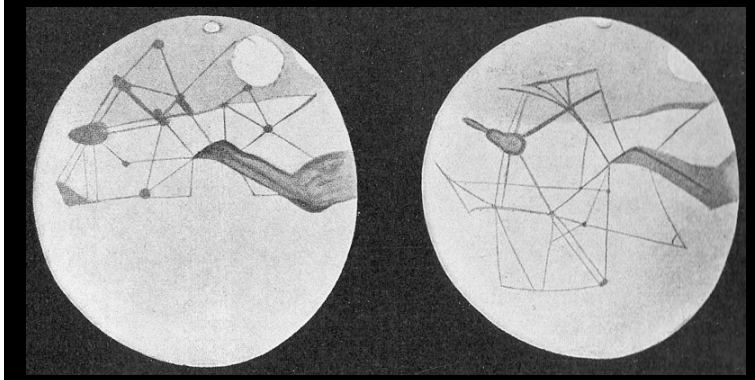
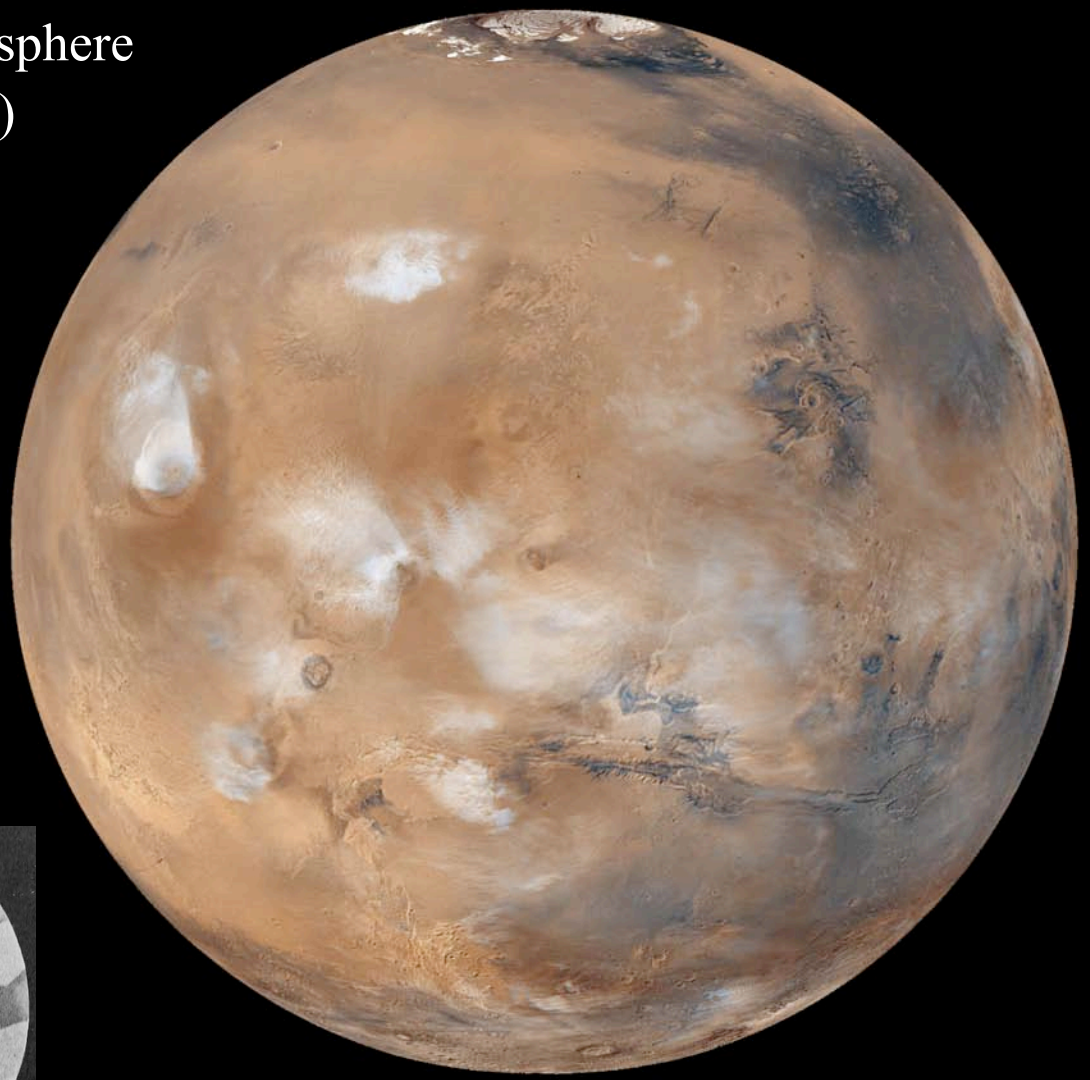
Possibilities of Life elsewhere in the Solar System

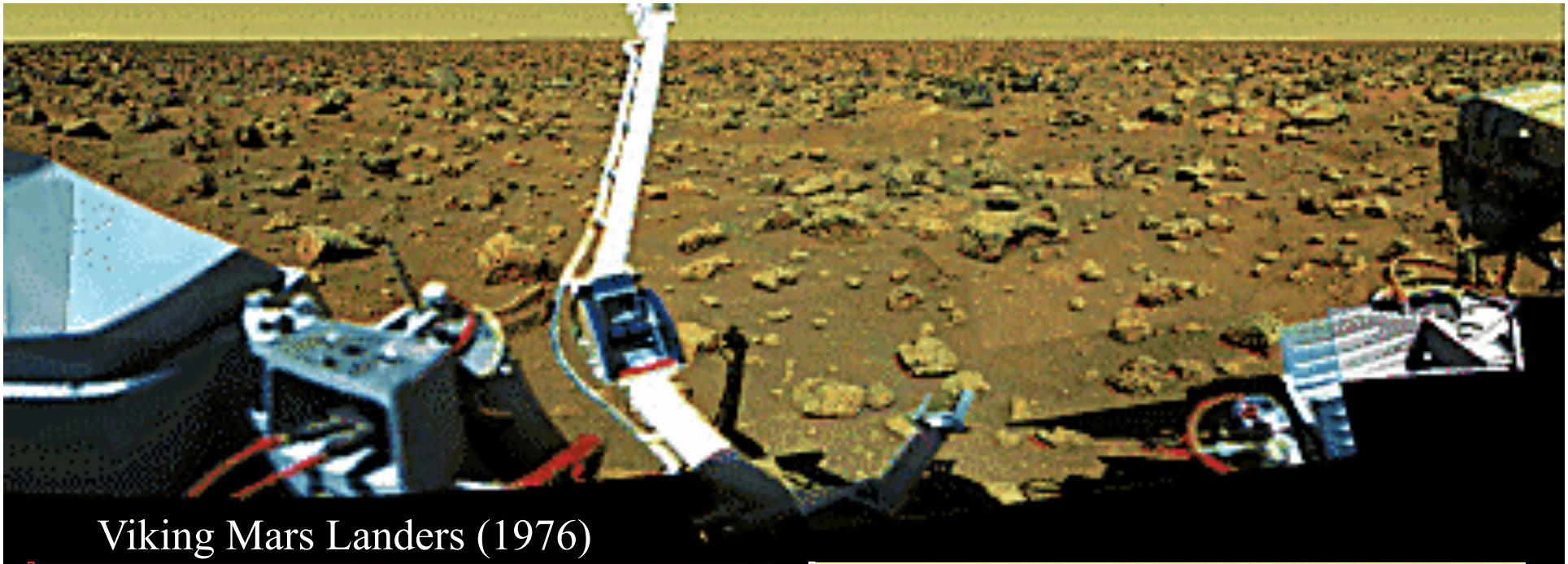
Mars

Is there, was there, life in Mars?

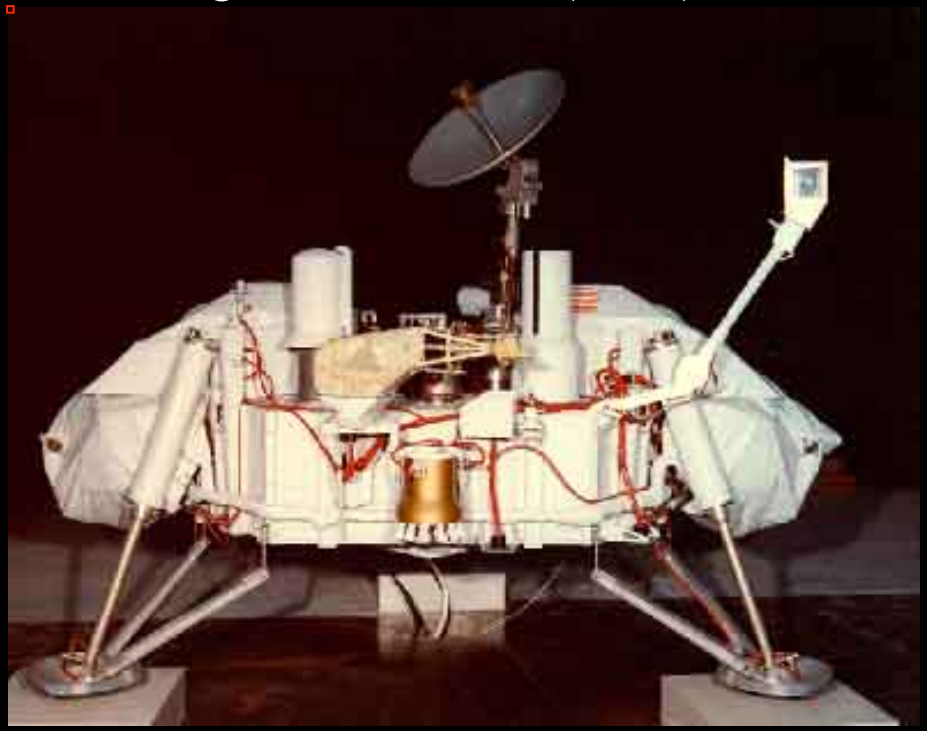
- Searches with telescopes
- Analyse composition of atmosphere
- Travel to planet (+meteorites)

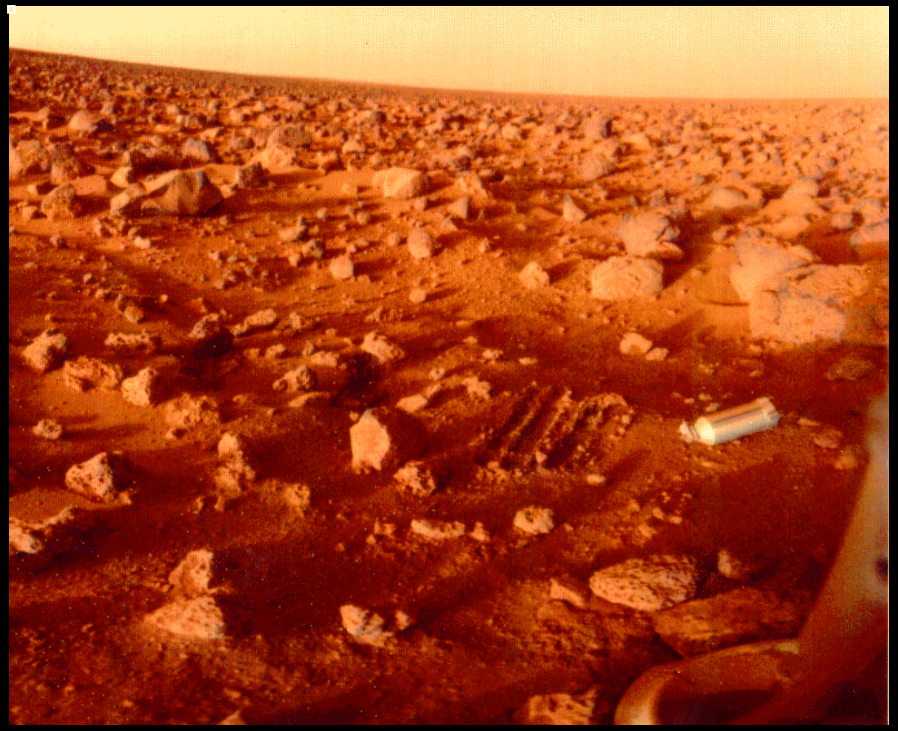






Viking Mars Landers (1976)





Viking life experiments

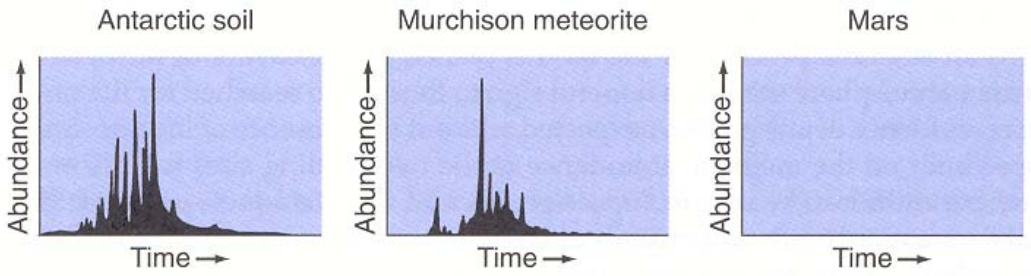


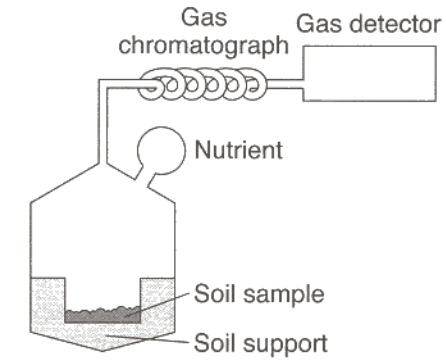
Figure 14.2 A test model of the *Viking* GCMS experiment analyzed Antarctic soil (left) and a piece of the Murchison meteorite (see Figure 11.14), which contains amino acids (center). The results show that each of these two samples contains a rich variety of organic compounds, since every peak in the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

Soil composition:

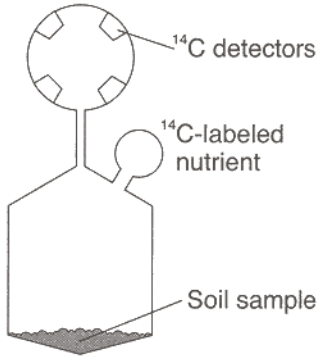
No hydrocarbons (c.f. Murchison meteorite) at 10 parts per billion-trillion (highly oxidized surface layer)

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?



GEX experiment



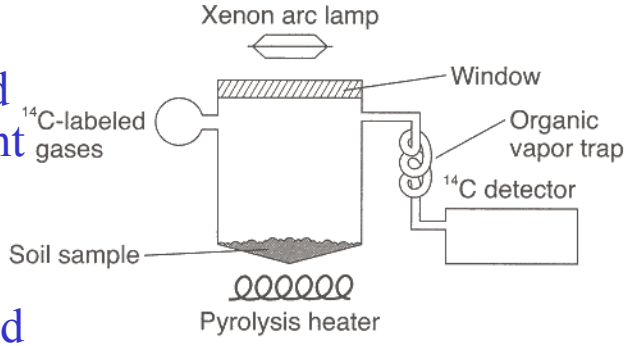
LR experiment

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



PR experiment

Atmosphere of Mars

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

Surface water cannot exist under these conditions but could have existed at higher pressures and warmer temperatures, before the runaway freeze-out of CO_2.

Subsurface water can exist, especially in form of ice.

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

Evidence of past surface liquid water

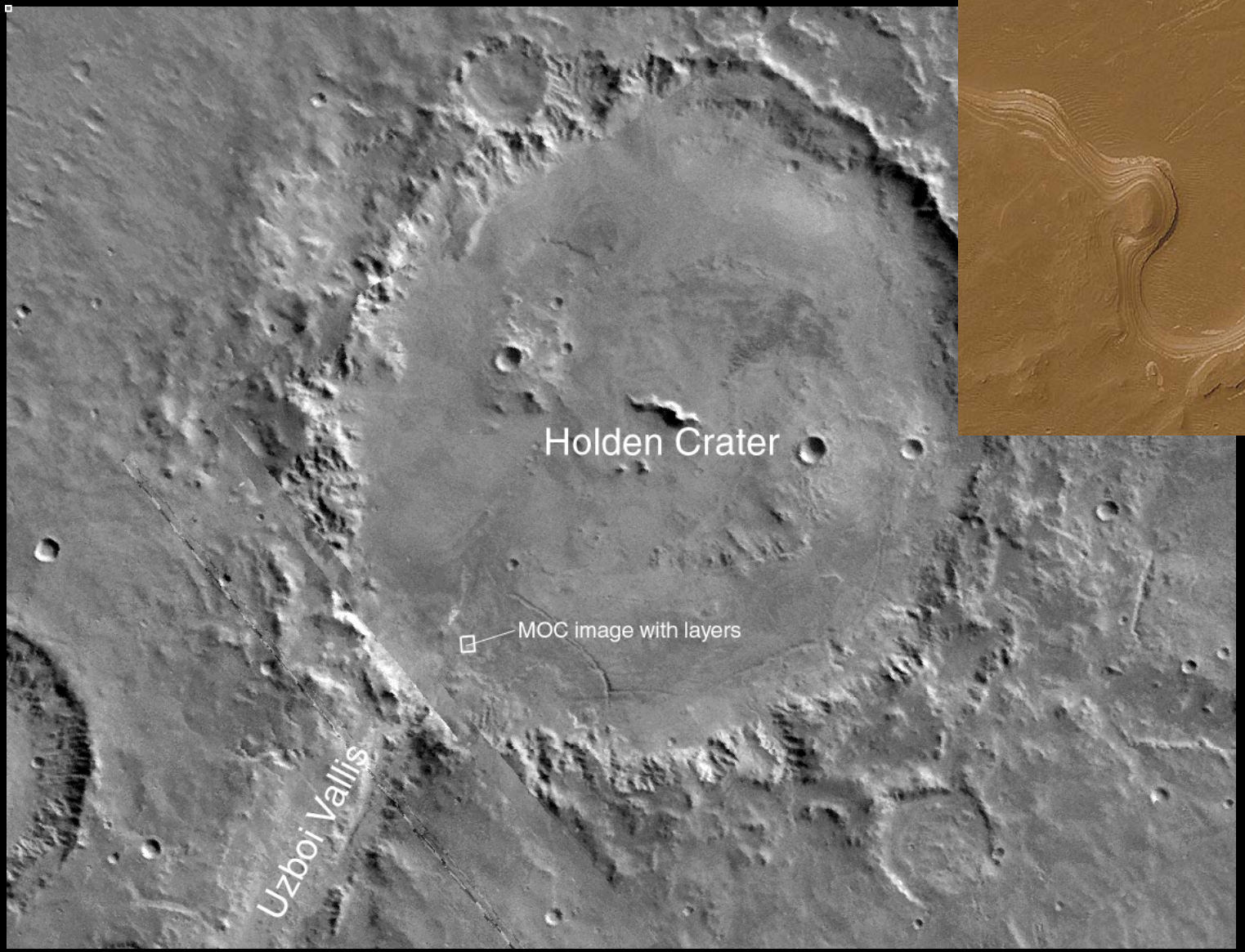
- There are certainly large km-thick permanent H_20 ice caps under the seasonal CO_2 ones
- There is evidence for extensive H_2O ice in surface rocks

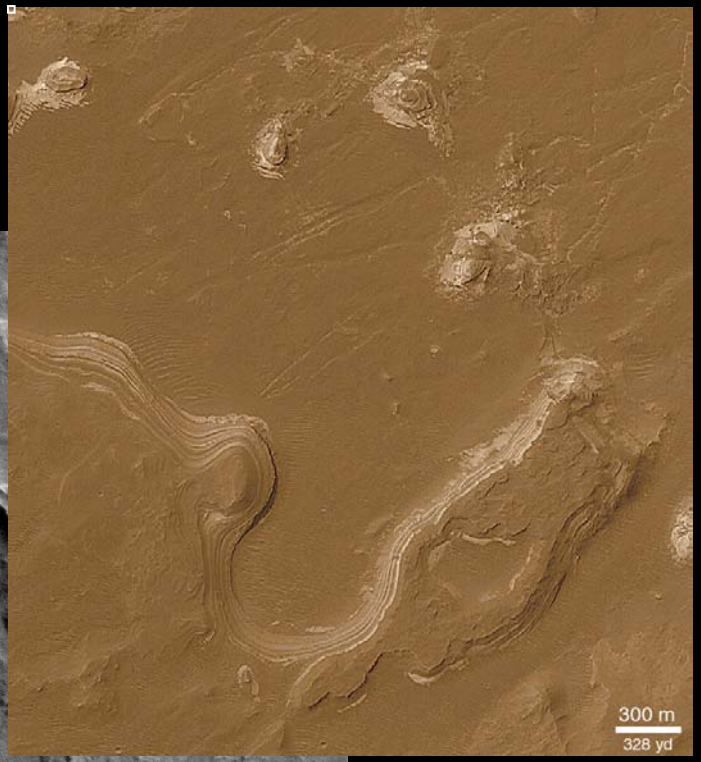
Evidence of (recent) liquid water flows:

1. Outflow channels:

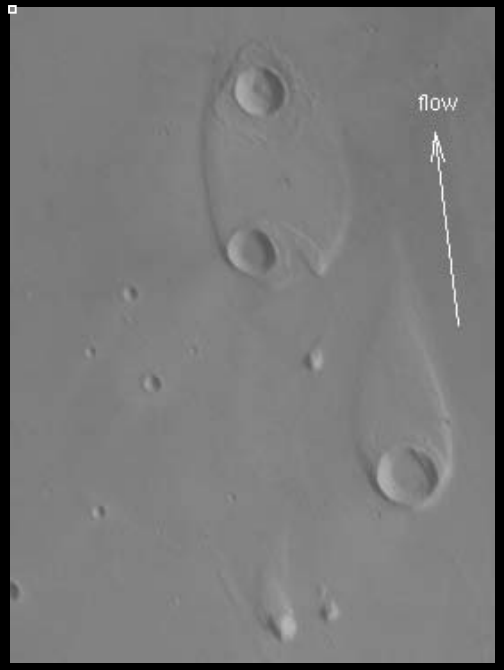
- Flows of debris carried by water
- Found even in young terrain (without craters)
- Flows sufficiently energetic that could be sustained under any atmospheric conditions
- Caused by sudden melting of sub-surface ice? (Impacts, volcanism etc.)

Sedimentary Rocks on Mars??



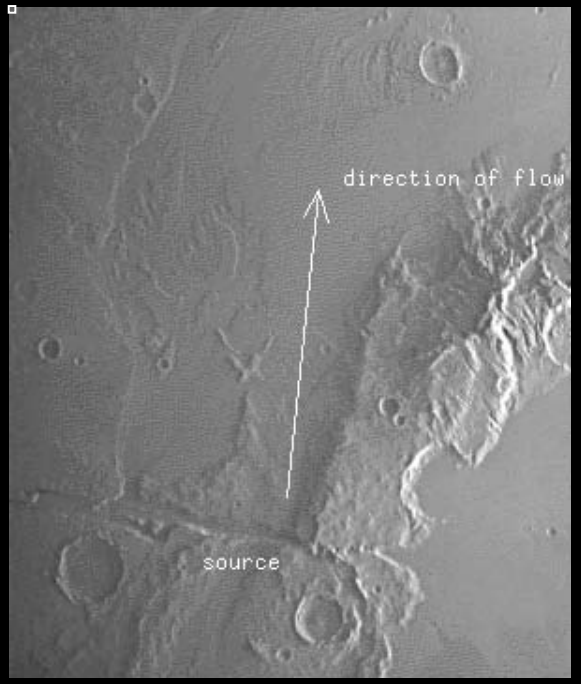


Outflow channels

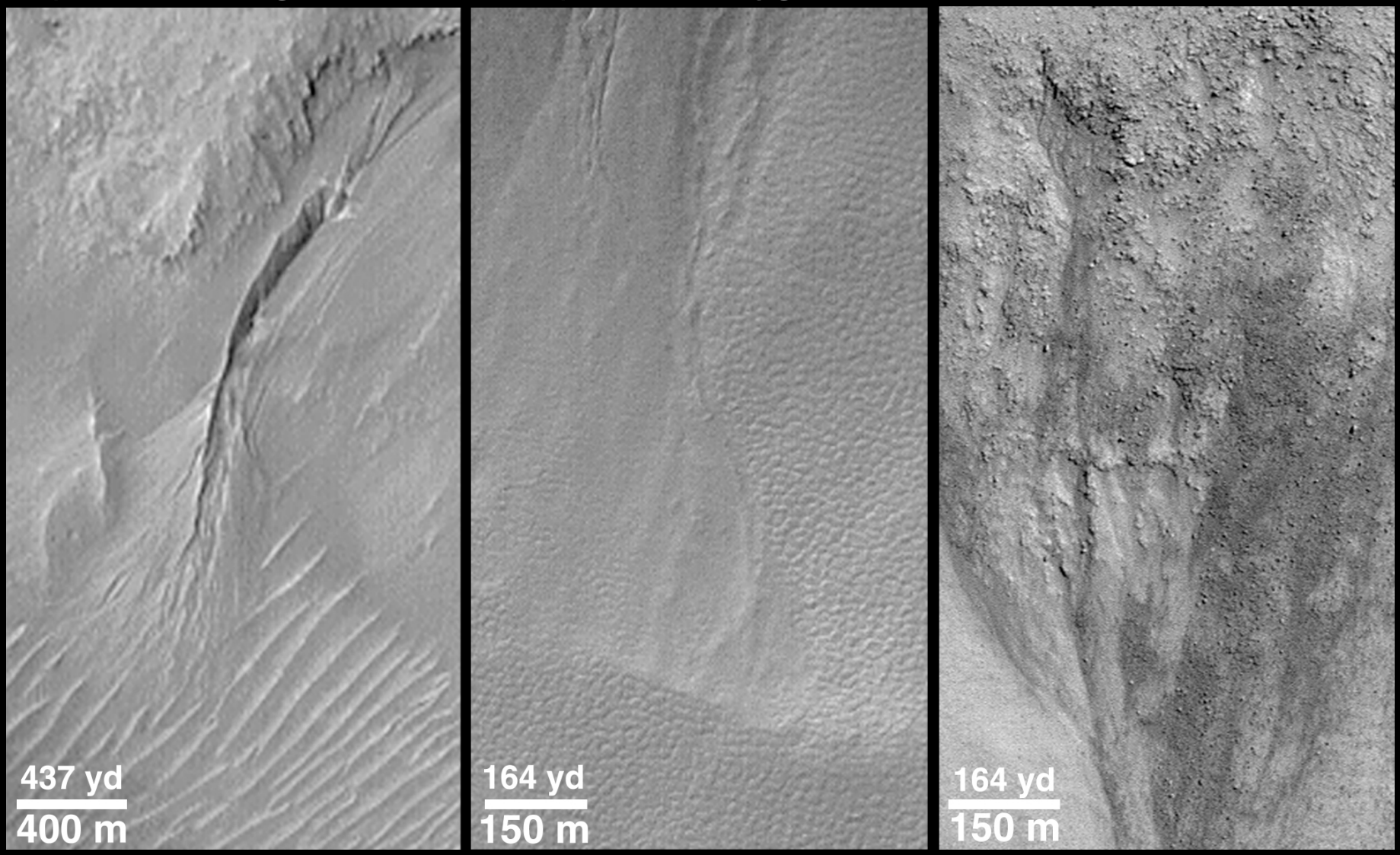


Erosion protection or deposition in lee of crater?

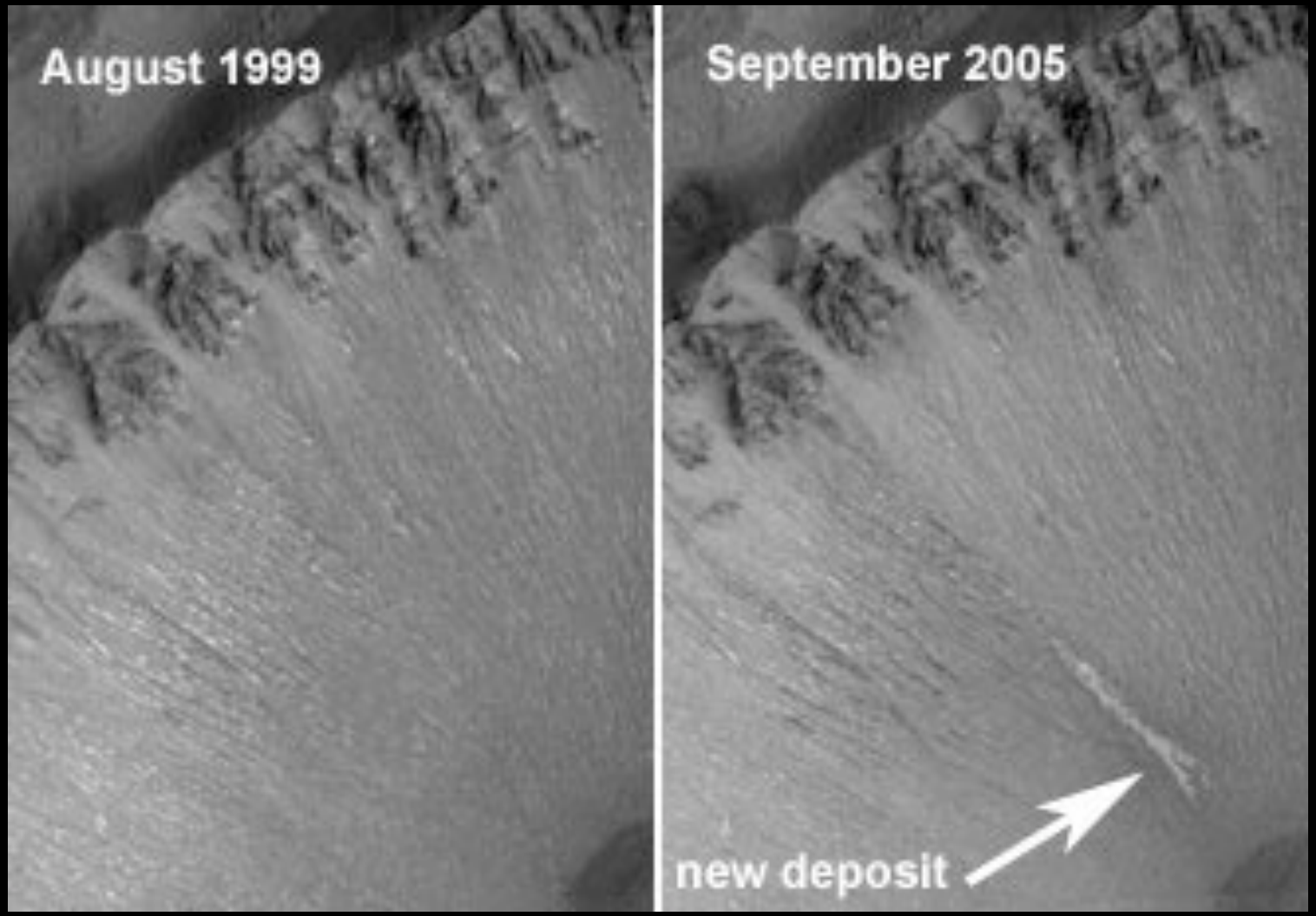
Origins in collapsed regions

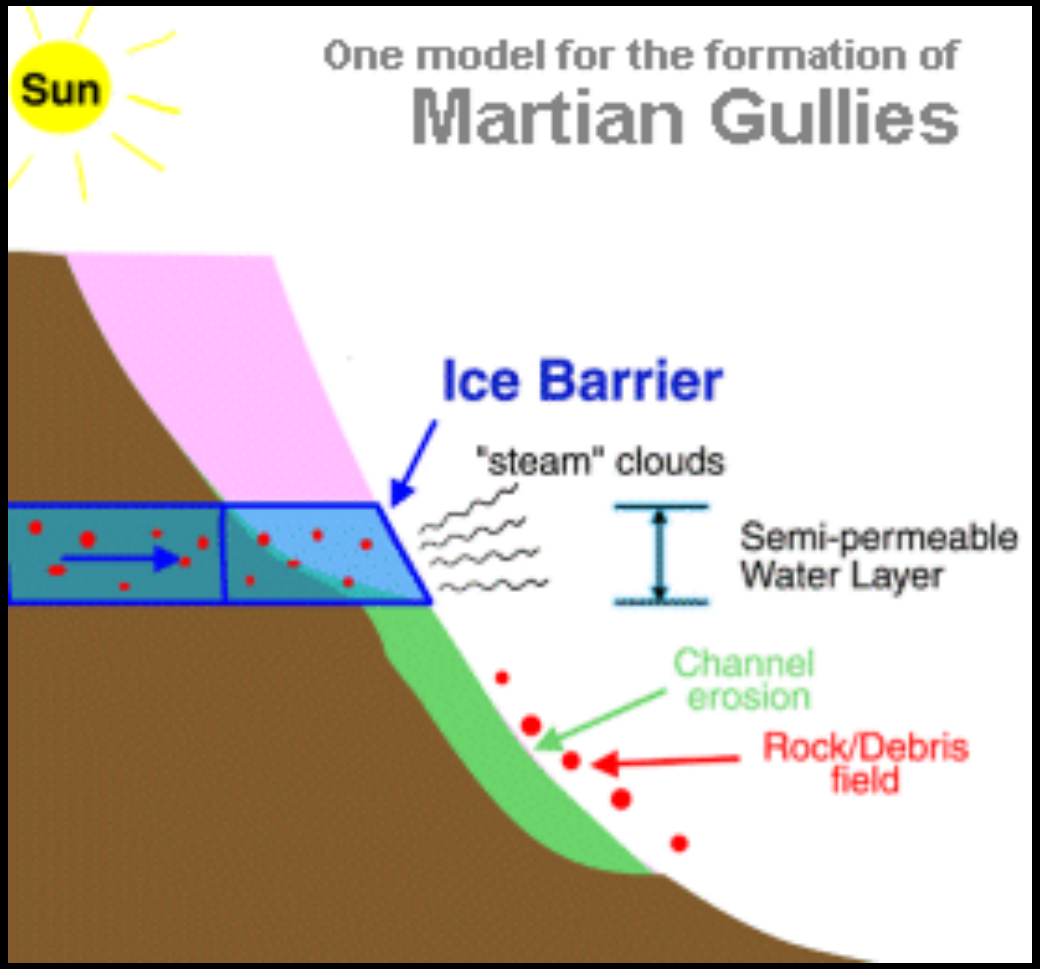


Recent “flows” covering sand dunes – only 10 years old??



Newly appearing bright deposits





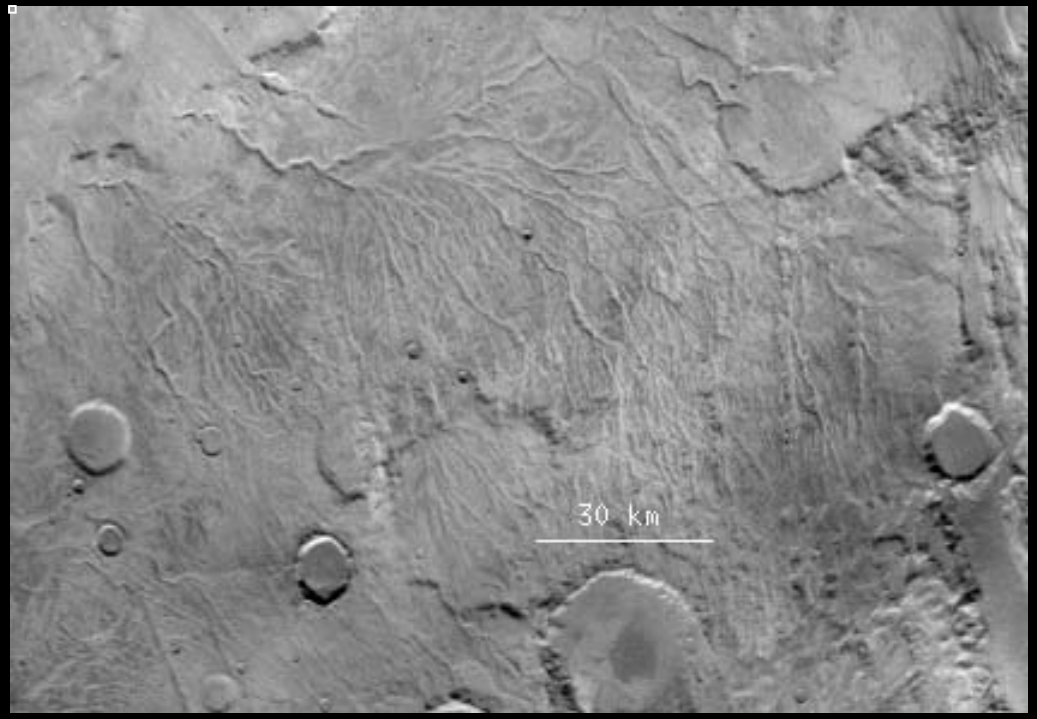
H_2O or liquid CO_2? (gullies seen in coldest(?) areas at 210K)

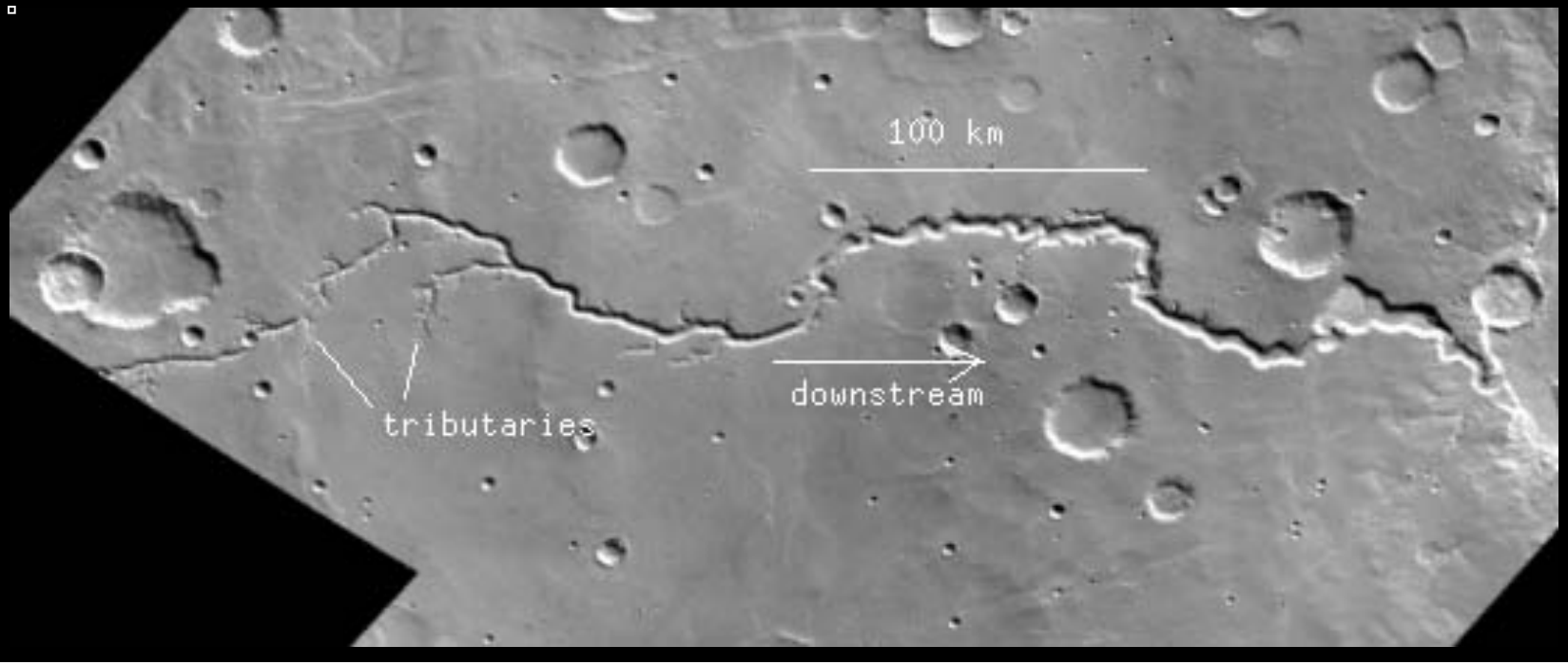
2. Valley networks

- Generally in ancient terrain, formed even before the end of the period heavy cratering.
- Surface flow or sapping of sub-surface flows?
- Some surface features resemble glaciation

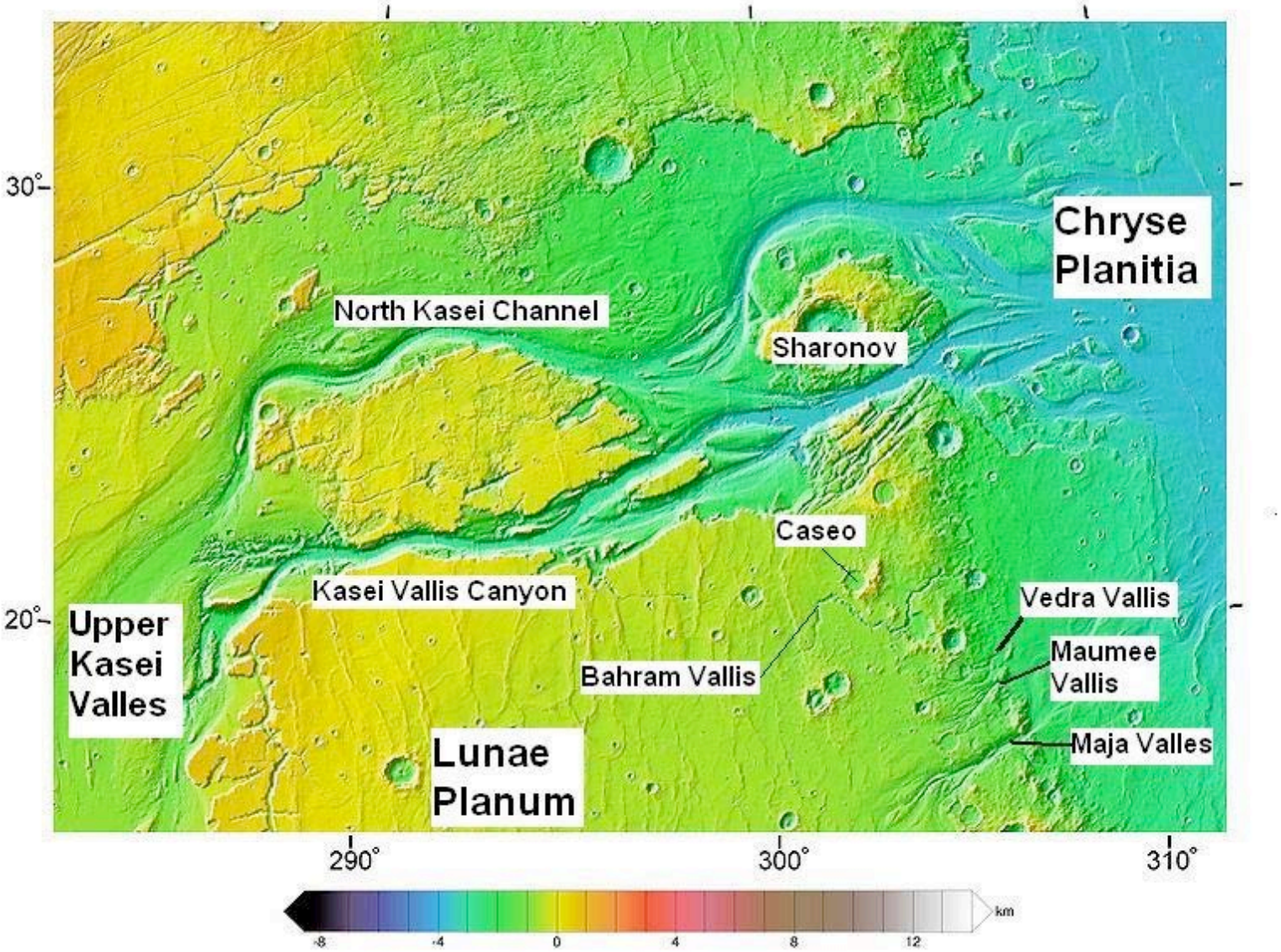
Martian valley systems

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





Entrance to low lying Chryse Planitia



Valley systems

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 heavily contaminated by salts
  - Vertical gradient of Cl and Br indicative of evaporating water.
  - Physical structure indicative of sedimentation in slowly flowing water

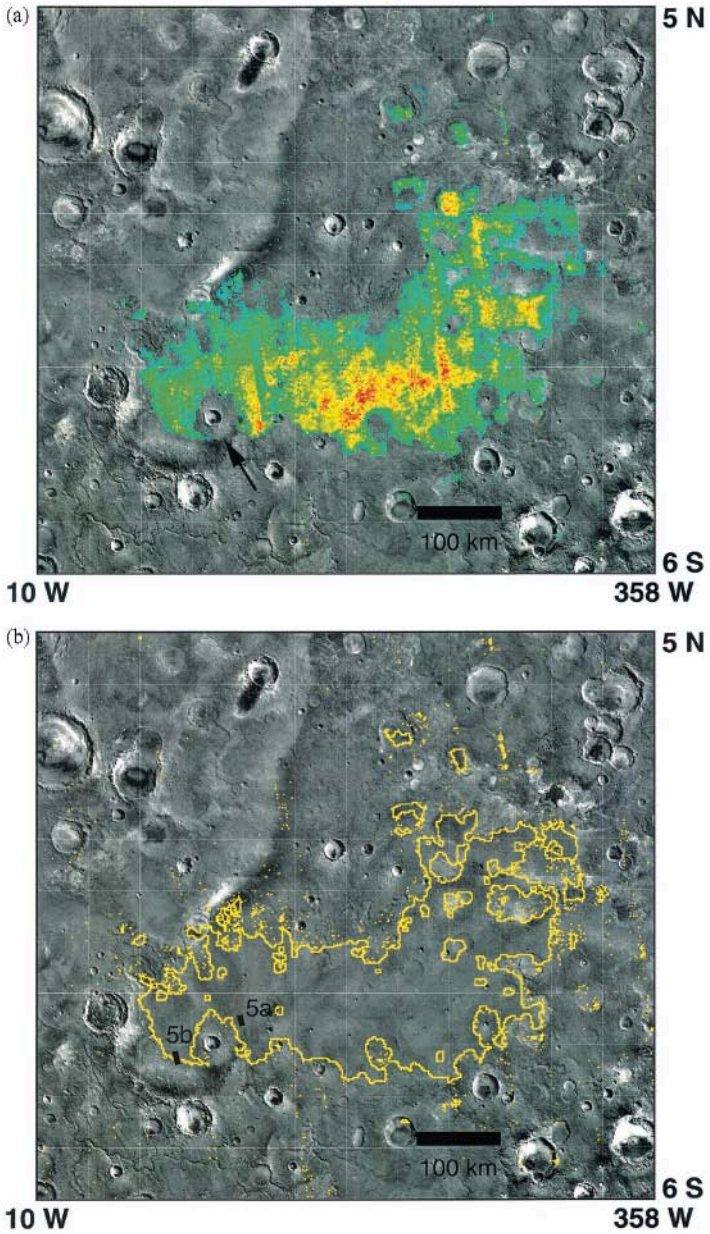
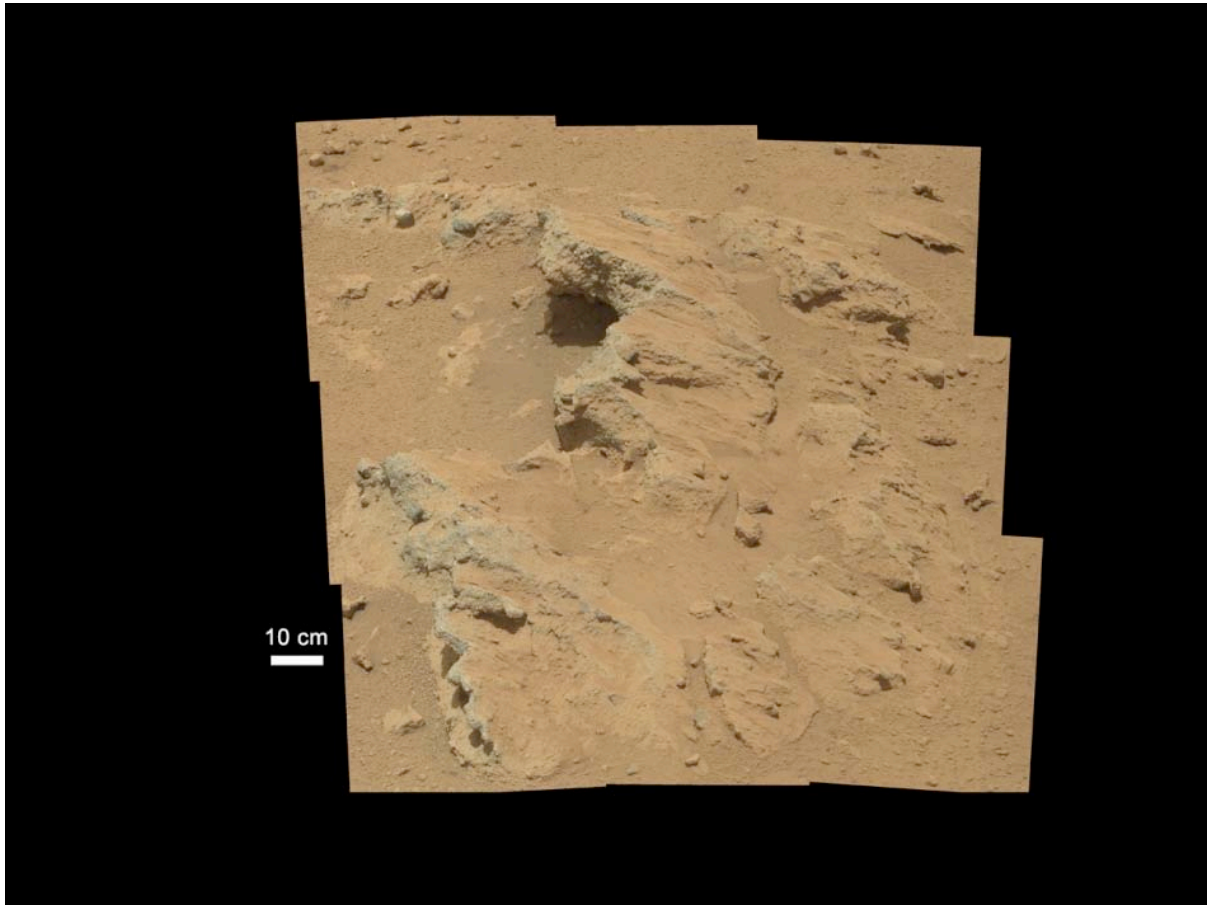
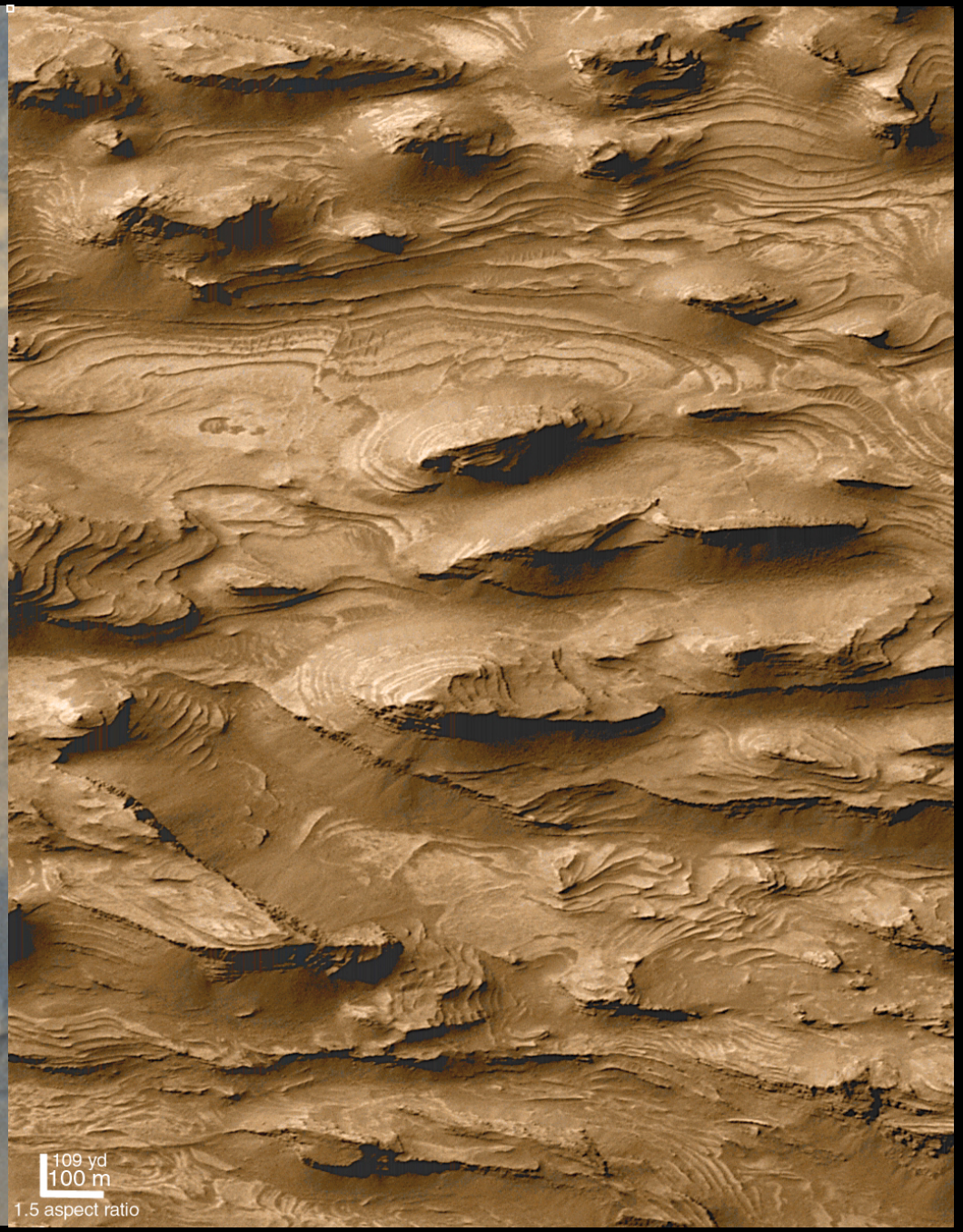


Plate 2. TES-derived hematite abundance in Sinus Meridiani. (a) TES-derived hematite abundance ov on a Viking base digital photomosaic image. Hematite index values of <1.018 have been made transpar allow the underlying morphology to be visible. This value was chosen as a conservative upper limit of the 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 geomorphol 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.

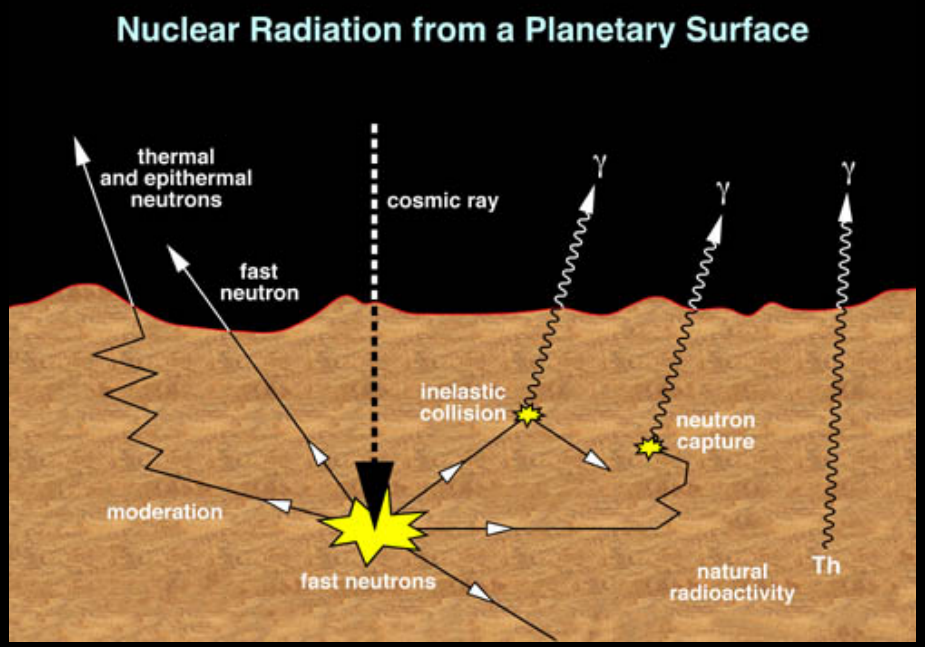
- Surface features indicative of “stream bed” (Curiosity 2012)



Evidence for sedimentary landscape forms

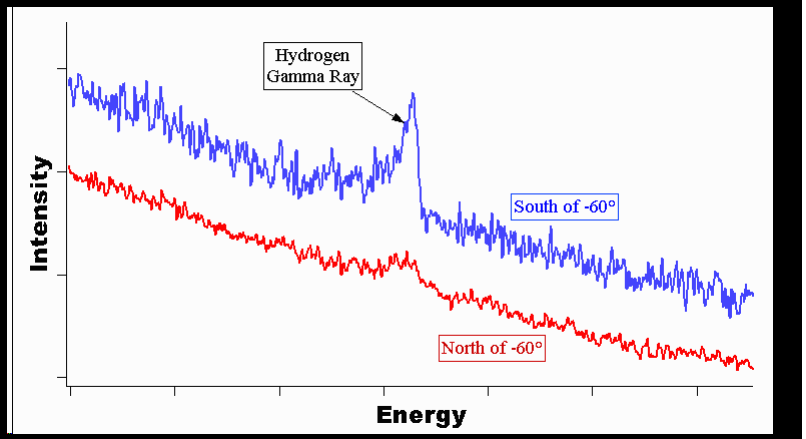


Best evidence for extensive H_2O: remote sensing of surface and sub-surface composition

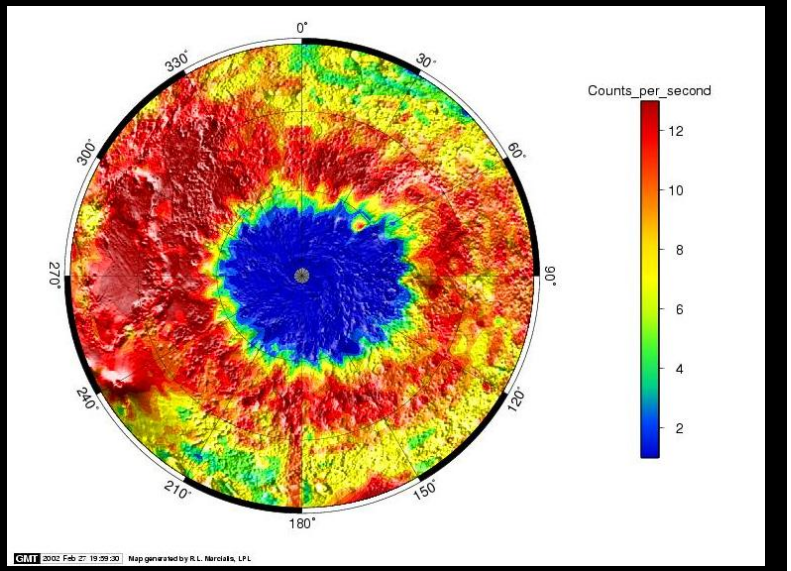


- Cosmic-ray (relativistic p^+) impacts an atomic nucleus in surface producing shower of $p^+ + n$.
- Neutrons are slowed (moderated) and finally absorbed by other nuclei, both with emission of γ-ray photons
- Hydrogen is particularly effective moderator, so few high energy neutrons returned to space

Emission of g-rays from surface

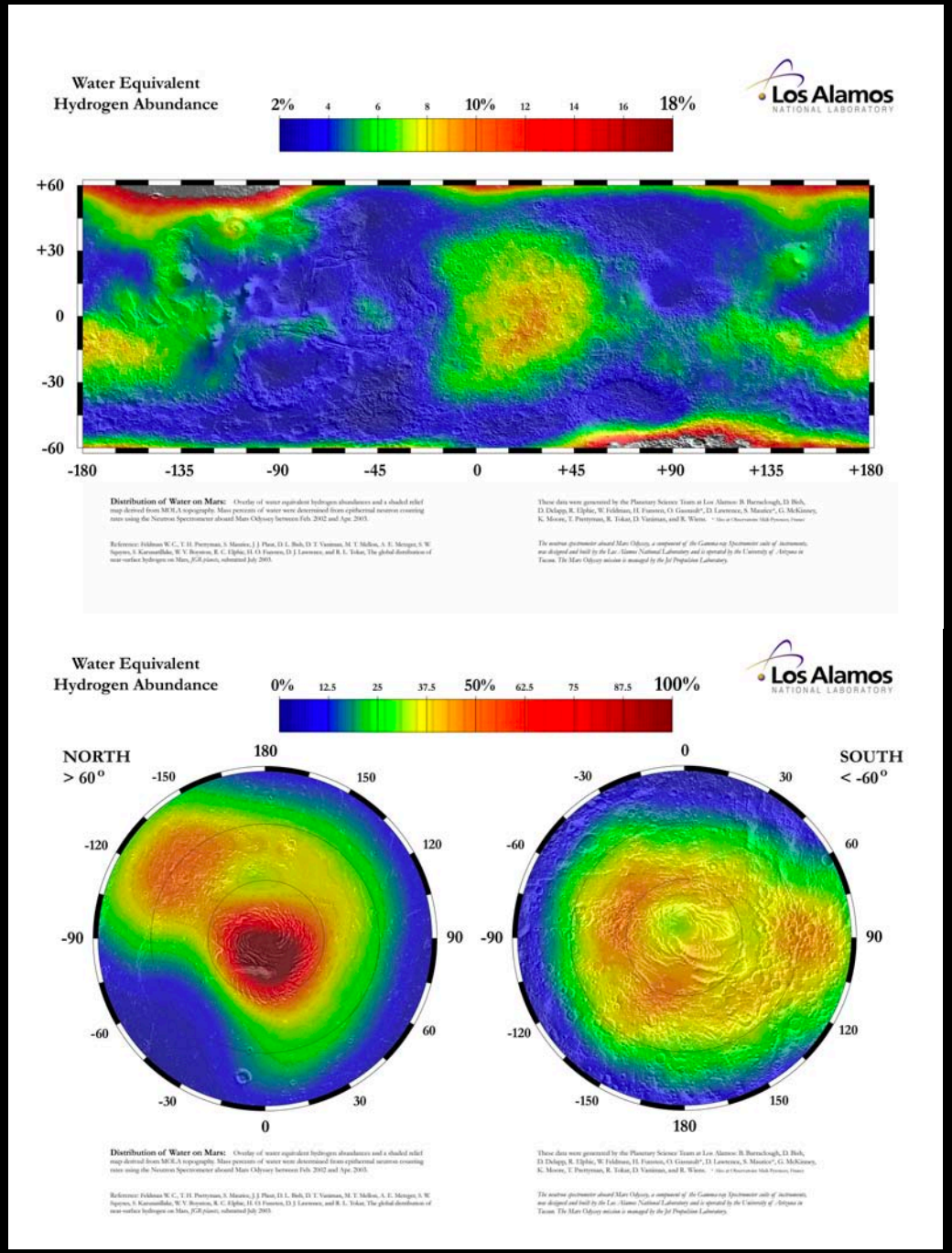


Emission of neutrons from surface



Water equivalent Hydrogen abundance in top 1m of surface:

Few % upto 100% at North Pole



Water ice in the bottom of a 35km wide crater 70^{o} N

What happened to the surface water?

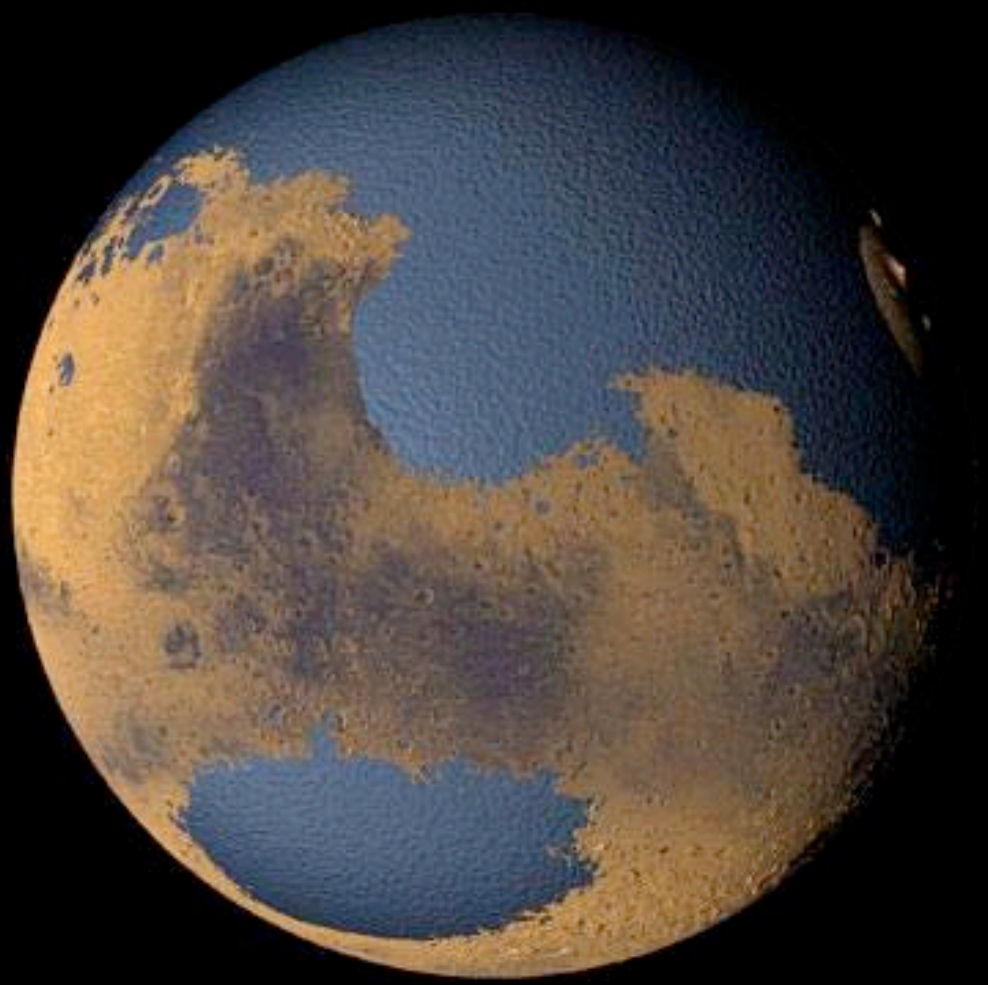
- Early evidence of erosion in oldest surface features, followed by loss of liquid water from surface, (possible glaciation) and finally loss of all surface H_2O.
- Significant loss to space indicated by D/H ~ 3 times terrestrial value and also 3x that in oldest Martian meteorites.
- Timescale and mechanism(s) of transition from a relatively warm and wet world to current cold and dry one are still uncertain.

How much water was present?

- Present polar caps several km thick → enough for 20-30 m planet wide.
- Elsewhere, gamma-ray spectroscopy + neutrons indicates substantial H (most likely H_2O) in sub-surface (> meter depth) rocks.
- Estimates of total water flow ~ 10^{-3} to 10^{-2} of Earth's oceans.
- D/H ratio indicates that most of the hydrosphere was lost, up to ~ 0.1 Earth ocean.
- If northern hemisphere basin was once ocean, need > 0.01 Earth ocean.

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

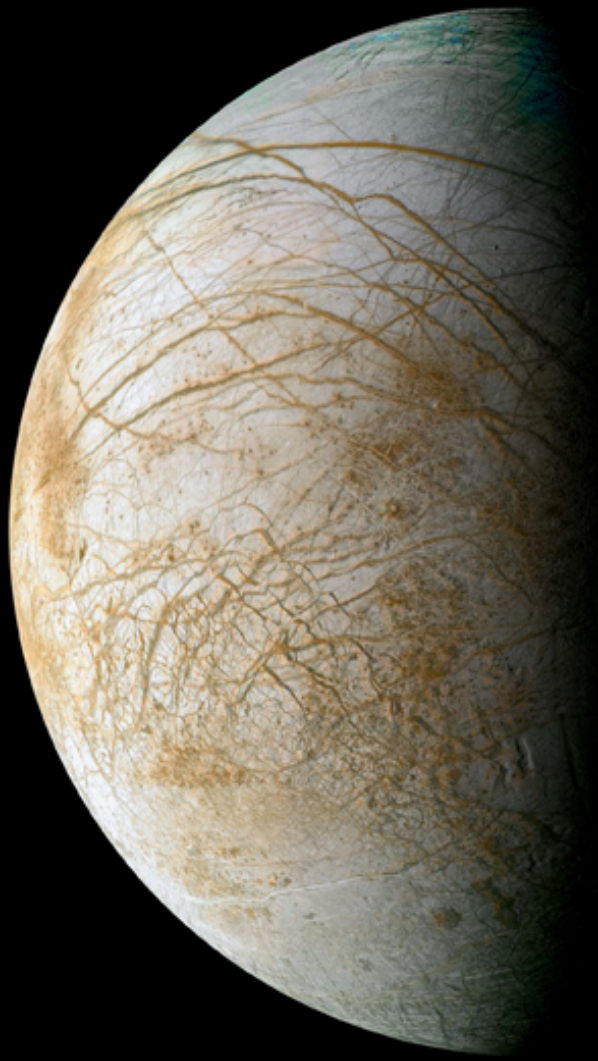
Was there once a standing sea in the northern hemisphere, subsequently lost within about first 0.5 Gyr?



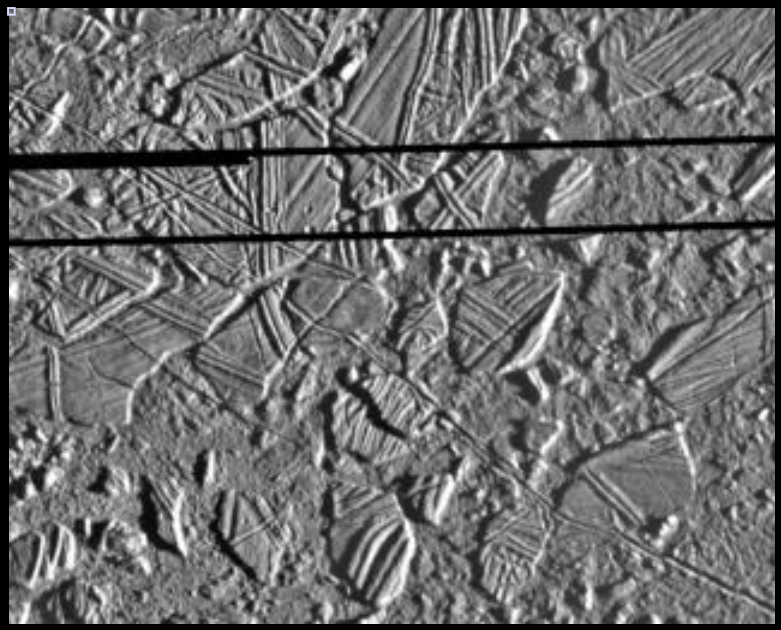
The satellites of the Outer Planets

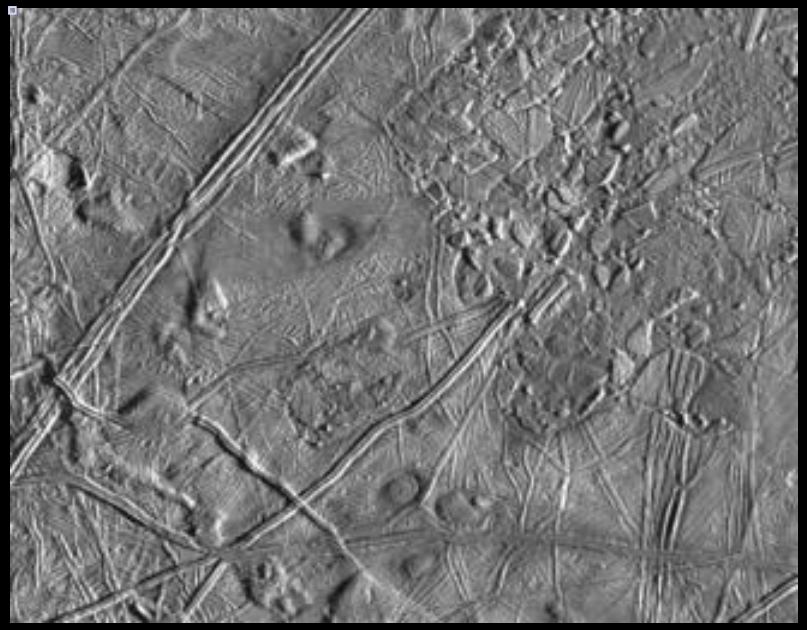
Europa in the Jupiter moon system

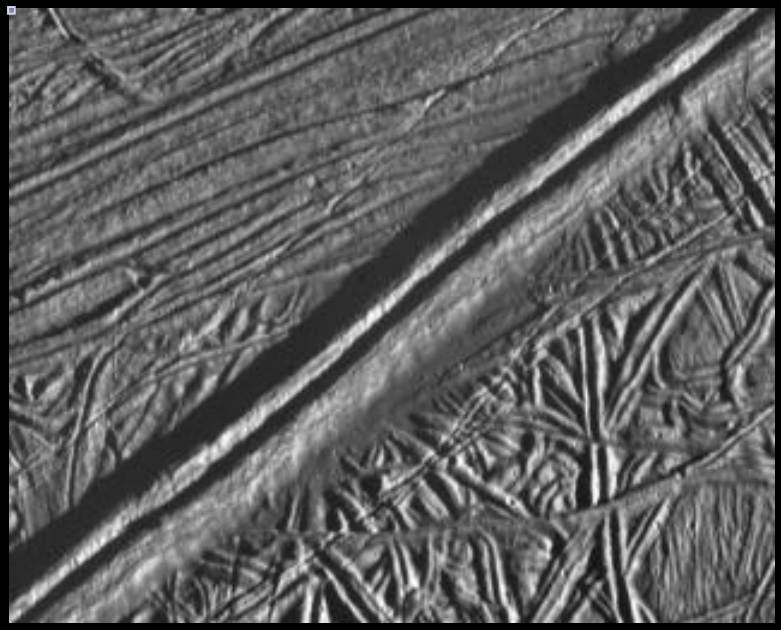
- Extremely smooth H_20 ice surface above a liquid H_20 ocean.
- Thickness of ice layer is controversial (estimates: 300m – 30 km).
- Depth of ocean estimated to be up to 100 km (→ more H_2O than Earth's ocean?)



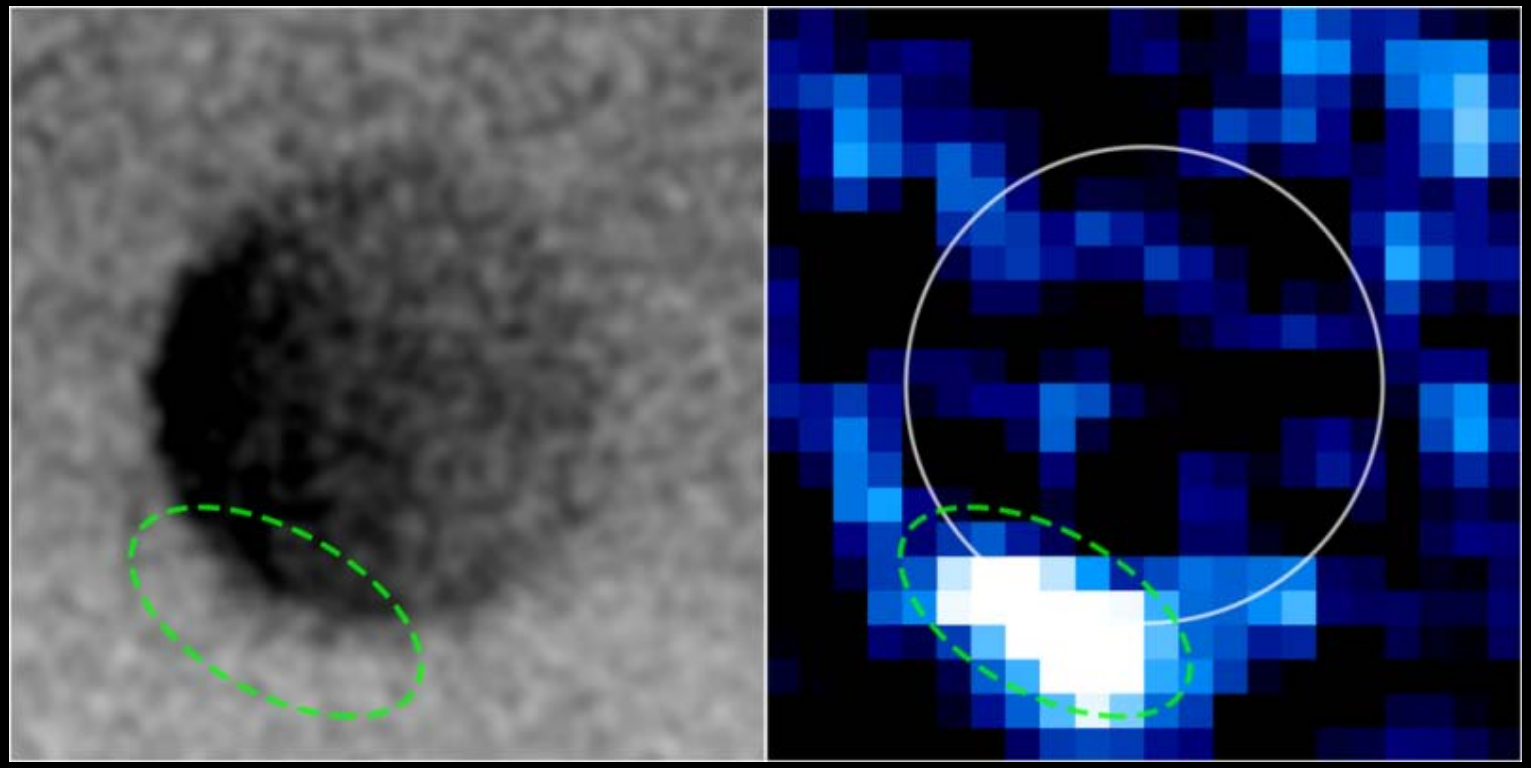
- Evidence for liquid sea beneath ice:
  - Young uncratered surface - geologically active
  - “Ice Rafts”
  - Upwelling at cracks and holes
- Possible water ocean tens of km deep?
  - Cracks contain Ca, Mg salts (no organics yet?)

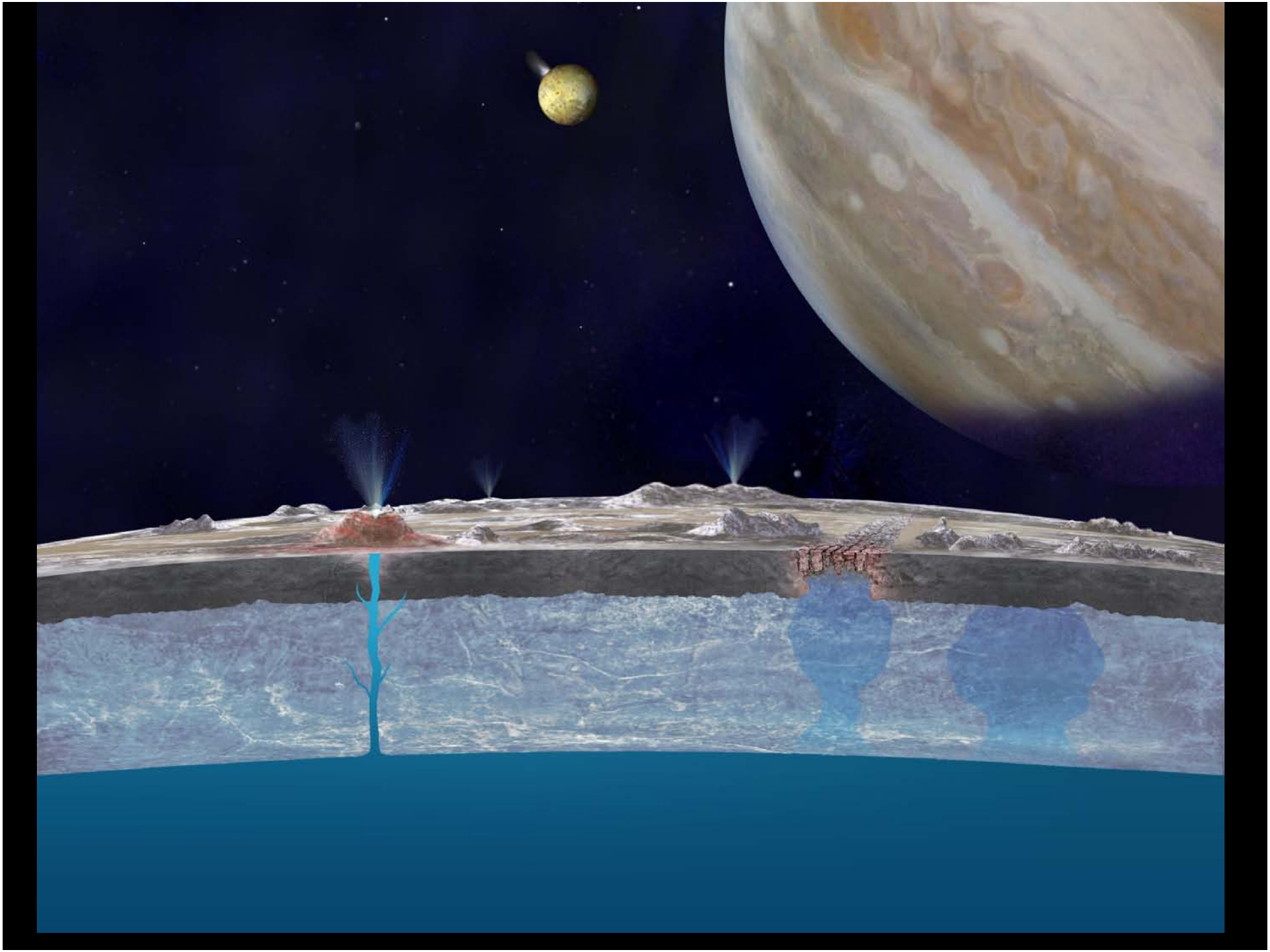


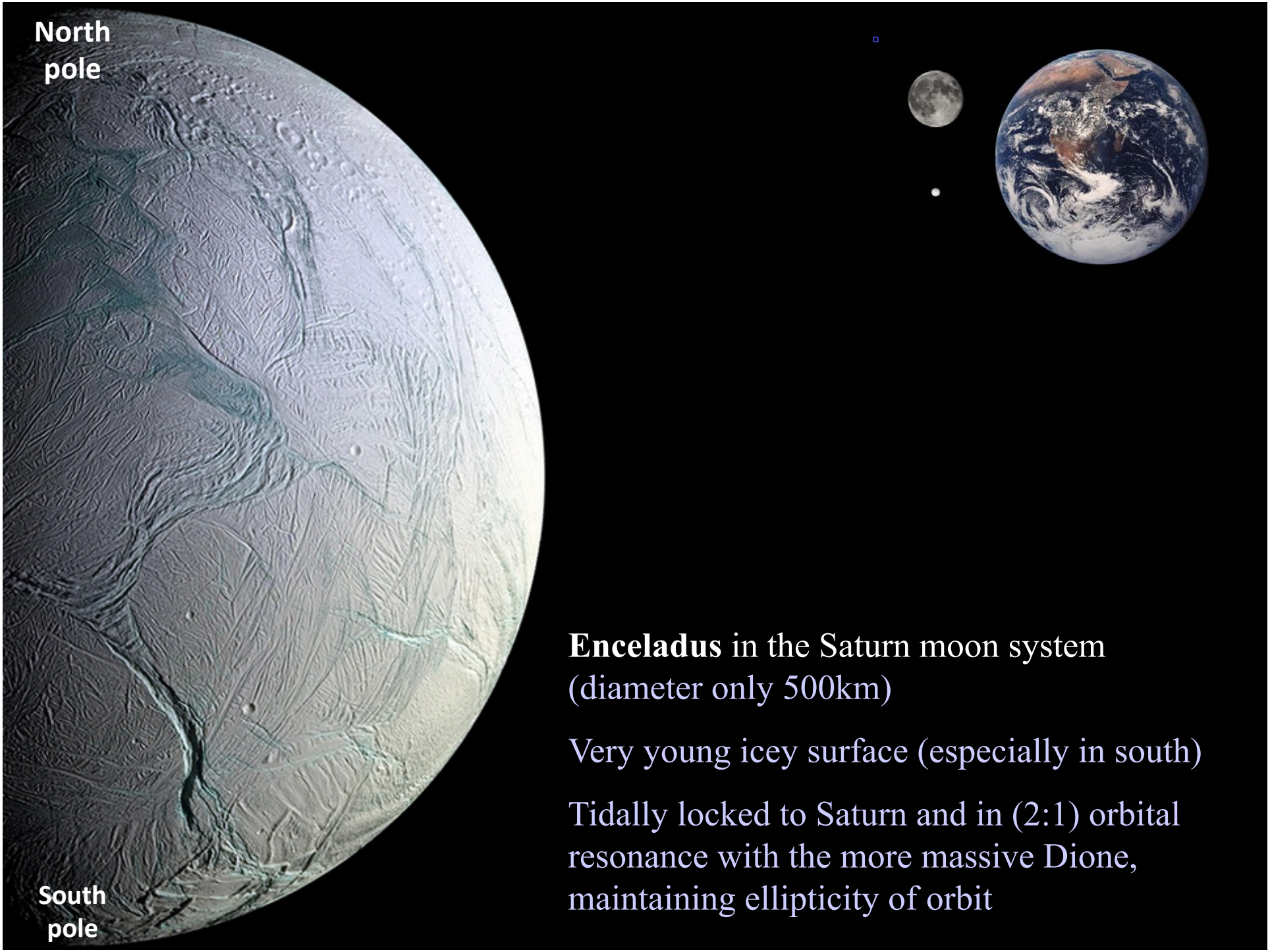




H_2O (intermittently) seen in ultraviolet absorption above limb of Europa when Europa passes in front of Jupiter (as seen from Earth by HST) → geysers of liquid water







Enceladus in the Saturn moon system (diameter only 500km)

Very young icey surface (especially in south)

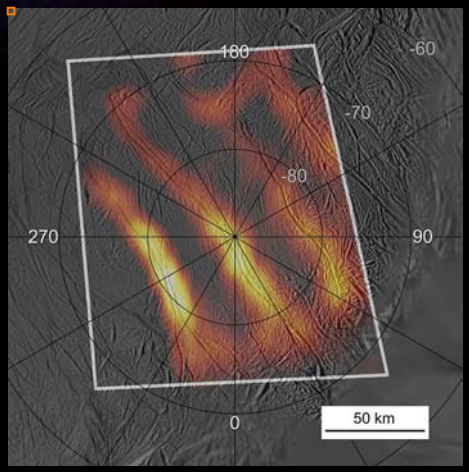
Tidally locked to Saturn and in (2:1) orbital resonance with the more massive Dione, maintaining ellipticity of orbit

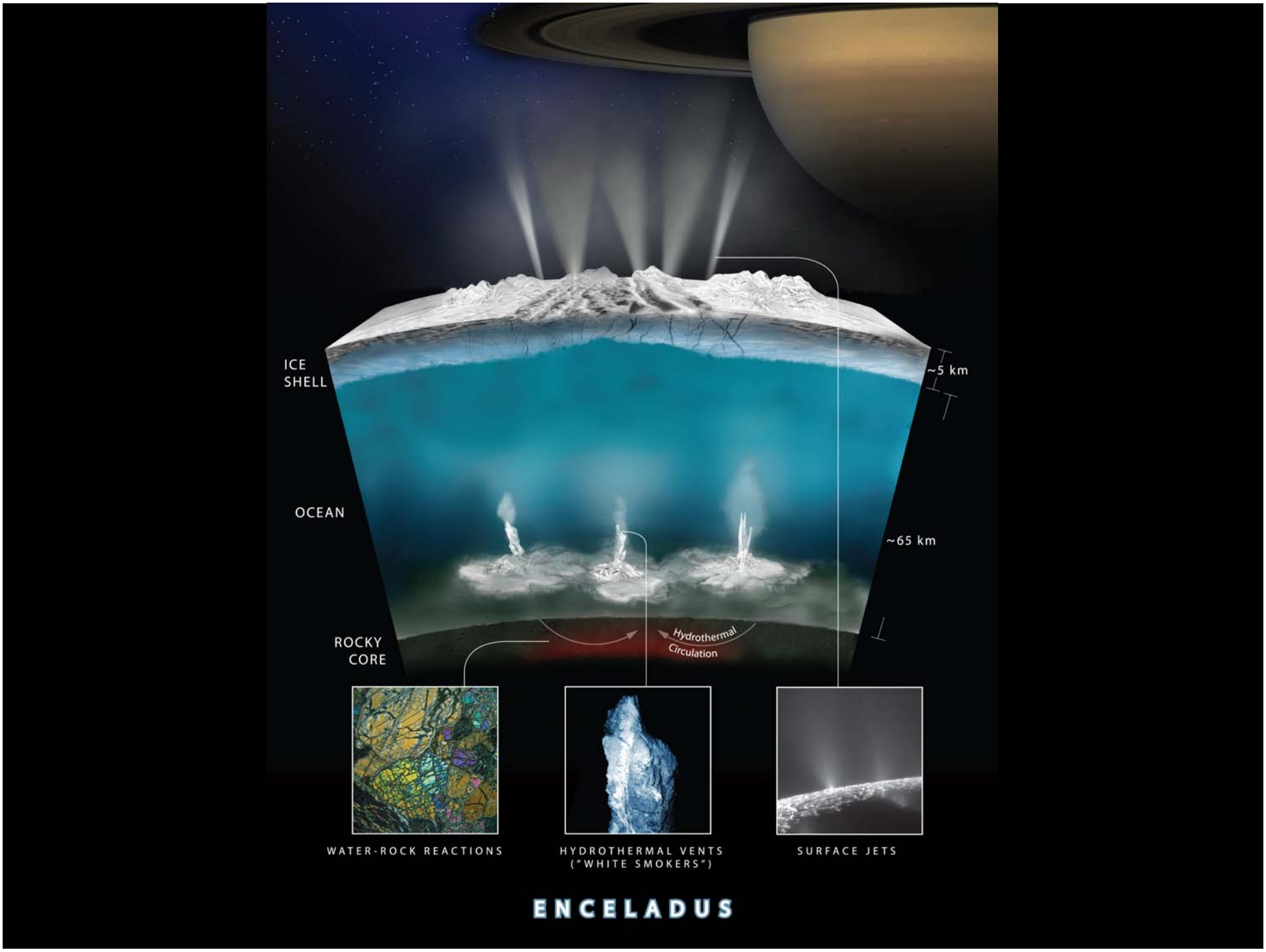
Direct detection of plumes (200 kg/s) from south polar region by Cassini spacecraft (2005+, including “fly-through”)

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.

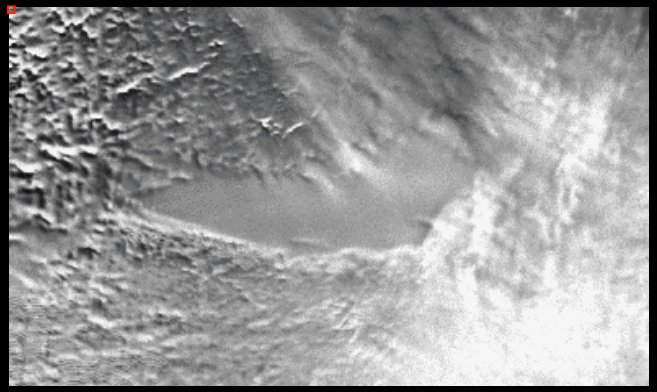
Evidence for 30km subsurface ocean of salty water over the entire moon.

Geysers are more like curtains and come from cracks in south polar regions



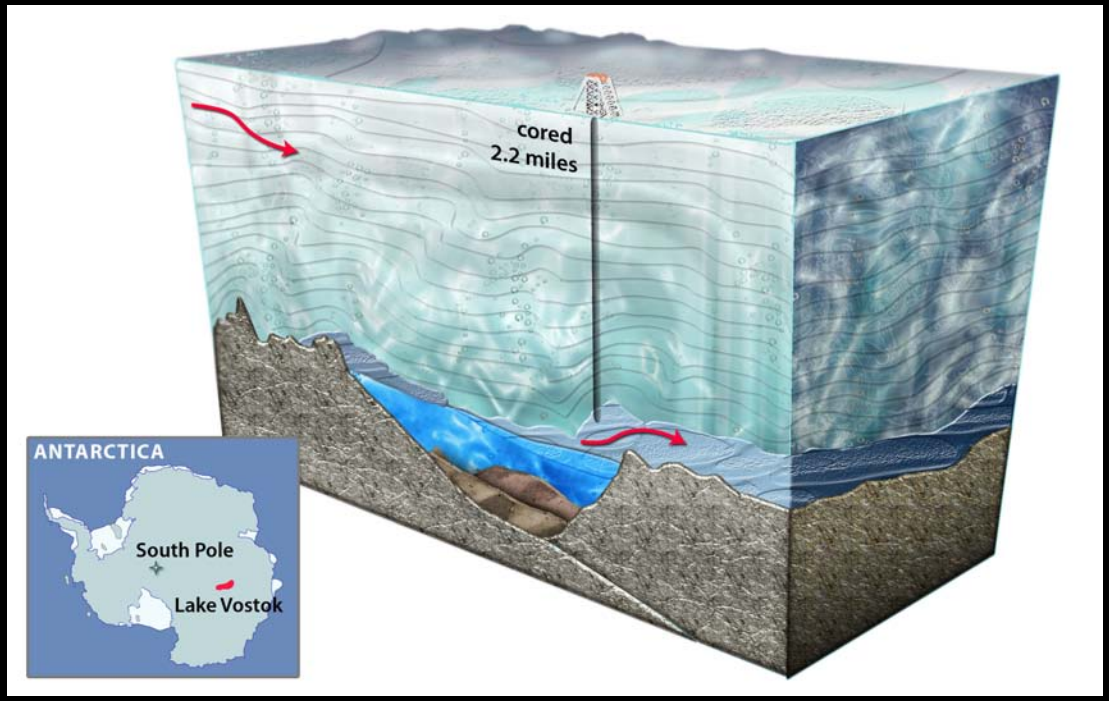

ICE SHELL
~5 km
OCEAN
~65 km
ROCKY CORE
Hydrothermal Circulation
WATER-ROCK REACTIONS
HYDROTHERMAL VENTS ("WHITE SMOKERS")
SURFACE JETS
ENCELADUS

Lake Vostok



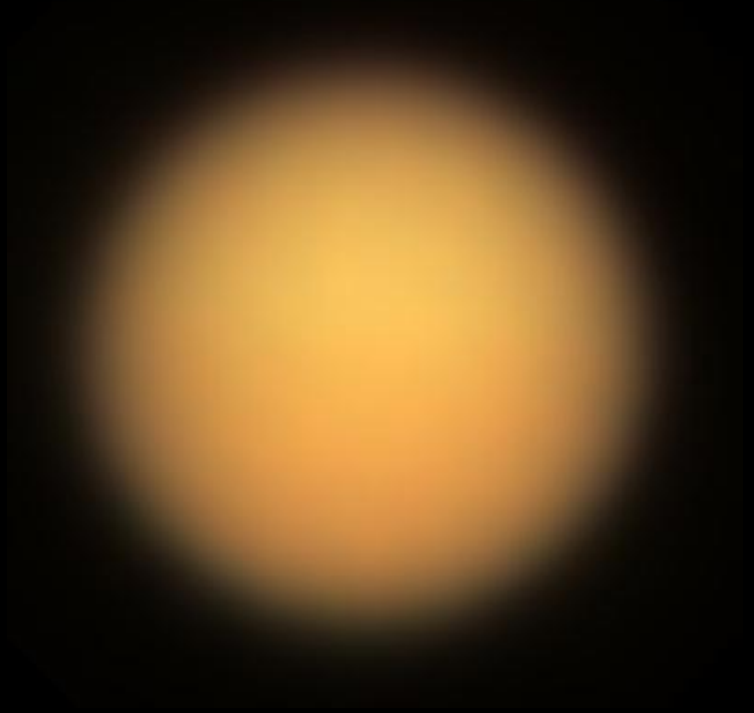
Conditions on Europa and Enceladus not unlike Lake Vostok in Antartica.

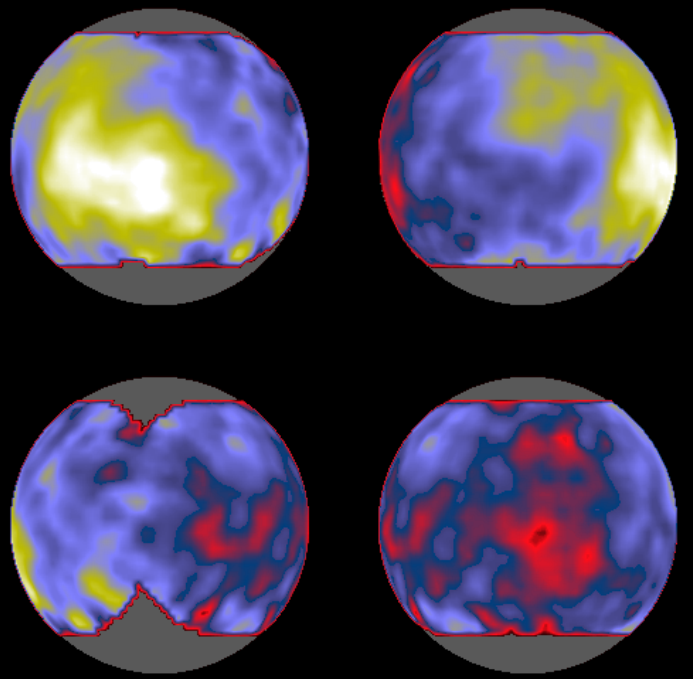
Good(?) evidence (but still controversy about contamination) that life survives/thrives in Lake Vostok. Extensive DNA sequences found in accreted ice above lake surface (~90% bacteria, plus eukarya)

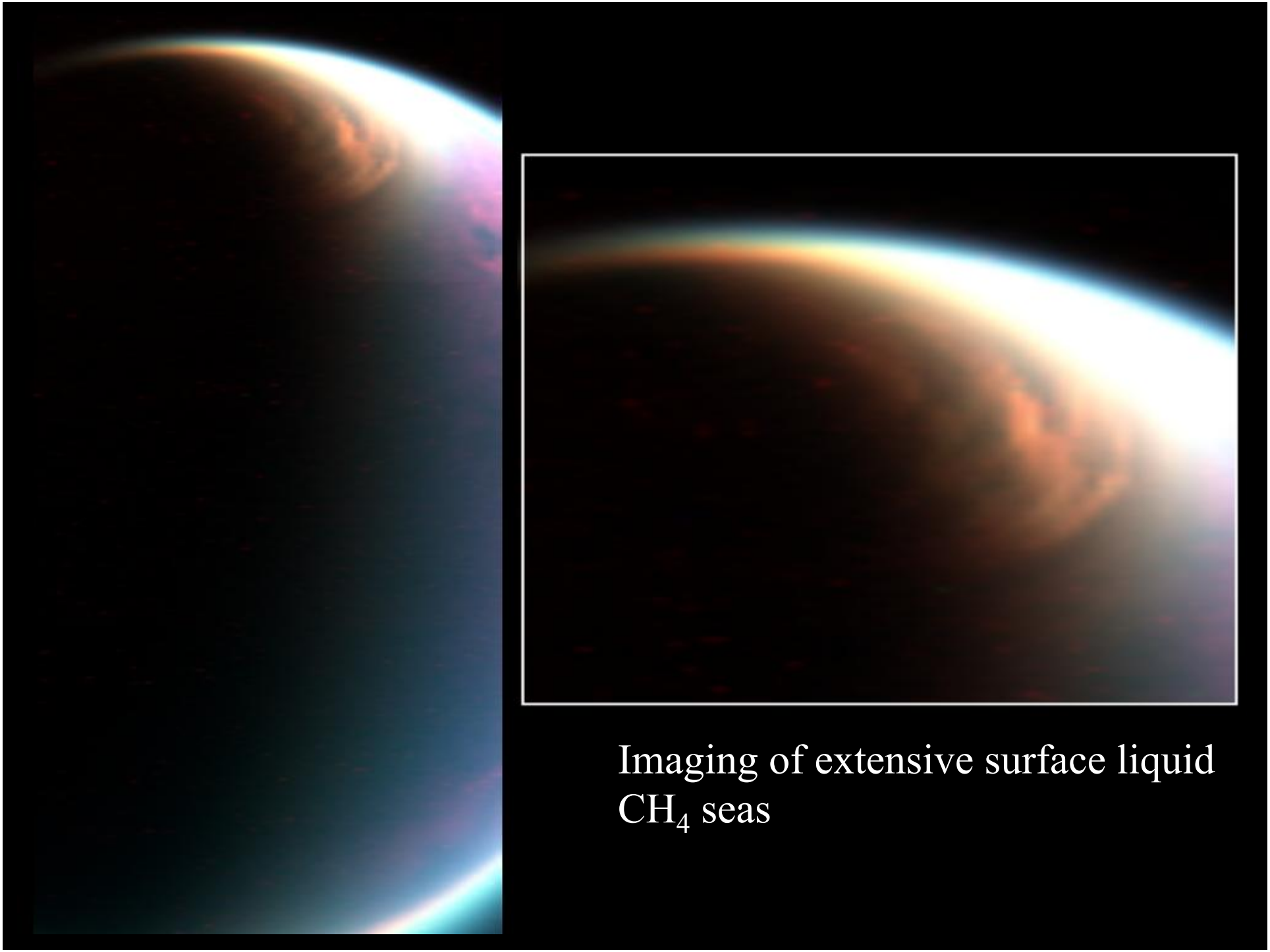


Titan

- Saturn's largest moon in Solar System - more massive than Mercury
- Retains a 1.5 bar atmosphere (N_2 + CH_4) at 85K , able to support liquid on the surface.
- H_20 completely frozen out so little of the CH_4 was oxidised to CO_2
- Interesting atmospheric chemistry from e^- from Saturn's magnetosphere: CH_4, N_2 → 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

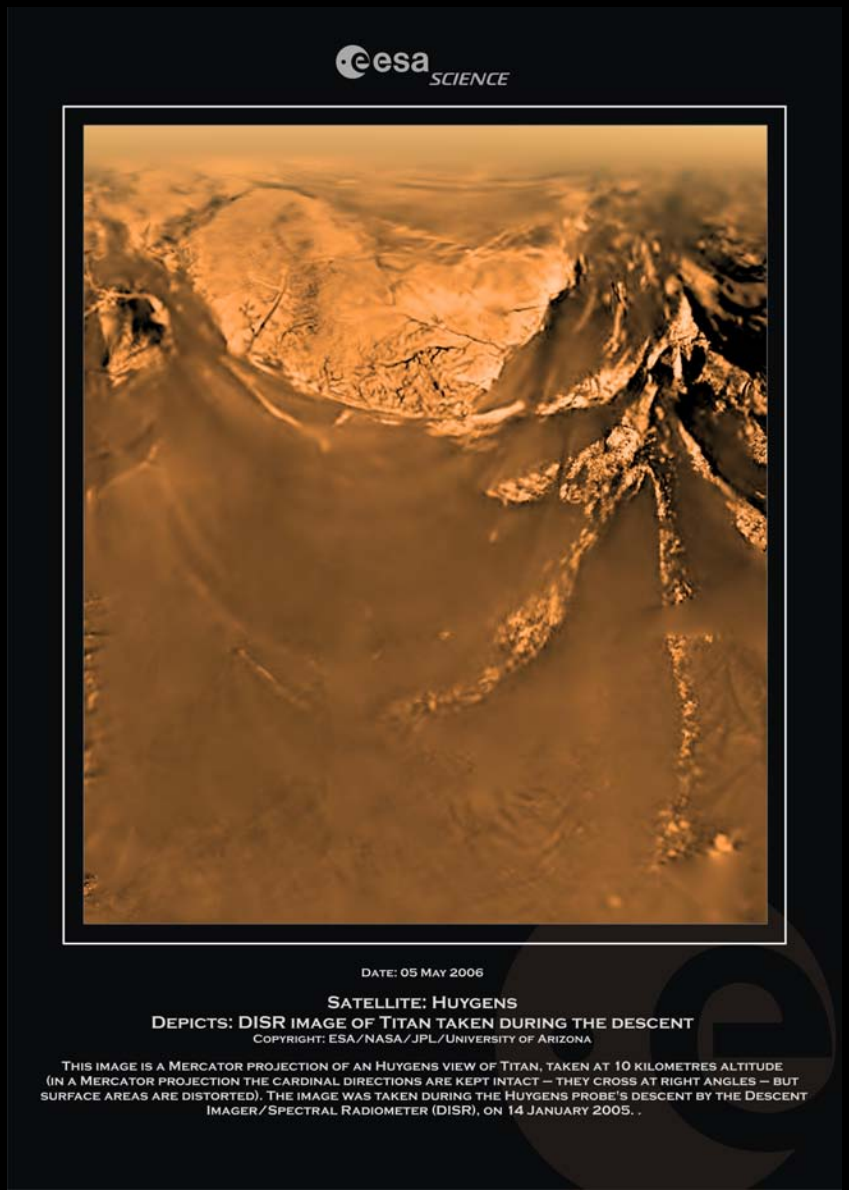


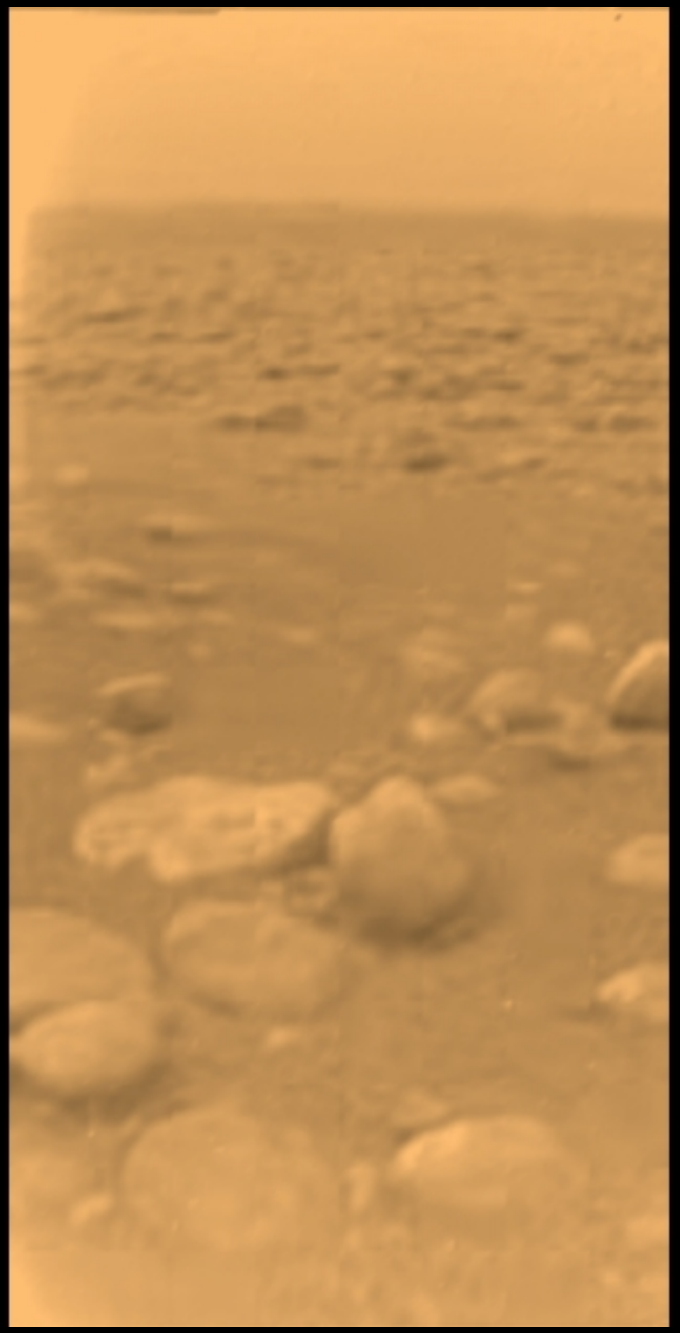




Imaging of extensive surface liquid CH_4 seas

Landing of ESA Huyghens probe (2006)





Astrobiological interest of Titan

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

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

3. Actual Life in Titan's interior?
- At tens of km depth, ammonia-water still liquid? Heated by radioactivity
- Kilo-bar pressures OK?
- Hard to access!!

Summary:

- The evidence for lots of surface/sub-surface water ice on Mars now, and of surface liquid water in some distant past, is compelling.

- During the last 15 years or so, the Outer Solar System has been looking more promising more for life than previously imagined. Note how tidal heating broadens the concept of habitable zone.

- Note too how "accidents" have consequences:
  - Enceladus orbitally locked with Dione
  - Energetic e^- in the Saturn environment affect Titan's chemistry
- Conclusion: we are always likely to have surprises!