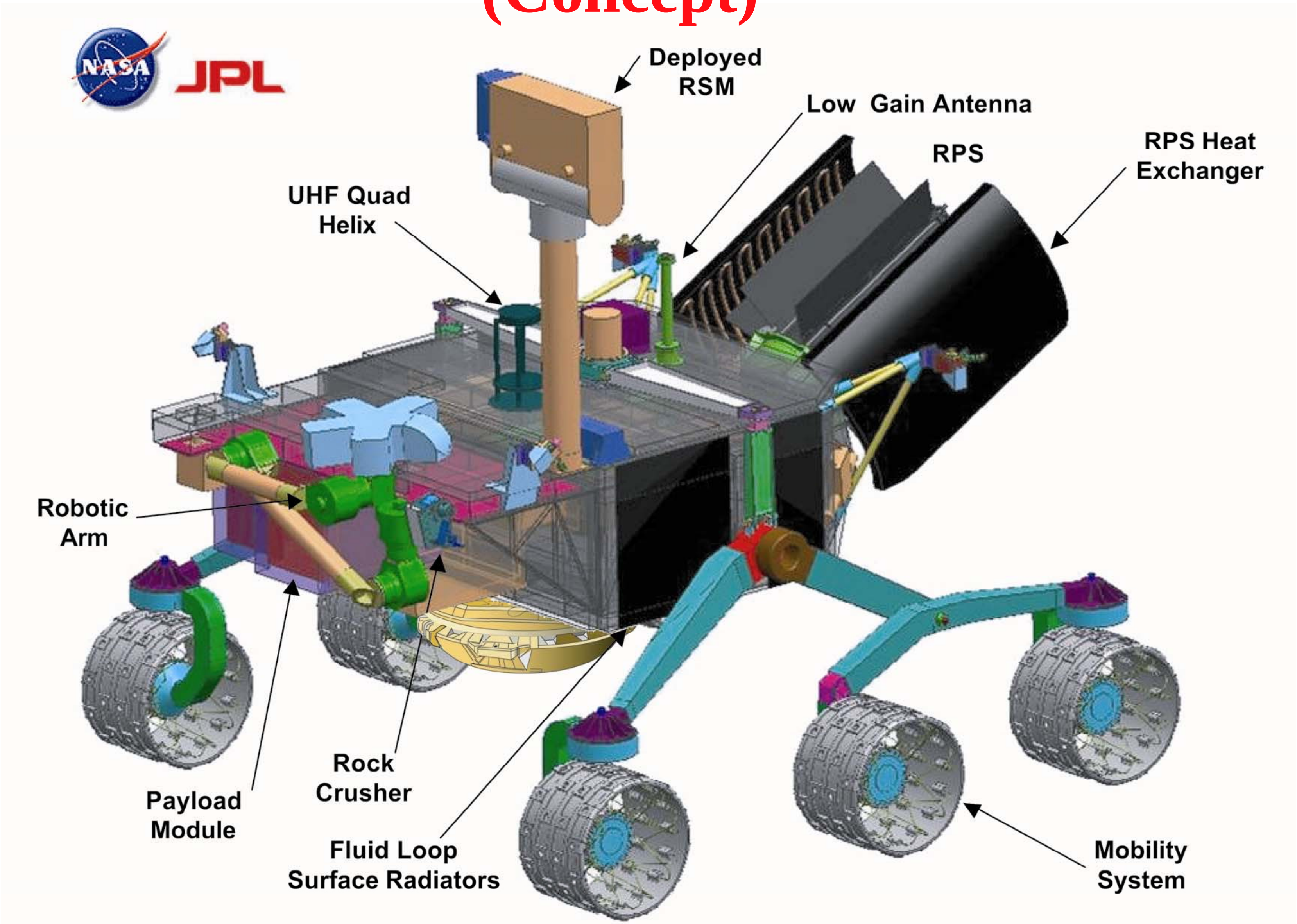
Hematite Concretions on Earth often have a Ņ



http://marsrovers .jpl.nasa.gov/newsroom/ pressreleases /20040318a.html

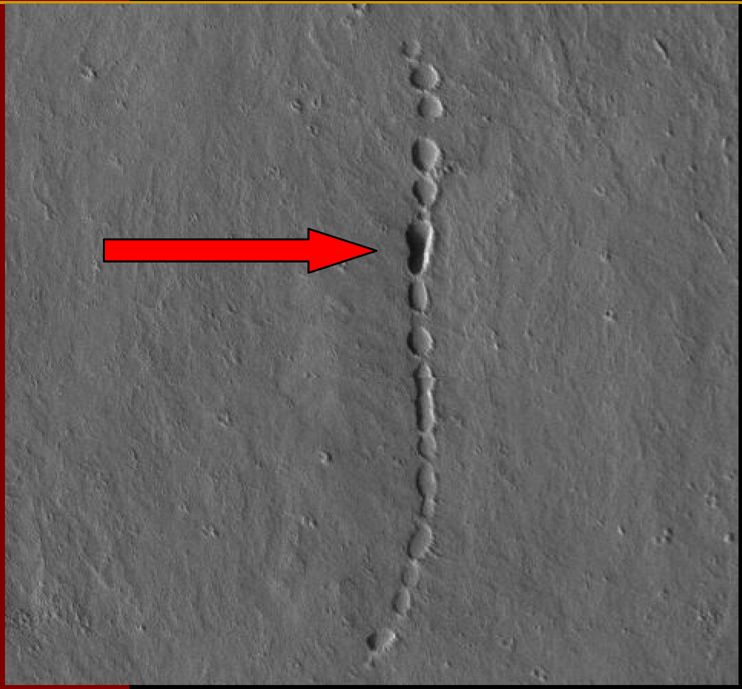

Thus far, the MARS EXPLORATION ROVERS have discovered 37 STARBUCKS locations. But still no sign of meaningful life.
NASA
BIZARRO.COM
© DAN PIRARO. 5·8·03
Dist. by King Features

Beagle 2 aboard MSL - 2
(Concept)

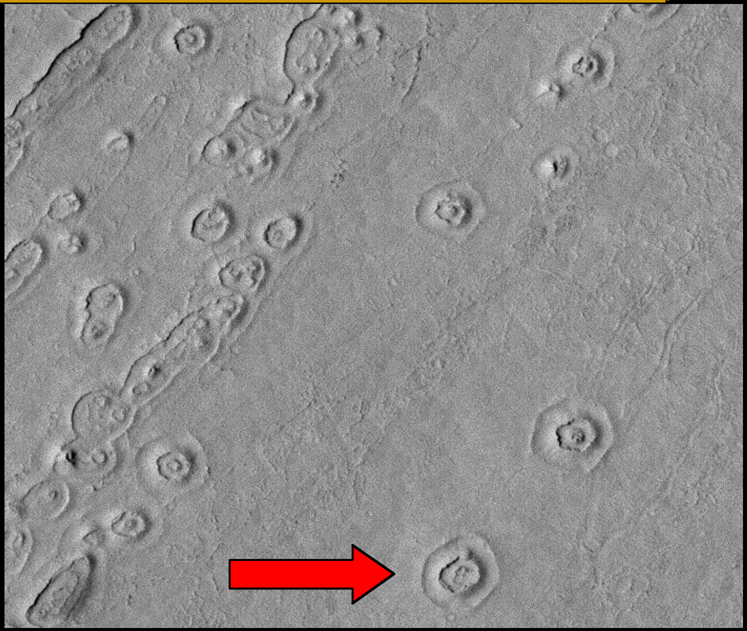


MARS IN THE PAST and TODAY

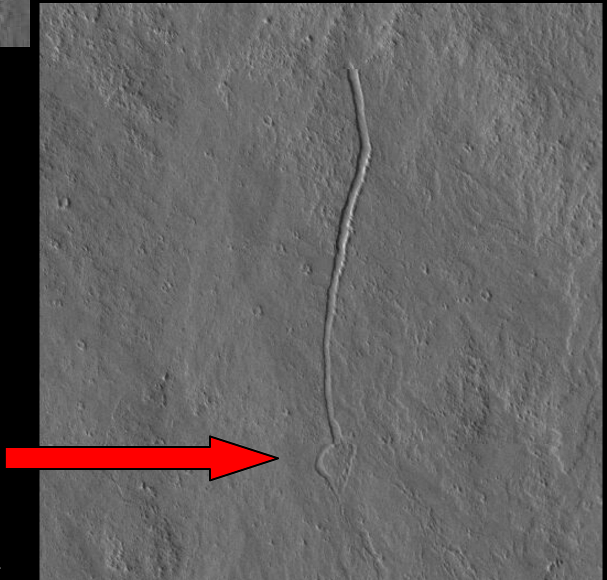
Recently Active Volcanoes? Living Mars



Pit crater chain of vents



Volcano-ice interactions



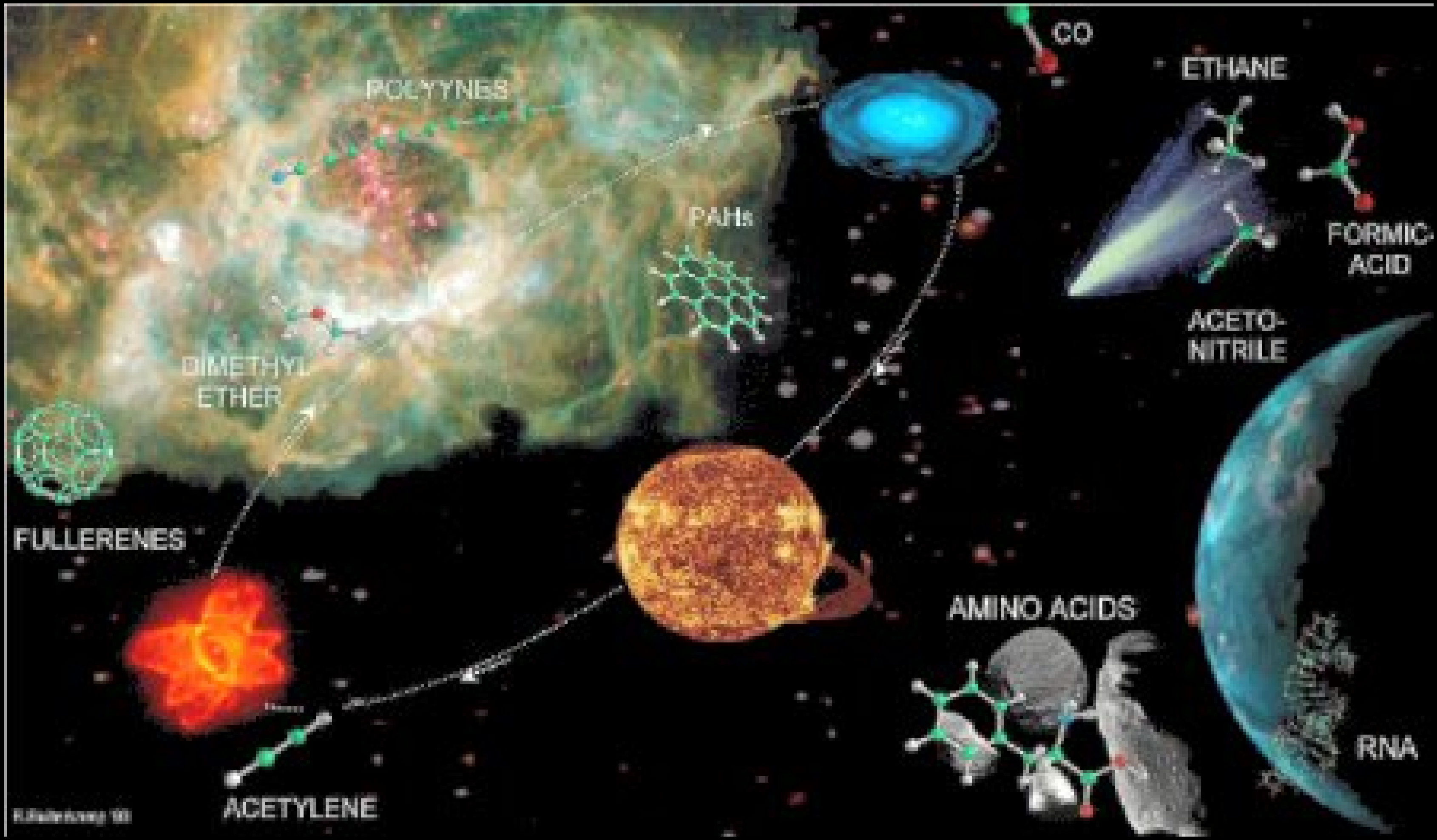
Rille and filled vent

KNOWN VENTS:
The *"Yellowstones"*
of Mars?

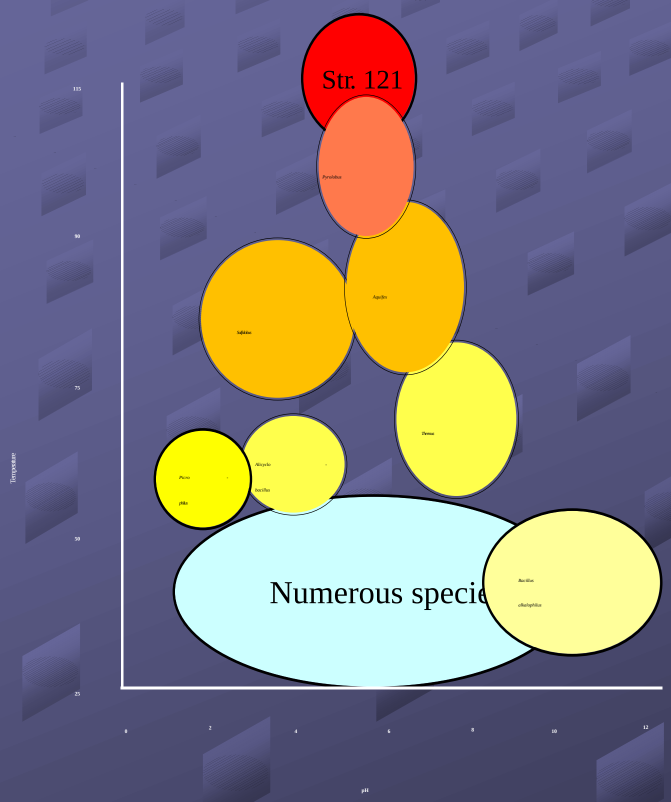
Living Vent, Earth

HOW DOES LIFE BEGIN ?

PROPER INGREDIENTS REQUIRED



The Biological Envelope



The biological envelope is defined by the volume of multi-dimensional space occupied by known organisms

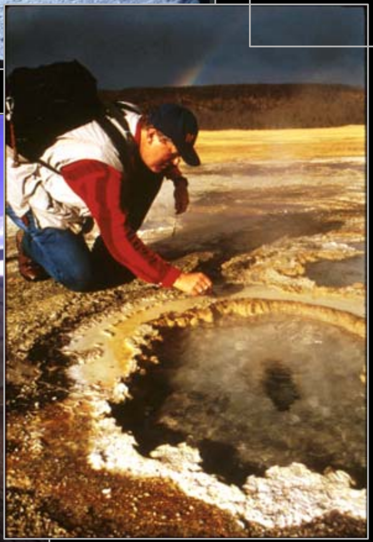
⇓**Lower Temperature (??) needs investigating**

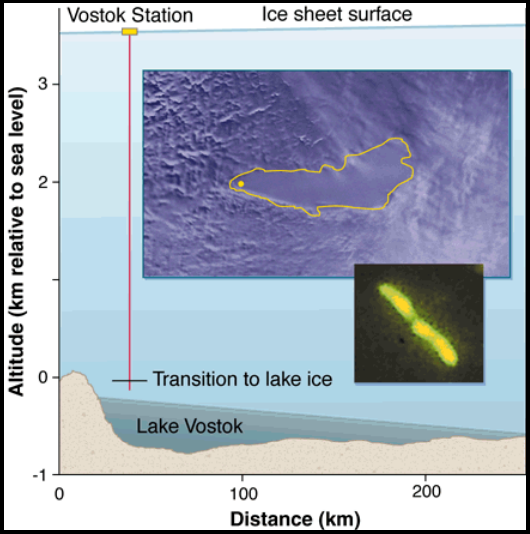
(Don Cowan, 2004)

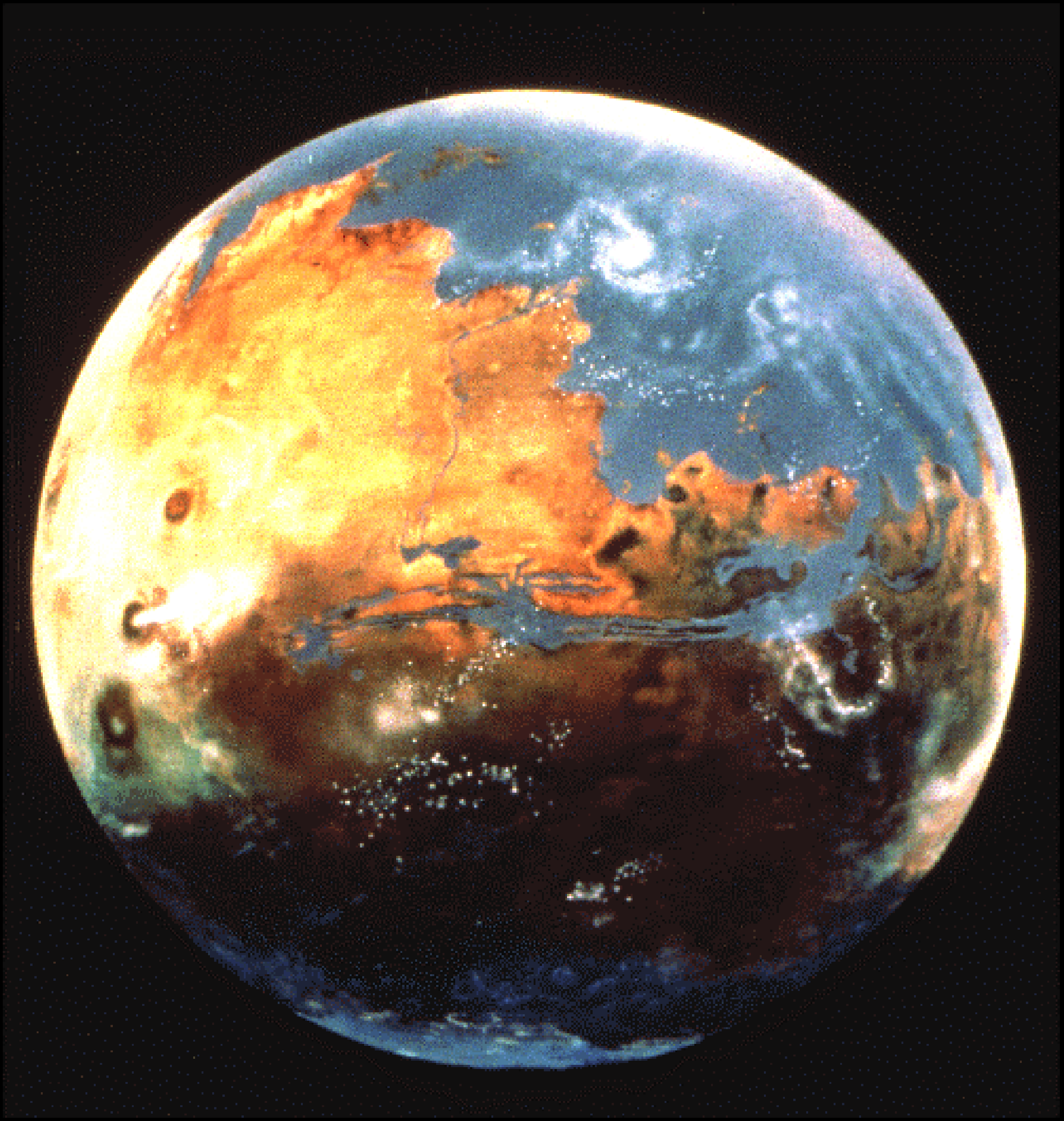
On Earth, water, energy, C sources are readily available so we find microbial life on *modern* Earth anywhere and everywhere….

Water is key to sustaining life as we know it.

Life in the Extreme







Early Mars:

Water

Energy

C source

Life on Mars?

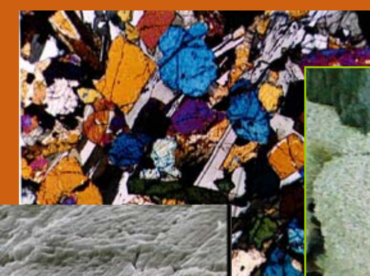
Rocks are Science's "Gold"

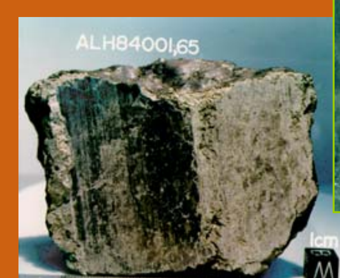
- Samples from the Moon were PROFOUND!
- Meteorites have given us the chemistry of our Solar System
- Meteorites from Mars have shown us the promise that samples from Mars will deliver

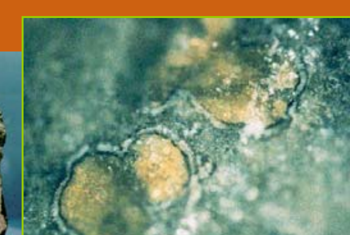
- Rock (and dust/soil) samples provide…
  - Chronology of key events
  - Chemistry related to LIFE
  - History of climate
  - Volatile reservoirs
  - Definitive Measurements of Provenance
  - Ground-truth to direct future exploration

- The Record of Life will be preserved in rocks (like artifacts) if it is there

Importance of Sample Return

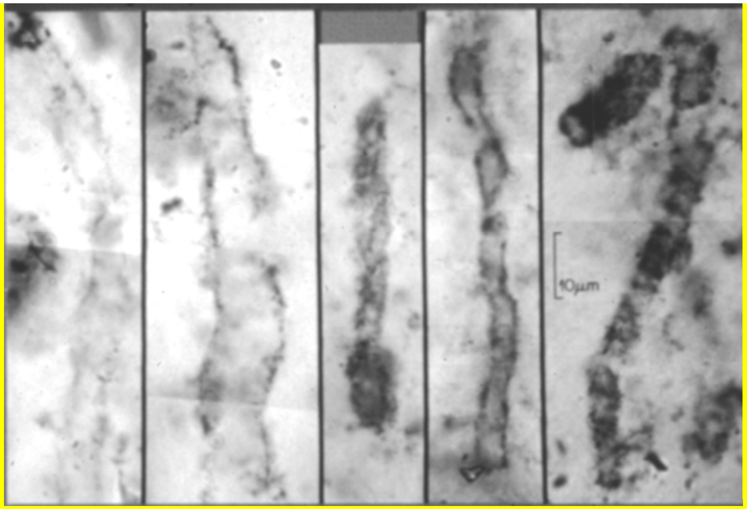



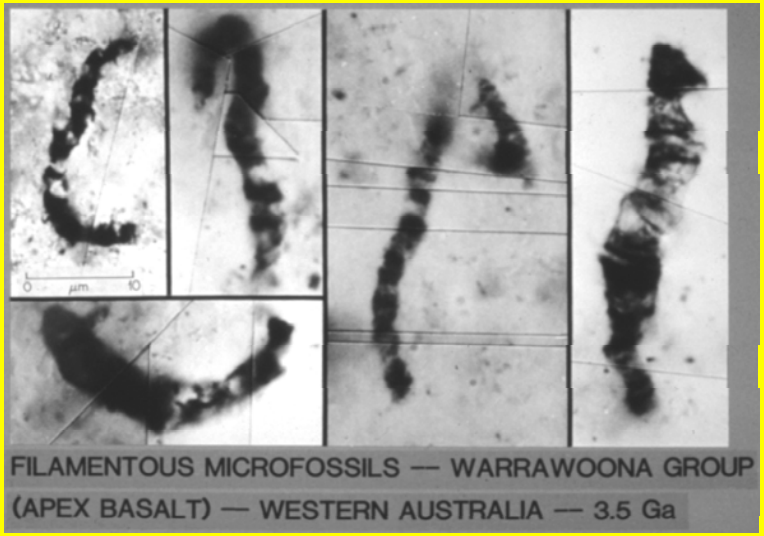



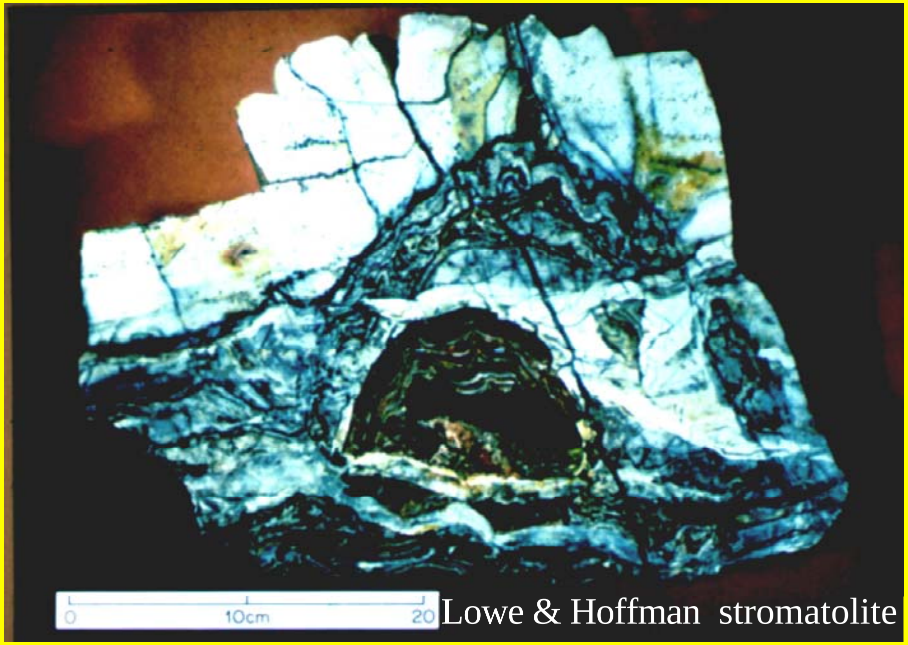


Oldest Microfossils on Earth?

Warrawoona Group, N. Pole Dome/ Marble Bar, WA; 3.5 Ga







Lowe & Hoffman stromatolite

Ancient Life on Earth: The 2002 Debate

letters to nature

Laser–Raman imagery of Earth's earliest fossils

J. William Schopf*, Anatoliy B. Kudryavtsev†, David G. Agresti†, Thomas J. Wdowiak† & Andrew D. Czaja*

* Department of Earth & Space Sciences, and Institute of Geophysics & Planetary Physics (Center for the Study of the Evolution and Origin of Life), University of California, Los Angeles, California 90095-1567, USA
† Astro and Solar System Physics Program, Department of Physics, University of Alabama at Birmingham, Birmingham, Alabama 35294-1170, USA

Unlike the familiar Phanerozoic history of life, evolution durin the earlier and much longer Precambrian segment of geologi time centred on prokaryotic microbes[1]. Because such micr ganisms are minute, are preserved incompletely in geol materials, and have simple morphologies that can be m by nonbiological mineral microstructures, discr between true microbial fossils and microscopic

Questioning the evidence for Earth's oldest fossils

Martin D. Brasier*, Owen R. Green*, Andrew P. Jephcoat*, Annette K. Kleppe*, Martin J. Van Kranendonk†, John F. Lindsay‡, Andrew Steele§ & Nathalie V. Grassineau‖

* Earth Sciences Department, University of Oxford, Parks Road, Oxford OX1 3PR, UK
† Geological Survey of Western Australia, 100 Plain Street, East Perth, Western Australia, 6004, Australia
‡ Research School of Earth Sciences, Australian National University, Canberra ACT 0200, Australia
§ School of Earth, Environmental and Physical Sciences, University of Portsmouth, Burnaby Road, Portsmouth PO1 3QL, UK
‖ Department of Geology, Royal Holloway University of London, Egham Hill, Surrey TW20 0EX, UK

Structures resembling remarkably preserved bacterial and cyanobacterial microfossils from ~3,465-million-year-old Apex cherts of the Warrawoona Group in Western Australia[1–4] currently provide the oldest morphological evidence for life on Earth and have been taken to support an early beginning for oxygen-producing photosynthesis[5]. Eleven species of filamentous prokaryote, distinguished by shape and geometry, have been put forward as meeting the criteri

In *Nature*
March 7, 2002

ŅTwo scientists bicker over whether a stone contains the oldest fossils on Earth or just junk.
How will they ever decide about life on Mars?Ó

Oliver Morton, Newsweek, International Issue, March 18, 2002

Evidence for Life on Mars

Martian Meteorite Evidence - 3 rocks

magnetites, indigenous reduced carbon,
lack of ^{14}C, Ņstructures Ó, biofilms

Persistent Presence of Water and Evaporites

ŅLife requires presence of water Ó

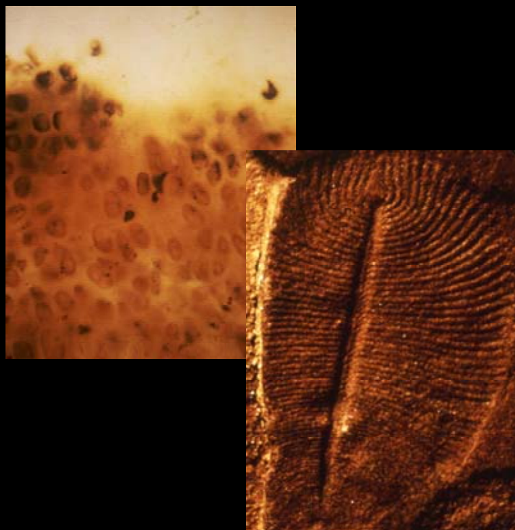
Unique ÓFeaturesÓ within Soils and Rocks (filaments, spirals, etc.)

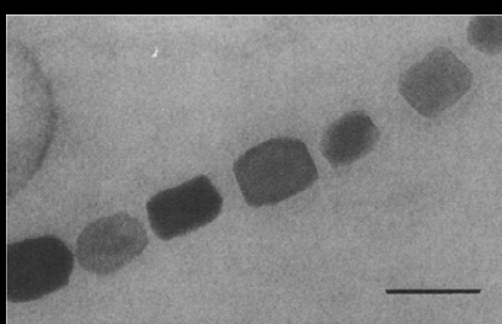
. **Presence of Methane in Atmosphere-NEW!**

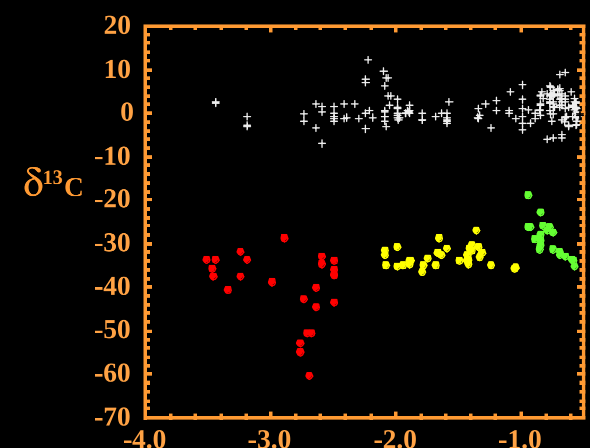
3 measurements ~10-20 ppbV

Hydrothermal-?? Biogenic-Possibly

. **Label-Release Data from Viking ??**



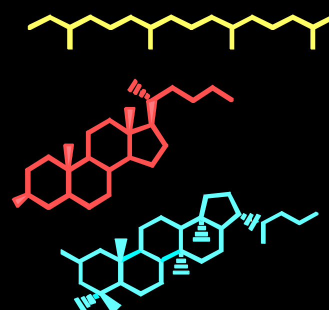




(After DesMarais, 2005)

Fossil Biosignatures : What we look for …

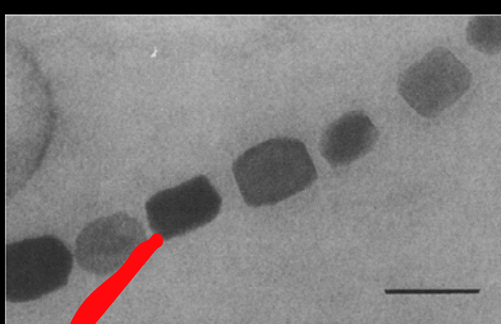

Body Fossils



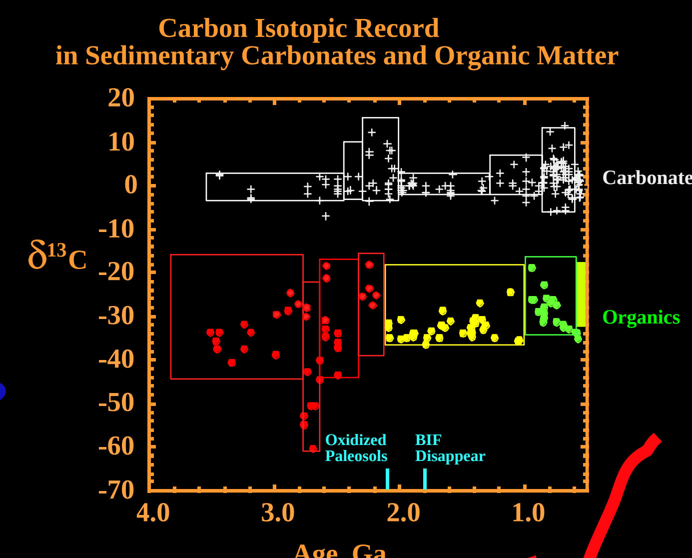
Chemical Fossils (Biomarkers)

Destroyed by UV?

Biofabrics

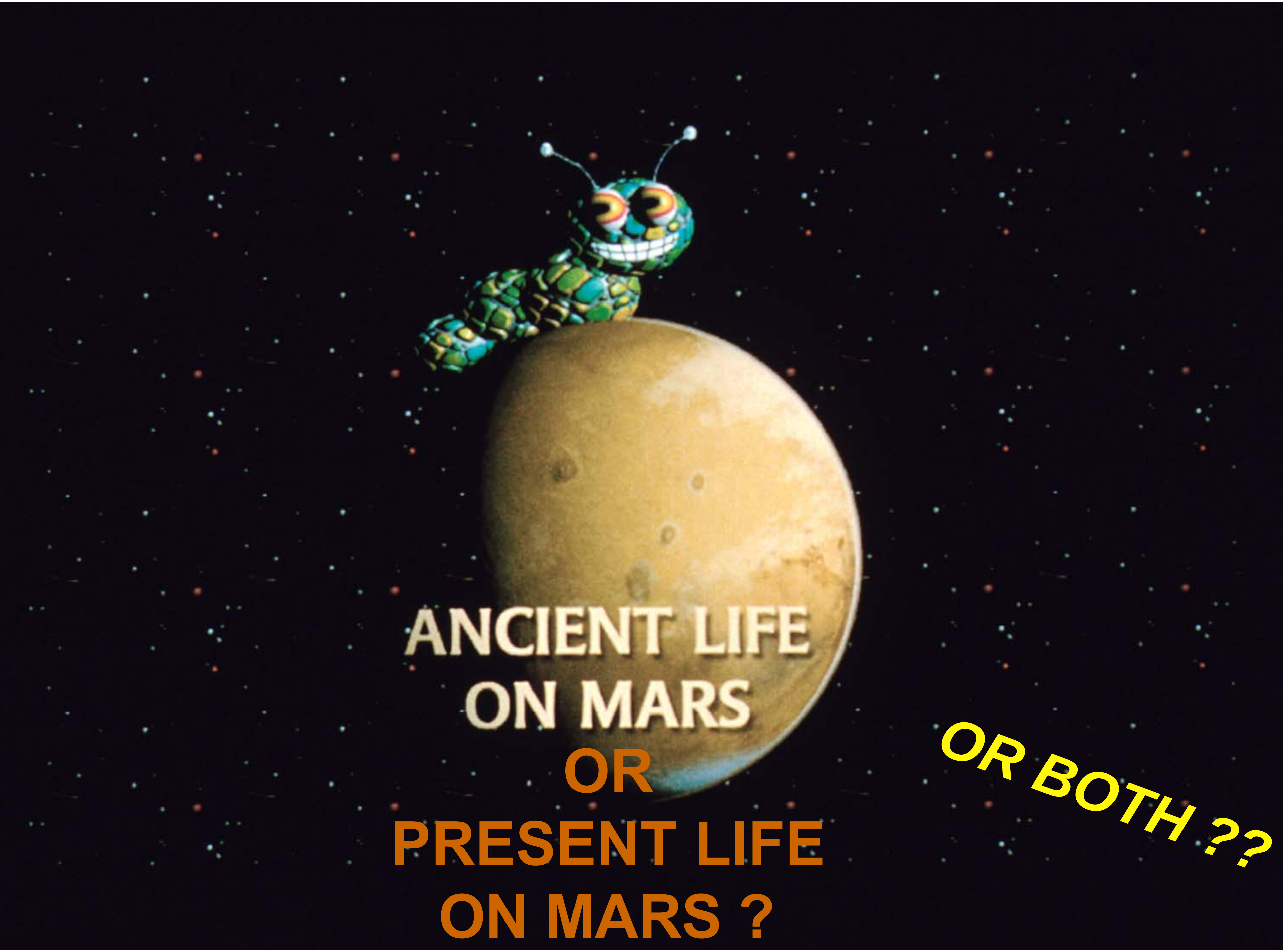


Biominerals



Stable Isotopes

After DesMarais, 2005


ANCIENT LIFE
ON MARS
OR
PRESENT LIFE
ON MARS ?
OR BOTH ??