Astrobiology in the inner Solar System

Planets and Astrobiology (2018-2019)
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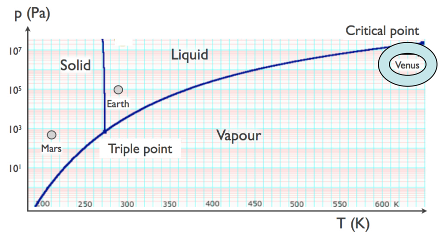
Venus

Surface conditions

T_s=735 K
p_s=92 x 10^5 Pa

Atmospheric composition dominated by CO_2, without O_2
Absence of tectonics

Surface conditions do not satisfy the liquid water criterion: currently non habitable



Venus has probably undergone a "runaway greenhouse effect" in the early stages of its history

Search for habitable environments and life in the Solar System

Most studies of the Solar System are based on results obtained from interplanetary space missions

These investigations are complemented by laboratory experiments and studies of extremophiles simulating planetary space conditions

Observational astronomy is still providing important data in the context of Solar System astrobiology but its role is less important than in the past

Venus

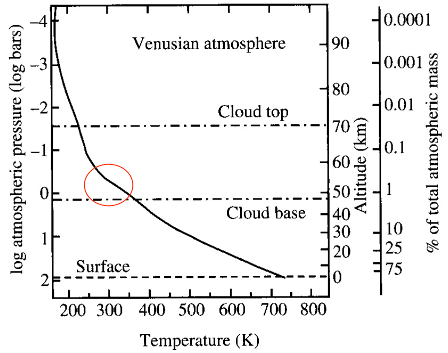
Origin of the CO_2-rich, dense atmosphere

Possible scenarios:

- As a result of a runaway greenhouse instability, water would be photodissociated and hydrogen lost, leaving free oxygen that would combine with carbon (the absence of hydrogen inhibits the chemical pathways that lead to organic chemistry, e.g. CH_4)
- The atmosphere was CO_2-rich and dense since the beginning; in this scenario, the loss of water through runaway greenhouse instability prevents the formation of oceans and the possibility of tectonics; without oceans and without tectonics it is not possible to remove CO_2 from the atmosphere

Searching for "habitable" layers in the atmosphere of Venus

- At a height of ~50-60 km, p and T lie within the liquid water limits, being roughly similar to the values found at the surface of the Earth
- Based on the liquid criterion alone, life could in principle exist
- However, based on other criteria of habitability, it is very unlikely that life could exist in those layers
- Due to strong winds and convective motions no type of material would be able to remain suspended in the "habitable" layer



Search for water in Mars

The search for water has been one the main astrobiological goals of Mars studies

Evidence of water in present-day Mars

Traces of recent erosion at the border of craters

Interpreted as transient outflows of water in liquid phase ("gullies")

Mars Reconnaissance Orbiter, NASA (2006)

Mars

Surface habitability

At present time the Mars surface is not habitable

The surface is slightly below the triple point of water (611 Pa)

T_s = 210 K

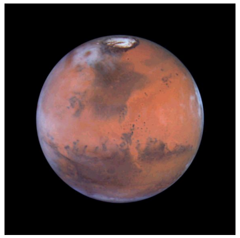
P_s ~ 600 Pa (~ 6 mbar)

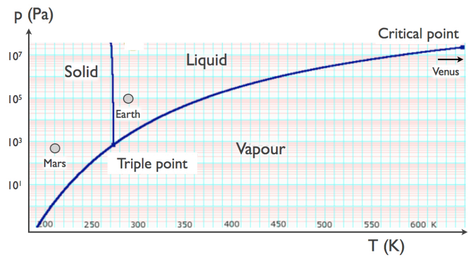
The atmospheric composition is dominated by CO_2

Tectonics is absent

At some proper depth below the surface we expect conditions suitable for liquid water due to pressure and temperature gradients

Salinity would help to decrease the freezing point



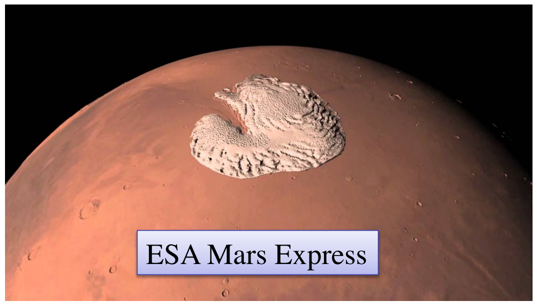


Search for water in Mars

Evidence of water in present-day Mars

The bulk of the polar caps is constituted by CO_2 ice, but the North polar cap must also contain H_2O

this would explain why such polar cap is able to persist, to some extent, during the Mars summer, when CO_2 sublimates into the atmosphere



ESA Mars Express

Search for water in Mars

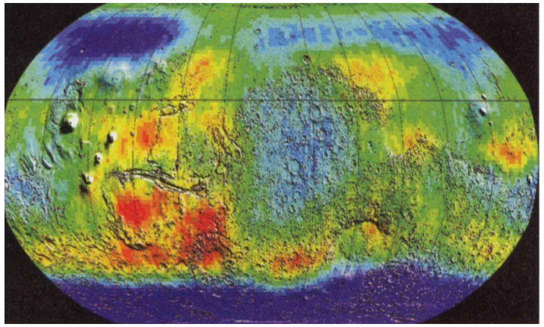
Evidence of water in present-day Mars

Space probes are collecting evidence of underground water ice

The distribution of hydrogen below the ground, inferred from the data collected from the probe "Mars Odyssey", suggests the existence of a layer of water ice at a depth of about one meter

Blue areas: maximum concentration

Mars Odyssey, NASA (2001)



Mars habitability in the past

The evidence for water in Mars is compelling, but at present time water seems to be largely confined in ice phase below the surface, with sporadic signatures of outflows and sublimation

However, the situation must have been very different in the past of Mars

Several independent evidences suggests that Mars was habitable in the past

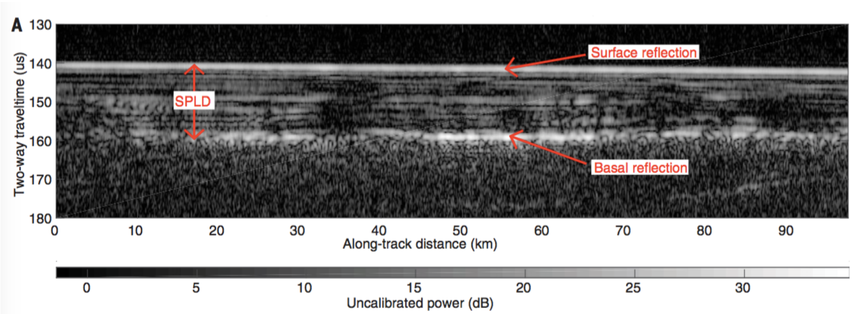
- These evidences are particularly important in astrobiology, because of the possibility that life might have emerged on Mars

Among the different evidences of past habitability we mention:

- Statistics of impact craters
- Geomorphological evidence
- Martian meteorites collected on Earth

Radar evidence of subglacial liquid water on Mars

South Polar Layered Deposits



Reflected signal interpreted as evidence of
a stable body of liquid water at ~1.5 km below the surface

Orosei et al. (2018)

Mars habitability in the past

Evidence for the presence of a thick atmosphere in the past

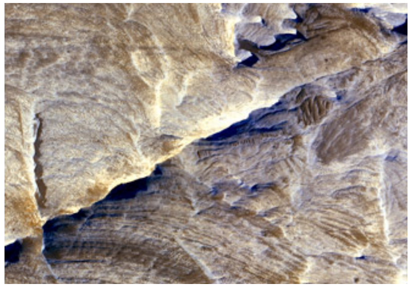
- Statistics of the diameters of impact craters
- Deficit of small size ancient craters with respect to recent craters
- The presence of a past atmosphere may have caused this deficit by means of:
  - Fusion of small size meteoroids due to friction during the crossing of the atmosphere
  - Erosion of the shallowest craters by means of atmospheric weathering

A thick atmosphere would have dramatically enhanced the habitability of Mars:

- increasing the pressure above the triple point of water
- increasing the greenhouse effect and surface temperature
- protecting the planetary surface from ionizing radiation

Mars: evidence for <u>past</u> geological activity

Tectonic fractures, ridge-like shapes
These features suggest that episodes of fluid alteration along the fractures must have taken place in past geological times



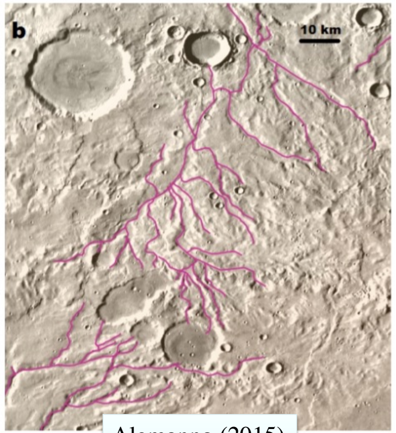
Mars Reconnaissance Orbiter, NASA (2006)

Presence of water in the past: valley networks

Mapping of Martian valley networks has lead to the determination of formation timescales

The obtained results for the formation timescales range from 10^5 to 10^8 years (depending on erosion rate)

Mars experienced at least short periods of clement conditions towards the end of the Noachian Era (~4.1 to 3.7 Gya) that supported a hydrological cycle and potentially a biosphere



Alemanno (2015)

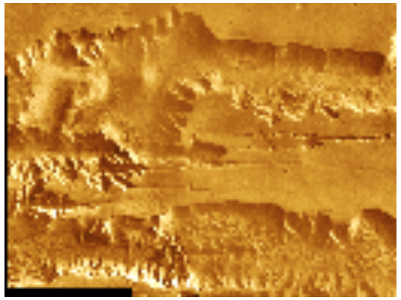
Mars habitability in the past

Evidence for the presence of liquid water in the past

<u>Geomorphological</u> evidence

Network of valleys similar to those excavated by terrestrial rivers

The presence of valley networks suggests that Mars contained a significant amount of water *at the liquid state* in the past



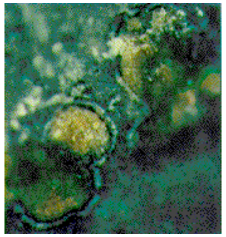
Mars habitability in the past

Evidence for the presence of liquid water in Mars meteorites

Some meteorites recovered in Allan Hills (Antarctica), are of martian origin and suggest that liquid water was present on Mars in its early geological eras

SNC meteorite ALH 84001 (found in 1984)

Radiodating: 4.1 Gya (Lapen et al. 2010)

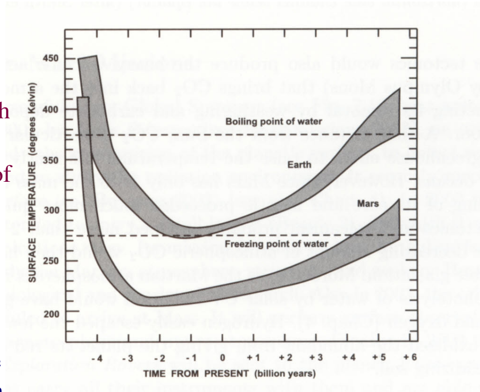


Mars habitability in the past

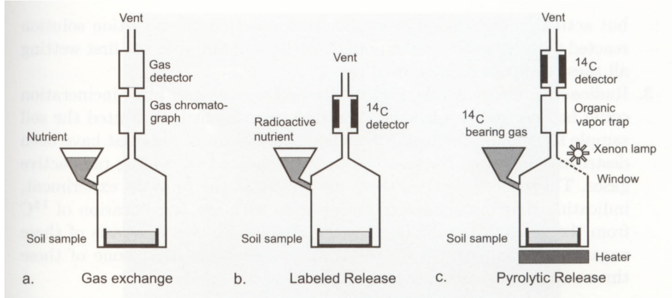
- In light of the "faint young sun paradox", the requirement for a primordial CO_2-rich atmosphere is more compelling for Mars than Earth
- An intense, early vulcanic activity may have generated large amounts of atmospheric CO_2

The greenhouse effect would have provided a temperature sufficiently high for water being in the liquid phase

However, the atmospheric pressure should have been much higher than today (several bars of CO_2)



Searches for <u>life</u> on Mars



Viking experiments (1976) searched for traces of biological activity from the analysis of samples collected in a few martian landing sites

Several experiments were carried out and analysed *in situ*, searching for evidence of biochemical processes

A signal from the Labeled Release (LR) experiments was consistent with the presence of biochemical activity, but this signal is generally believed to be a "false positive" because it was not confirmed by the Gas Chromatograph - Mass Spectrometer (GCMS) experiment

Atmospheric loss in early Mars

The large amount of atmospheric CO_2 required to solve the faint young paradox for Mars is not confirmed by the geochemical evidence of Mars surface

It is possible that Mars atmosphere was quickly dissolved by intense solar wind at early stages of Mars evolution

The Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft has been orbiting Mars since 2014 to address this problem

This mission aims at characterizing the upper atmosphere and ionospheric structure and composition, the interactions of the sun and the solar wind, and the processes driving loss of atmospheric gas to space (Jakosky et al. 2015)

Results from the MAVEN mission indicate that major episodes of solar activity are extremely efficient at driving loss of Mars atmosphere

Perchlorates and search for life on Mars

Experiments conducted in 2008 by the Phoenix lander discovered the presence of perchlorate ($Cl\ O_4^-$), a reactive compound, in Martian soil

This finding is potentially important for the interpretation of Viking results, because the presence of perchlorate might have destroyed organics at the higher temperatures of the GCMS experiment

NASA astrobiologist Chris McKay has estimated that if Phoenix-like levels of perchlorates were present in the Viking samples, the organic content of the Martian soil could have been as high as 0.1% and still would have produced the negative result that the GCMS returned

Thus, while conventional wisdom regarding the Viking biology experiments still points to "no evidence of life", recent years have seen a small shift toward "inconclusive evidence"

Lessons from the Viking experiment

The ambiguous results of the Viking experiments teach us how difficult is to reveal the presence of life, even when we can analyse samples

Analysis of Martian samples in Earth laboratories would be much more accurate than the analysis performed in situ, but bringing the sample back to Earth would increase dramatically the cost of the mission

The negative (or ambiguous) results of the Viking experiments do not exclude that life might exist in other locations on Mars

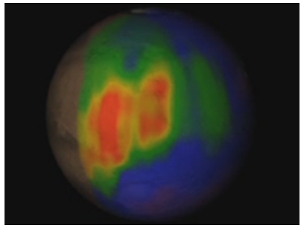
Active biological processes might take place in underground layers at a proper depth, where the temperature and pressure gradients would allow liquid water to be present

If so, we would expected to find some biosignatures, such as traces of surface gas of biological origin

The search for atmospheric methane in Mars

Claims of detection:

- remote observations of a gas plume (Mumma et al. 2009)
- occasional detections by NASA's Curiosity rover
- ESA's Mars Express spacecraft (Giuranna et al. 2019)



Unsuccesful search:

Trace Gas Orbiter (European-Russian)

Methane undetected at a height of 5 km from the surface

Criticism

CH_4 could be real, but may result from contamination of terrestrial rovers (Kevin Zahnle)

Search for atmospheric biosignatures in Mars

The atmospheric composition is dominated by CO_2

Given the low value of partial pressure, the greenhouse effect driven by CO_2 is insufficient to make Mars habitable at present time

O_2, the most classic atmospheric biomarker on Earth, is absent in the atmosphere of Mars

Detections of traces of CH_4 in the Mars atmosphere have been reported several times

Methane emissions seem to have a local and seasonal character

If confirmed, outgassing of CH_4 would suggests the presence of underground chemical activity

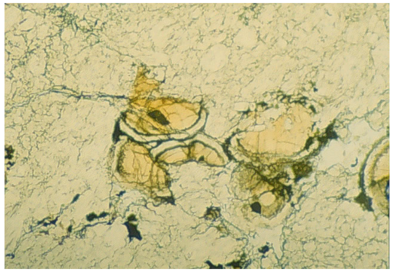
The activity could be geochemical or even biochemical, based on the biogenic production of methane on Earth

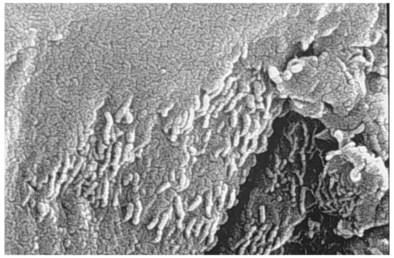
Searches for life in the past history of Mars

The analysis of the meteorite ALH 84001 revealed microstructures with morphology suggestive of a biological origin

Carbonate globules with an age of 3.9 Ga have been found in its interior

However, the sizes of those structures, between 20 and 100 nm, are too small with respect the smallest sizes of the living cells that we know

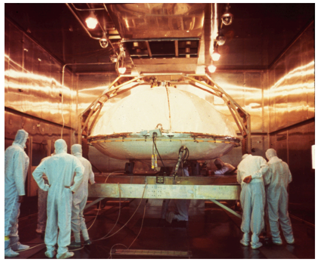




Planetary protection

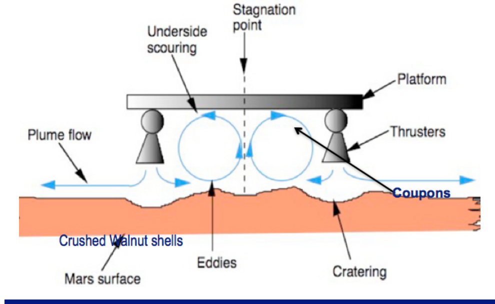
Planetary protection is a guiding principle in the design of an interplanetary mission, aiming to prevent biological contamination of both the target celestial body and the Earth

Reflects both the unknown nature of the space environment and the desire to preserve the pristine nature of celestial bodies until they can be studied in detail



A Viking lander being prepared for dry heat sterilization

Mars contamination



Different planetary protection cleanliness levels for different parts of a spacecraft do not necessarily prevent soil contamination because these cleaning strategies evolved without consideration of the effects of the descent engine plumes.