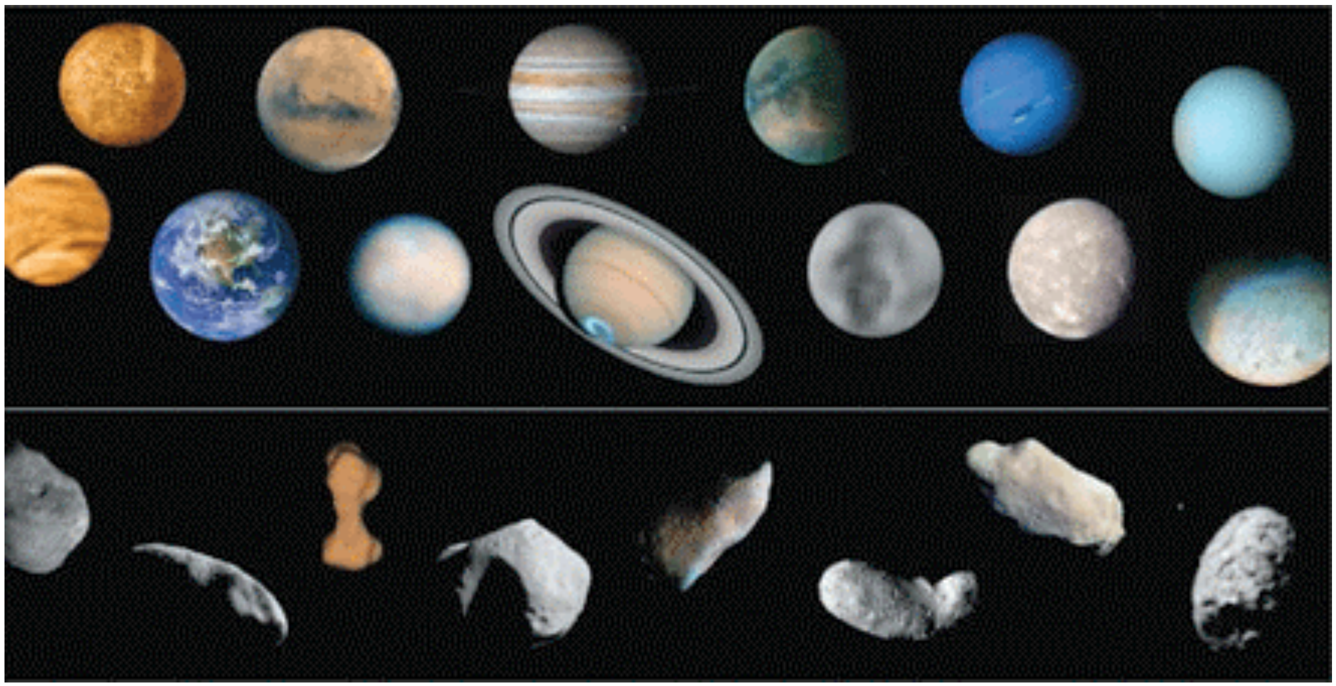
Life in the Solar System



Life in the Solar System

7.1 Environmental requirements for life

Where would you find basic molecular building blocks?

Elements *(H, C, N, O):*
Anywhere (from spectra of stars, galaxies)

Organic molecules*:* Three possibilities your book likes best
a. chemical reactions in atmosphere
b. chemical reactions near deep-sea vents
c. molecules brought to Earth on comets or asteroids

c. would hold for all worlds, but still require **atmosphere**, and a **surface** (or subsurface) **liquid medium** (water would be nice). And the molecules have to survive the the trip through the atmosphere, so not at all trivial.

More complex prebiological or biological molecules:
Nobody has any idea how these were able to form, even on the Earth, so we aren't considering this aspect, only "habitability" In the sense of above

7.1 Environmental requirements for life (cont'd)

Where would you expect to find an energy source?

Note: not just for "metabolism;" all chemical production of organics *a la* Miller-Urey requires an energy source.

Starlight is obvious largest potential source, but need to utilize UV part of spectrum for reactions, at least until the advent of photosynthesis. Many others available--

Chemical (textbook means "heat source for chemical reactions")

Lightning--need an atmosphere, but no one can predict conditions for lightning energy.

Radioactive heating, geothermal heat (deep-sea vents included): These depend on mass of body (consider Moon, Mercury, Mars…). *Why?*

Tidal heating -- In our solar system, only moons of giant planets get this source (ch. 9--we'll discuss in detail). *Notice how this enlarges the "habitable zone."*

7.1 Environmental requirements for life (cont'd)

Does life need liquid water? Already covered pp. 239-240.

Many arguments in favor of water, but of course we can't rule out other liquids (e.g. ethane on Titan).

Remember general argument for liquid requirement: If molecules were "just sitting there" on some solid surface, their migration would be *very* slow and they would not react fast enough to produce more complex molecules; a liquid medium provides a "mixing medium" in which the molecules can diffuse, and therefore react, more rapidly.

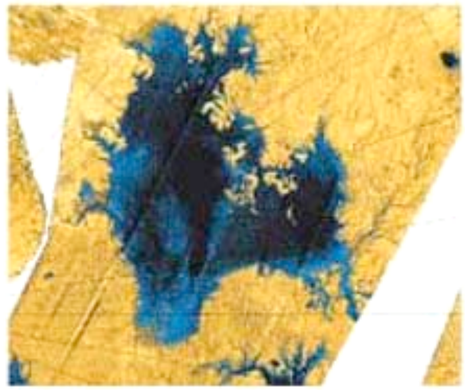
→ ***Can see that the requirements for habitability boil down to a liquid medium (preferably water), plus a surface and (probably--we'll see an exception) an atmosphere. Sounds easy enough…***

7.2 Biological Tour of the Solar System

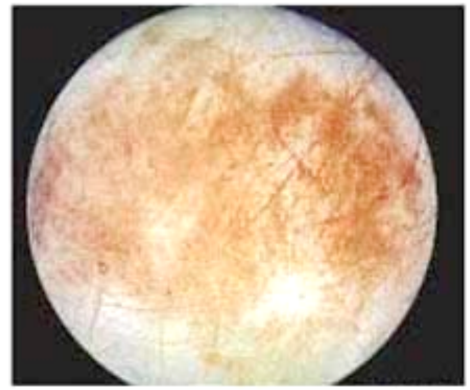
The top candidates (with their own chapters)

MARS
A scoop into Martian soil by the Phoenix lander recently revealed frozen water ice (white patches). Mars once had liquid lakes and rivers. Did it then — or does it now — support life?

TITAN
Saturn's largest moon has a dense atmosphere and what scientists believe are hydrocarbon lakes of the organic compounds methane and ethane, seen in a radar map of Titan's north pole, below.



EUROPA
About the size of Earth's moon, Jupiter's moon Europa is covered in a crust of ice that probably conceals an ocean of salty water more than 60 miles deep.



NASA PHOTOS

So before covering these, we cover the "low-probability" objects in our solar system: Moon or Mercury (7.2), Venus or Mars (7.2), Jupiter & Saturn (7.3), Uranus & Neptune (7.3); satellites of Jupiter (Europa, Io, Ganymede, Callisto) and Saturn (Titan) covered in Ch. 9.

New object of fascination: water "geysers" of Enceladus

Moon and Mercury

- Small, so have lost most of their internal heat
→ no outgassing and weak gravity → no atmosphere.

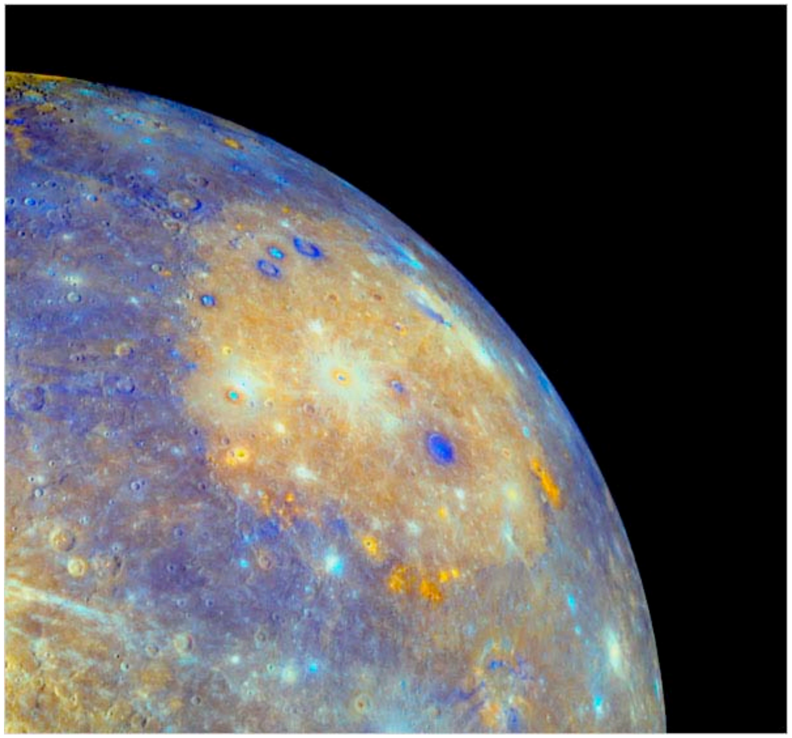
- They are also the least likely to have liquids anywhere.

- Could have ices in craters near poles (protected from sunlight by shadow), delivered by comets, but not liquid.

Remember, with no atmosphere (or even a very thin one like Mars'), heated ice sublimes directly into gas phase, not liquid.

Also, without an atmosphere, the Moon and Mercury suffered the full brunt of the "heavy bombardment" era of our solar system, when chance giant impacts may have determined the final state of our solar system. Depending on how long this heavy bombardment continued, this must have been a crucial time for the origin of life on Earth (Hadean era). With no geology to smooth over the damage (erosion), the surfaces of Moon and Mercury still bear the imprint in the form of their cratering record--in fact that is one of the most important uses of the Moon for understanding the early evolution of the Earth and other planets. See next slide on Mercury.

Volcanic eruptions on Mercury?
Or remnant of giant impact during its formation?



The Caloris basin of Mercury, close to 1,000 miles wide, is the scar from a *giant impact*. Mariner 10 revealed flat plains that looked like lavas from volcanic eruptions, but these could have been material melted by the impact. Sharper images of Mercury during the recent Messenger flyby have answered the 30-year-old question: All impact. This is strong support for the idea that the formation of our solar system, and probably others, was dominated by chaotic collisions of giant planetesimals, resulting in improbable and in some cases catastrophic events. The slow, strange, rotation of the planet Venus is another likely example of the result of an early catastrophic collision.

The formation of Earth's moon is another, biologically relevant, example. If life on Earth required this large moon, then the chances of it occurring elsewhere are extremely slim.

Venus

Most basic facts:

- Earth's "sister planet" in size and mass.
- But *hot !* Surface too hot for complex molecules (even for lead!)
- Clouds: sulfuric acid droplets

➙ So completely inhospitable (at least to most people)

- Very thick CO_2 atmosphere. But at 0.7 AU from sun, temperature so high that water stayed as gas in atmosphere, solar UV photons dissociated them, and the H then escaped.

➙ After only a few million years (theoretically), the water was gone.
➙ Without liquid water, the CO_2 couldn't dissolve, leaving Venus with a severe runaway greenhouse effect. (This was covered when we discussed the limits of the "habitable zone.")

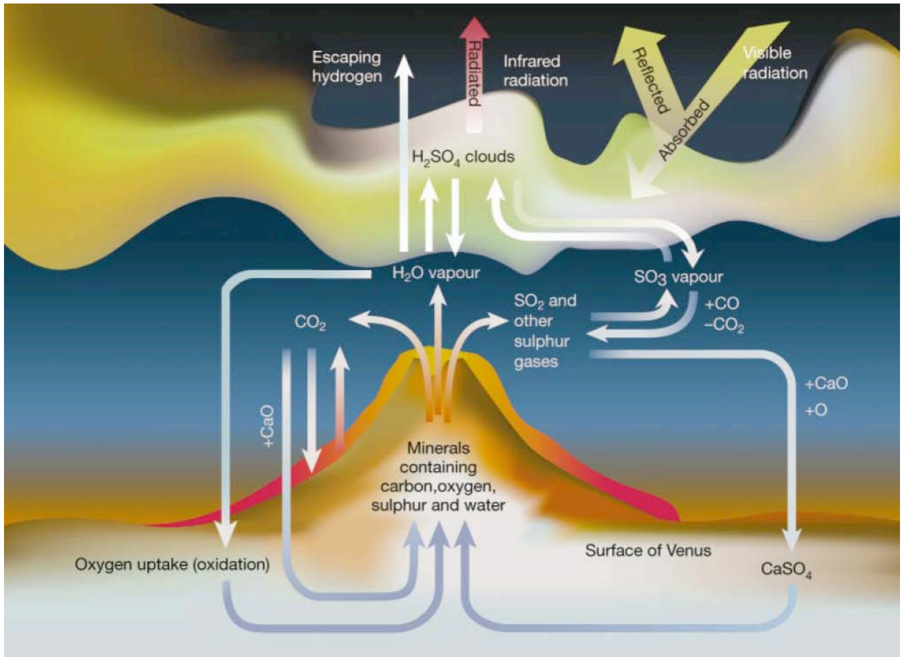
- *However* the time for the water to disappear is extremely uncertain. If longer, Venus could have had oceans before the greenhouse effect had heated the planet to inhabitability.

➙Could life have begun during that interval and then adapted to temperatures as large as current surface?
We assume not—even **extremophiles** have limits set by strength of the strongest molecular bonds.

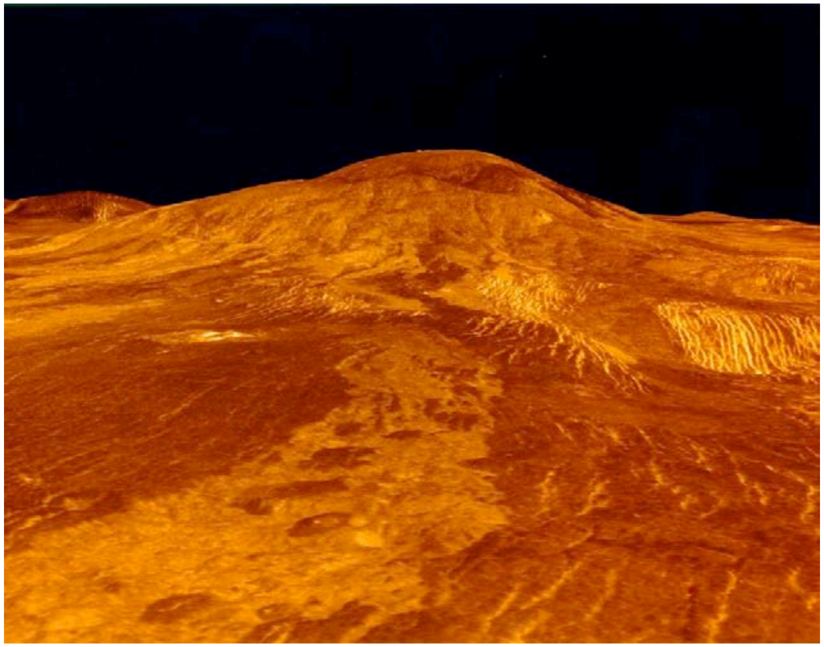
There is some speculation that life could have adapted to the atmosphere, where it is cooler and there might even still be some liquid water. But it does not seem like a good bet, so we are removing it from our list of targets. *Next slide shows examples of the hostility of the environment, but also the possibility of a complex climate and chemistry.*

VENUS

A complex but inhospitable climate



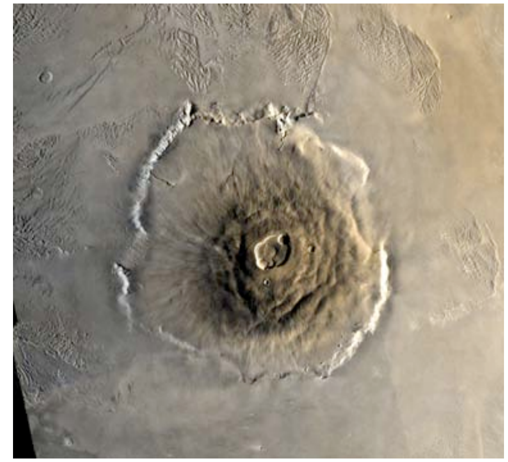
View of Venus from radar mapping



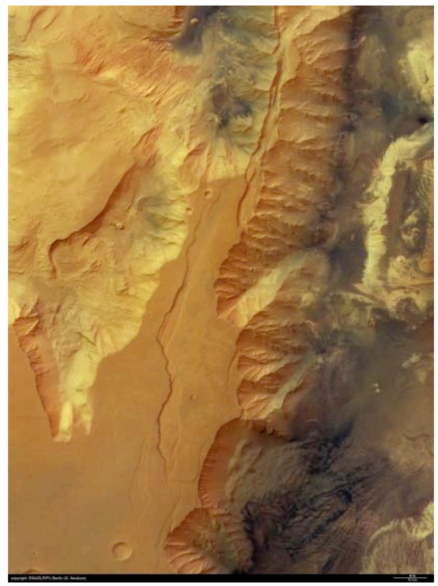
(This slide only for your interest--you don't have to understand the diagram!)

Mars

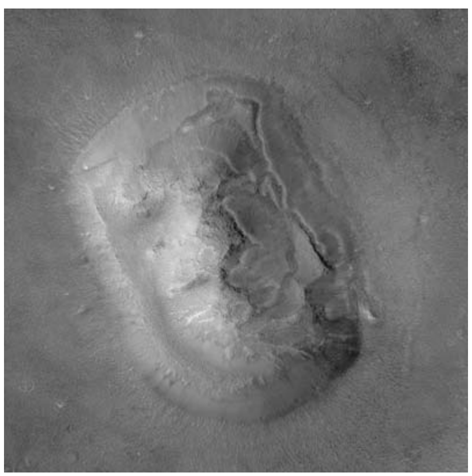
Polar ice caps



Ancient Volcanos
Olympus Mons
Largest volcano in solar system

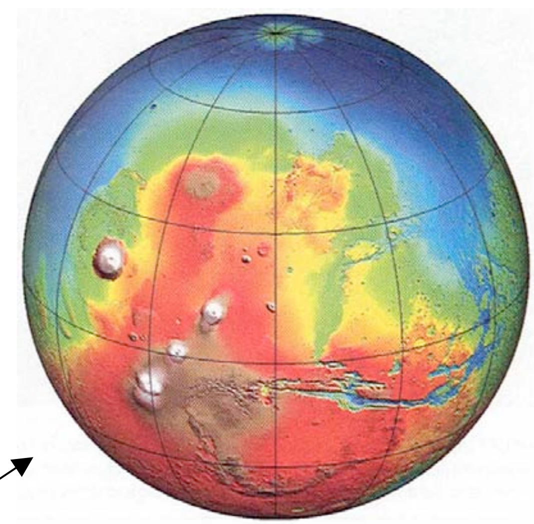


Evidence of erosion?



The face on Mars gets erased

Basin of an ancient giant ocean?



This map shows Mars color-coded by elevation. Blue areas are the farthest below "sea level," and red and brown areas are the highest above it. Note that the entire north polar region is quite low in elevation. Some scientists speculate that this low-lying region may once have held an ocean.

Jupiter

Big R = 11R(Earth)
Massive M = 300 M(Earth)
= 2.5 x all the rest

So no problem holding on to atmosphere.

Mostly H_2, He thick atmosphere

But also more complex organic molecules

Colors, storms

Great Red Spot: reddish material usually called "Tholins," probably complex organic molecules or aerosols

Conditions like Miller - Urey:

So why not candidate for life ?

The main problem for Jupiter and Saturn: no surface, so convection to hot depths

Atmosphere: Methane, **ammonia**, **hydrogen sulfide**, **water vapor**, but mostly molecular hydrogen. Jupiter and Saturn are so massive and cold that they retain this gaseous hydrogen-rich envelope.

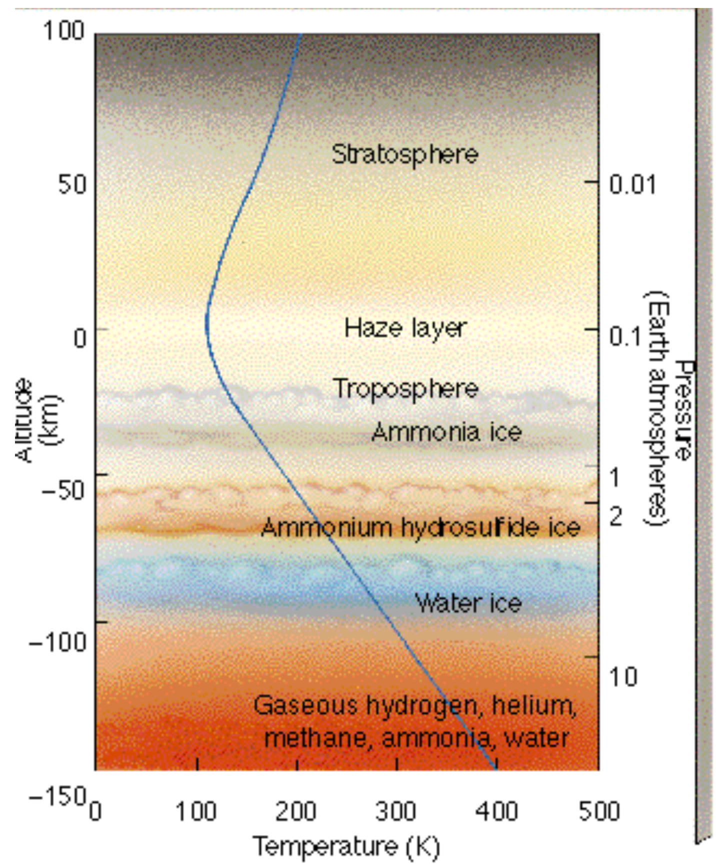
→ This means ***Jupiter has no surface***: just hotter and denser as you descend into the "slush."

So no opportunity to catalyze chemical reactions on mineral surfaces, as speculated for the Earth (think back to clay mineral surfaces in Ch. 6)

There is a more serious problem: convection currents
Very cold at the top of the atmosphere, but about 100km down the temperature is warm enough for liquid water droplets.

But if a life form wanted to use the layer whose temperature is right for liquid water, it would have to be a "floater" *or else it would sink to the hotter depths*. The reason:

→ **Vertical convection** (mixing, circulation) takes gas between cool upper layers and deeper layers where temperatures exceed 1000 ^{O} C, and where ***complex molecules would be destroyed.***



Sagan & Salpeter 1977 paper: ecology of buoyant organisms:

Sinkers	(Plankton)
Floaters	(Fish)
Hunters	(Fish)

Uranus and Neptune

Possibly more likely for life than Jupiter or Saturn: At least they have outer mantles of water, methane, and ammonia ices.

They *could* have deeper liquid, but no way to search for it: the outer icy mantle is far too thick.

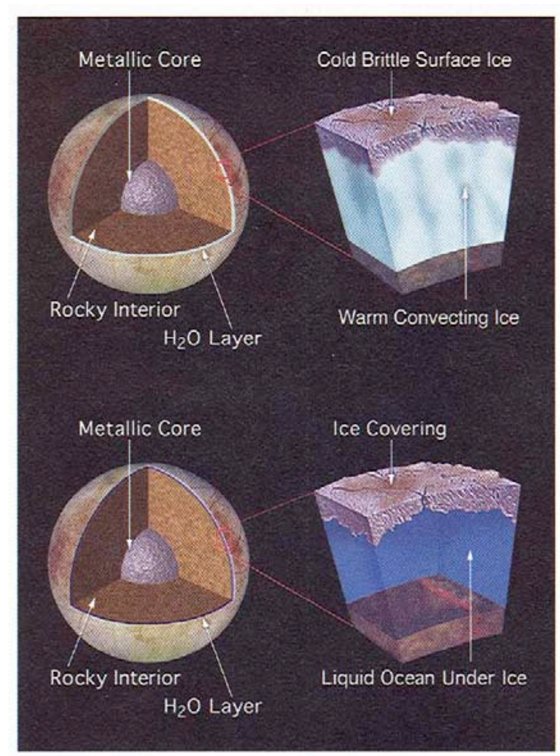
Moons of the giant planets

All smaller than Mars, so would think no way to retain interior heat.

However many are subject to ***tidal heating*** by their parent planet (will explain when ch. 9 discussed).

This could lead to an *ice geology* instead of a rock geology like ours.

Model for Europa



Next: Mars

(students should read Ch. 8 by Thursday)