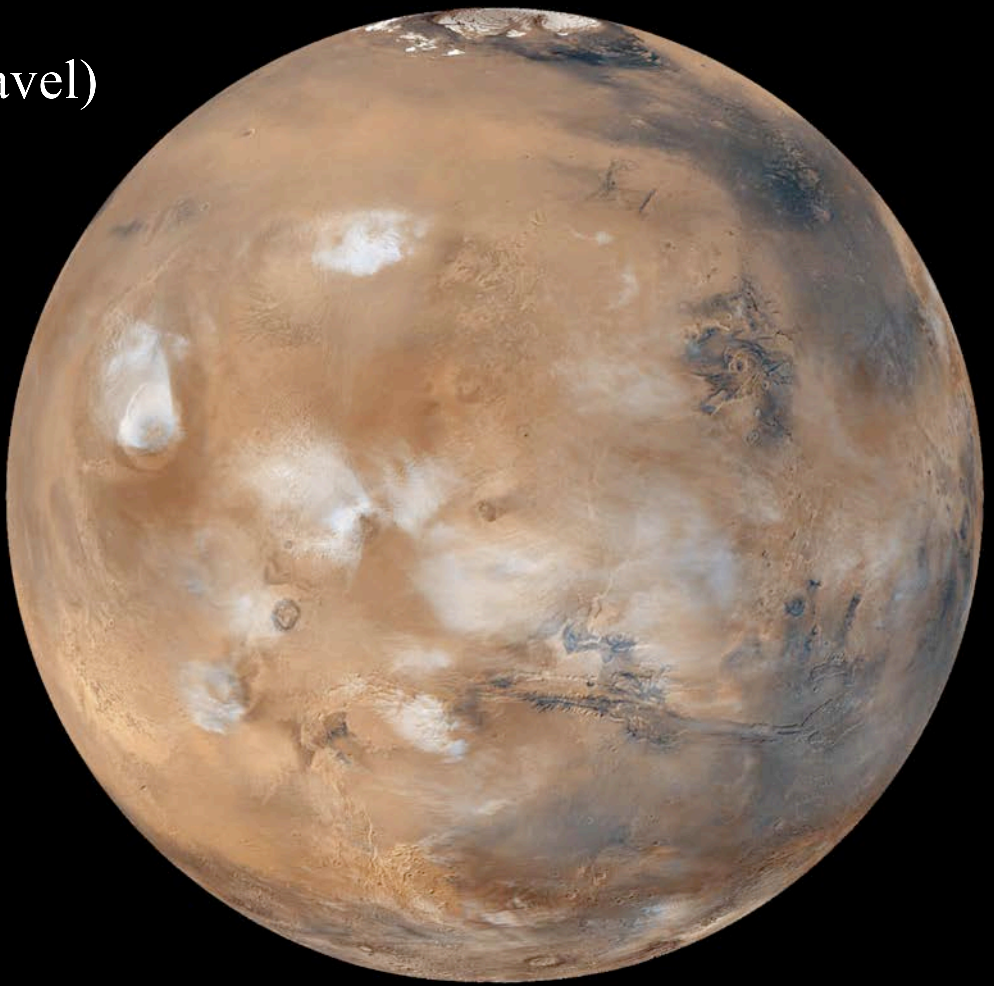
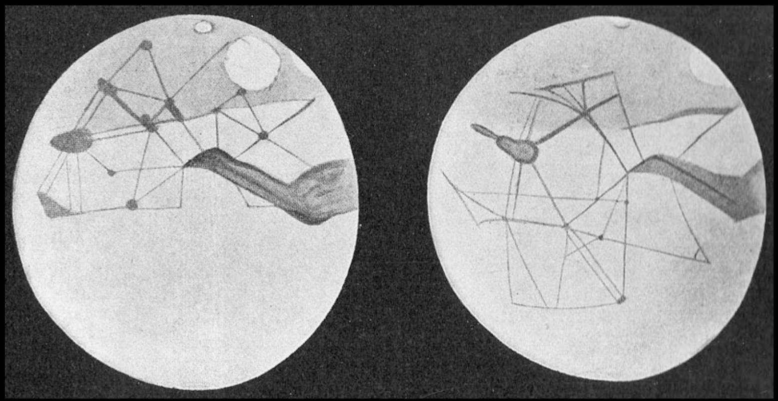
6. Possibilities of Life elsewhere in the Solar System

1. Mars

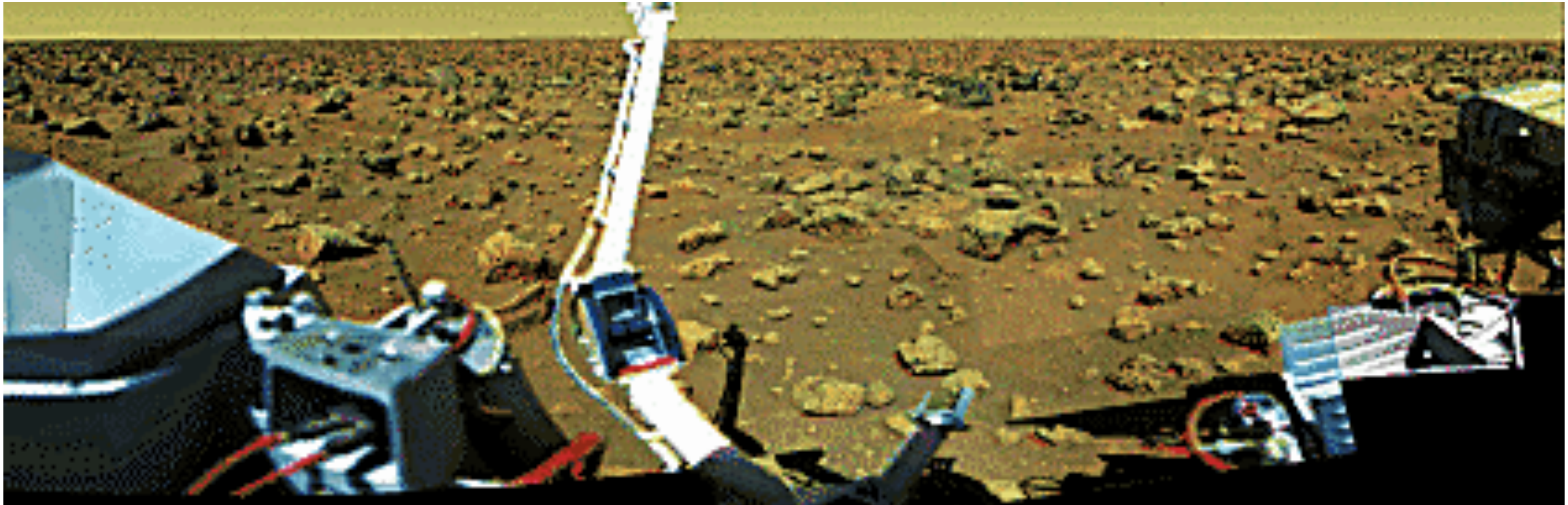
Is there, was there, life in Mars?

- Searches with terrestrial telescopes
- Analyse composition of atmosphere
- Travel to planet e.g. Mariner in 1965, Viking in 1976
- Analyze Martian meteorites (reverse travel)

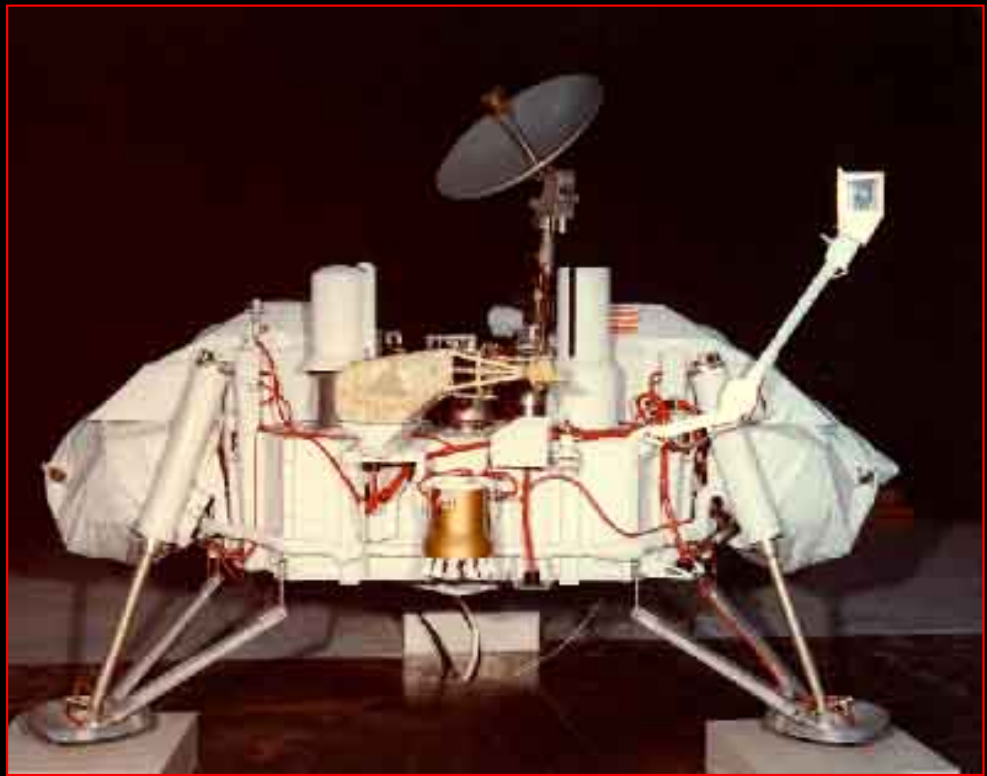


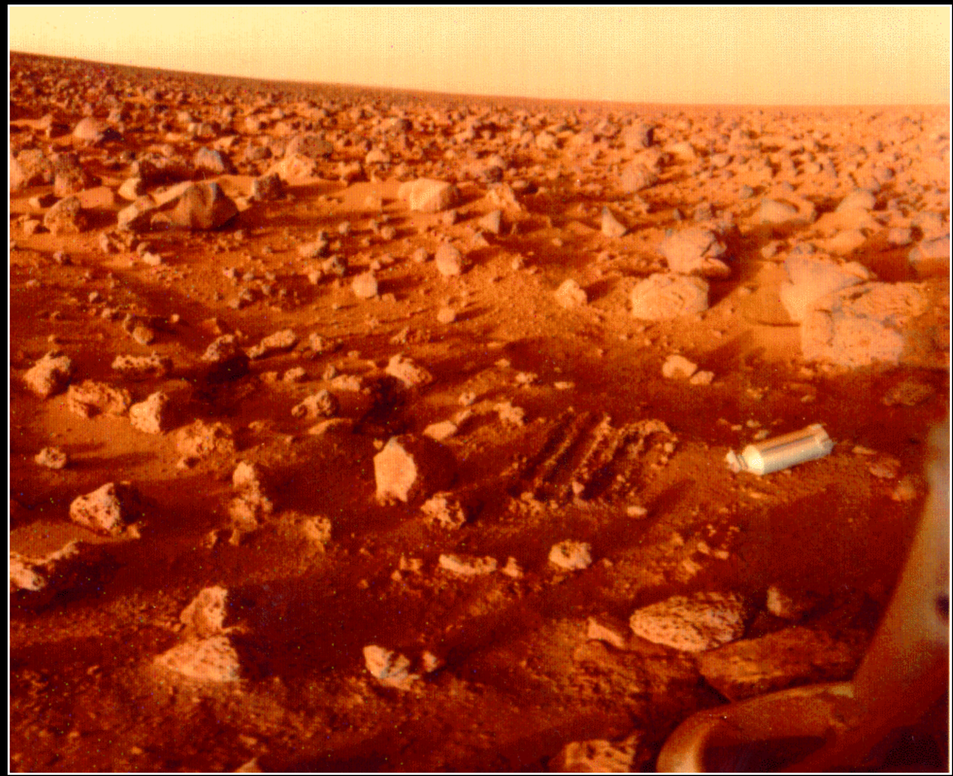


Imagined "canals" on Mars – widespread belief in dying Martian civilization ~ 1900 (esp. P. Lowell)



Viking Mars Landers (1976) - only seven years after Apollo 11





Viking search for life experiments

Soil composition:

No hydrocarbons at 10 parts per billion-trillion (c.f. Murchison meteorite!)

→ highly oxidized surface layer)

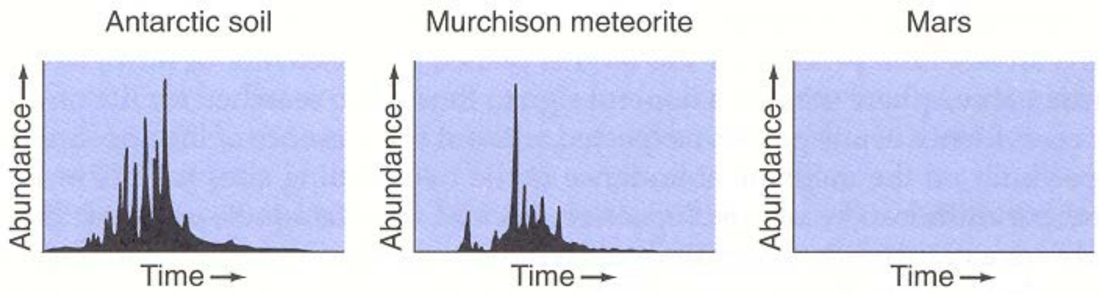


Figure 14.2 A test model of the *Viking* GCMS experiment analyzed Antarctic soil (left) and a piece of the Murchison meteorite (see Figure 11.14), which contains amino acids (center). The results show that each of these two samples contains a rich variety of organic compounds, since every peak in the graphs represents one or more such compounds. On this scale, the GCMS analysis of martian soil shows nothing whatsoever (right).

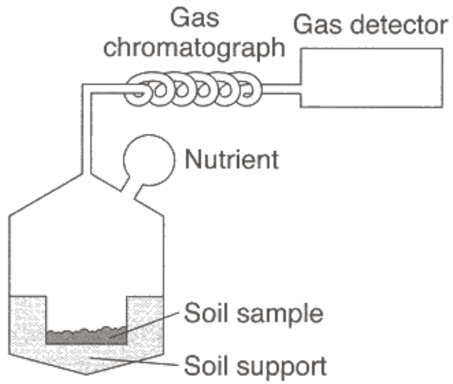
Viking "Biological experiments"

- Gas Exchange: Do nutrients added to soil produce change in atmosphere above soil?
- Labelled release: Does ^{14}C in nutrients appear as CO_2 or CH_4 in atmosphere?
- Pyrolitic release: Does ^{14}C in simulated Martian atmosphere produce organic molecules in the soil?

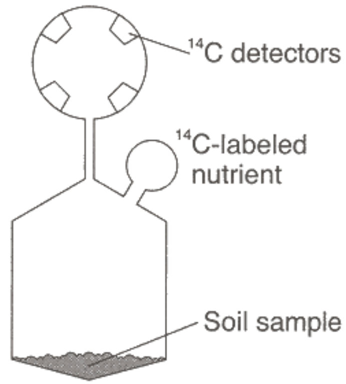
O_2 produced! But, the same result in sterilized soil → water in nutrient reacting with arid soil

CO_2 produced! But, a second release produced no further increase.
$H_2O_2 + HCOOH \rightarrow CO_2 + 2H_2O$

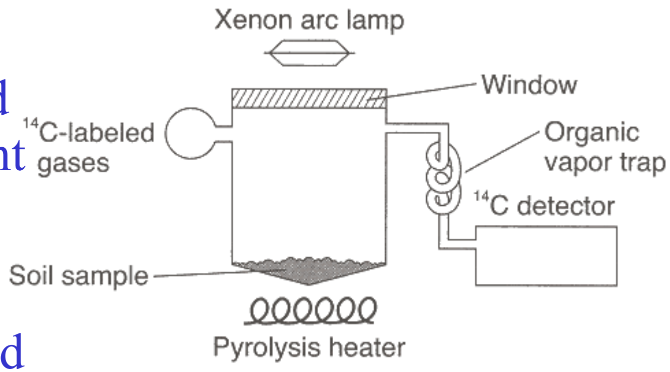
^{14}C in soil! Likely due to NH_3 contamination from descent engine



GEX experiment



LR experiment



PR experiment

Conclusion: purely chemical effects in soil, not biology.

Water and the current atmosphere of Mars

- Surface pressure now only 0.006 bar
- CO_2 with small amounts of N_2. H_20 is at 10^{-5} level with (intermittent?) detection of CH_4 at 10^{-8} ?
- Large temperature variations (~0°C at equator, -80°C at poles).
- CO_2 is in equilibrium with the large and seasonal CO_2 ice caps at the poles.

Surface water cannot exist under these atmospheric conditions but could have existed at higher atmospheric pressures and warmer temperatures, before the "runaway freeze-out" of CO_2 led to cooling of planet and loss of atmosphere.

Subsurface water can (and does) exist in the form of solid ice. Also extensive water ice under the CO_2 polar caps and in high latitude craters.

If interested see https://en.wikipedia.org/wiki/Water_on_Mars

Evidence of past surface liquid water:

- There are certainly today large (km-thick) permanent H_20 ice caps under the seasonal CO_2 coverage
- There is evidence for extensive H_2O ice within surface rocks

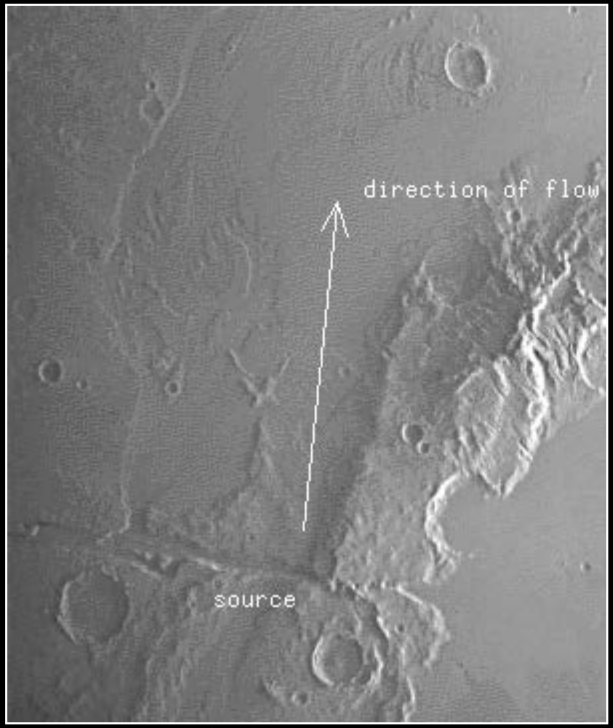
Evidence of (recent) liquid surface water:

1. Outflow channels:

- Flows of debris carried by water?
- Found in young terrain (without craters)
- Flows sufficiently energetic that they could have been sustained under present atmospheric conditions.
- Likely caused by sudden melting of sub-surface ice (due to heating from impacts, volcanism etc.)

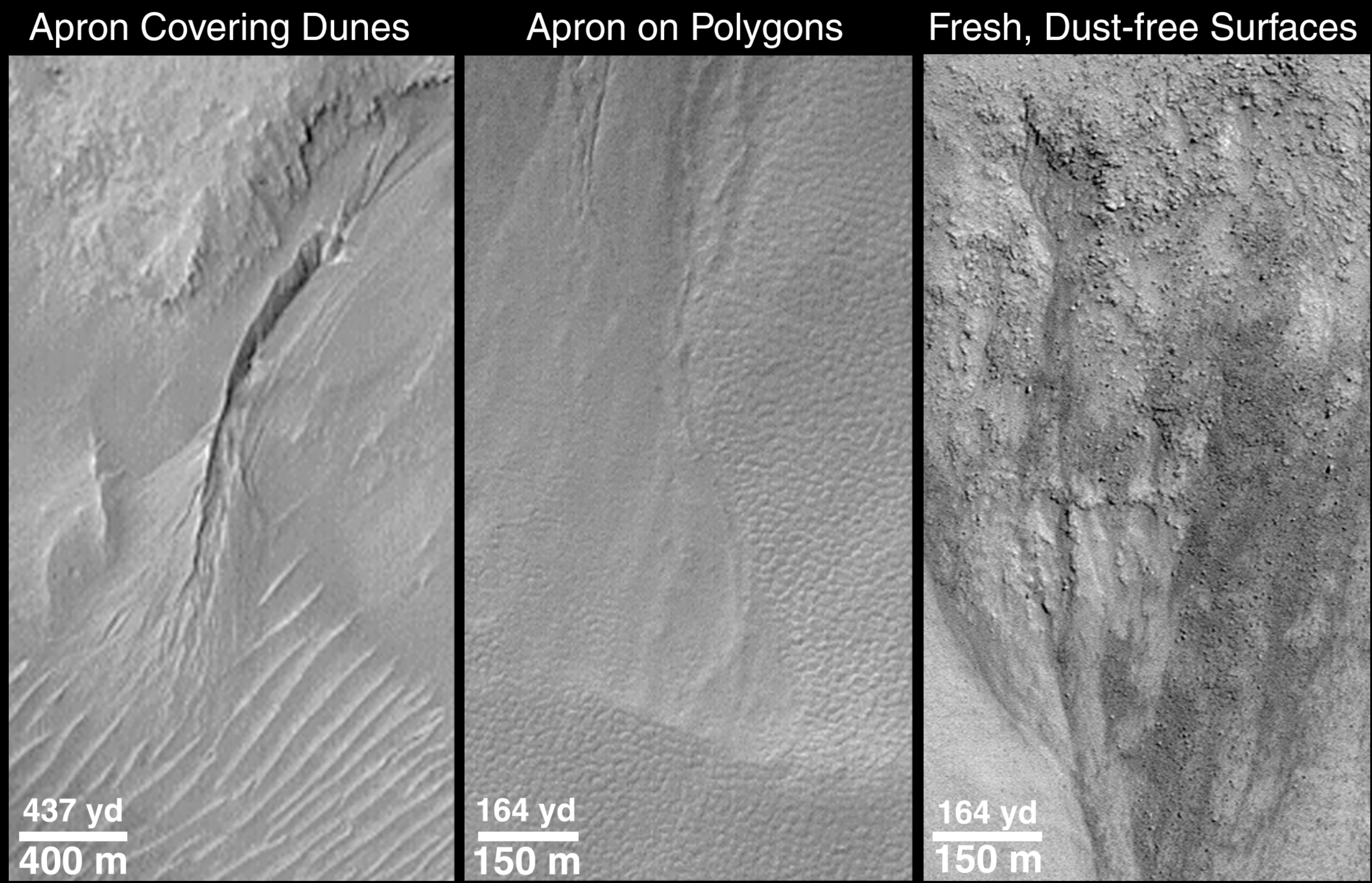
Recent outflow channels

Erosion protection or deposition, down-stream of crater?

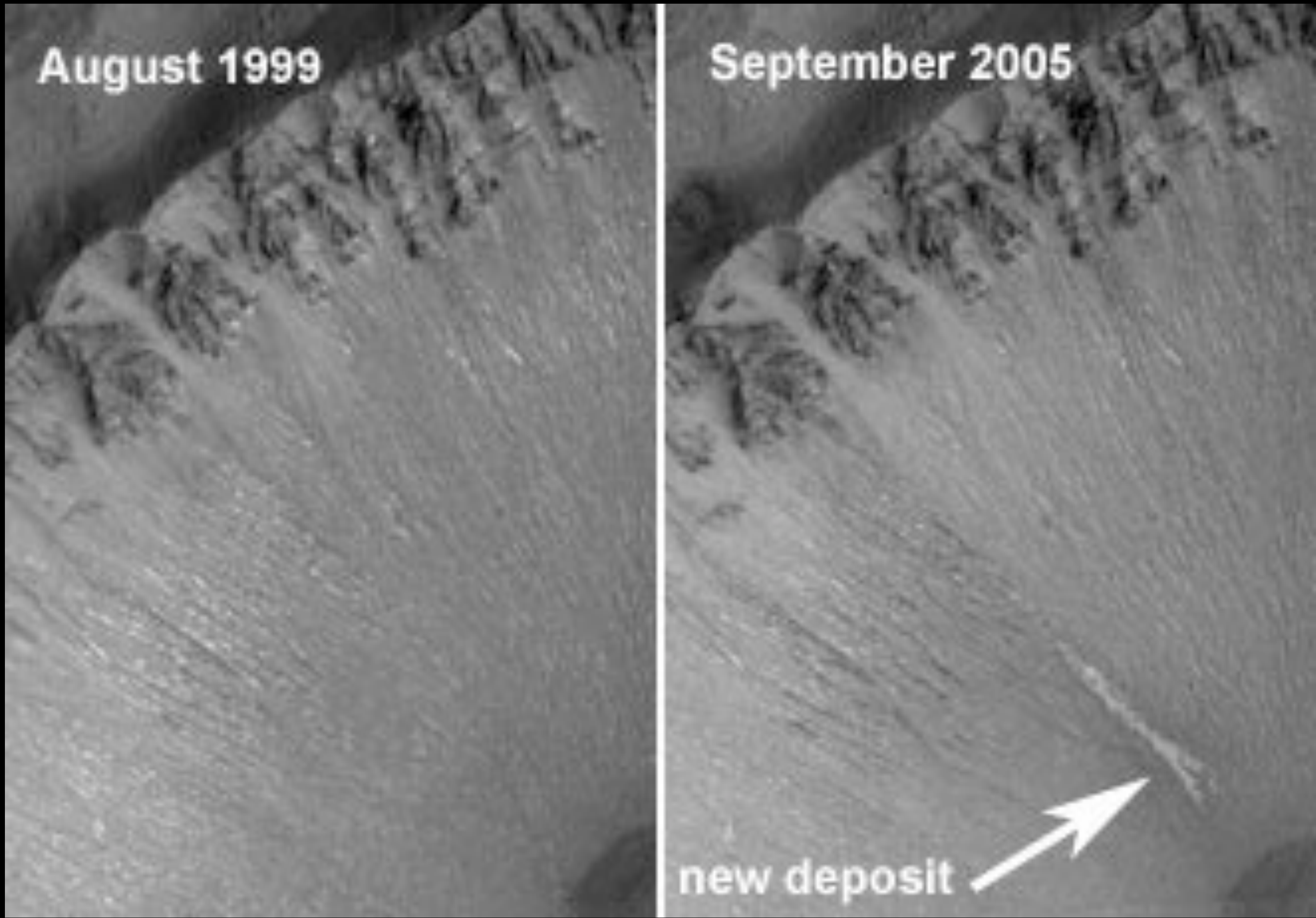


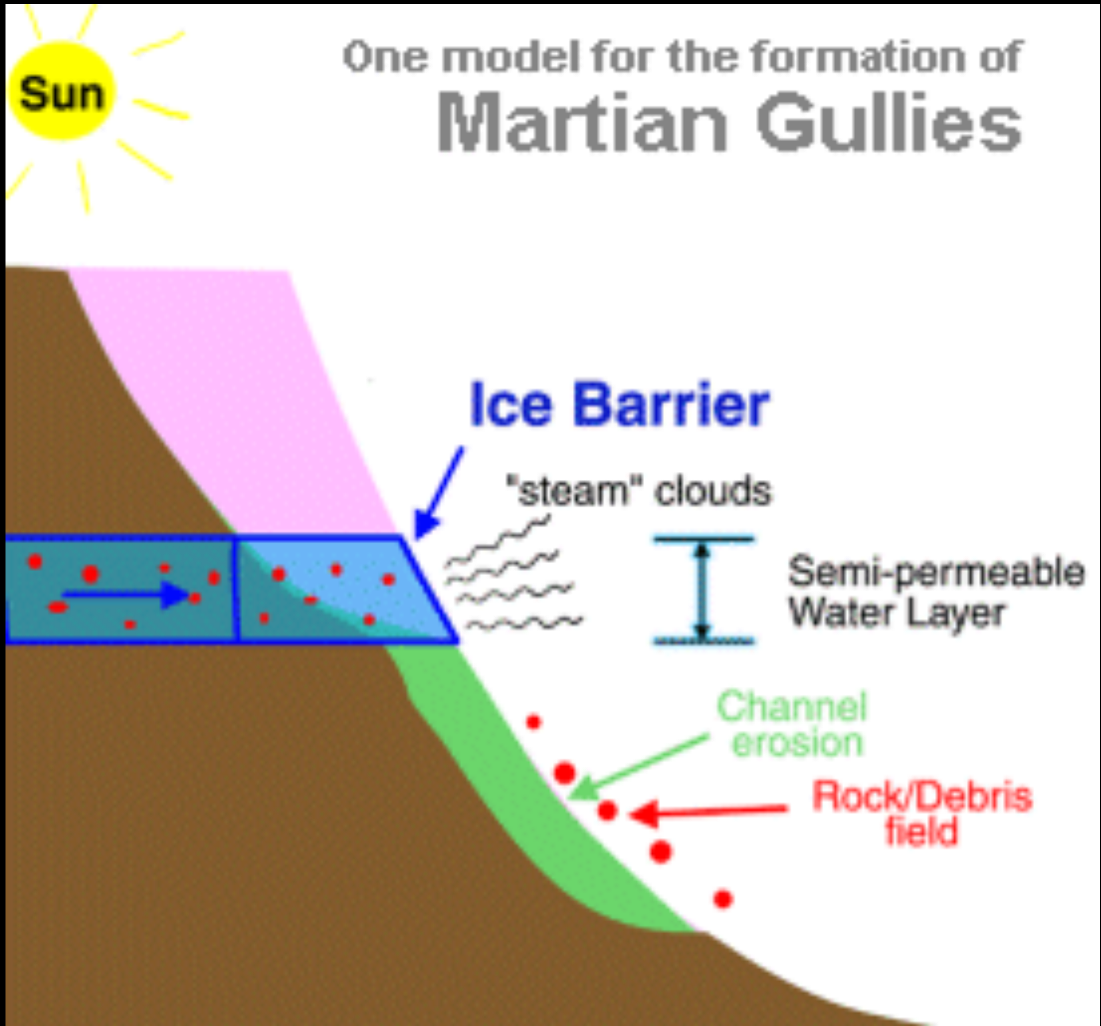
Origins traced back to regions showing collapse

Recent "flows" covering sand dunes – only 10 years old. Dry or wet?



Newly appearing bright deposits: salty seasonal outflows





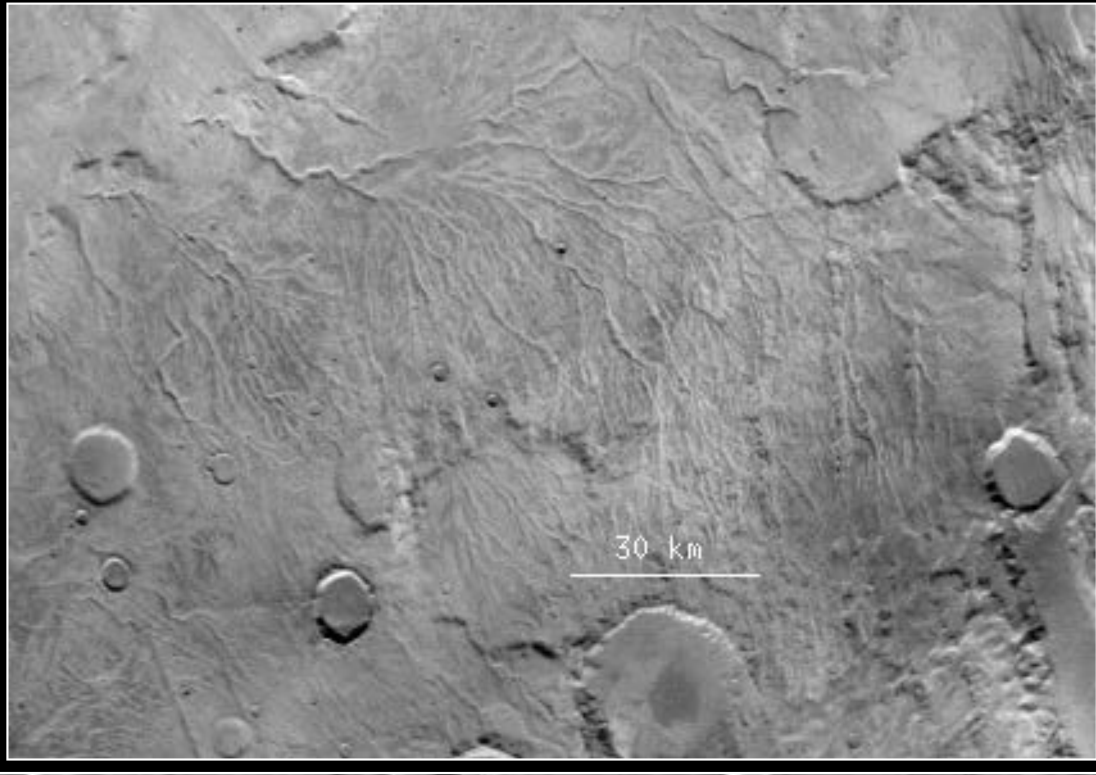
H_2O or liquid CO_2?
(gullies are seen in coldest(?) areas at 210K)

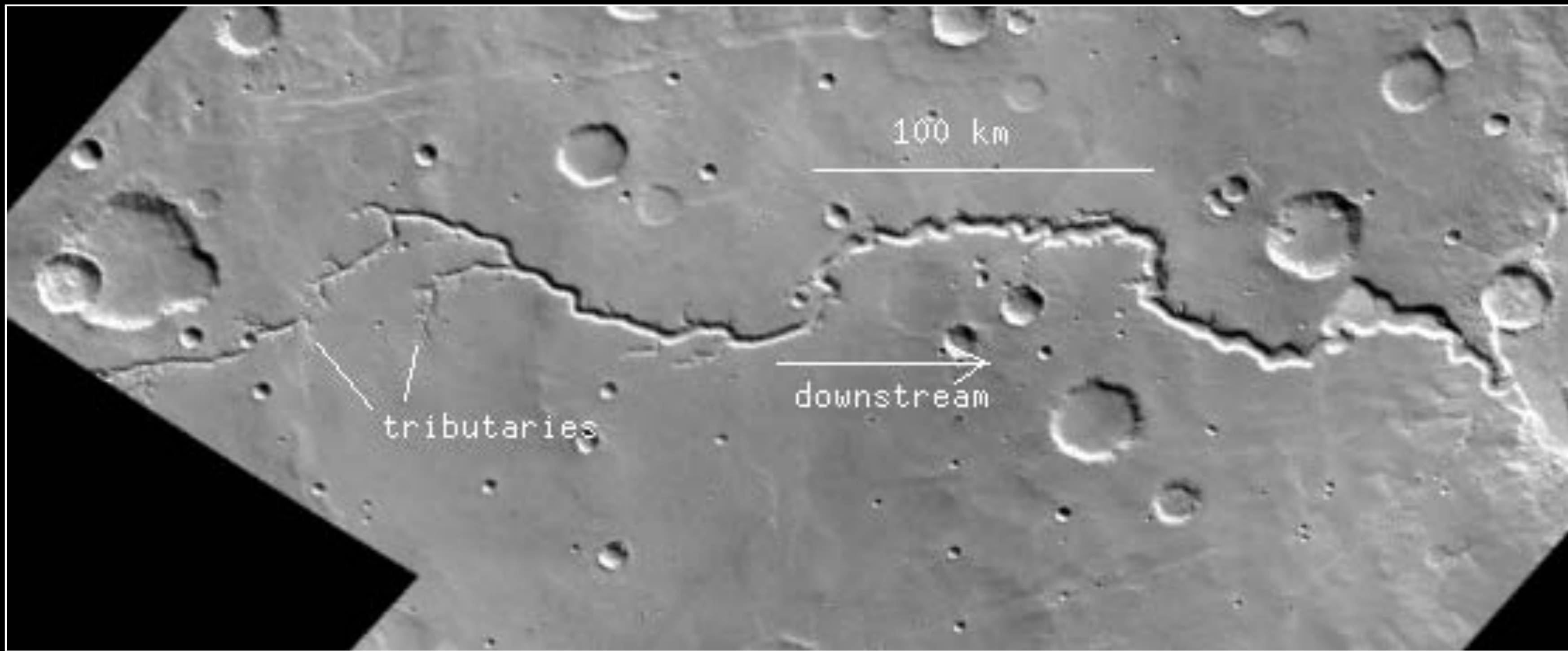
2. Extensive ancient valley networks

- Generally formed even before the end of the period of heavy cratering, i.e. in ancient terrain.
- Highly suggestive morphologies: tributaries, deltas
- Surface flow (or possible "sapping" of sub-surface flows?)
- Some surface features resemble effects of glaciation

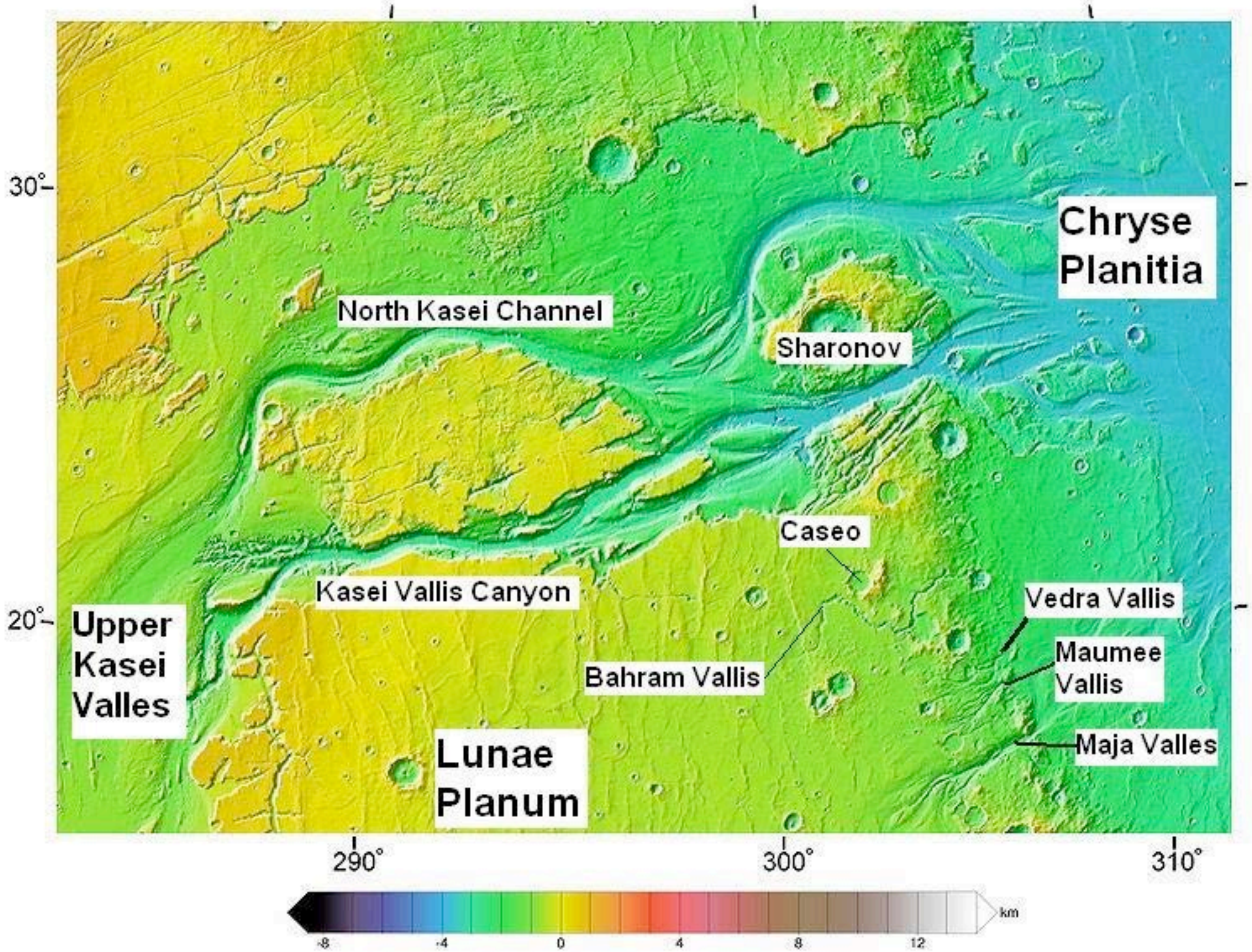
Martian canyon systems

Flowing water or
"sapping" due to
ground-water erosion



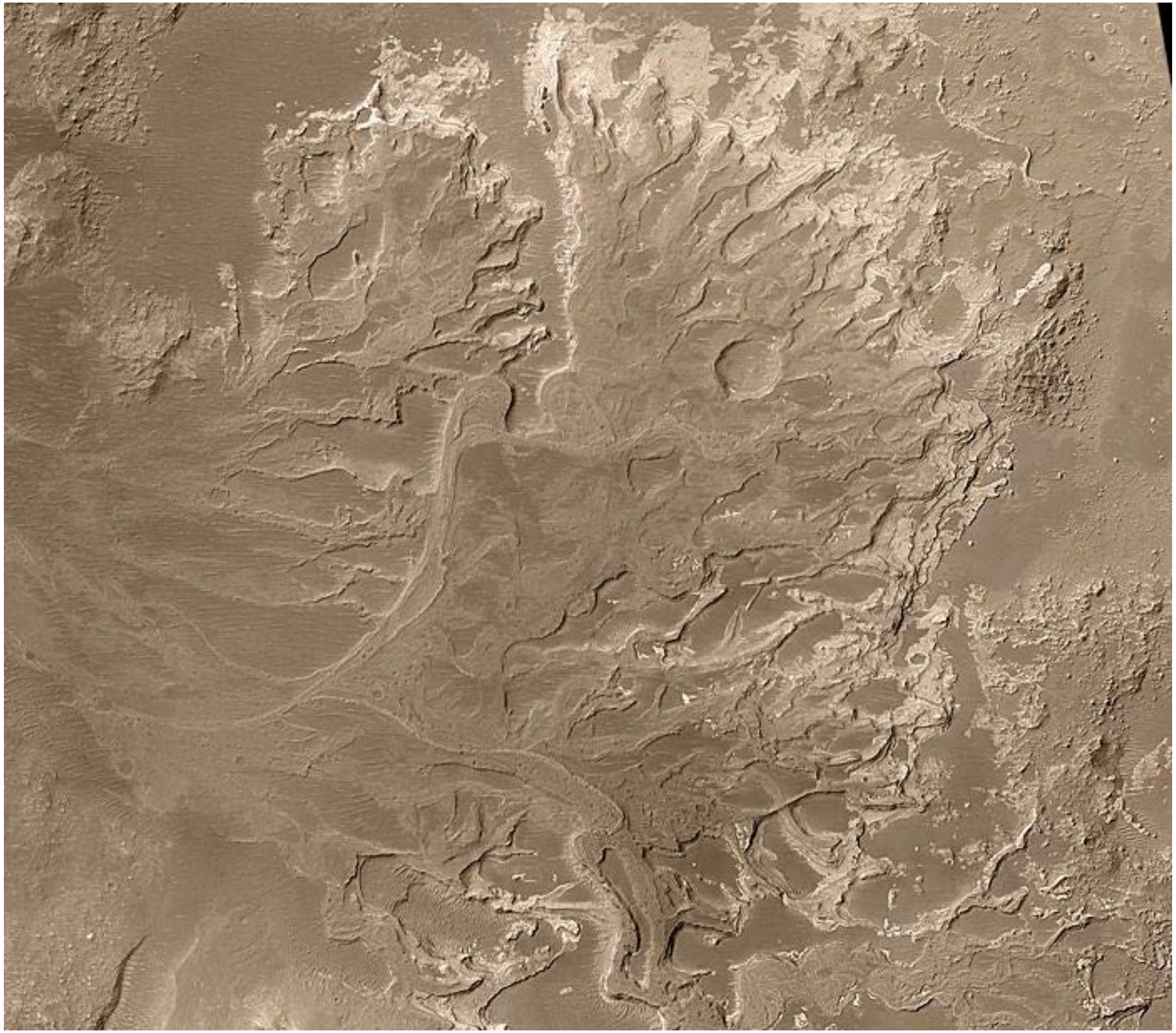


Entrance to low lying Chryse Planitia (1600 km across)



Valley systems

Deltas probably require flow into deep water for long periods of time



Delta in Eberswalde Crater

3. Mineral evidence

- Surface deposits seen from orbit of grey hematite – iron oxide that usually forms in the presence of liquid water.
- Meridani Planum landing site (Opportunity):
  - Jarosite mineral heavily contaminated by salts.
  - Vertical gradient of Cl and Br indicative of evaporating water.
  - Physical structures indicative of sedimentation in slowly flowing water

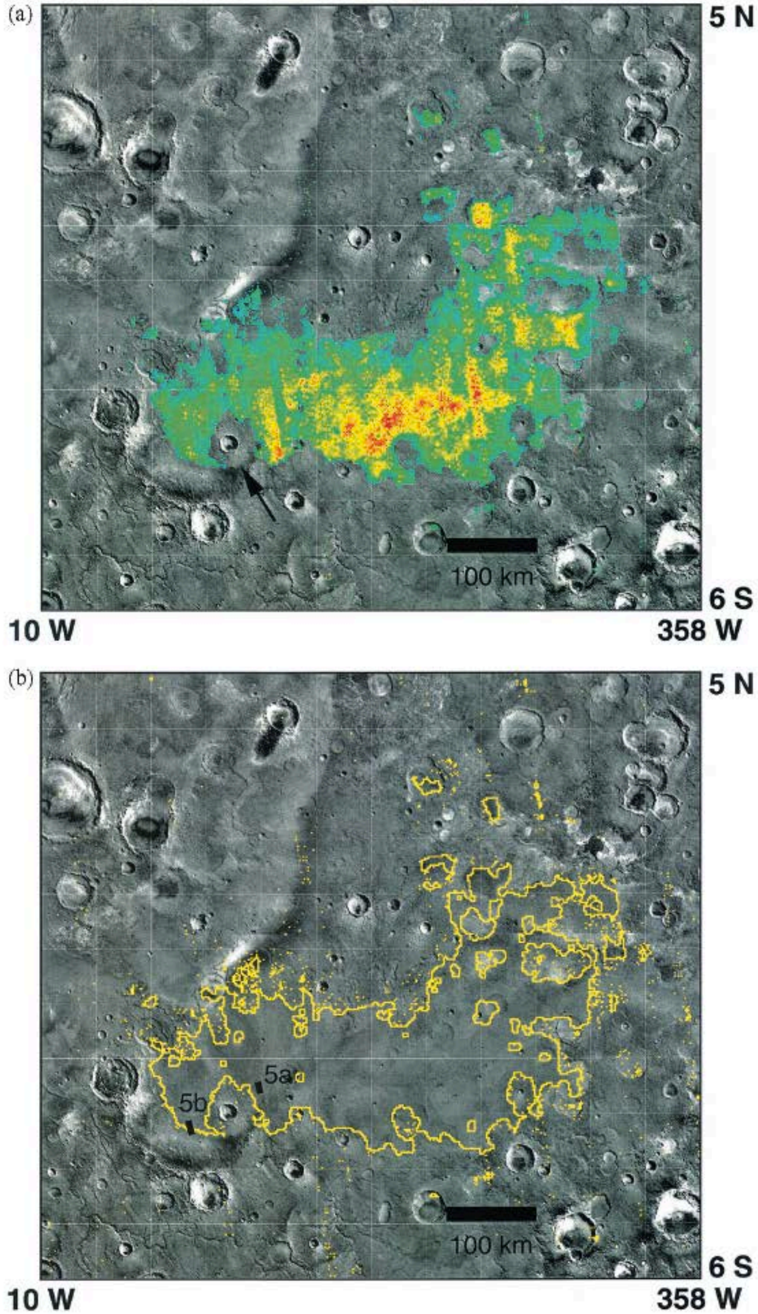
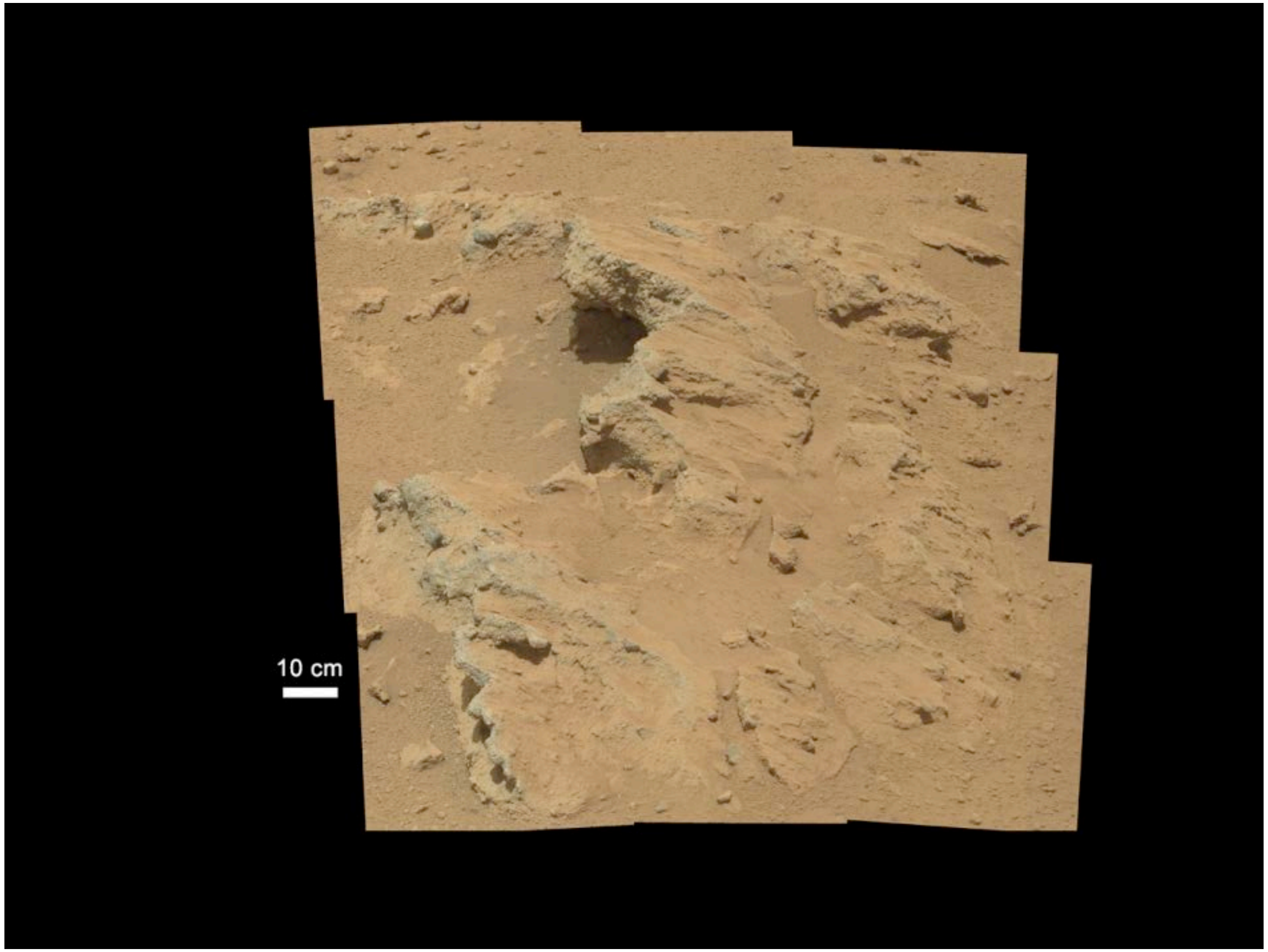
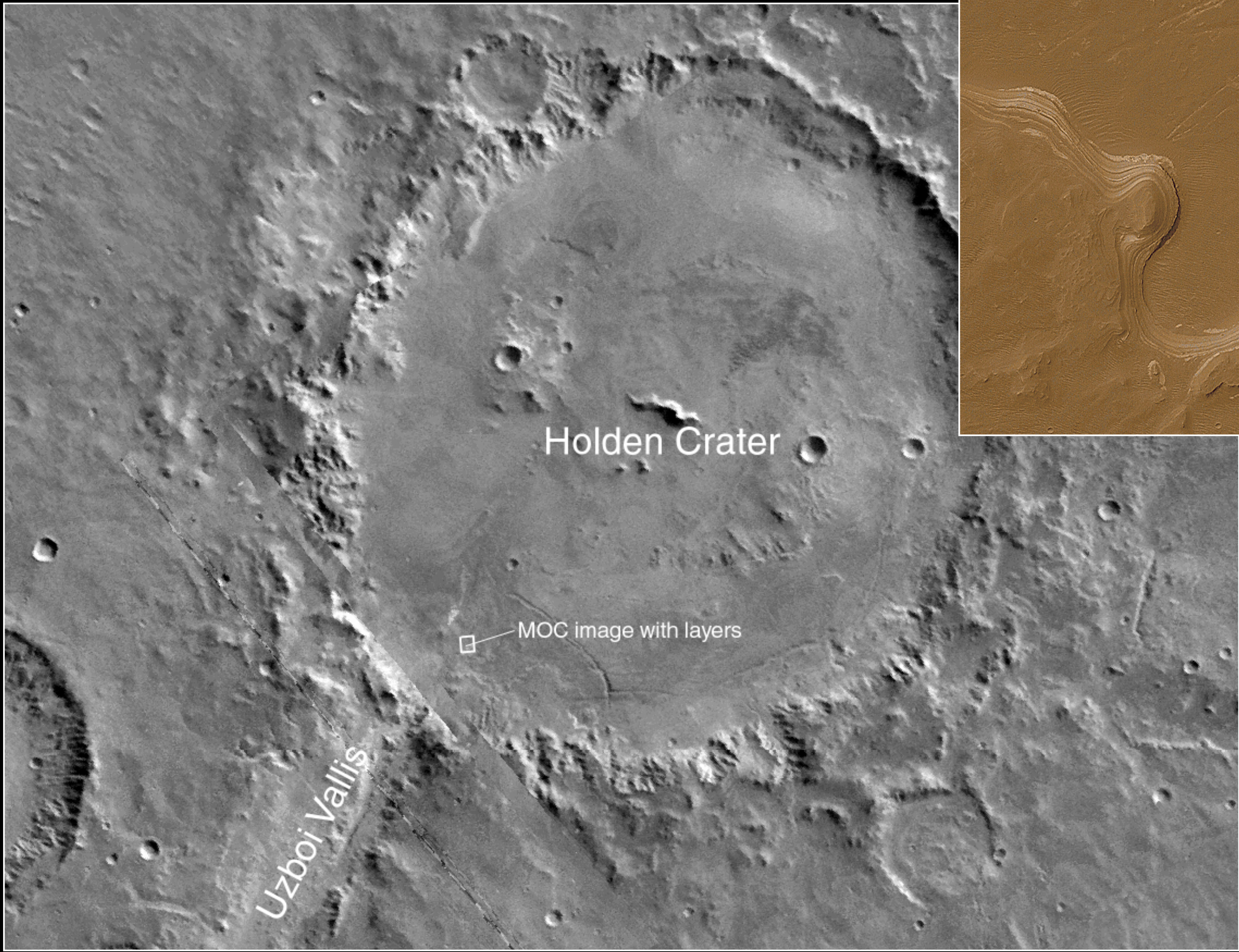


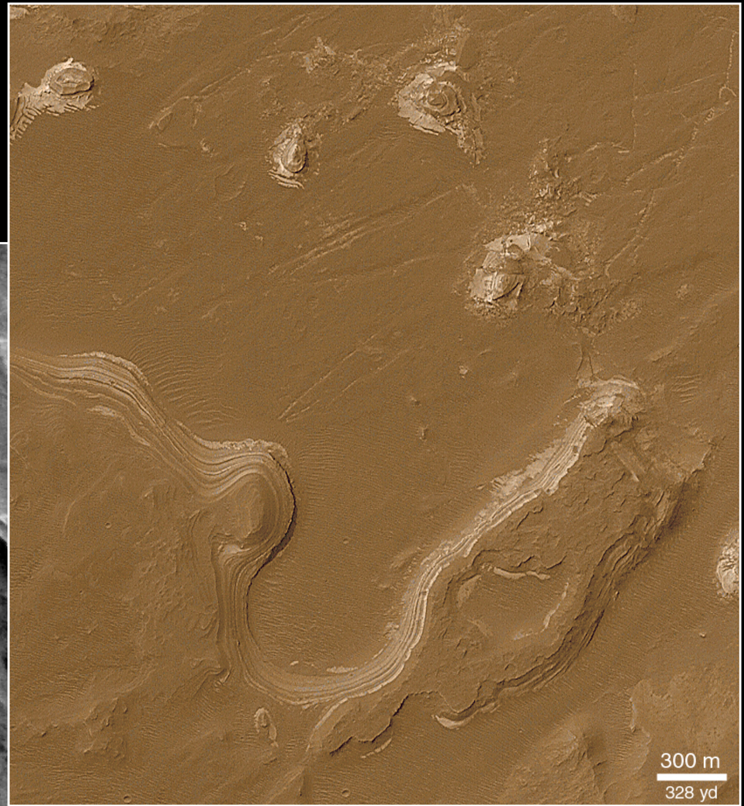
Plate 2. TES-derived hematite abundance in Sinus Meridiani. (a) TES-derived hematite abundance ov on a Viking base digital photomosaic image. Hematite index values of <1.018 have been made transpar allow the underlying morphology to be visible. This value was chosen as a conservative upper limit of the detection limit (~2%) in the presence of instrument and atmospheric variability. Crater with ejecta bl mantling the hematite unit is shown by arrow. (b) Outline of hematite-rich area showing geomorpholo underlying unit and excellent correlation with the smooth, layered unit that overlies the heavily cra terrain. The locations of Figures 3a and 3b are indicated.

- Surface features indicative of a “stream bed” (Curiosity 2012)

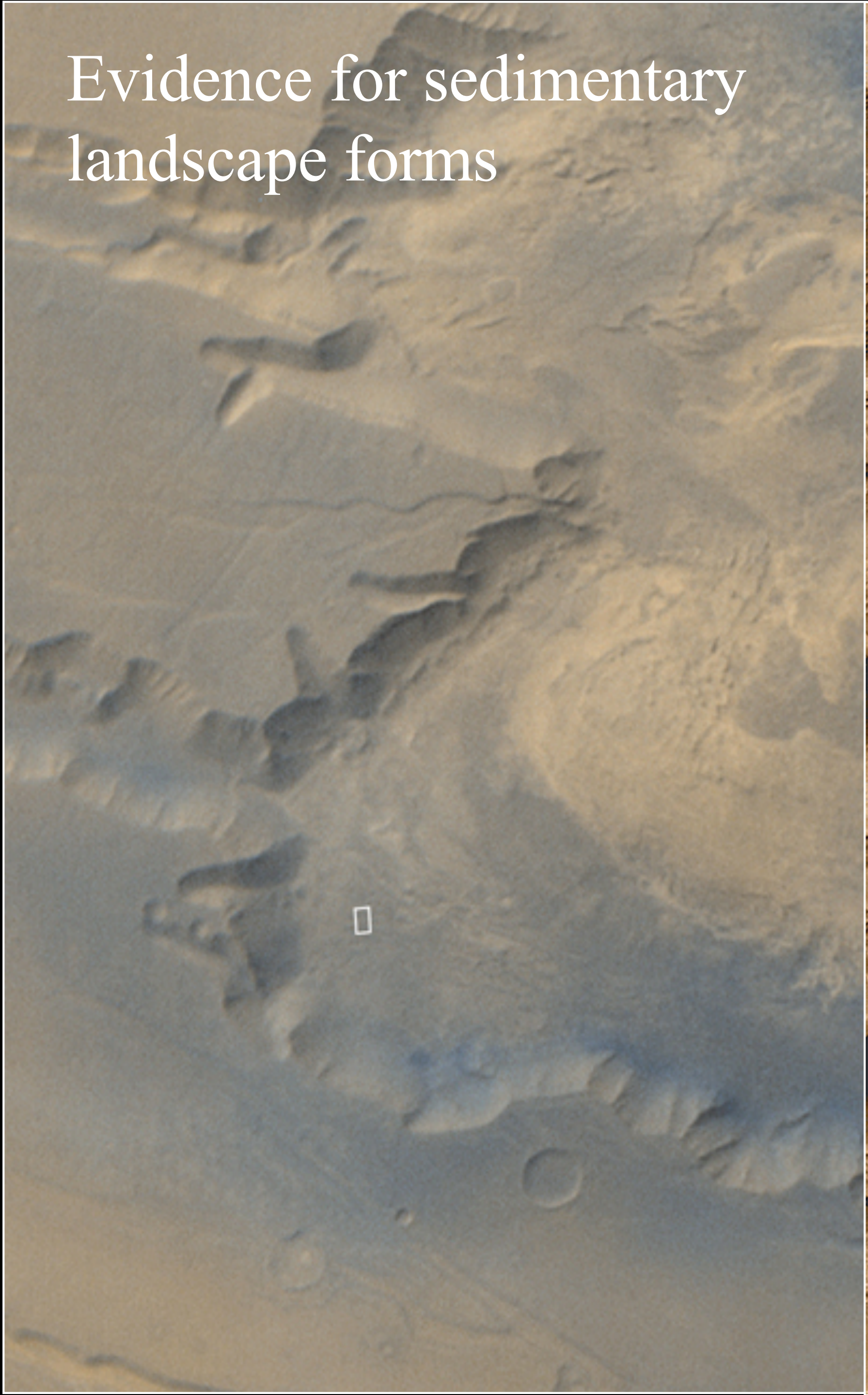


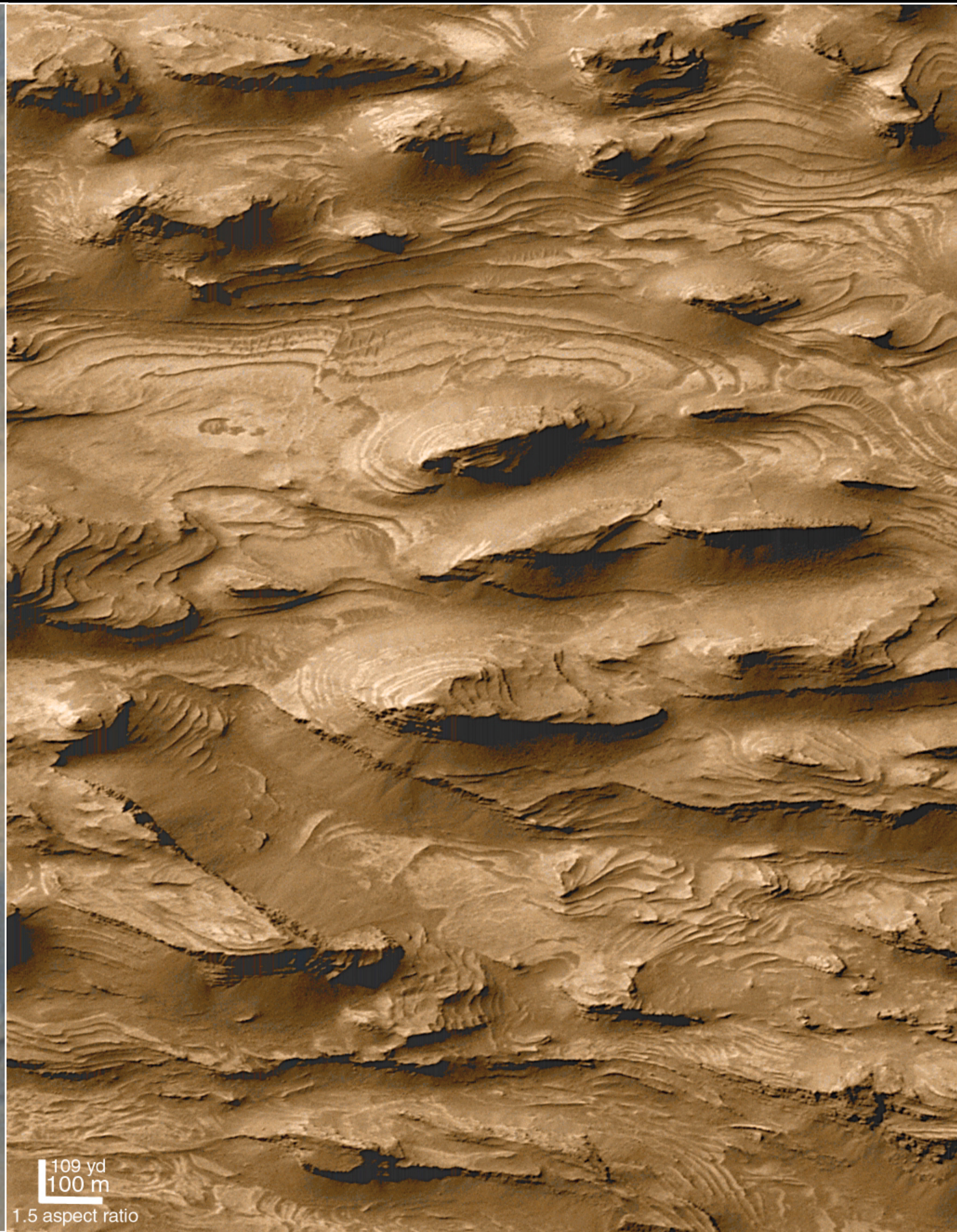
Sedimentary Rocks on Mars caused by evaporating water in impact craters



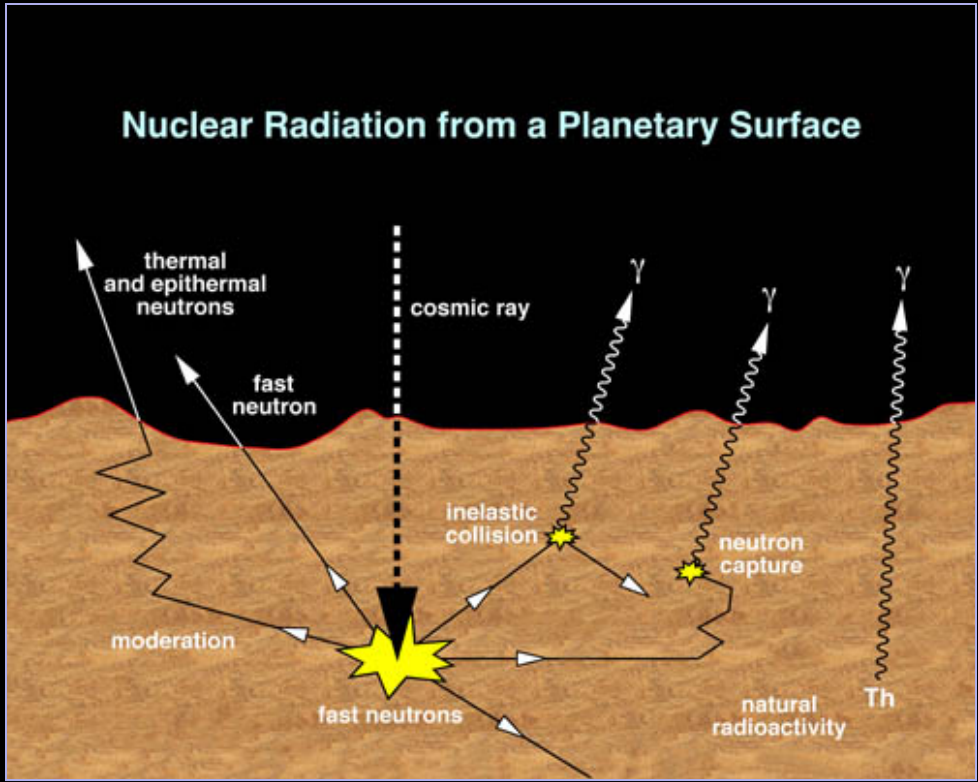


Evidence for sedimentary landscape forms

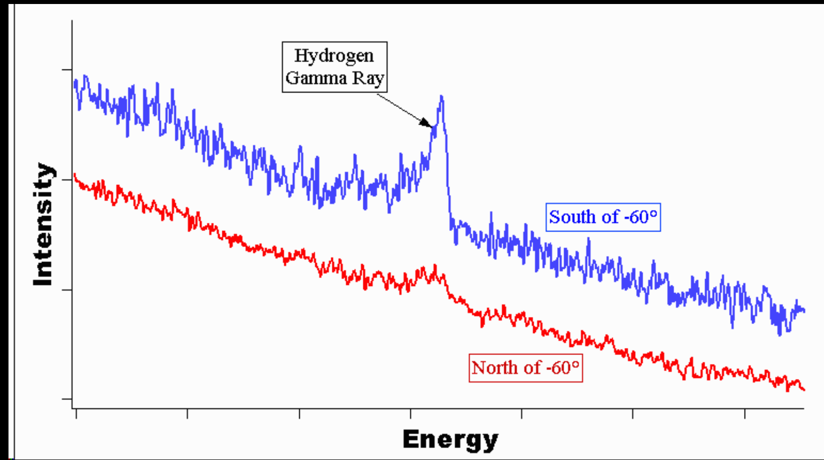




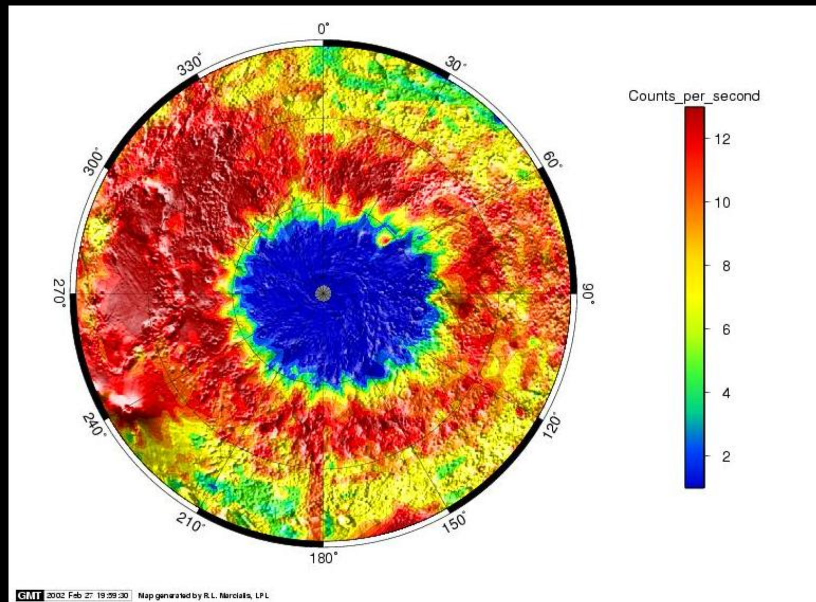
4. **Strong evidence for substantial amounts of H_2O (more precisely of H) currently in surface rocks comes from neutron and g-ray spectroscopy.**



Emission of γ-rays from surface



Emission of neutrons from surface

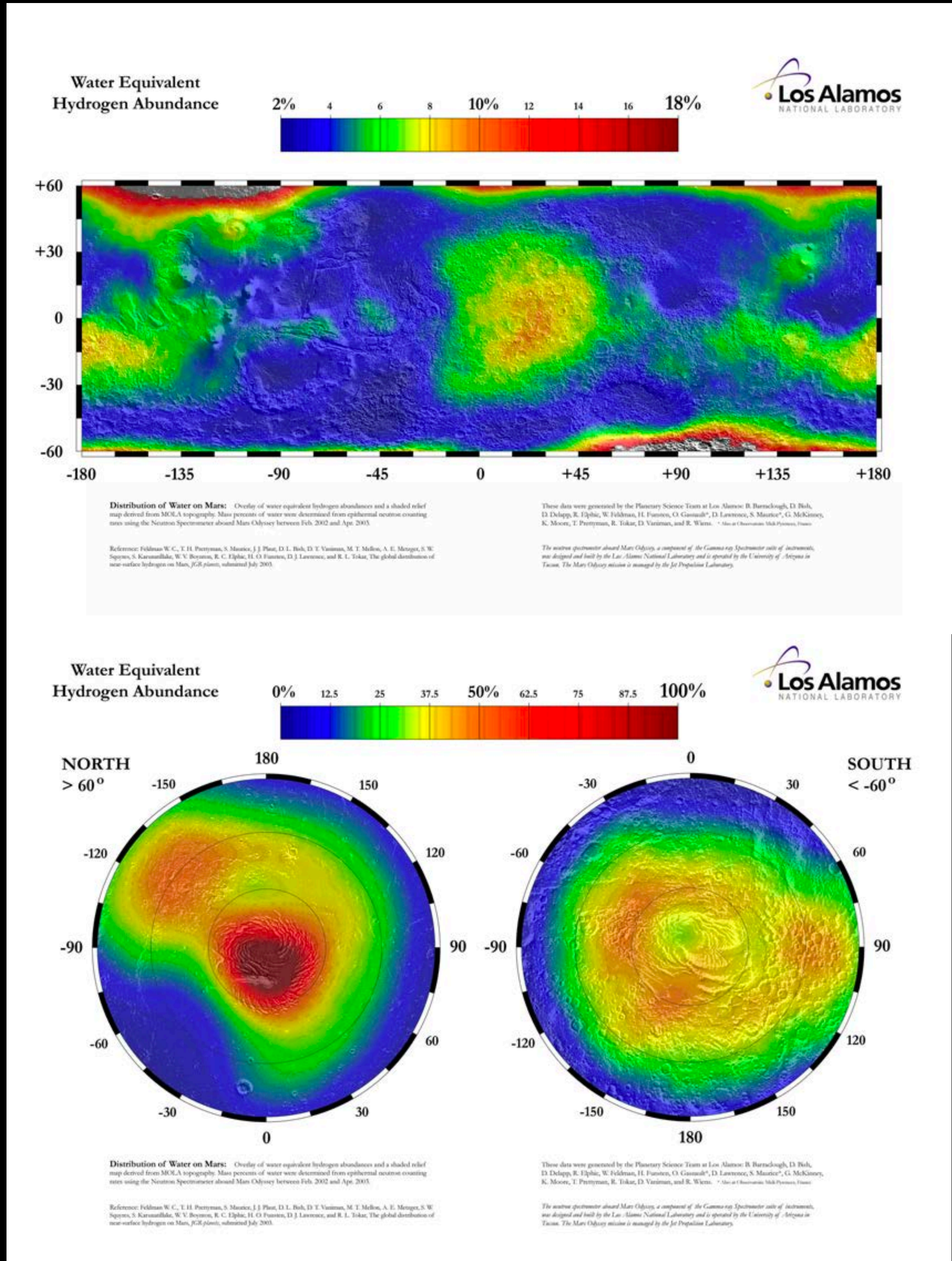


- Cosmic-ray (relativistic p^+) impacts an atomic nucleus in surface producing shower of $p^+ + n$.
- Neutrons are slowed (moderated) and finally absorbed by other nuclei, both with emission of γ-ray photons detectable from orbit.
- Hydrogen is particularly effective moderator, so few high energy neutrons returned to space

Map of “water equivalent” Hydrogen abundance in the top 1m of Martian surface:

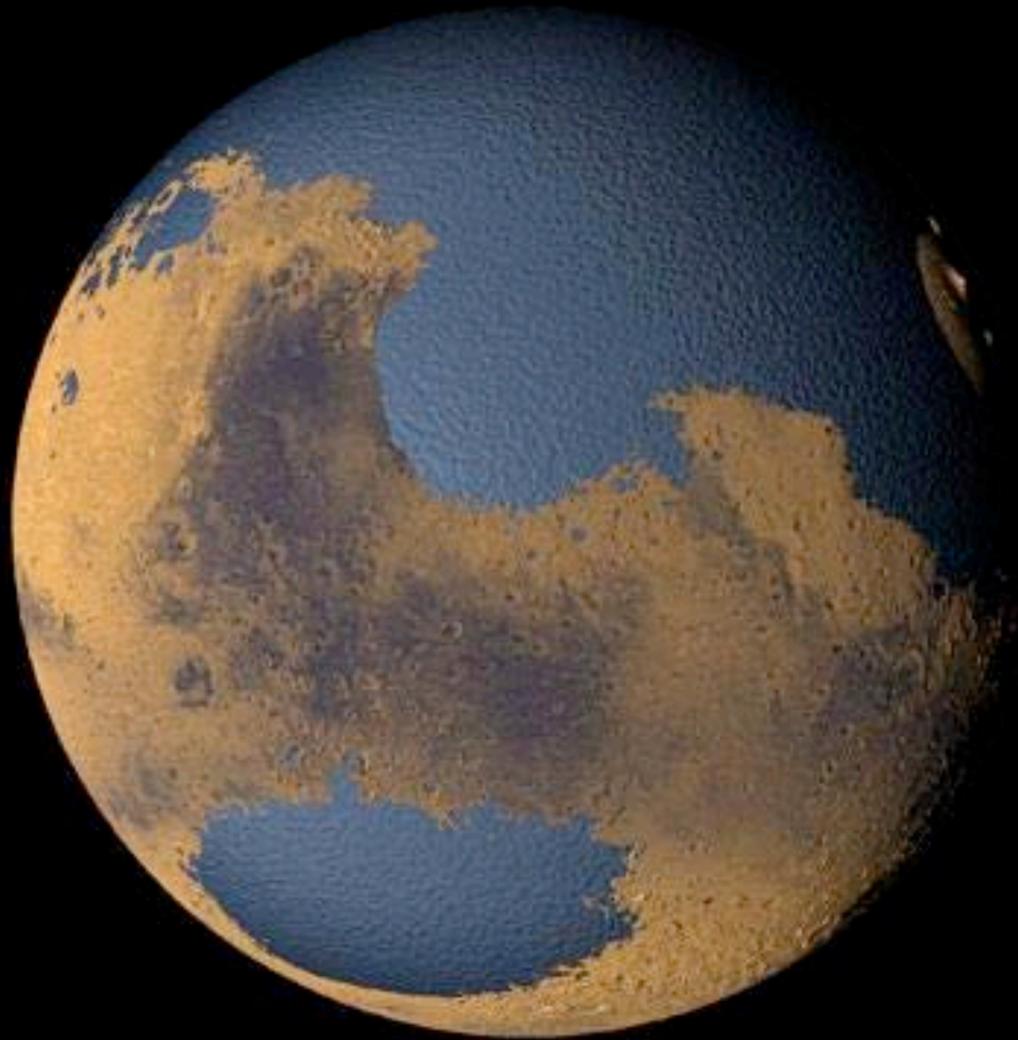
Few % upto 100% at North Pole

Average over the surface is ~ 15%




A beautiful picture
Water ice in the bottom of a 35km wide crater at 70^{o} N, plus morning frost

There is very good evidence for subsnatial amounts of standing water early in the history of Mars.



Was there even once a standing sea in the northern hemisphere, subsequently lost within about first 0.5 Gyr?

How much water was ever present?

- Present polar caps several km thick → enough for 20-30 m across the entire wide.
- Elsewhere, gamma-ray spectroscopy + neutrons indicates still substantial H (most likely H_2O) in sub-surface (> meter depth) rocks.
- Estimates of the total water involved in flows ~ 10^{-3} to 10^{-2} of Earth's oceans.
- If the northern hemispheric basin was once an ocean, we'd need more than 0.01 Earth ocean.
- D/H ratio indicates that most of the hydrosphere was lost, from as much as ~ 0.1 Earth ocean.

- Estimates of initial water content indicate a water layer 100m to a few km thick would be be plausible.

What happened to the surface water?

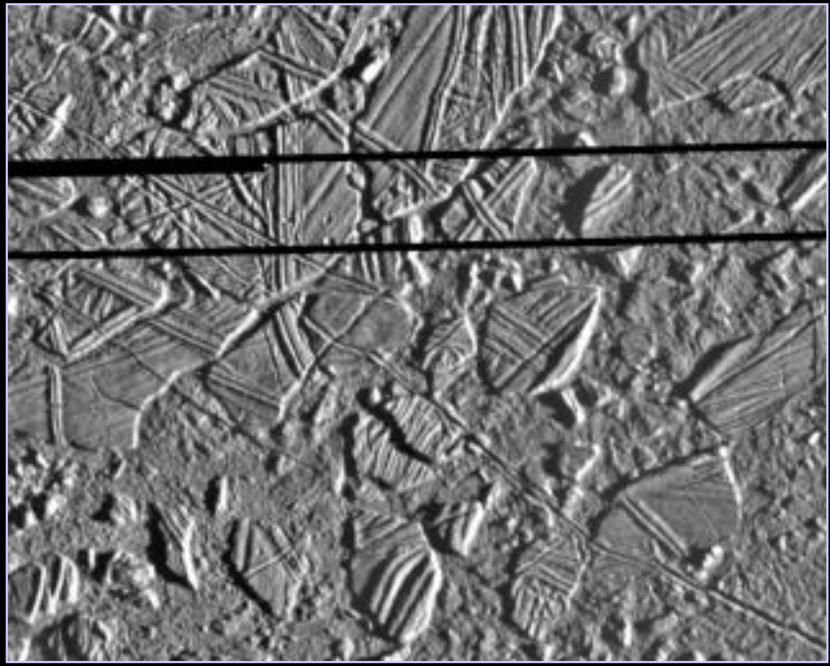
- Early evidence of erosion in oldest surface features, followed by loss of liquid water from surface, (possible glaciation) and finally loss of all surface H_2O.
- Significant loss to space indicated by D/H ~ 3 times terrestrial value and also 3x that in the oldest Martian meteorites.
- The timescale and the mechanism(s) for the transition from a relatively warm and wet world to the current cold and dry one are still very uncertain.
- As is the question of whether conditions allowed the emergence of primitive Life, and whether or not this could survive. These are open questions.

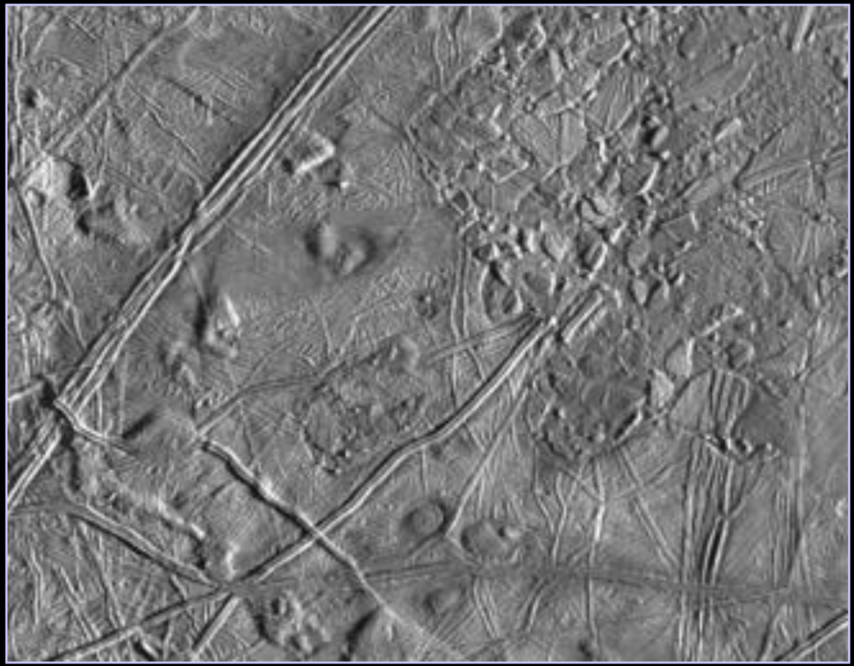
2. Europa and Enceladus

Europa in the Jupiter moon system

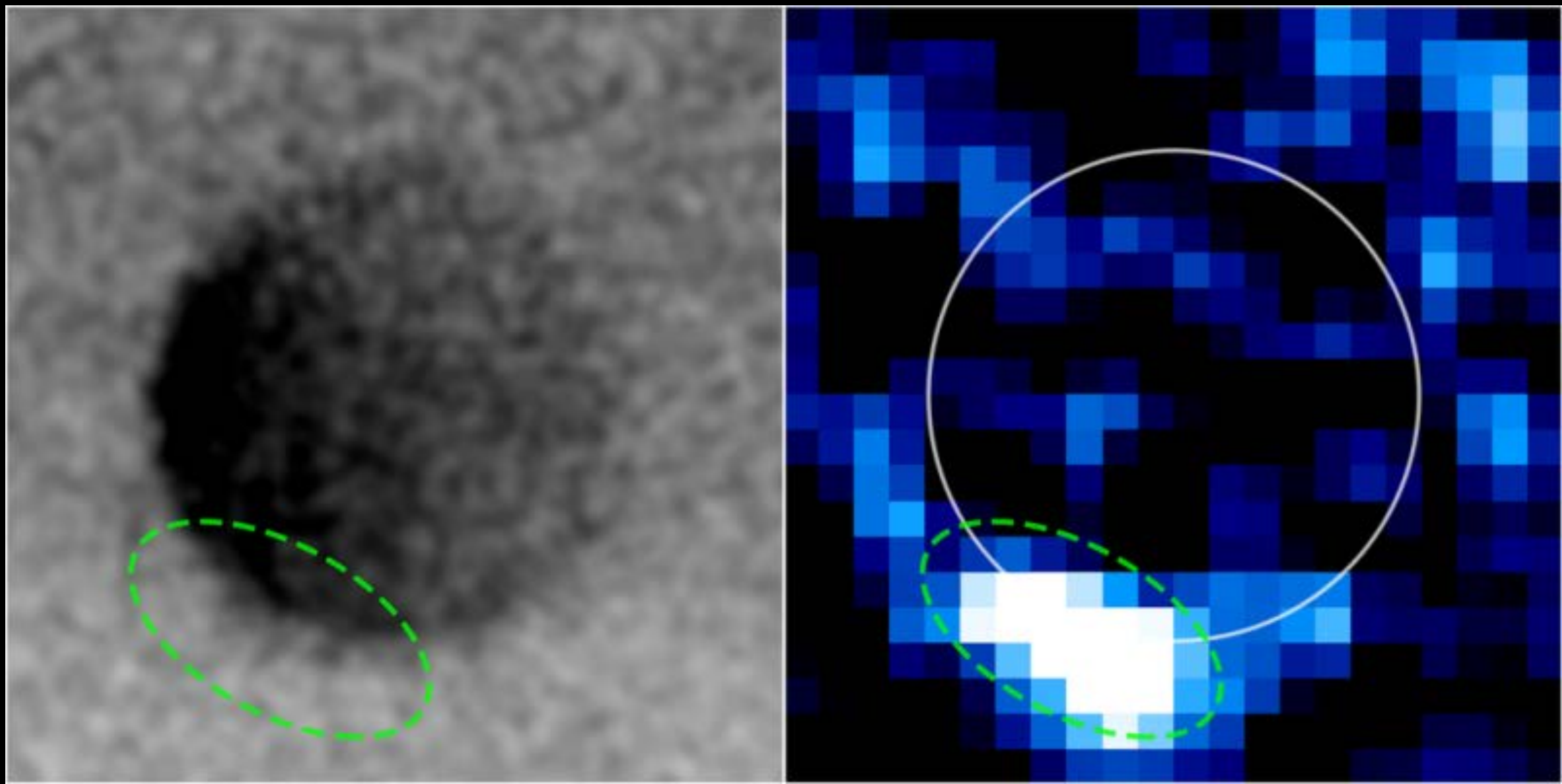
- Extremely smooth H_20 ice surface above a liquid H_20 ocean.
- Thickness of ice layer is controversial (estimates: 300m – 30 km).
- Depth of ocean estimated to be up to 100 km (→ more H_2O than Earth's ocean?)

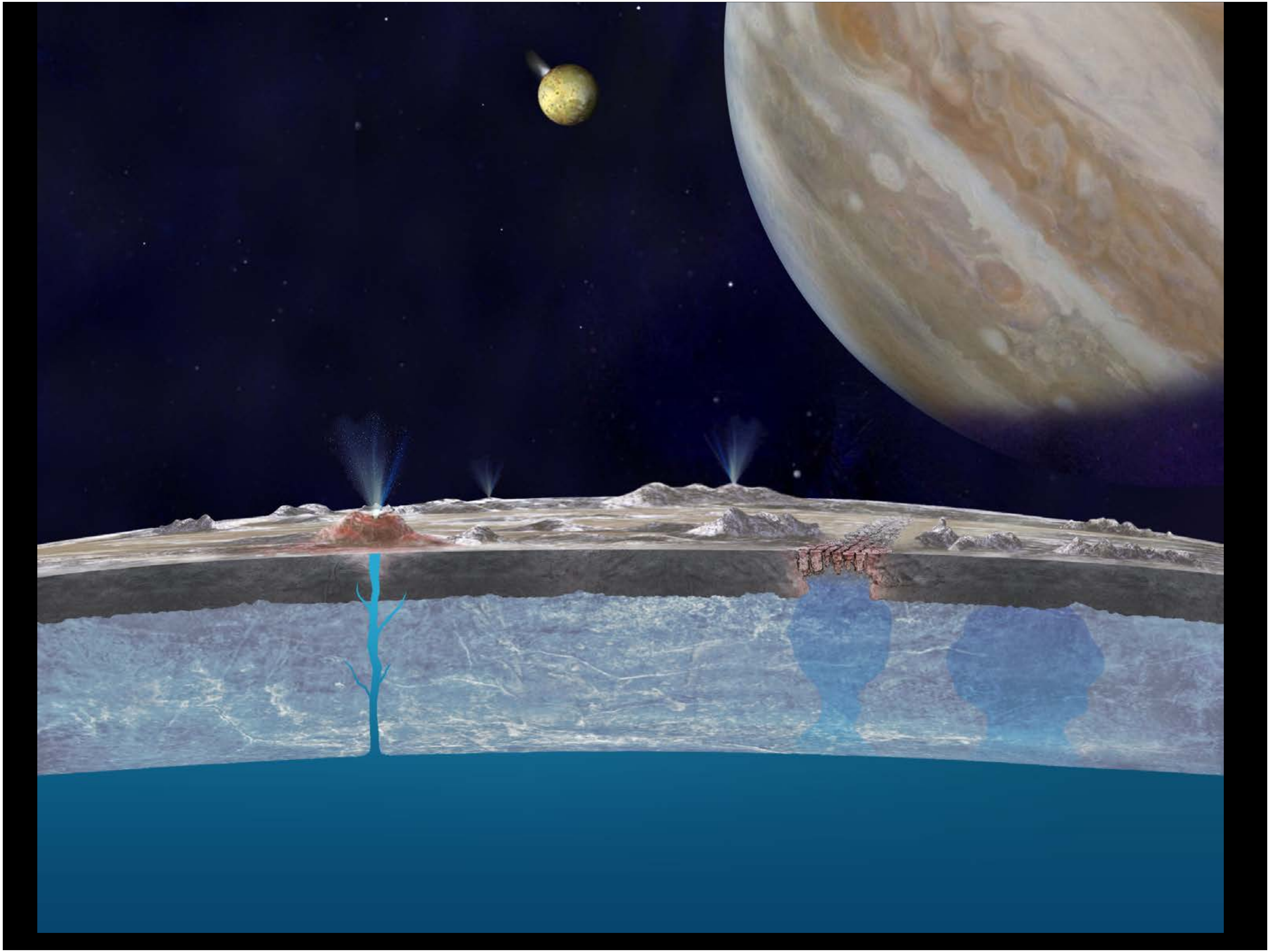
- Evidence for liquid sea beneath the ice:
    - Young uncratered surface – "geologically" active with outflows
    - Floating "Ice Rafts"
    - Upwelling at cracks and holes
- Possible water ocean tens of km deep?
    - Cracks contain Ca, Mg salts (no organics yet?)

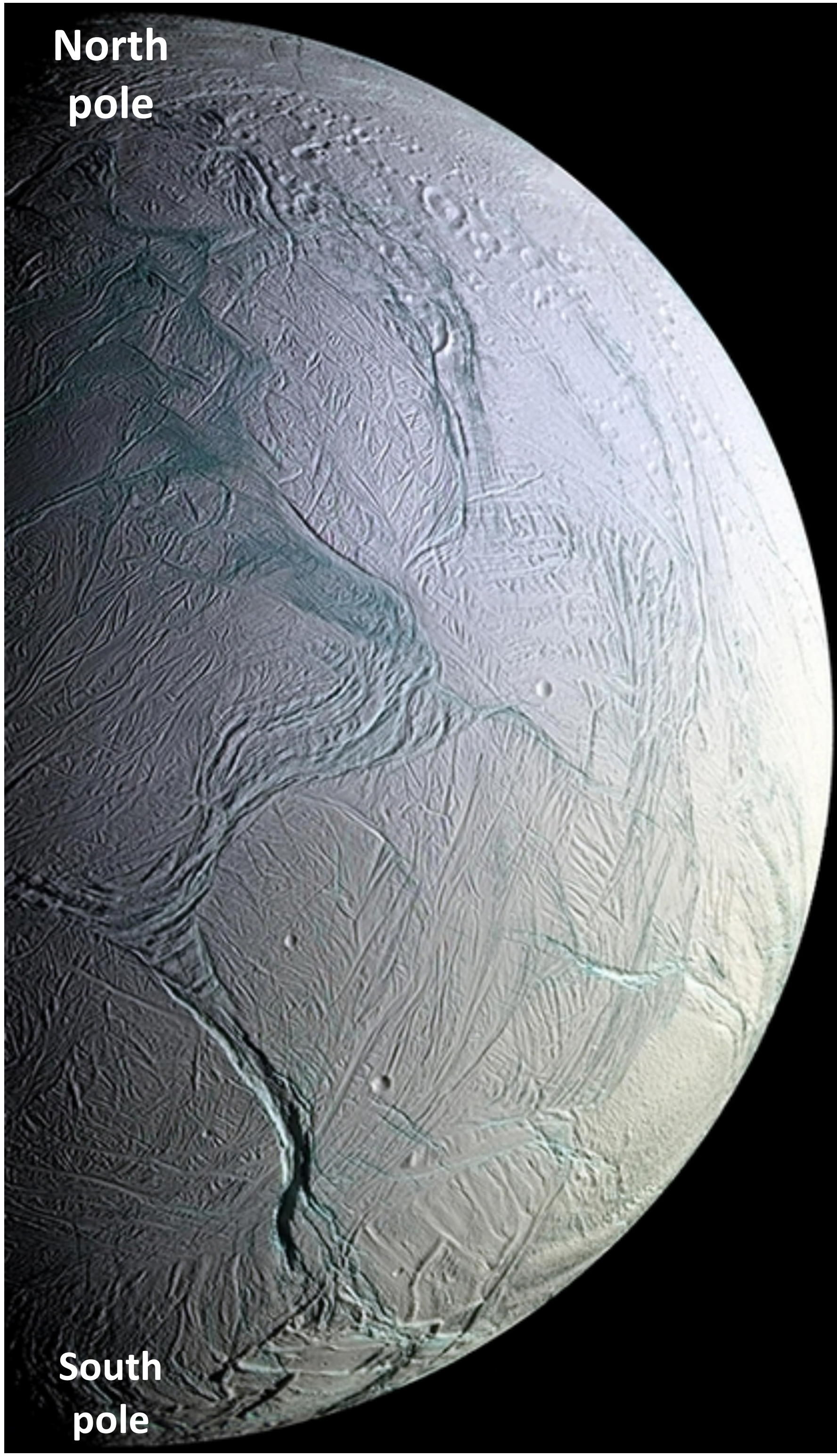




H_2O (intermittently) seen in ultraviolet absorption above the limb of Europa when it passes in front of Jupiter (as seen from Earth by HST) → geysers of liquid water erupting from surface







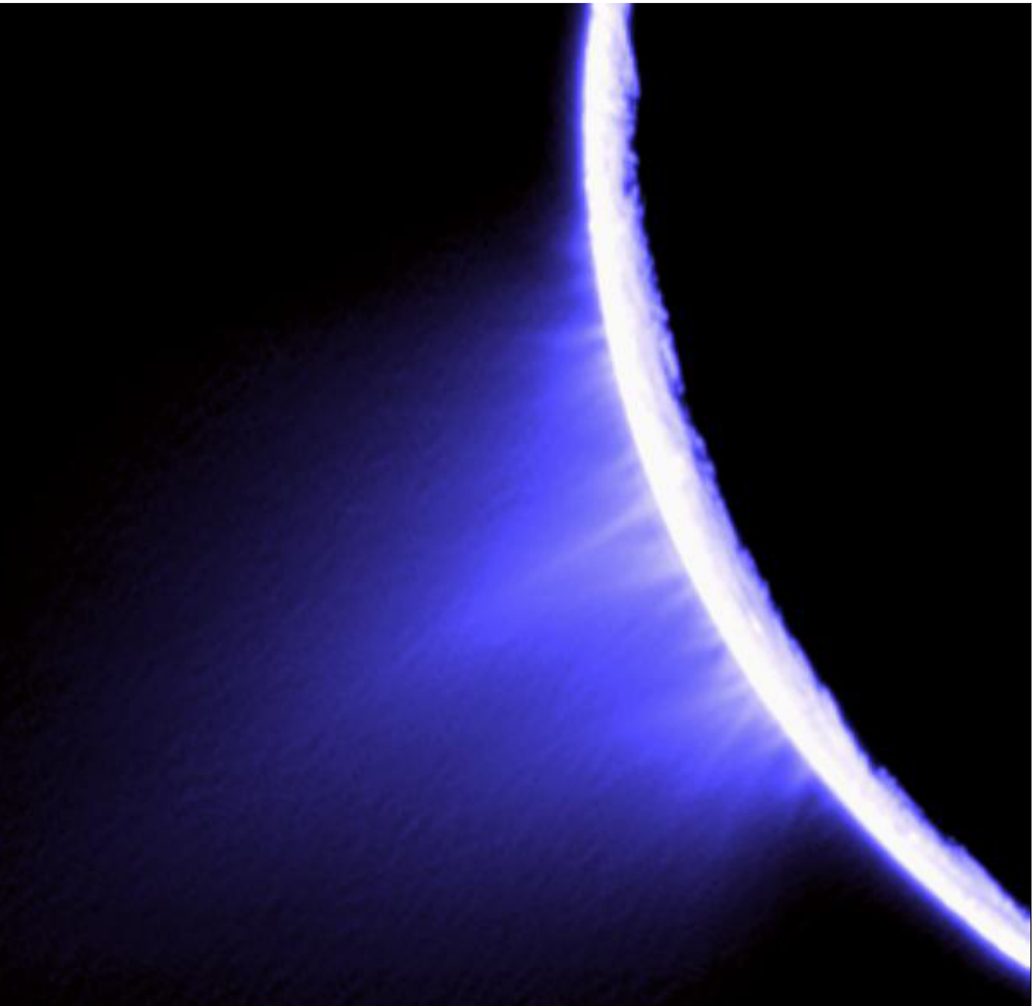
Enceladus in the Saturn moon system (diameter only 500km, much smaller than Europa)

Very young icey surface (especially in south)

Tidally locked to Saturn and in a (2:1) orbital resonance with the more massive Dione,which maintains the ellipticity of orbit at 0.005, causing significant tidal heating

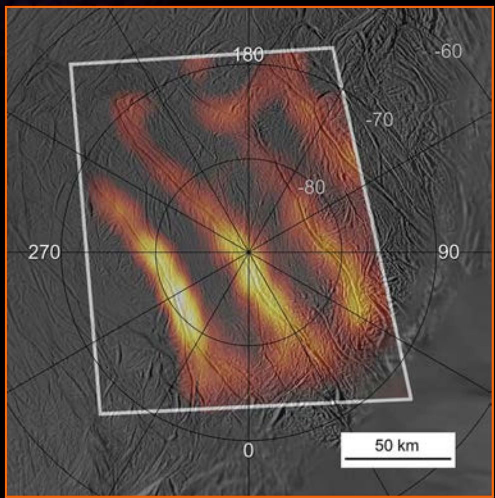
Direct detection of plumes (200 kg/s) from south polar region by Cassini spacecraft (2005+, including “fly-through” of plume).

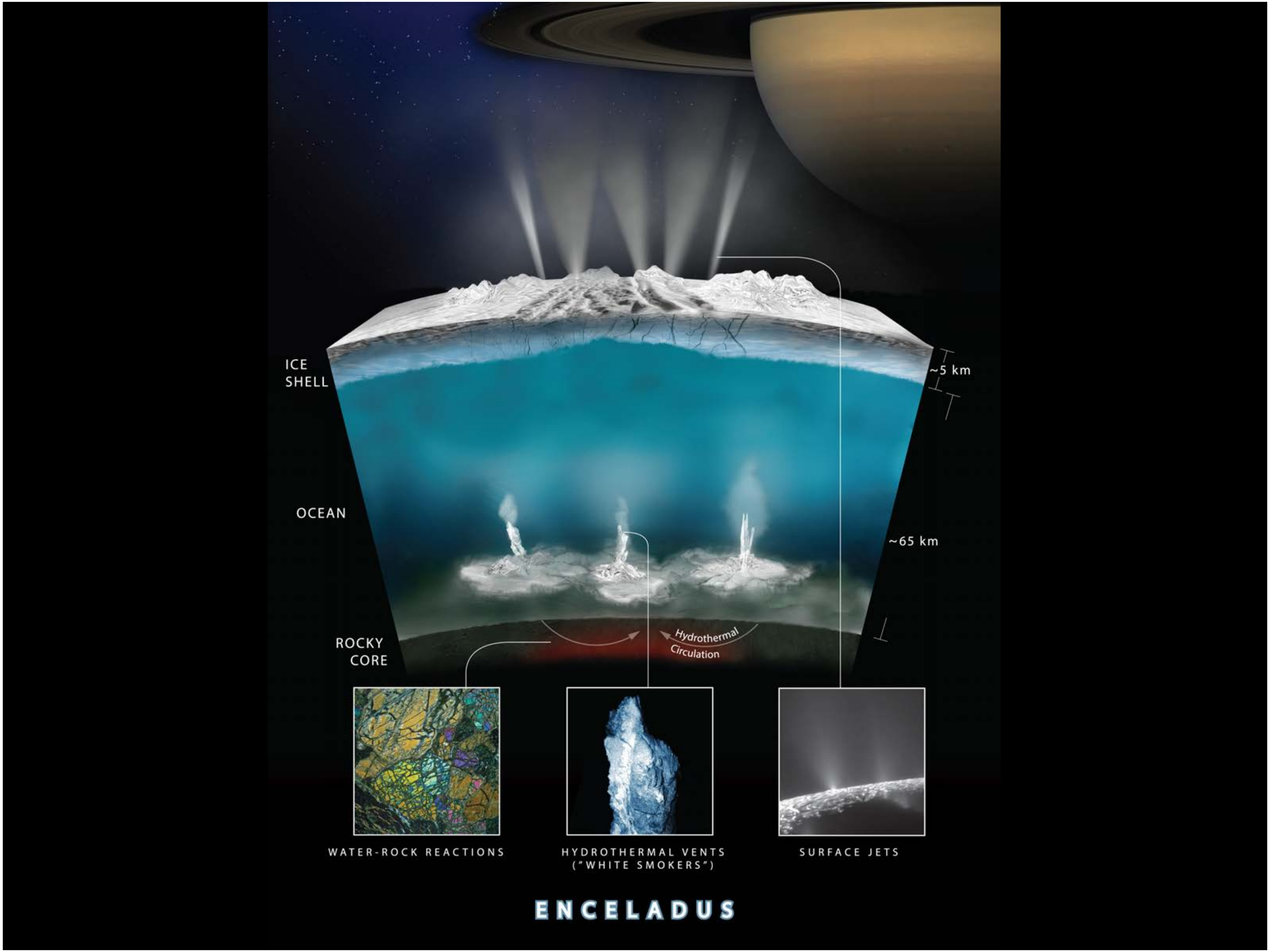
Composition of plumes: H_20, traces of N_2, NH_3, CH_4, CO_2, H_2, propane (C_3H_8), acetylene (C_2H_2), formaldehyde (CH_2O),.. up to C_6H_6.



Evidence for 30km subsurface ocean of salty water over the entire moon.

Geysers are more like “curtains” and come from parallel cracks in the south polar regions.

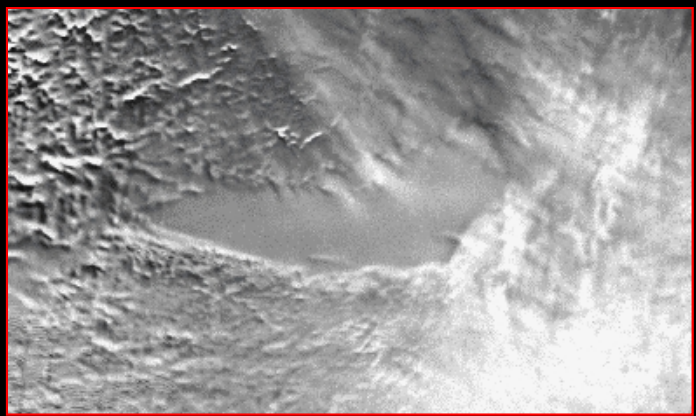


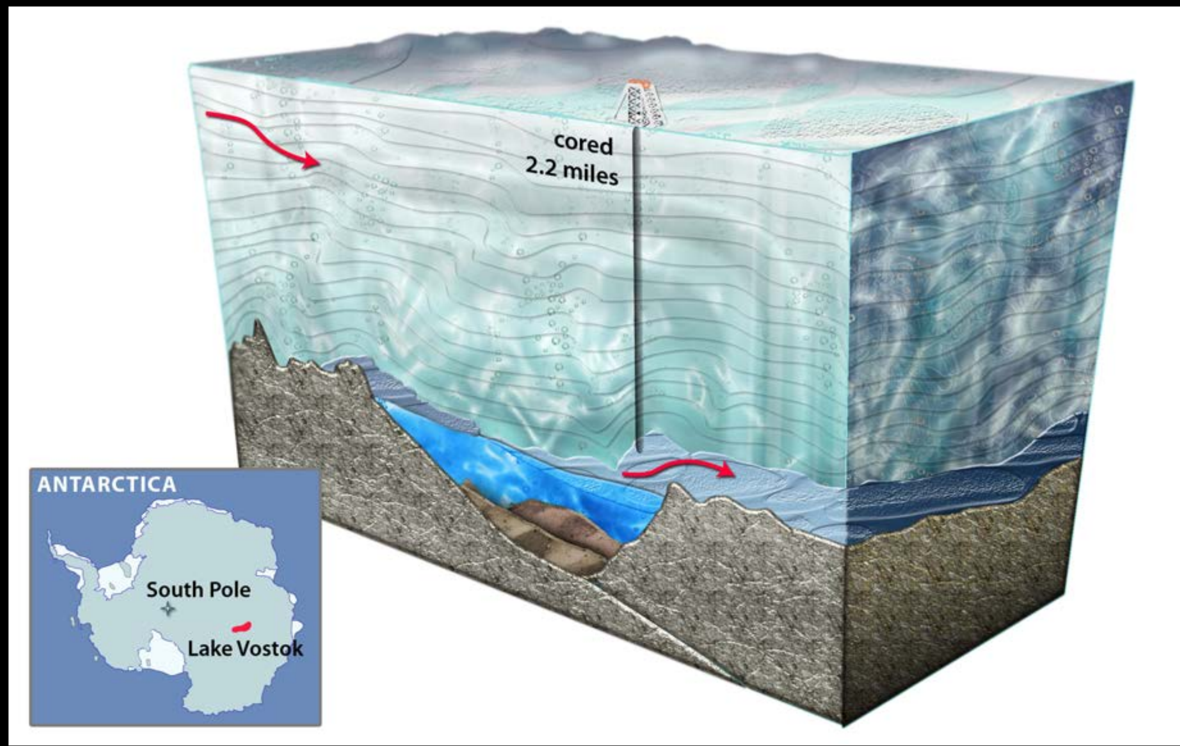

ICE SHELL
~5 km
OCEAN
~65 km
ROCKY CORE
Hydrothermal Circulation
WATER-ROCK REACTIONS
HYDROTHERMAL VENTS ("WHITE SMOKERS")
SURFACE JETS
ENCELADUS

Conditions on Europa and Enceladus are not unlike Lake Vostok in Antartica under 3.5 km of ice.

Good(?) evidence (but still controversy about contamination) that life survives/thrives in Lake Vostok. Extensive DNA sequences found in accreted ice above lake surface (~90% bacteria, plus eukarya).. But survival is not the same as creation.

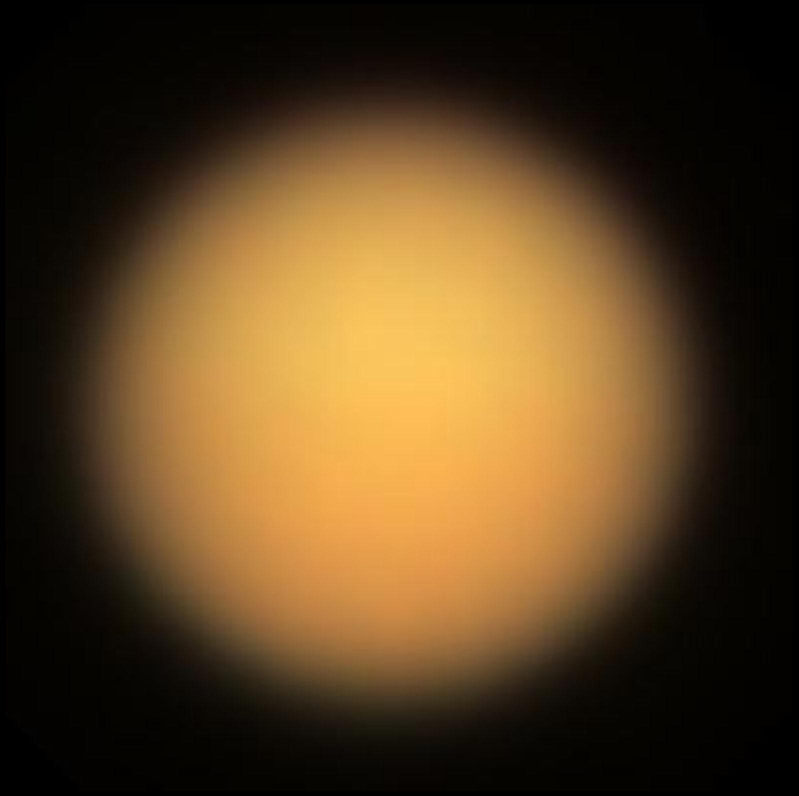
Lake Vostok

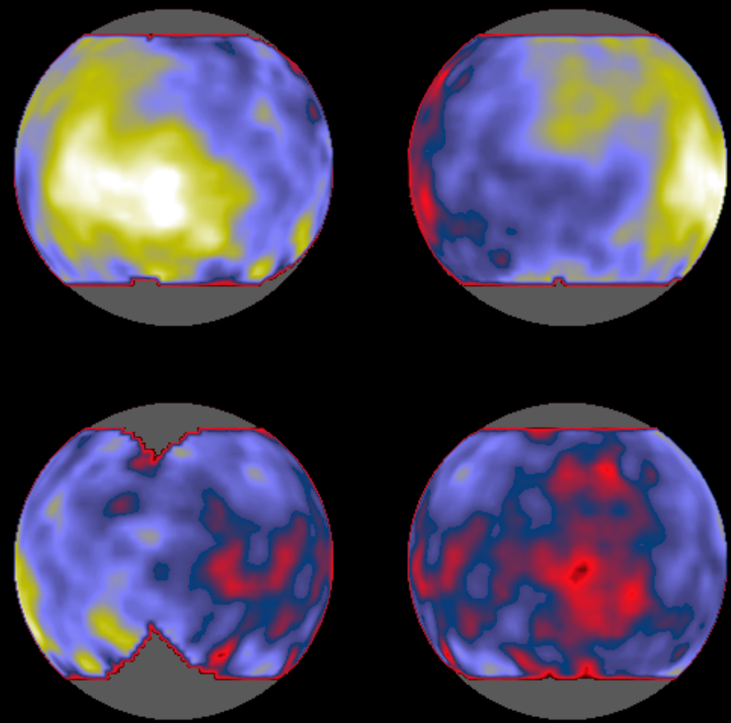


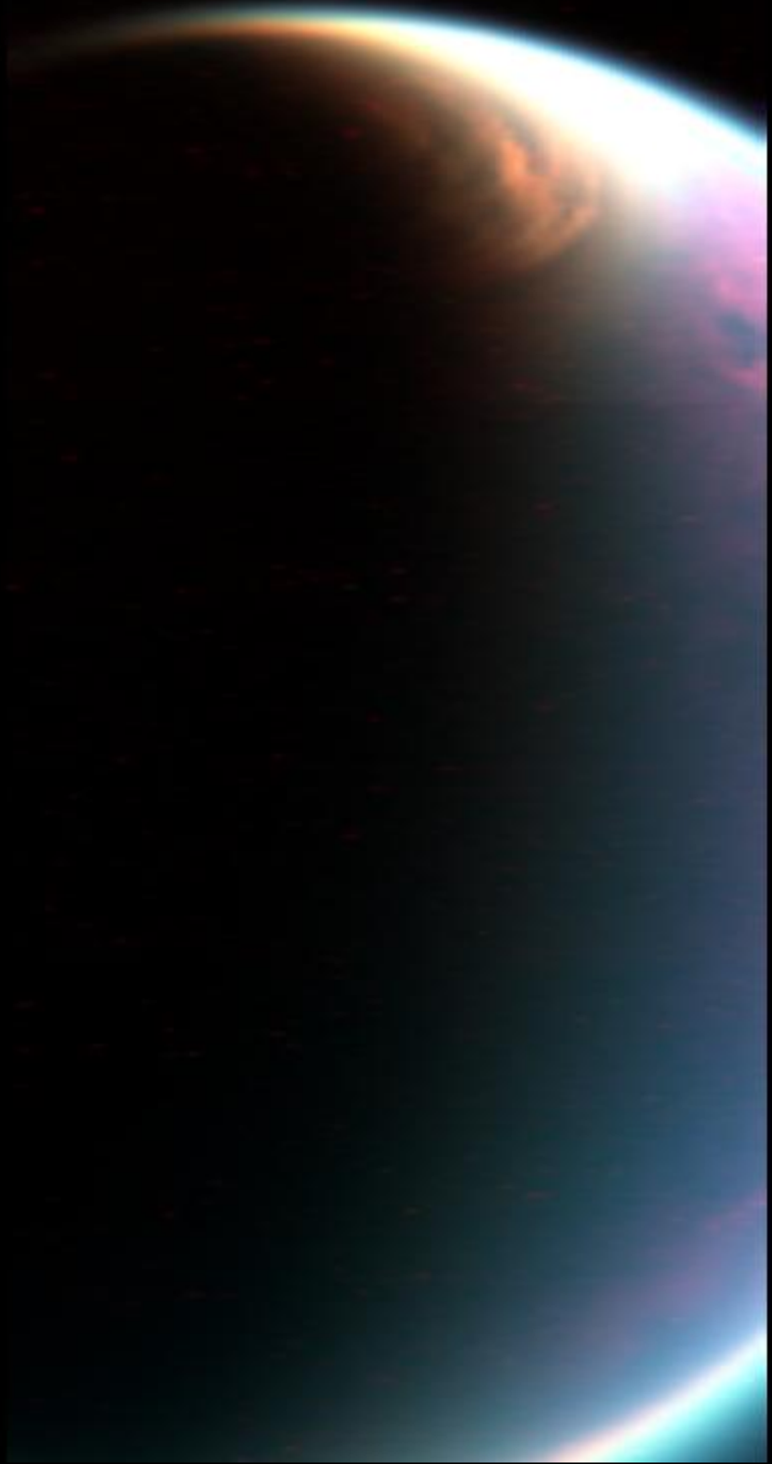


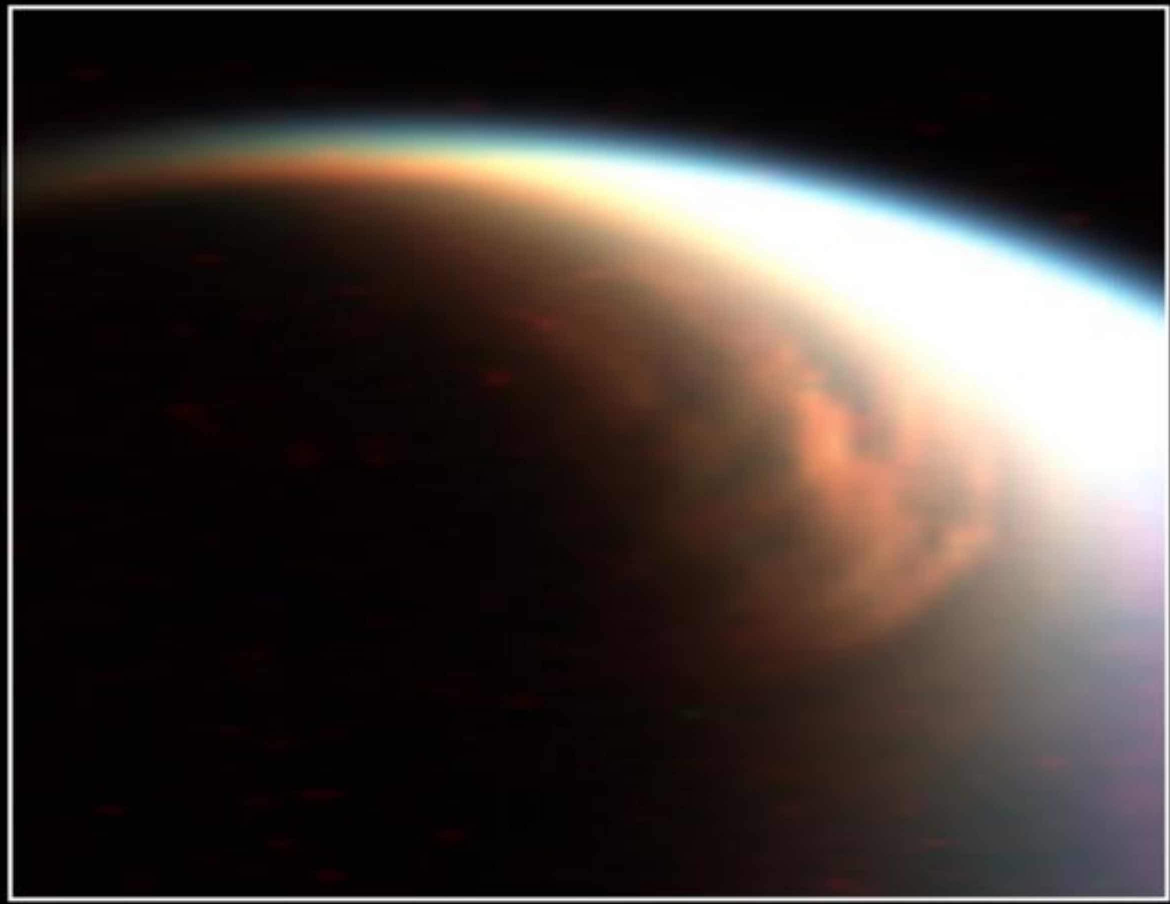
3. Titan

- Titan is Saturn's largest moon in Solar System and is more massive than Mercury.
- It retains a 1.5 bar atmosphere ($N_2 + CH_4$) at 85K , which is able to support liquid CH_4 on the surface.
- H_20 was completely frozen out so little of the CH_4 was oxidised to CO_2
- Interesting atmospheric chemistry comes from e^- from Saturn's magnetosphere: CH_4, $N_2 \rightarrow C_2H_2$, C_2H_6,C_3H_8, HCN, C_2N_2, some CO, CO_2
- Expect condensation on surface from these compounds (Ethane ponds?)
- Surface features discernable through haze, including large reflecting seas



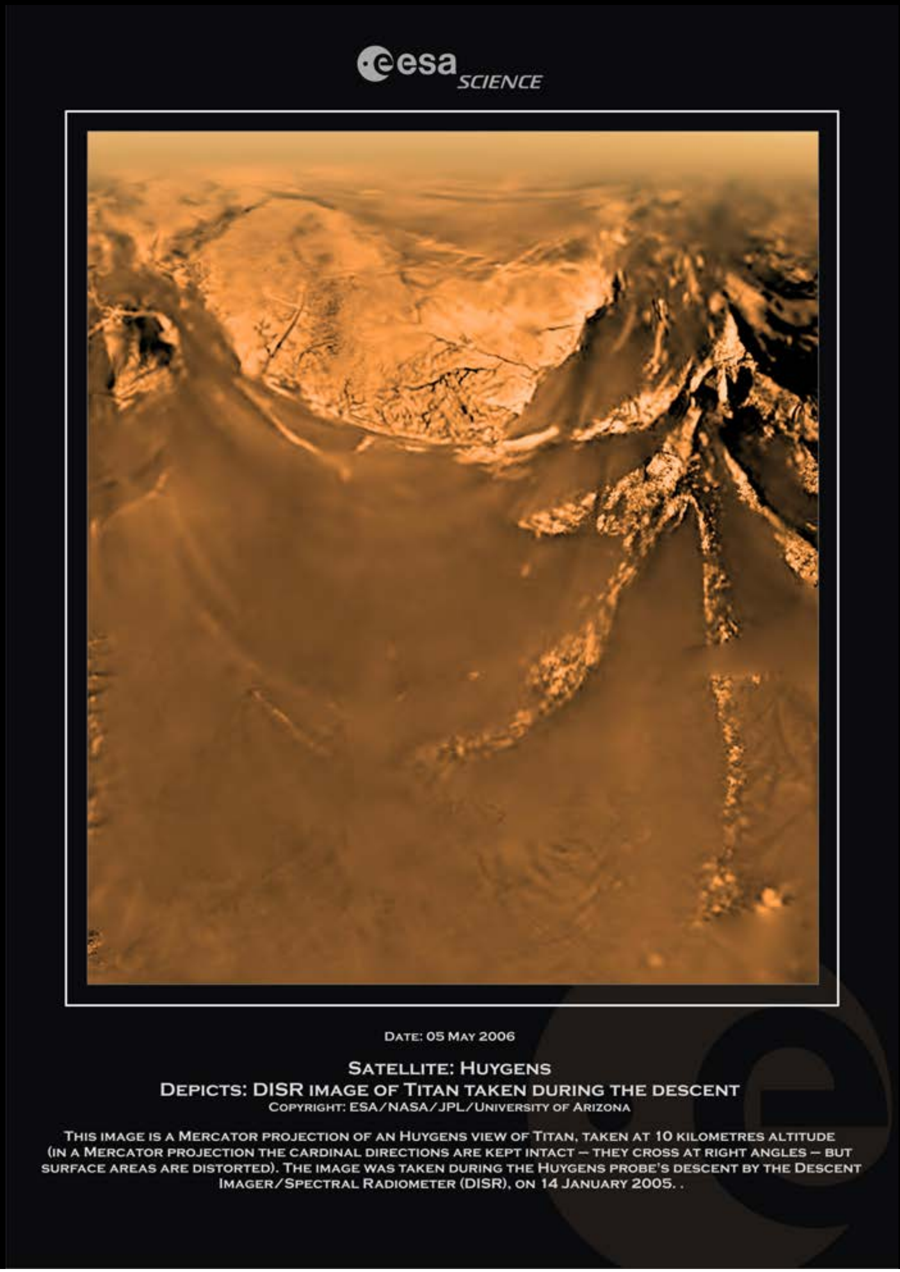


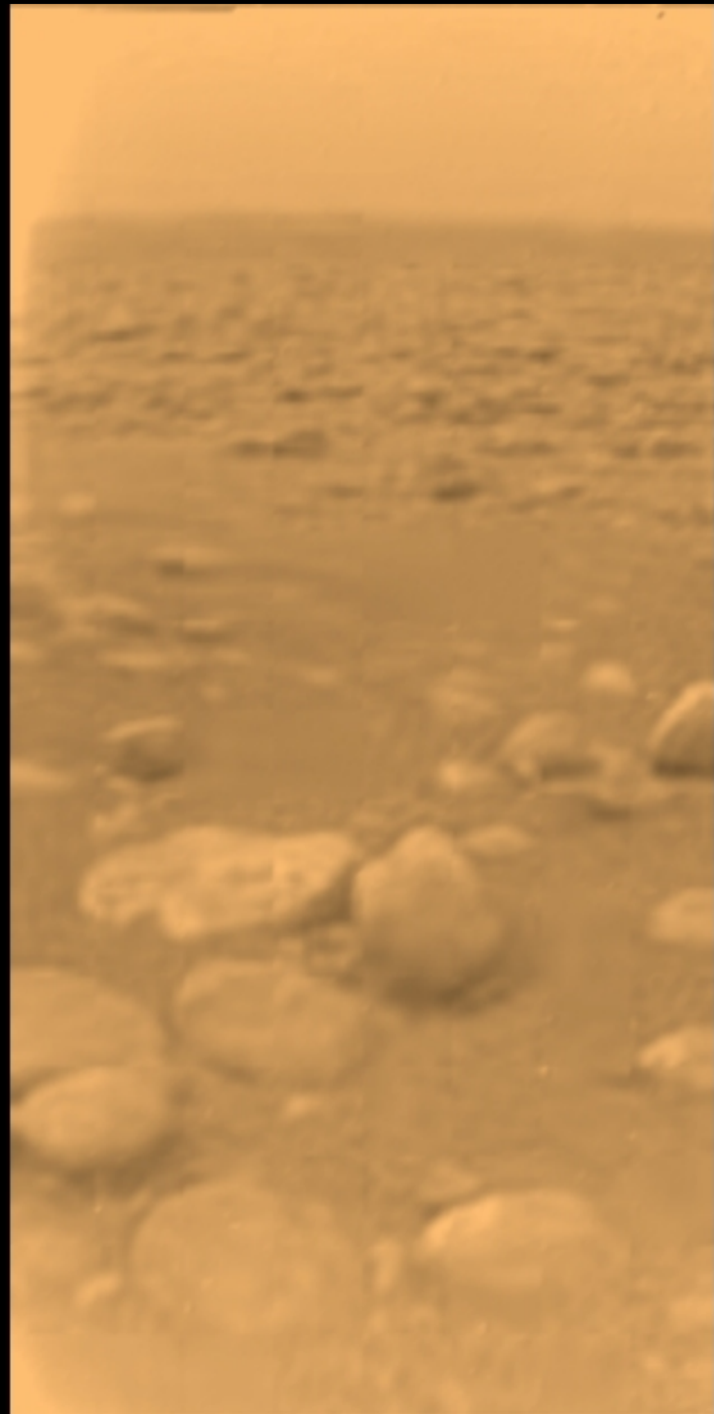




Imaging of extensive surface liquid CH_4 seas reflecting sunlight.

Landing of ESA Huyghens probe (2006)





Astrobiological interest of Titan

1. Organic chemistry in non-aqueous organic solutions
- Self-organizing polymers?
- Liquid hydrocarbons as solvents (but non-polar, unlike H_2O)

2. Organic chemistry in aqueous organic systems
- Short exposure of organic compounds to liquid water (e.g. in craters following melting), followed by re-solidification

3. Actual Life in Titan's interior?
- At tens of km depth, ammonia-water would still be liquid, heated by radioactivity.
- But at kilo-bar pressures, OK (extremophiles at bottom of Earth oceans)?
- Will be hard to access!!

Summary of this part:

- The evidence for lots of surface/sub-surface water ice on Mars now, and for lots of surface liquid water in some distant past, is compelling. Exactly how long Mars stayed wet is however uncertain.

- During the last 15 years or so, the Outer Solar System has been looking more promising for Life than previously imagined. Tidal heating broadens the concept of "habitable zone" into colder regions.

- Note too how "accidents" have consequences:
  - Enceladus is orbitally locked with Dione producing eccentricity and thus high tidal heating.
  - Energetic e^- in the Saturn environment affects Titan's hydrocarbon chemistry

- Conclusion: we are always likely to have surprises! Predictions are difficult.