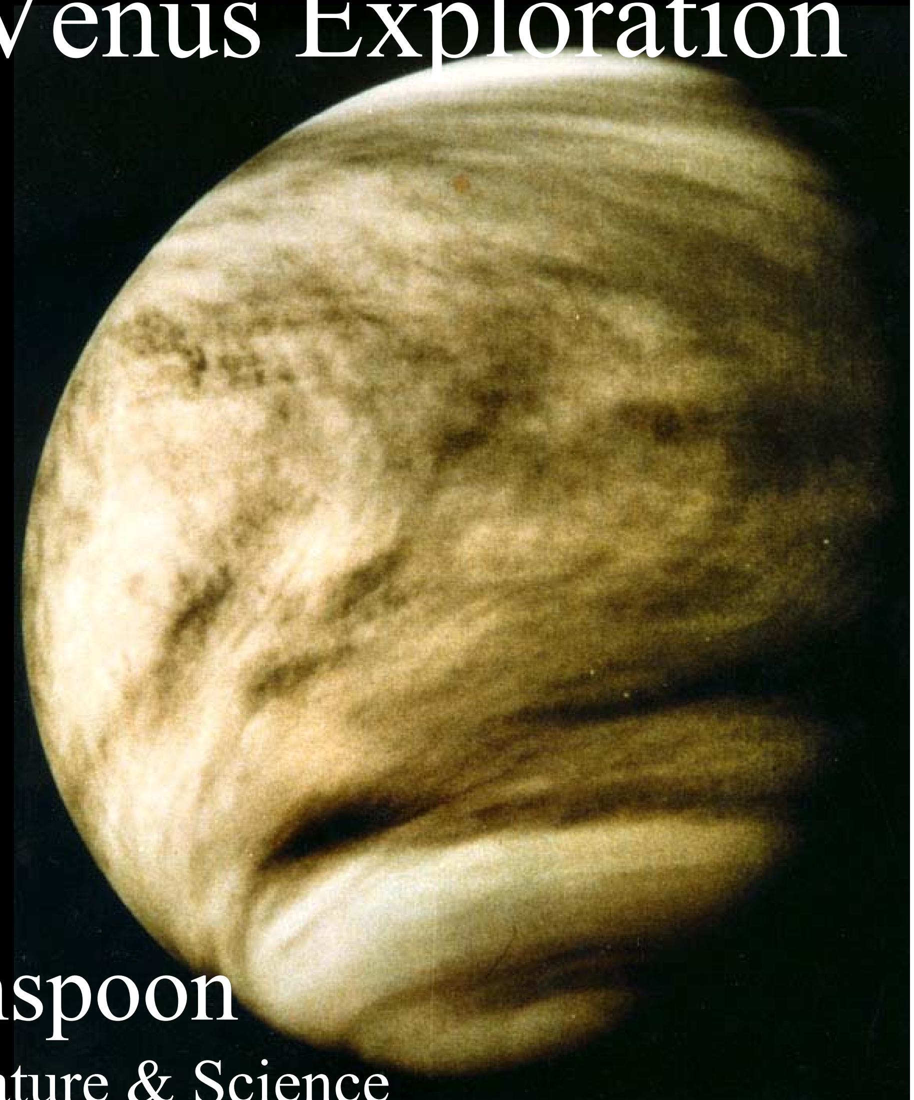
Astrobiology and Venus Exploration



David Grinspoon

Denver Museum of Nature & Science

AGU Chapman Conference on Exploring Venus as a Terrestrial Planet 2/16/06

NASA Mission Statement:

- To understand and protect our home planet.
- To explore the universe, and search for life.
- To inspire the next generation of explorers, as only NASA can.

NASA Mission Statement:

- To understand and protect our home planet.
- To explore the universe, and search for life.
- To inspire the next generation of explorers, as only NASA can.

ESA
Cosmic Vision: Space Science for Europe 2015-2025

- What are the conditions for planet formation and the emergence of life?
- How does the Solar System work?
- What are the fundamental physical laws of the universe?
- How did the Universe originate and what is it made of?

New York Times 11/16/1928

SAYS LIFE MAY BE ON VENUS

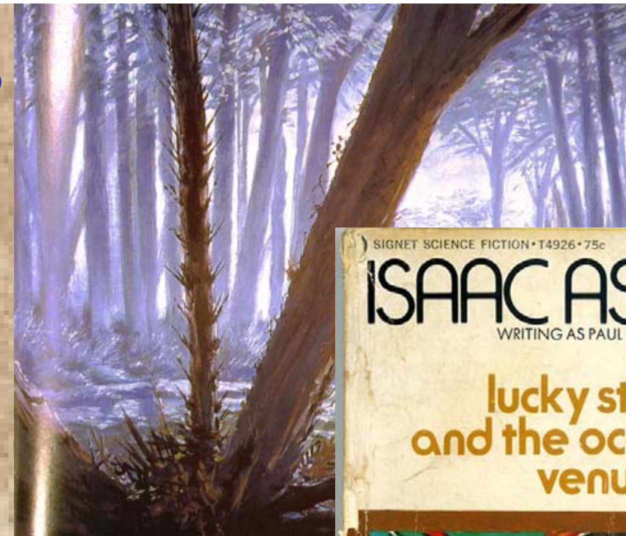
Cambridge Savant Believes Mars Also Has Essentials for Existence.

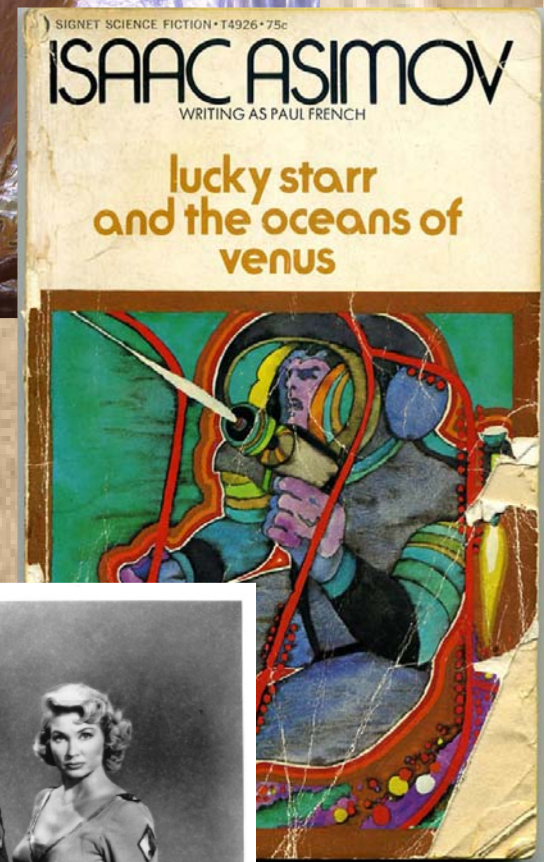
Special Cable to THE NEW YORK TIMES.

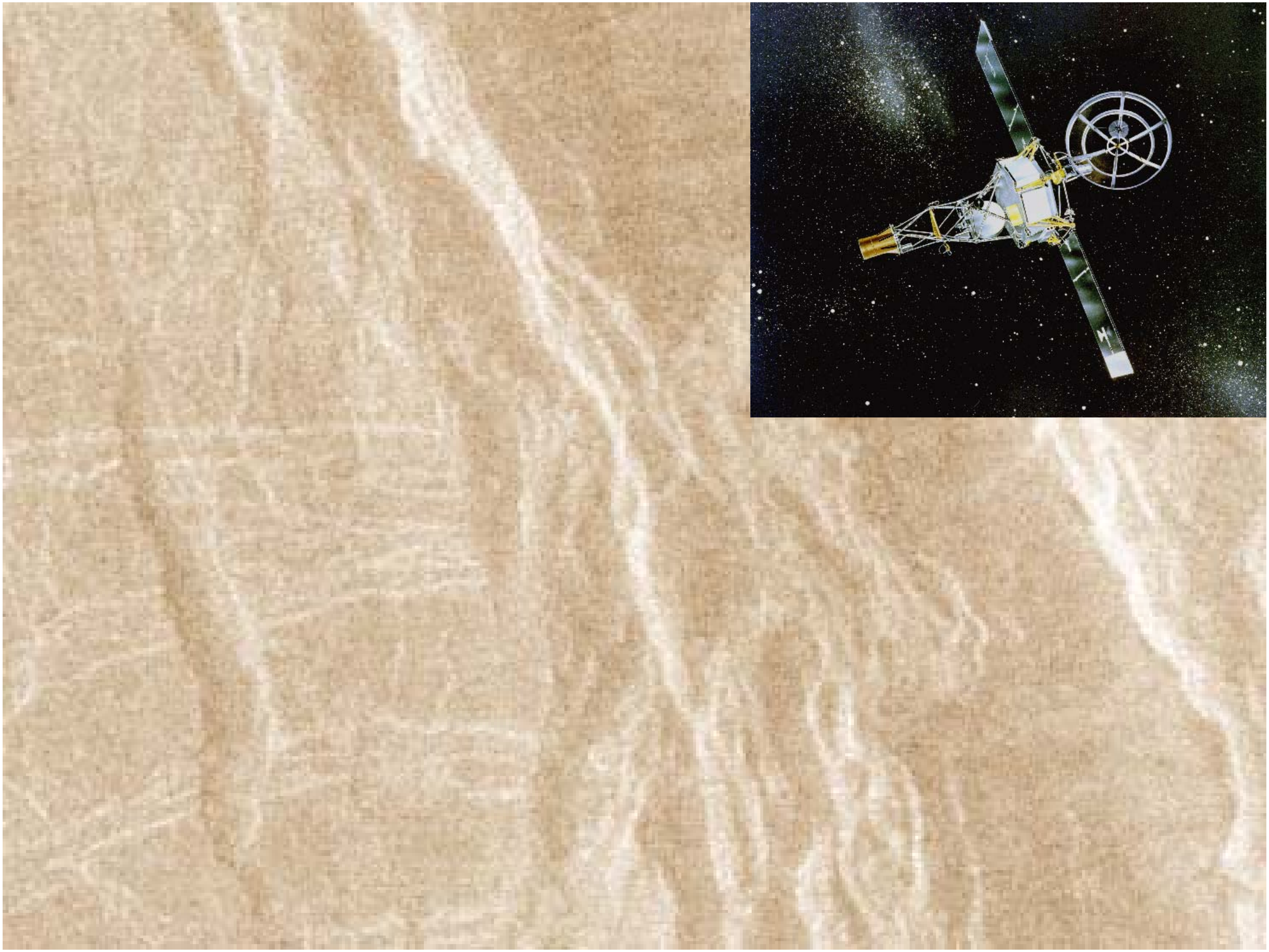
LONDON, Nov. 15.—That life may exist on both Venus and Mars is the conclusion reached by Dr. A. S. Eddington, professor of astronomy at Cambridge. In a book to be published tomorrow he says that Venus, so far as is known, would bewell adapted for life similar to ours. The planet is about the same size as the earth, nearer the sun but probably not warmer, and possesses an atmosphere of satisfactory density.

As regards Mars, Professor Eddington says that the two essentials, air and water, are both present but scanty. The Martian atmosphere is thinner than ours, but perhaps adequate. It has been proved to contain oxygen.

If animal life exists on that mysterious planet, he says, it probably is a different form of life from ours, as "Mars has every appearance of being a planet long past its prime."







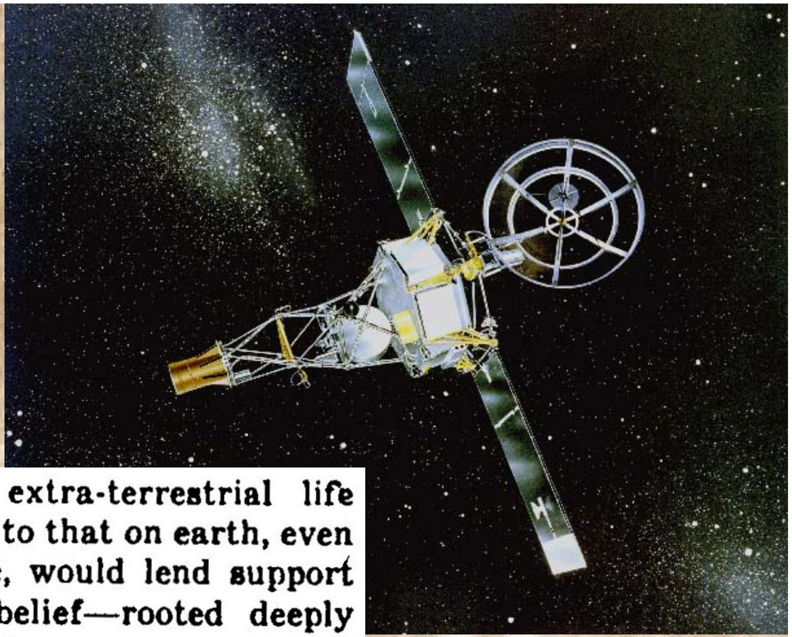
New York Times 2/26/1963

Venus Says 'No'

The first message from the Venus probe, Mariner 2, deciphered shortly after its historic fly-by of the planet on Dec. 14, at a distance of 21,564 miles, added important knowledge about Venus's magnetic field, its rate of rotation and other information shedding light on some of its mysteries. But one all-important question remained unanswered—whether or not life in some form existed on Venus and hence elsewhere in our solar system and possibly also beyond it.

Now comes a second message from Venus, via Mariner 2, with the first definite eagerly-awaited answer to this vital question, and the answer is a disheartening, disillusioning "No! Not on Venus!"

The newest message from Venus, sent down by the "cosmic thermometer" on Mariner 2, which made the first direct measurements of the surface temperature of the planet, informs earthlings that the temperature at or near the surface of our cloud-covered, planetary neighbor is between 300 and 400 degrees Fahrenheit. This high temperature, established for the first time, definitely rules out the possibility of the existence of life in any form even remotely resembling life as we know it on earth.



The finding of extra-terrestrial life in some form similar to that on earth, even at the lowliest stage, would lend support to the widespread belief—rooted deeply in the aspirations of mankind—that life as we know it is not unique to this insignificant corner of the universe, but exists in many other systems similar to ours throughout the universe. Indeed, there has been speculation among scientists, philosophers and poets that some of these systems have reached a stage of evolution much superior to ours. The message from Venus now reduces the hope of finding evidence in support of this speculation to one half, so far as our solar system is concerned.

Mars now remains our only hope of turning this universal dream into reality, and the evidence so far is not very encouraging. The message from Venus may mark the beginning of the end of mankind's grand romantic dreams.

Astrobiology and Venus Exploration

- Putting Earth habitability in context: Rare planetary qualities of astrobiological interest.
- The possibility of extinct or extant life.
- The future of life on Earth.
- Increasing relevance for early Mars.
- Planetary protection issues?

Putting Earth's Habitability in Context

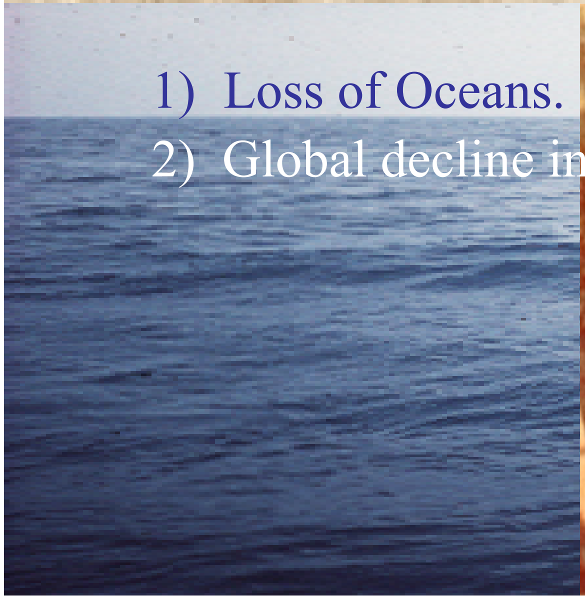
- Who kept its ocean longer, Venus or Mars? How was the habitable real estate distributed in the inner solar system?
- Understanding the longevity of oceans and loss mechanisms on terrestrial planets of differing size, composition and proximity to stars of various stellar types, and the range of physical parameters which facilitates plate tectonics, is key to defining stellar habitable zones.
- Further exploration of Venus will greatly advance this cause, and provide needed context for extrasolar terrestrial planet discoveries.

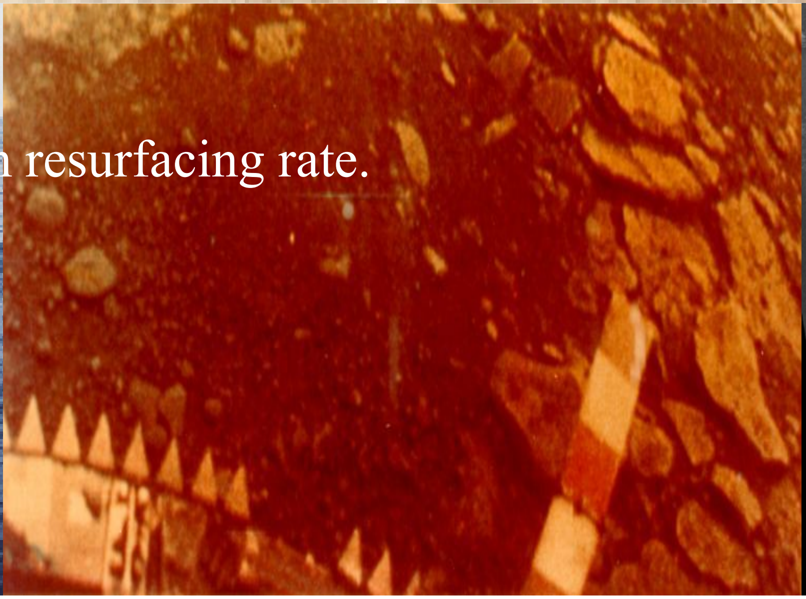
Longevity of an Early Venus Ocean?

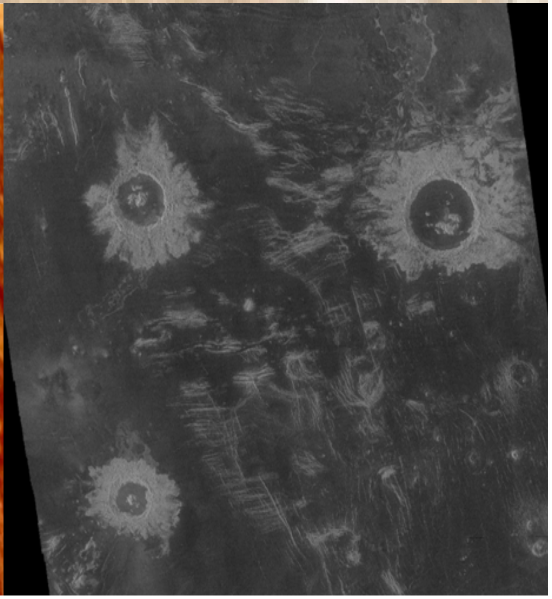
Kasting (1988) in many ways optimized to get rid of ocean quickly:

- Calculations produce **upper limit** on surface temperatures (and therefore upper limit on escape fluxes, and lower limit on lifetime of ocean).
- **Clouds excluded**. No cloud feedback which, qualitatively, is expected to stabilize surface temperatures with rising solar flux, and therefore extend the lifetime of the moist greenhouse.
- Preliminary new results (Grinspoon and Bullock, DPS 2004) suggest that the oceans of Venus may have persisted for ≈ 2 Gy. Venus may have been a habitable planet for much of Solar System history.
- Did Venus experience one great transition or two?

1) Loss of Oceans.
2) Global decline in resurfacing rate.





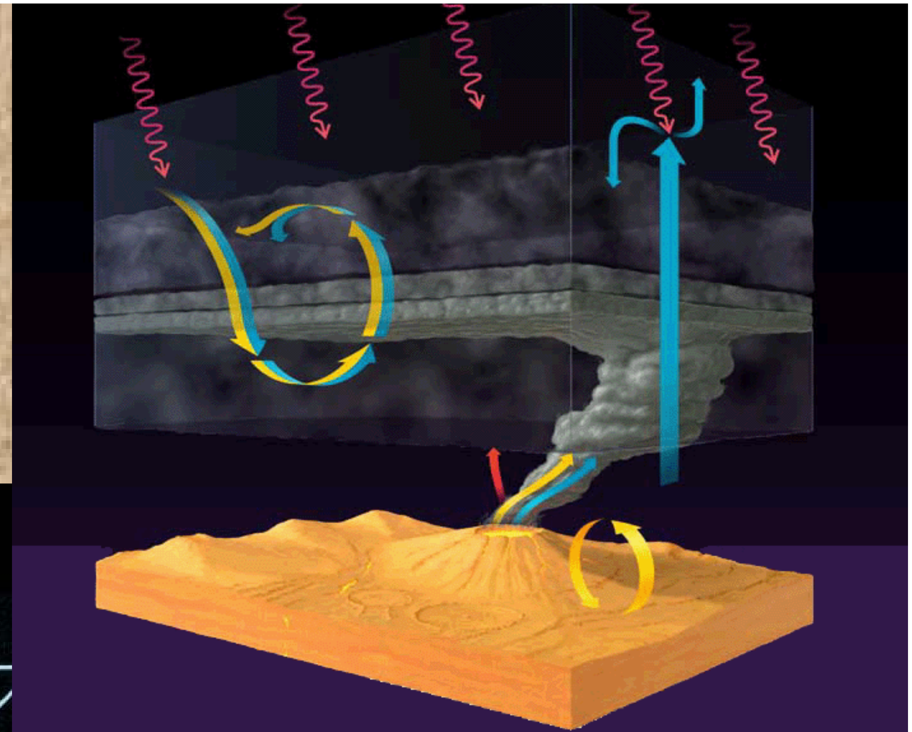


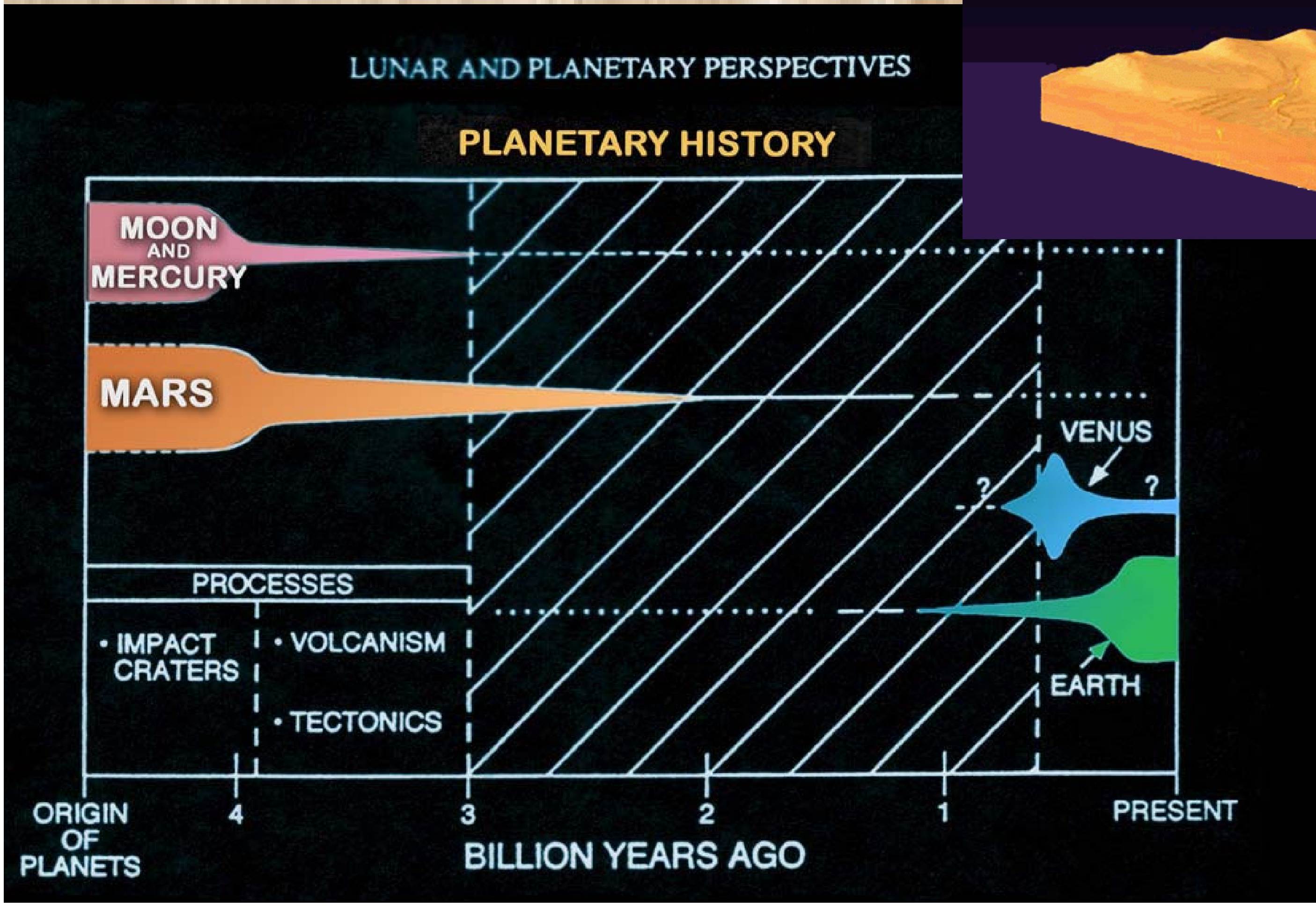
History of Venus: A Unified Scenario

- ≈ 2 Gy Loss of surface water, subduction of hydrated sediments ceases.
- Mantle becomes desiccated.
- Lack of water makes lithosphere thicker & more difficult to break.
- Loss of asthenosphere -> lithosphere is tightly coupled to mantle.
- Crustal recycling is inhibited.
- ≈ 1 Gy Plate tectonics ceases, Venus becomes a “1 plate planet”
- ≈ 700 My, global resurfacing rate declines precipitiously.
- 700 My to present: localized volcanism and tectonism, conductive heat release, production population of craters.

  - Tessera are remnants of more vigorous past tectonics. (continents?)
  - Plains record “global resurfacing”, or at least an epoch of much higher resurfacing rates that ended “suddenly” enough to allow very few craters modified by plains volcanism.
  - Venus may have been a habitable planet (with an oxygenated atmosphere) for much of Solar System history.

Rare Planetary Properties of Astrobiological Interest





Putting Earth's Habitability in Context

- Venus is our only other example of
  - an Earth-sized terrestrial planet.
  - a "currently active" terrestrial planet.
- Most of surface is "young"
- Endogenous geological activity and surface chemistry are, to some degree, controlling the atmosphere and climate.
- Climate history and surface history are coupled.

Currently we have a "Mariner 9" level of understanding of Venus.

Many extrasolar terrestrial planets will probably be "Venus like".

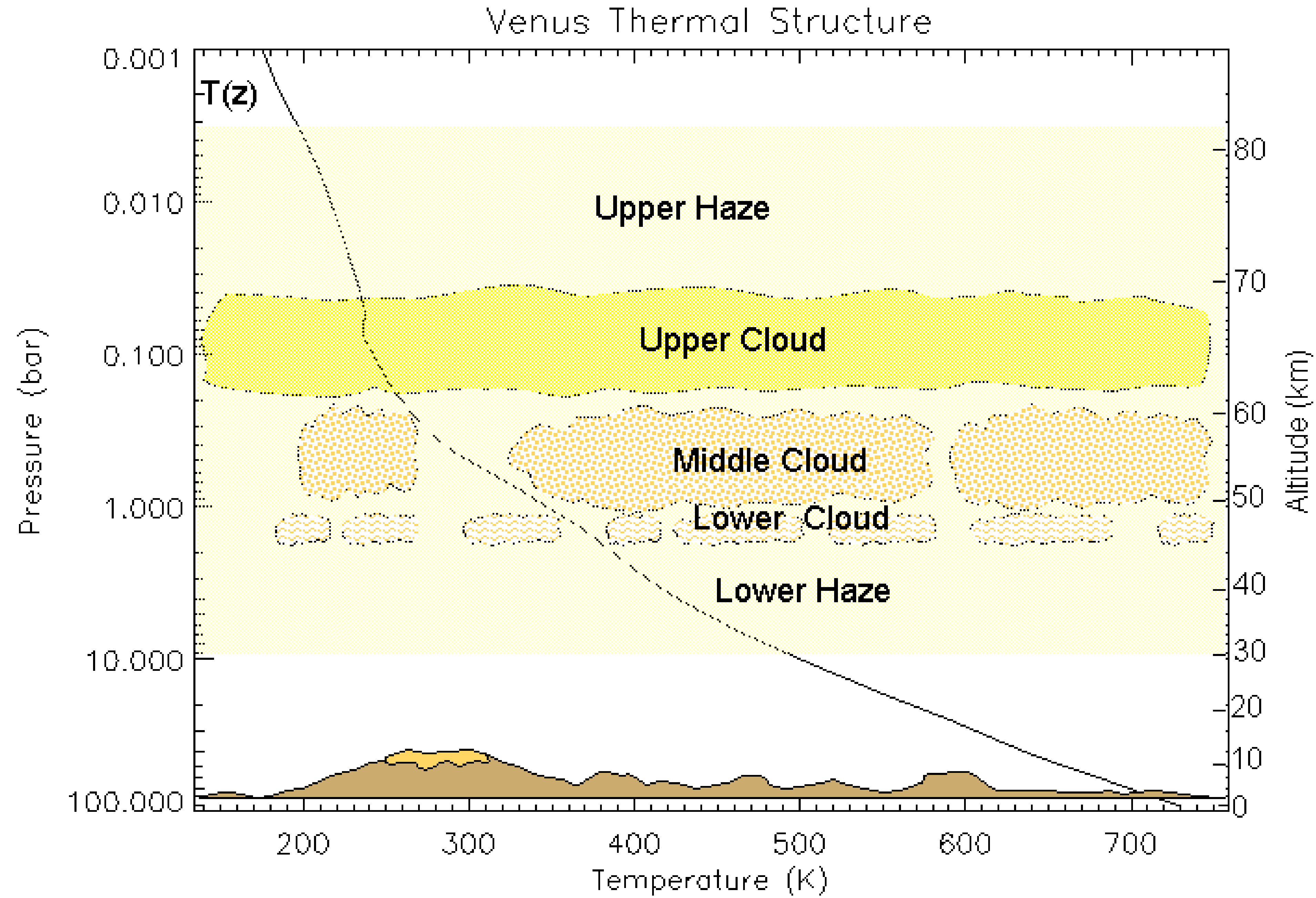
It doesn't make sense to put resources into Kepler and TPF and *not* explore Venus!

Rare Planetary Properties of Astrobiological Interest

- All ideas about extraterrestrial biochemistry are extrapolations from a single example. This is necessary, for now, but requires humility. All conclusions as to what is "universal" must be regarded as provisional.
- Our planetary exploration, with an increasing focus on Astrobiology, is designed to "follow the water". This is a reasonable strategy but it is based, at best, on an educated guess about life's universals.
- If we think beyond the specifics of a particular chemical system required to build complexity and heredity, we can ask what general properties an inhabited planet must possess. Judging from our sample of one inhabited planet, the answers might include an atmosphere with signs of flagrant chemical disequilibrium and active, internally driven cycling of volatile elements between the surface, atmosphere and interior.
- **At present, the two planets we know of which possess these characteristics are Earth and Venus**.

The Possibility of Extant Life

- Longevity of oceans remains highly uncertain. During an extended period of water loss, Venus probably enjoyed an oxygenated atmosphere.
- When young, the terrestrial planets were constantly exchanging material, thus forming a polybiosphere (a biopolysphere?)
- Favorable environmental conditions for origin or transplantation of life.
- As surface conditions became hostile, life could have adapted to an atmospheric niche under directional selection.



Venus Thermal Structure
T(z)
Upper Haze
Upper Cloud
Middle Cloud
Lower Cloud
Lower Haze
Pressure (bar)
0.001
0.010
0.100
1.000
10.000
100.000
Altitude (km)
80
70
60
50
40
30
20
10
0
200
300
400
500
600
700
Temperature (K)

Properties of Venus Clouds Hospitable to Life

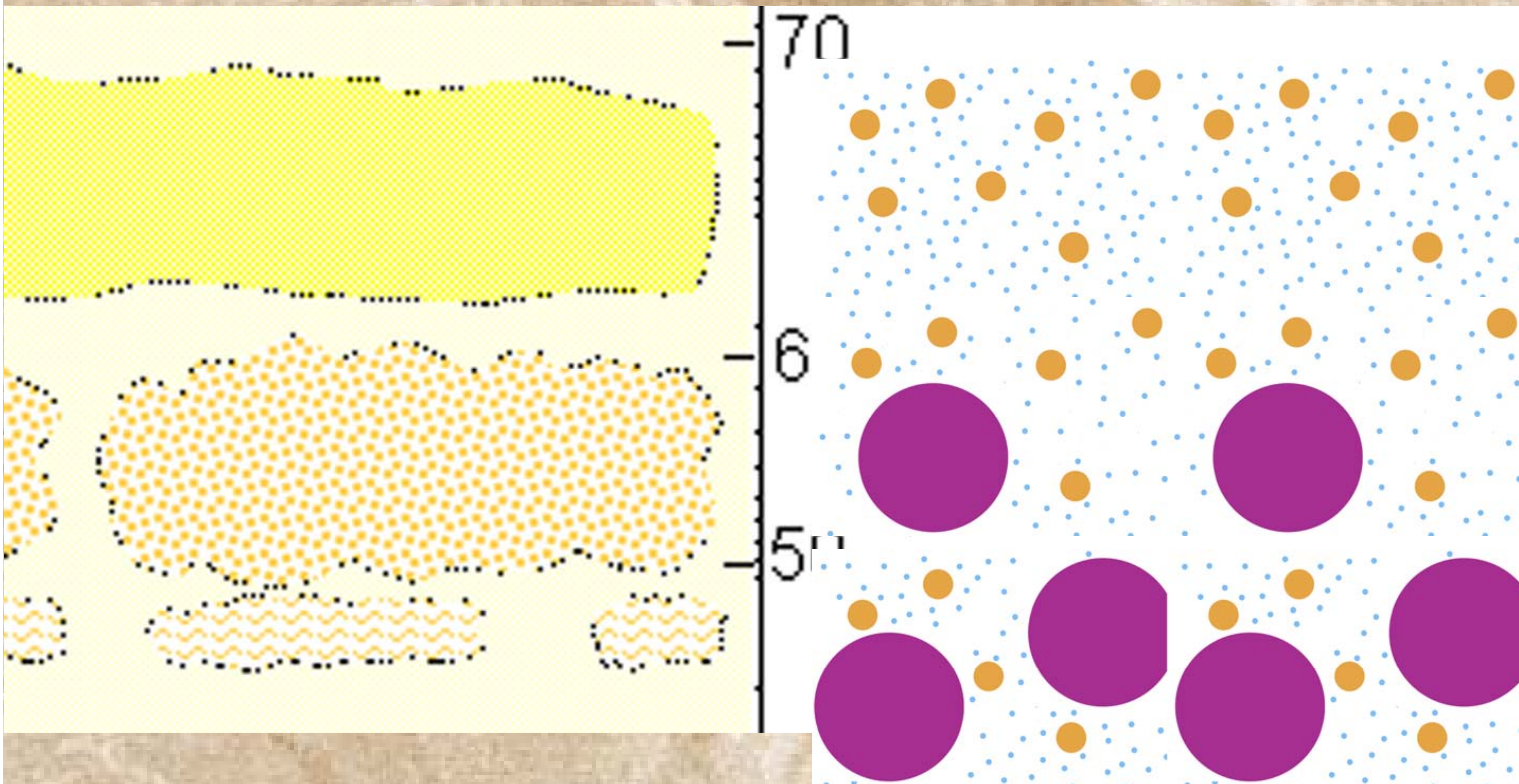
• Global clouds are much larger, more continuous, and stable than clouds on Earth. Particle lifetimes of months (Grinspoon et al, 1993). "Particles do not fall" (Imamura - this meeting)

• Large "mode 3" particles at lower cloud level (~ 50 km altitude)
  -- 1 bar atm pressure
  -- ~350 K
  -- make up most of the mass of the cloud deck
  -- may contain an unknown, non-absorbing core material which comprises up to 50% by volume of the particles (Cimino, 1982; Grinspoon et al. 1993).

• Superrotation of atmosphere shortens duration of the night

• Chemical disequilibrium => coexistence of H_2 and O_2
  H_2S and SO_2

Cloud Particles: Physical Properties



TODAY THE CLOUDS ARE THE OCEANS OF VENUS

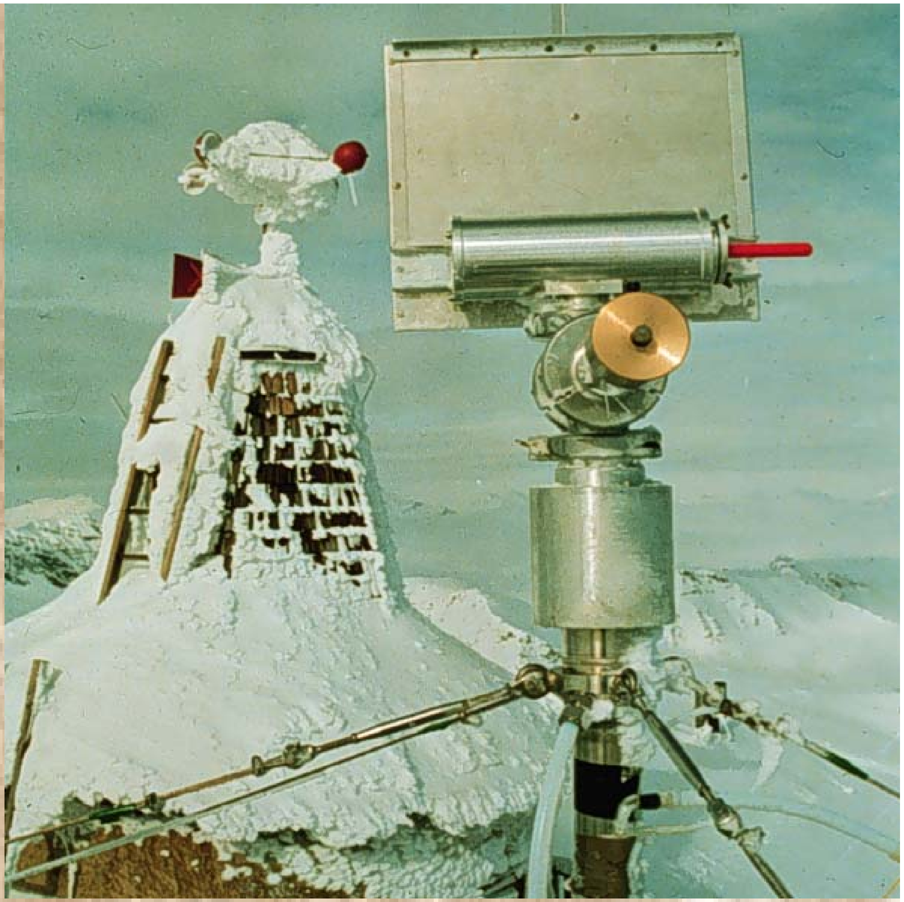
Could they support life?

OBJECTIONS:

- Why aren't the clouds green (on Earth)?
- Clouds are strong acid!
- High UV flux
- No access to the "biogenic elements"?

Bacterial Growth in Supercooled Cloud Droplets

B. Sattler, H. Puxbaum, and R. Psenner (2001) *Geophys. Res. Lett.* 28, 239-242

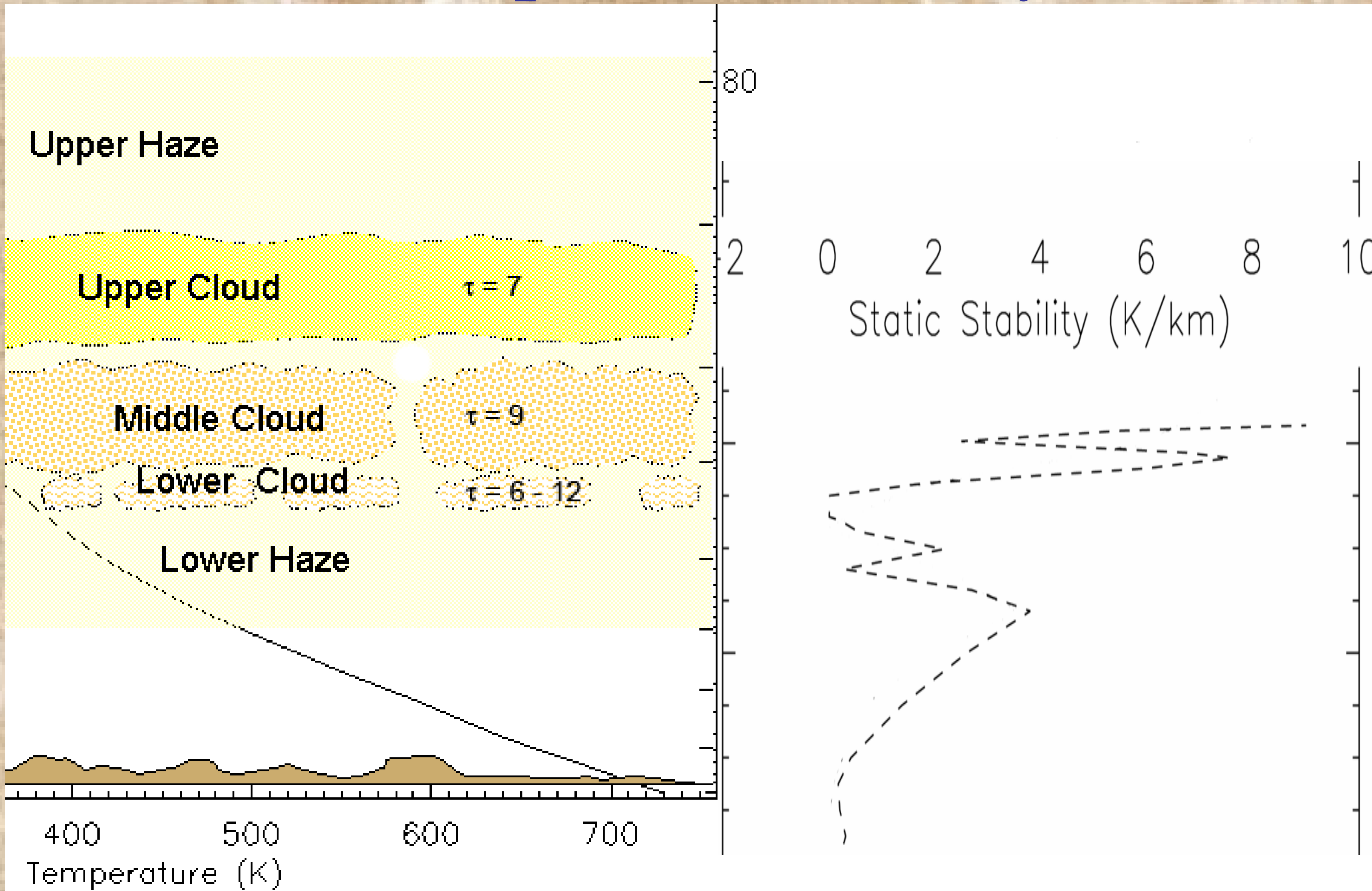


Conclusions:

•Bacteria in cloud droplets at high altitudes are actively growing and reproducing.

•The greatest limitation on the persistence of microbial life in cloud droplets is residence time in the atmosphere.

Atmospheric Stability



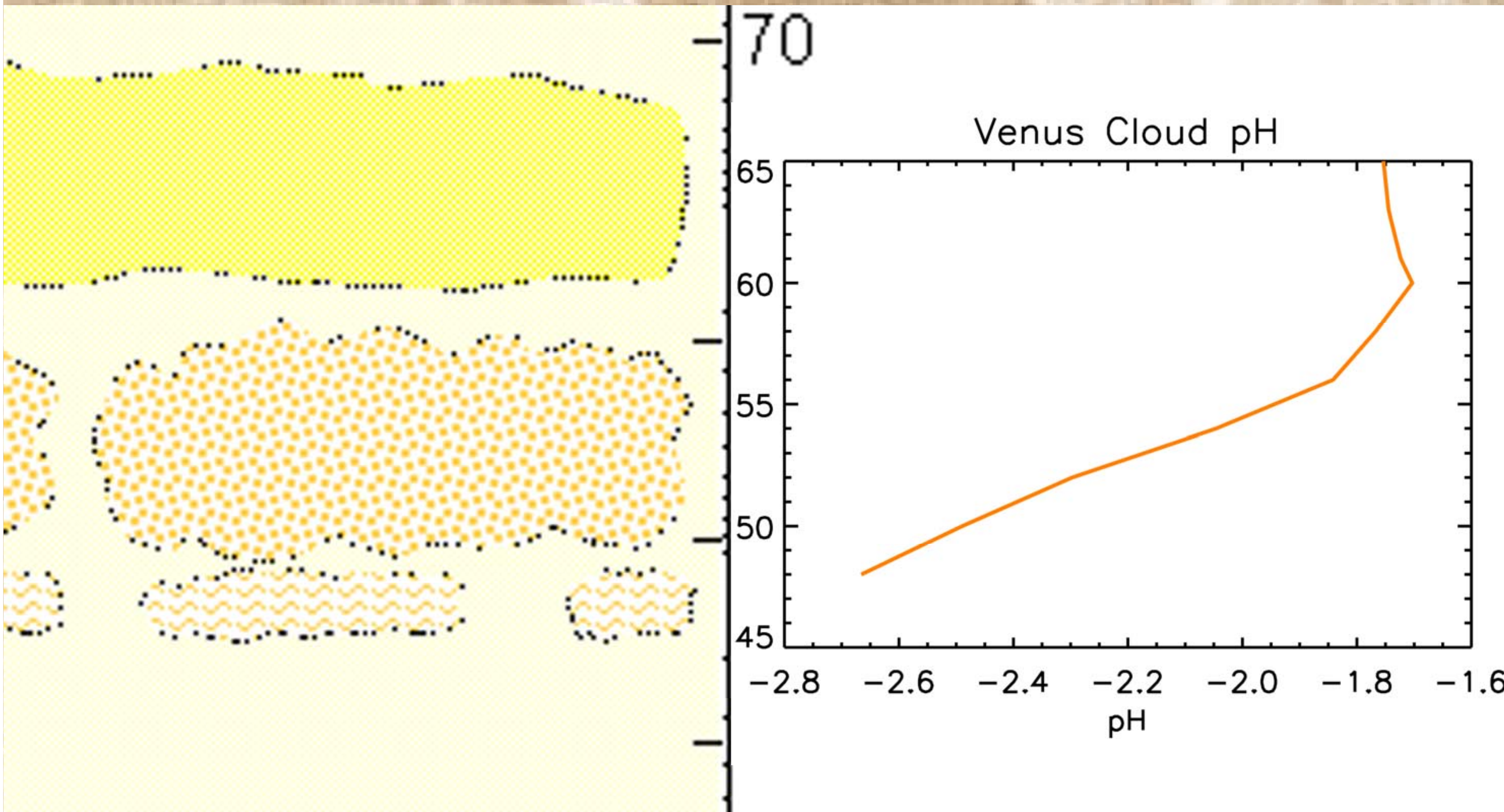
Takeshi Imamura 2006 (this meeting) “Cloud droplets do not fall.”

The low pH limit of Terrestrial life is not known.

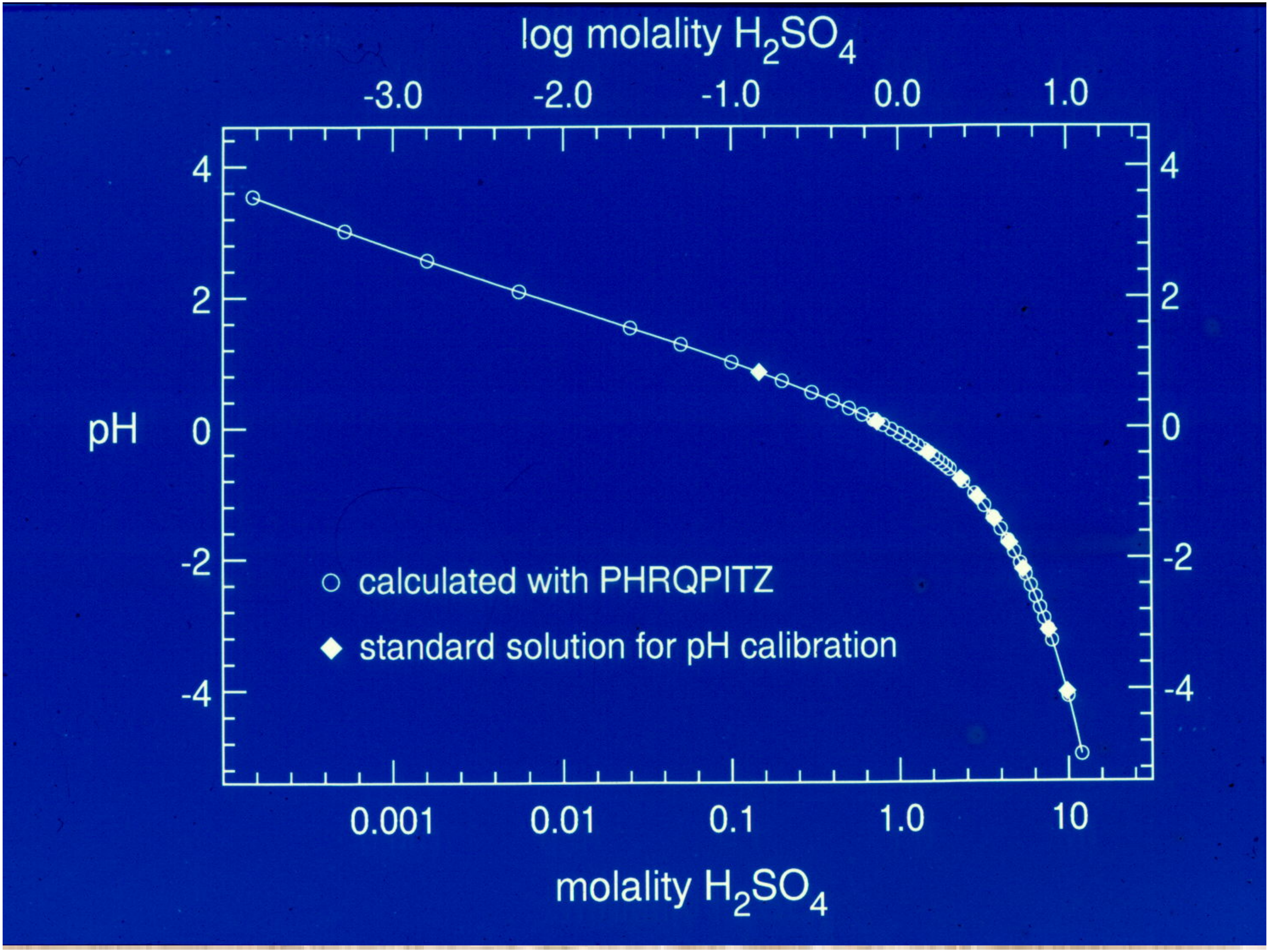
Several organisms have now been discovered that grow at very low pH

For example, the archaeon *ferroplasma acidarmanus* thrives at pH 0.

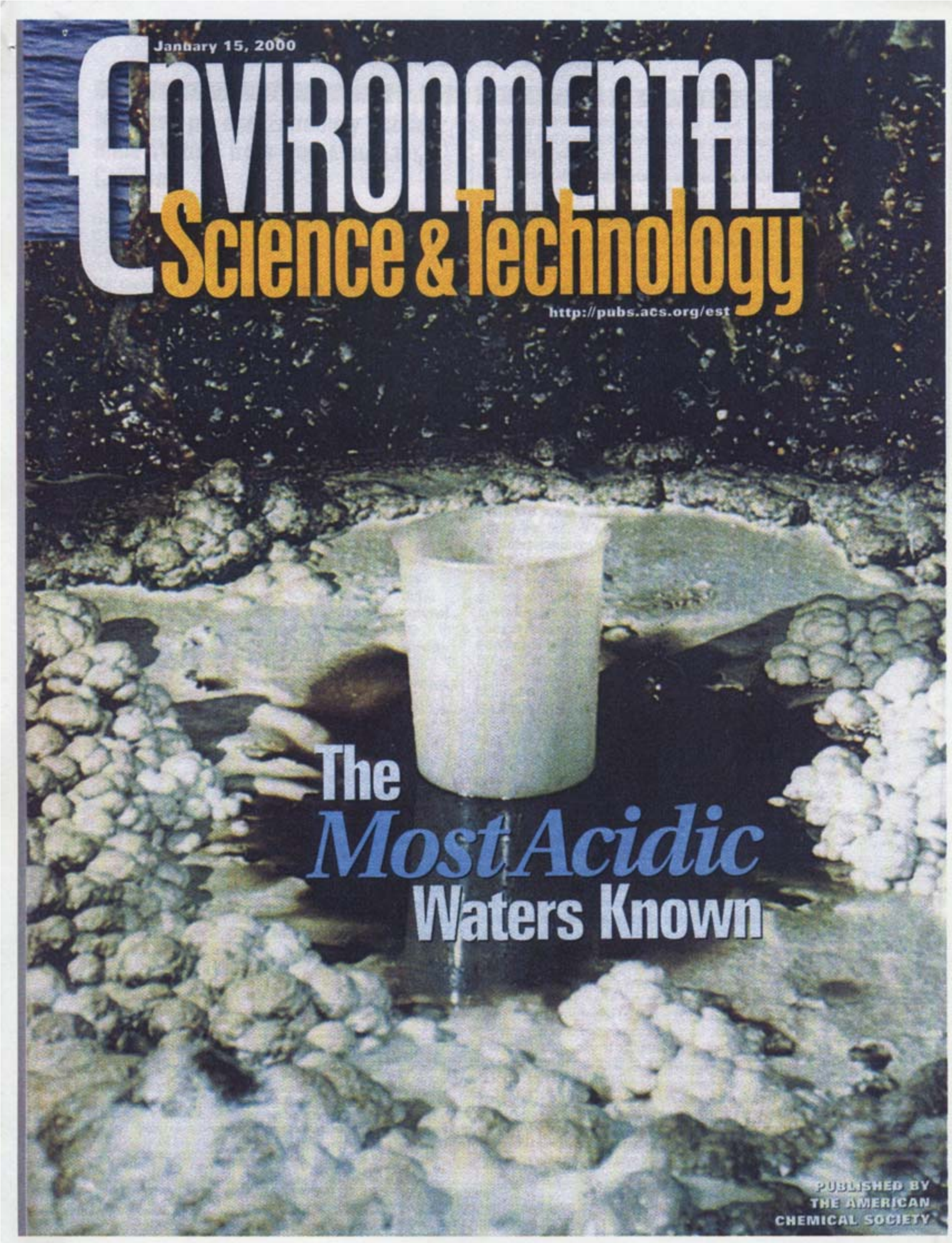
Cloud Particles: Chemical Properties



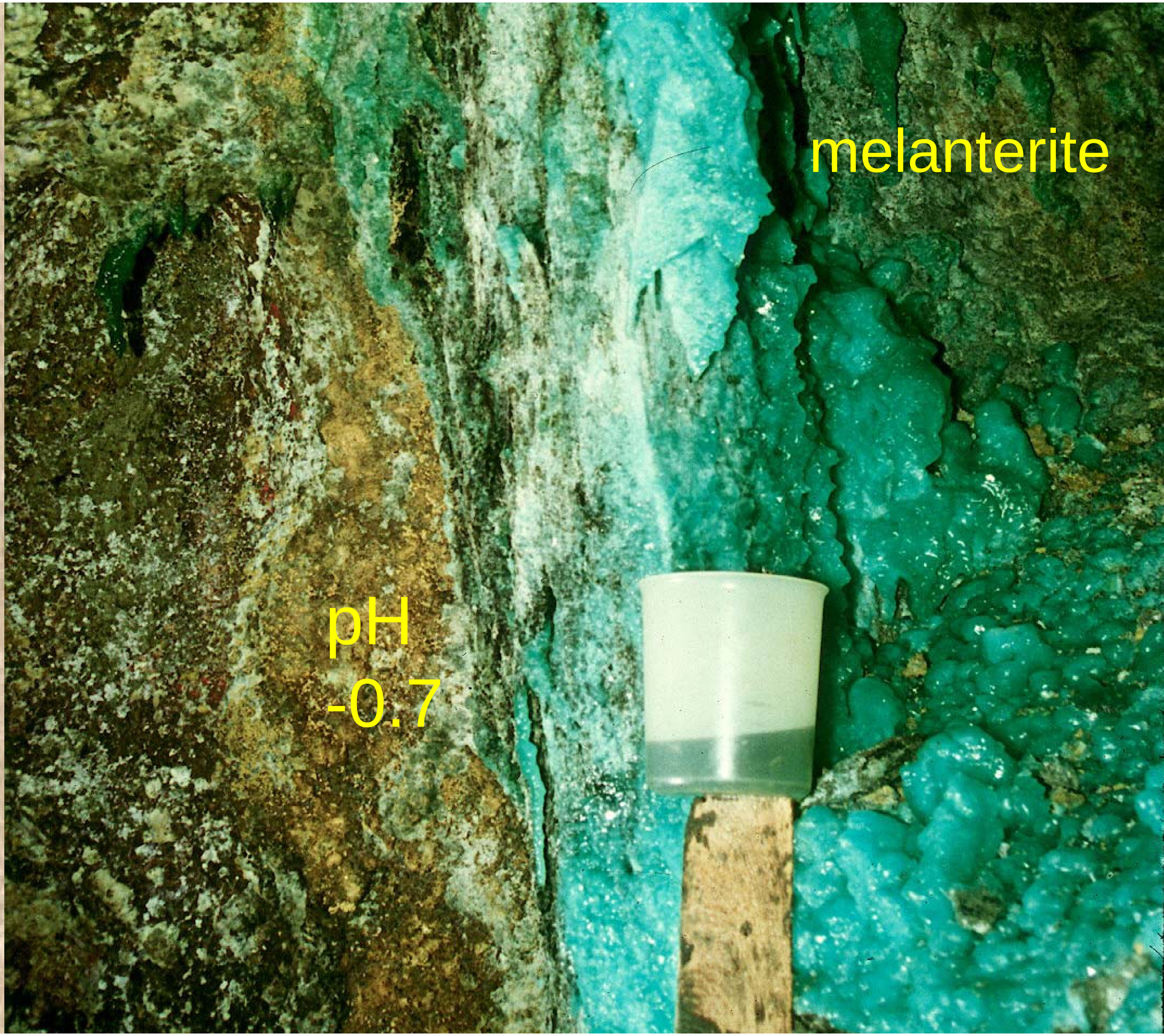
$pH = -\log[H_2SO_4]$

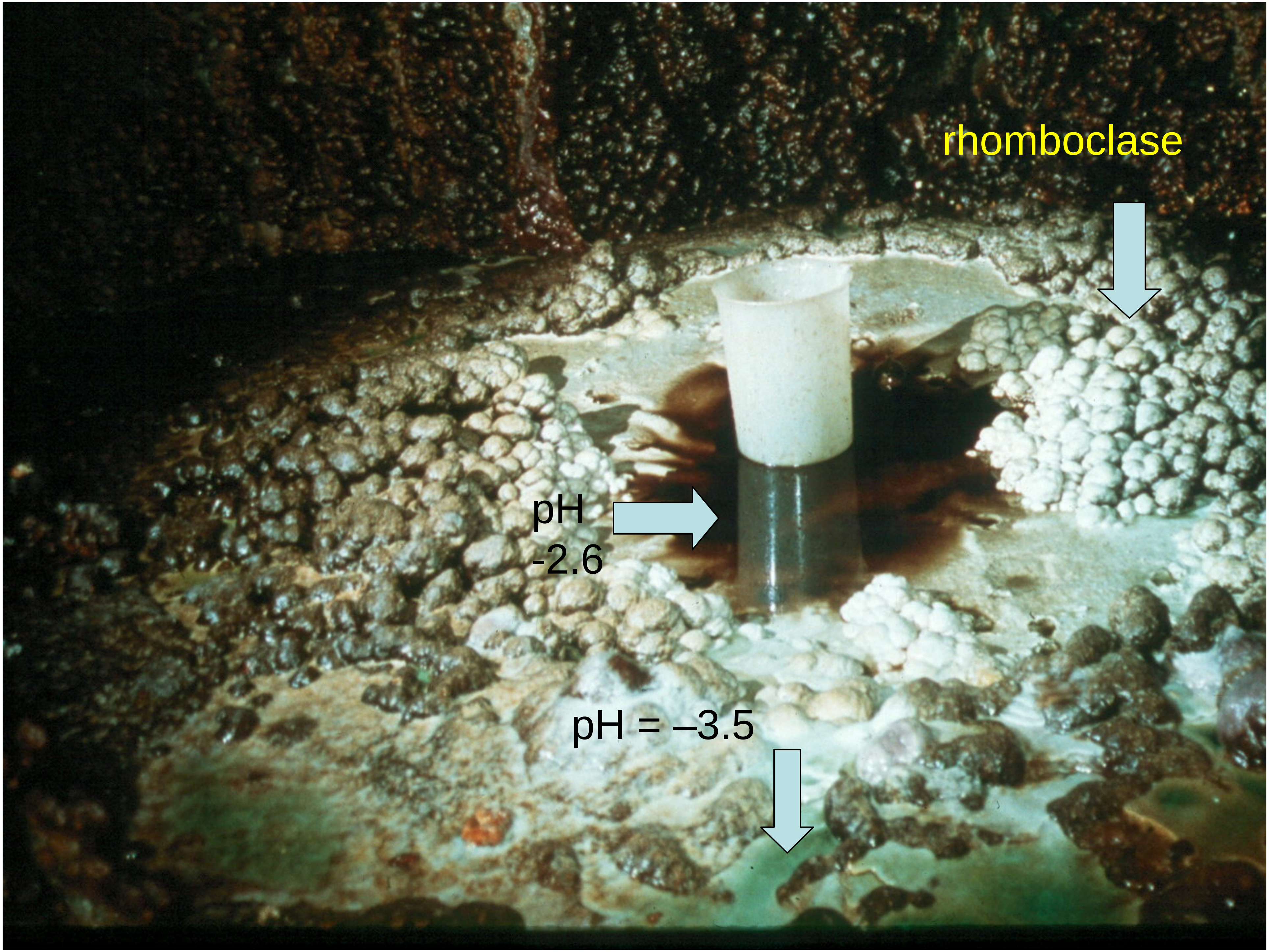


log molality H2SO4
-3.0
-2.0
-1.0
0.0
1.0
4
2
0
-2
-4
pH
○ calculated with PHRQPITZ
◆ standard solution for pH calibration
0.001
0.01
0.1
1.0
10
molality H2SO4


January 15, 2000
Environmental Science & Technology
http://pubs.acs.org/est
The Most Acidic Waters Known
Published by The American Chemical Society


122°30'
122°15'
Lake Shasta
Iron Mountain
40°45'
Spring Cr
Boulder Cr
Shasta Dam
Spring Creek Debris Dam
Slickrock Cr
Keswick Dam
Redding
Sacramento River
40°30'
Sacramento
Map Area


melanterite
pH
-0.7


rhomboclase
pH
-2.6
pH = –3.5

A Sulphur-Based Survival Strategy for Putative Phototrophic Life in the Venusian Atmosphere

D. Schulze-Makuch, D.H. Grinspoon, O. Abbas, L.N. Irwin & M. Bullock (2004) . *Astrobiology*, 4, 11-18.

Abstract

Several observations indicate that the cloud deck of the Venusian atmosphere may provide a plausible refuge for microbial life (Sagan, 1961; Grinspoon, 1997; Schulze-Makuch and Irwin, 2002; Schulze-Makuch and Irwin, 2004). Having originated in a hot proto-ocean or been brought in by meteorites from Earth (or Mars), early life on Venus could have adapted to a dry, acidic atmospheric niche as the warming planet lost its oceans. The greatest obstacle for the survival of any organism in this niche may be high doses of ultraviolet (UV) radiation. Here we make the argument that such an organism may utilize sulphur allotropes present in the Venusian atmosphere, particularly S_8, as a UV sunscreen, as an energy converting pigment, or as a means for converting UV light to lower frequencies that can be used for photosynthesis. Thus, life could exist today in the clouds of Venus.

TODAY THE CLOUDS ARE THE OCEANS OF VENUS
Could they support life?

OBJECTION:

• No access to the "biogenic elements"?

Biogenics: CHONSP minerals (Co, Mn,Mo…)

But, Is this list accepted by the GCOEL? (Galactic COEL)

Elements in Venus clouds and/or troposphere:
Known: CHONSP Cl Fe?
Suspected: I Br Al Br Se Te Hg Pb Al Sb As

Dr. John D. Rummel
Planetary Protection Officer
NASA Headquarters
Washington, D.C. 20546

February 24, 2006

Dear Dr. Rummel:

In your letter of February 7, 2005, to Space Studies Board (SSB) Chair Lennard Fisk, and reiterated at the February 9-11, 2005, meeting of the SSB's Committee on the Origin and Evolution of Life (COEL), you asked for advice on planetary protection concerns related to missions to and from Venus. **In particular, you asked that the NRC address three issues in terms of their implications for planetary protection:**

1. Assess the surface and atmospheric environments of Venus with respect to their ability to support Earth-origin microbial contamination, and recommend measures, if any, that should be taken to prevent the forward contamination of Venus by future spacecraft missions;

2. Provide recommendations related to planetary-protection issues associated with the return to Earth of samples from Venus; and

3. Identify scientific investigations that may be required to reduce uncertainty in the above assessments.

In response, the **Task Group on Planetary Protection Requirements for Venus Missions** (the Task Group) was formed and met at the COEL meeting on October 3-5, 2005, hosted by the Southwest Research Institute in Boulder, Colorado.

At the Boulder meeting, COEL heard presentations from David Grinspoon and Mark Bullock of Southwest Research Institute in Boulder, Colorado, and from Kirk Nordstrom of the USGS in Boulder. In addition, individual Task Group members held extensive discussions in open and closed sessions.

In its deliberations, the Task Group considered planetary-protection considerations affecting Venus missions. Full details are contained in the attached assessment.

With respect to planetary-protection issues, the Task Group concludes that:

- **No significant risk of forward contamination exists in landing on the surface of Venus.**
- **No significant risk exists concerning backward contamination from Venus surface sample returns.**
- **No significant forward contamination risk exists regarding the exposure of spacecraft to the clouds in the atmosphere of Venus.**
- **No significant risk exists concerning atmospheric sample returns from the clouds in the atmosphere of Venus.**

The Task Group recommends that the Category II planetary protection classification of Venus be retained. No scientific investigations are suggested for the purpose of reducing uncertainty in the above recommendations. The considerations that led to the above conclusions can be found in the attached appendix.

Sincerely,

Len Fisk	Jack Szostak
Chair	*Chair*
Space Studies Board	Task Group

NASA Categories for Planetary Protection

Category I includes any mission to a target body, which is not of direct interest for understanding the process of chemical evolution or the origin of life. No protection of such bodies is warranted and no planetary protection requirements are imposed.

Category II includes all types of missions to those target bodies where there is significant interest relative to the process of chemical evolution and the origin of life, but where there is only a remote chance that contamination carried by a spacecraft could jeopardize future exploration. The requirements are only for simple documentation. This documentation includes a short planetary protection plan is required for these missions, primarily to outline intended or potential impact targets; brief pre-launch and post-launch analyses detailing impact strategies; and a post-encounter and end-of-mission report providing the location of inadvertent impact, if such an event occurs.

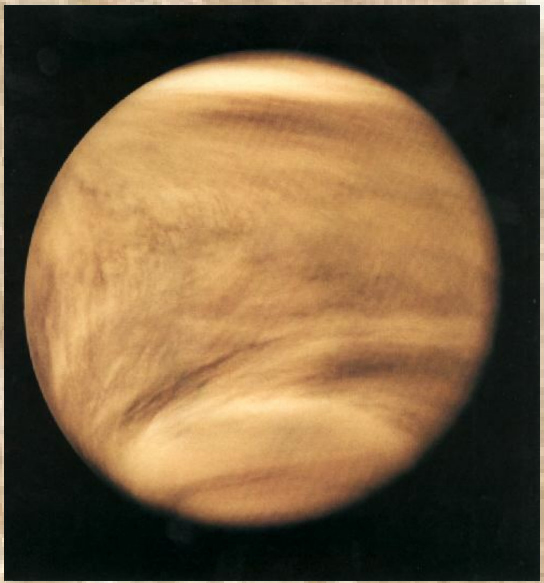
Category III includes certain types of missions (typically a flyby or orbiter) to a target body of chemical evolution or origin-of-life interest, or for which scientific opinion holds that the mission would present a significant chance of contamination which could jeopardize future biological exploration. Requirements consist of documentation (more involved than that for Category II) and some implementing procedures, including trajectory biasing, the use of clean rooms (Class 100,000 or better) during spacecraft assembly and testing, and possibly bioburden reduction. Although no impact is generally intended for Category III missions, an inventory of bulk constituent organics is required if the probability of inadvertent impact is significant.

Category IV (entry probe, lander or rover) to a target body of chemical evolution or origin-of-life interest, or for which scientific opinion holds that the mission would present a significant chance of contamination which could jeopardize future biological exploration.

Category V pertains to all missions for which the spacecraft, or a spacecraft component, returns to Earth.

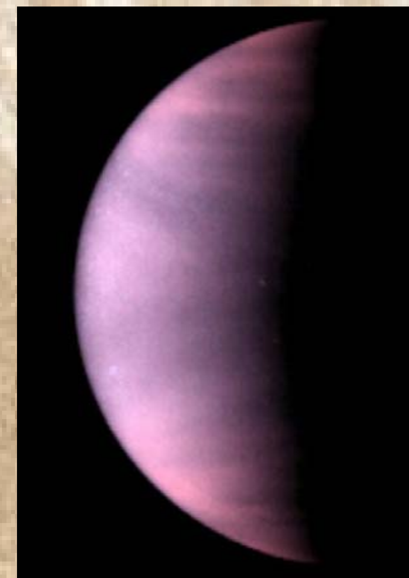
The Future of Life on Earth

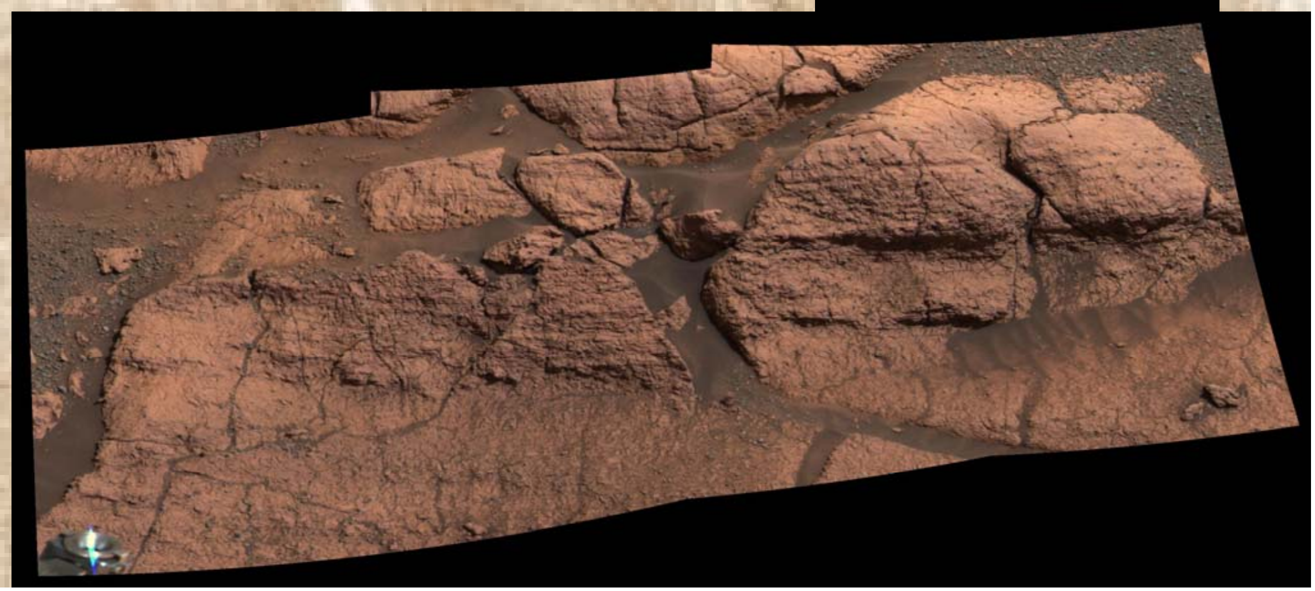
- In about 1 Gy, the Earth may experience a runaway H_2O greenhouse (Kasting).
- Currently, there are regions of the tropical oceans that are in this runaway state (McKay et al).



Increasing Relevance for Early Mars

- Both planets have sulfur-rich environments.
- Both planets may have experienced a watery past, followed by an acidic phase as they desiccated.





Astrobiology Questions Requiring Further Exploration:

•How and when was surface water lost? History of Climate?

•History of surface and interior?

•Mineralogy, evidence for water, isotopic biomarkers, zircons?

•Equilibrium state of lowest scale height?

•Origin and history of atmosphere - Noble gasses?

•Escape flux and response to solar variations?

•Unknown UV absorber?

•Composition of mode 3 cloud particles?

•How does atmospheric circulation affect cloud particle lifetimes?

•Trace constituents in clouds & surrounding atmosphere?

•Have clouds been a constant feature? (or at least continuous?)

•How has pH changed over time?