Chapter 18
Life in the Universe

We, this people, on a small and lonely planet
Travelling through casual space
Past aloof stars, across the way of indifferent suns
To a destination where all signs tell us
It is possible and imperative that we learn
A brave and startling truth.
— Maya Angelou

18.1 Life on Earth

Our goals for learning

- When did life arise on Earth?
- How did life arise on Earth?
- What are the necessities of life?

When did life arise on Earth?

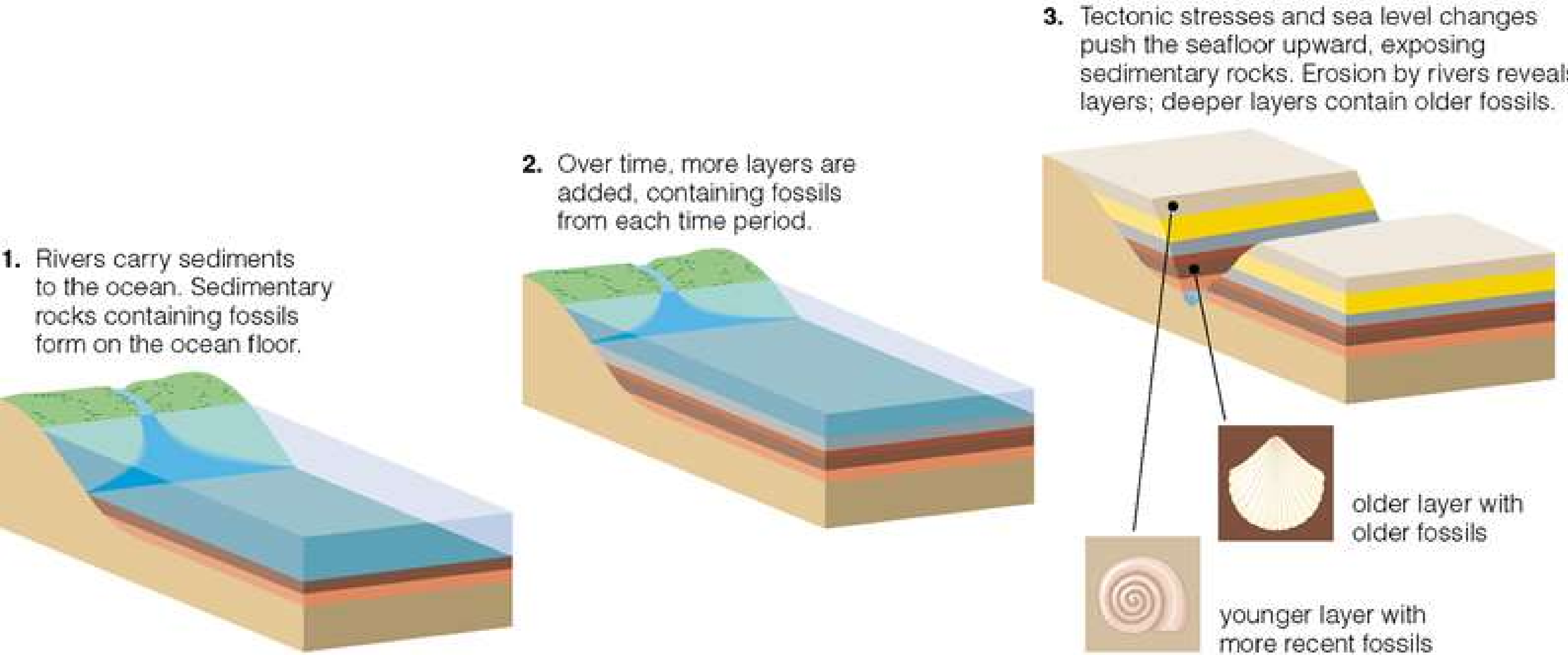
- Probably around 3.85 billion years ago.
- Shortly after end of heavy bombardment, 4.2-3.9 billion years ago.
- Evidence from fossils, carbon isotopes.

2 billion years…

Fossil evidence…

Geological time scales

- relative ages: rock layers build up over time.
- absolute ages: radiometric dating (Chapter 6.4)



Fossil stromatolite microbes date from 3.5 billion years ago

- Already fairly complex life (photosynthesis), suggesting much earlier origin.
- Carbon isotope evidence pushes origin to at least 3.85 billion years ago.

a These large mats at Shark Bay, Western Australia, are colonies of microbes known as "living stromatolites"; they stand about knee-high. Microbes near the top generate energy through photosynthesis.

b The bands visible in this section of a modern-day mat are formed by layers of sediment adhering to different types of microbes.

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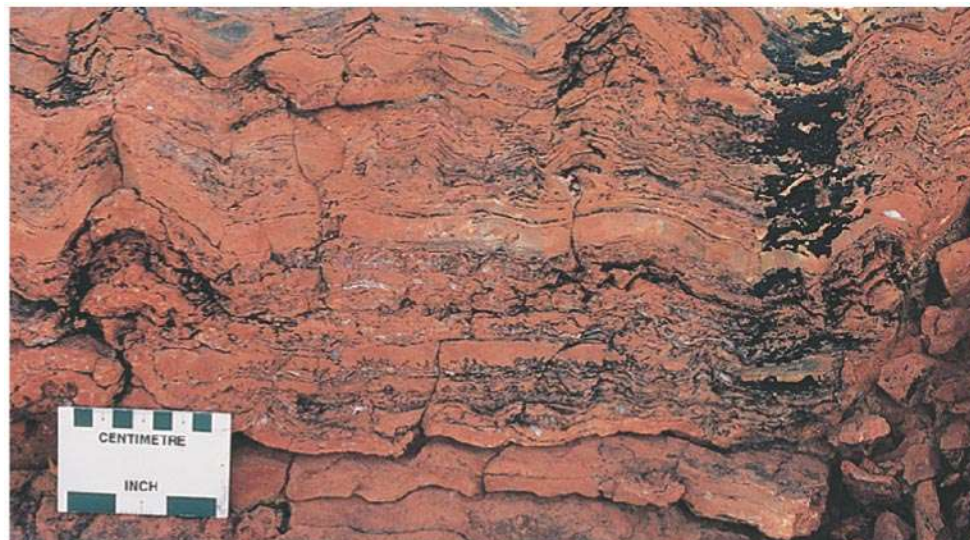
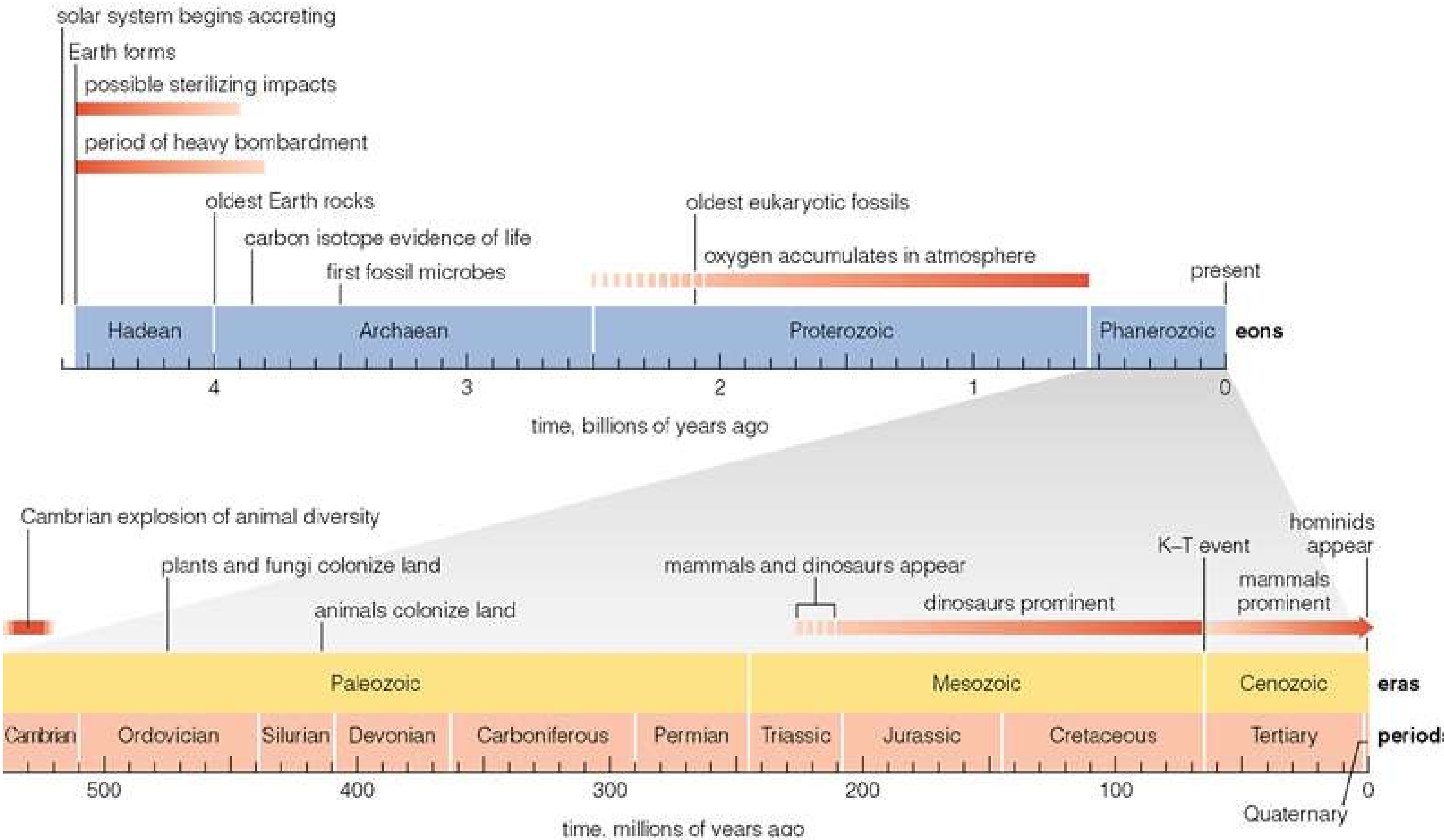


c This section of a 3.5-billion-year-old stromatolite shows a structure nearly identical to that of a living mat.

Brief History of Life

- 4.4 billion years - early oceans form
- 3.5 billion years - cyanobacteria start releasing oxygen.
- 2.0 billion years - oxygen begins building up in atmosphere
- 540-500 million years - Cambrian Explosion
- 225-65 million years - dinosaurs and small mammals (dinosaurs ruled)
- Few million years - earliest hominids

The Geological Time Scale

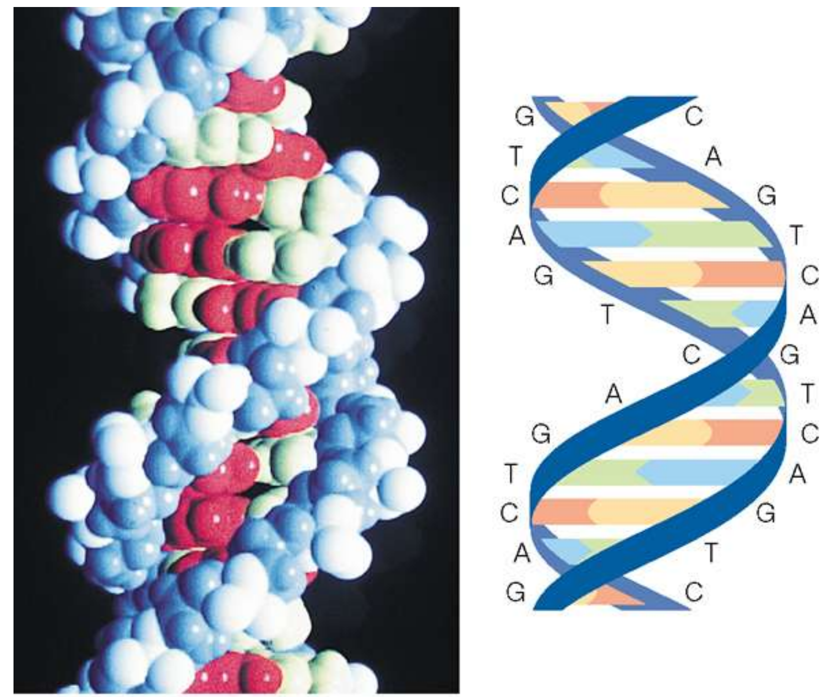


How did life arise on Earth?

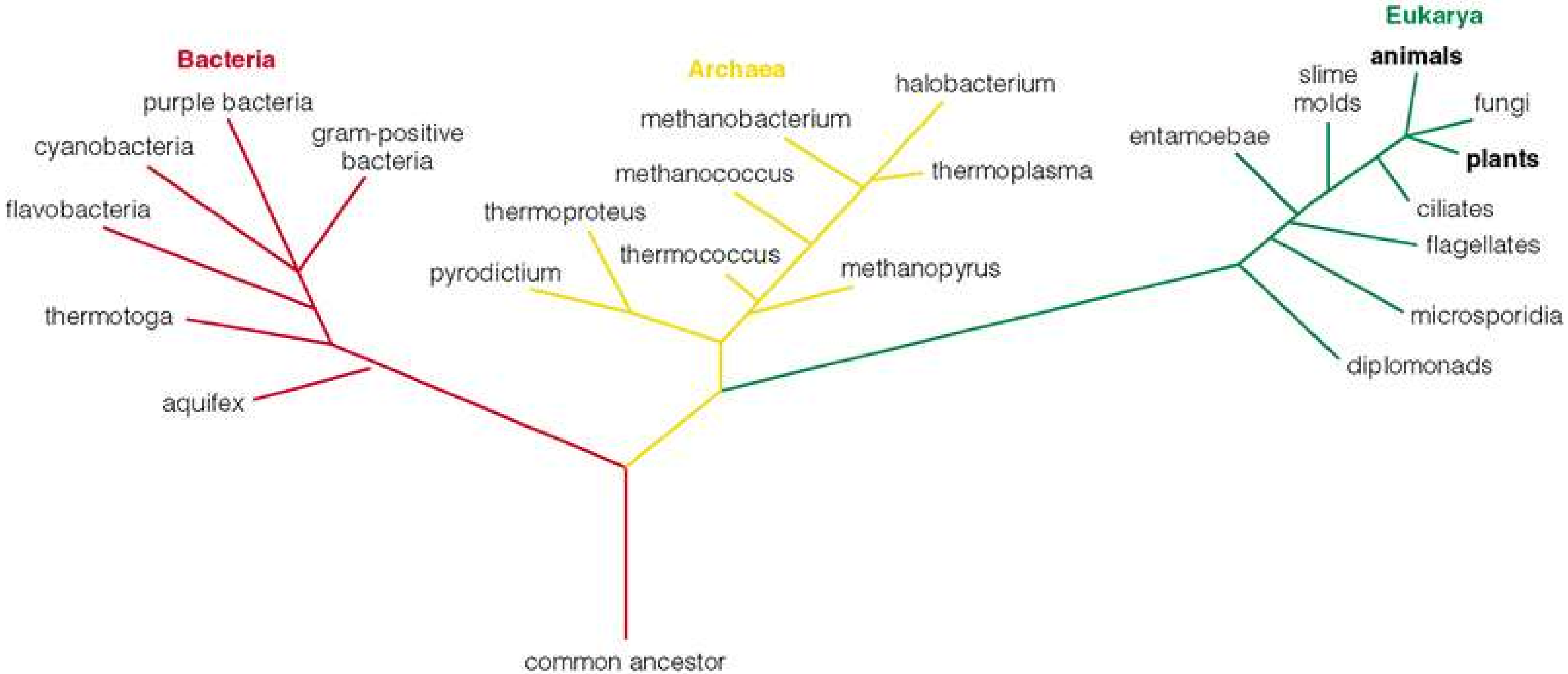
- Life evolves through time.
- All life on Earth shares a common ancestry.
- We may never know exactly how the first organism arose, but laboratory experiments suggest plausible scenarios.

The Theory of Evolution

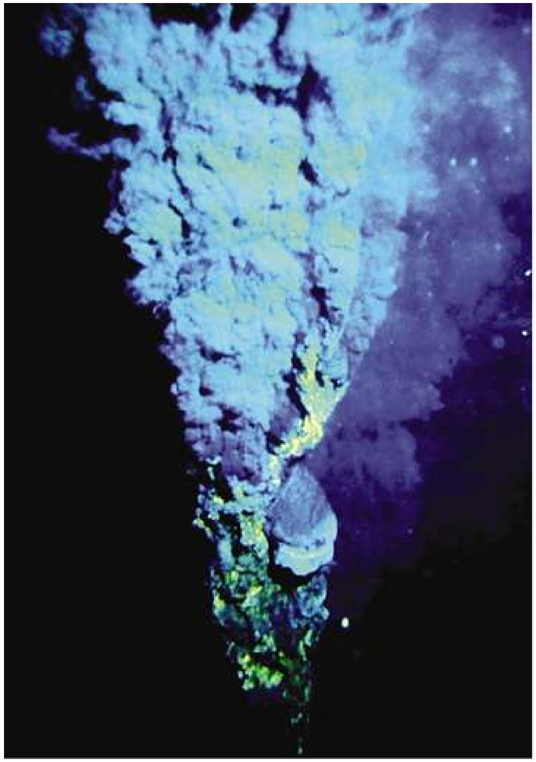
- The fossil record shows that evolution has occurred through time.
- Darwin's theory tells us <u>HOW</u> evolution occurs: through **natural selection.** Organisms pass on genetic traits to their offspring. Traits that enable an organism to have more offspring are typically more common in each succeeding generation.
- Theory supported by discovery of DNA: genetic traits change through **mutations**.

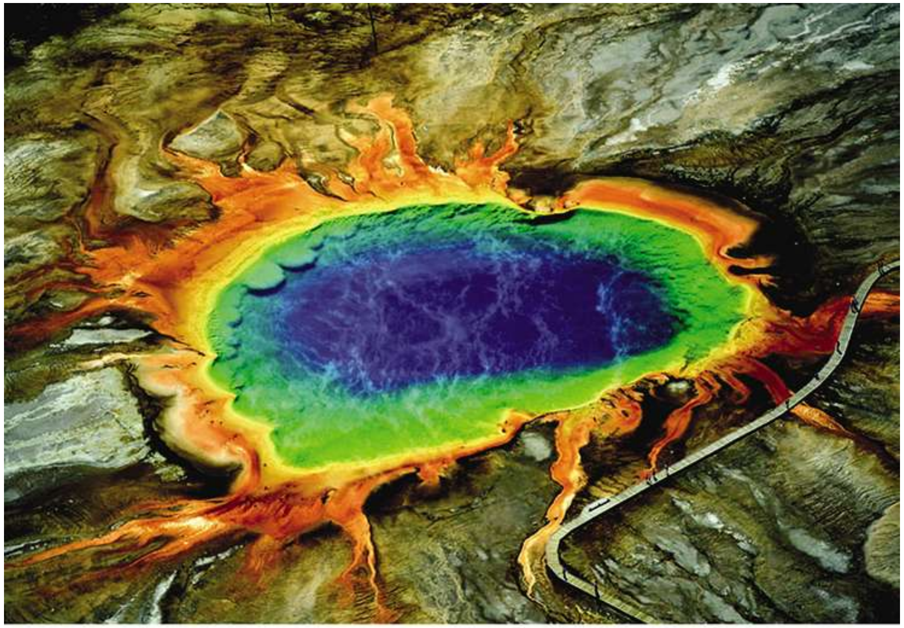


- Mapping relationships of genetic traits has enabled biologists to work out this new "tree of life."
- Plants and animals are a small part of the tree.
- Suggests likely characteristics of common ancestor

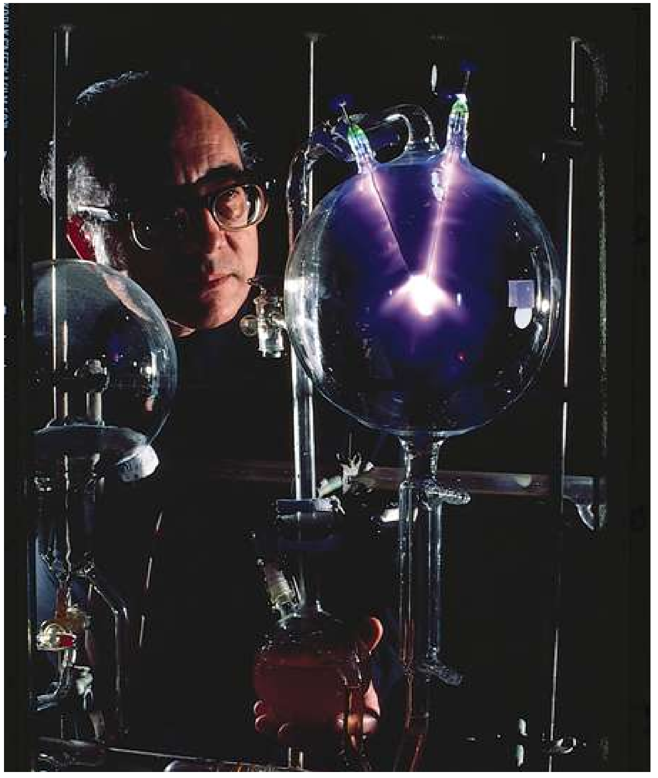


- These genetic studies suggest that the earliest life on Earth may have resembled the bacteria today found near deep ocean volcanic vents (black smokers) and geothermal hot springs (& possibly deep underground)



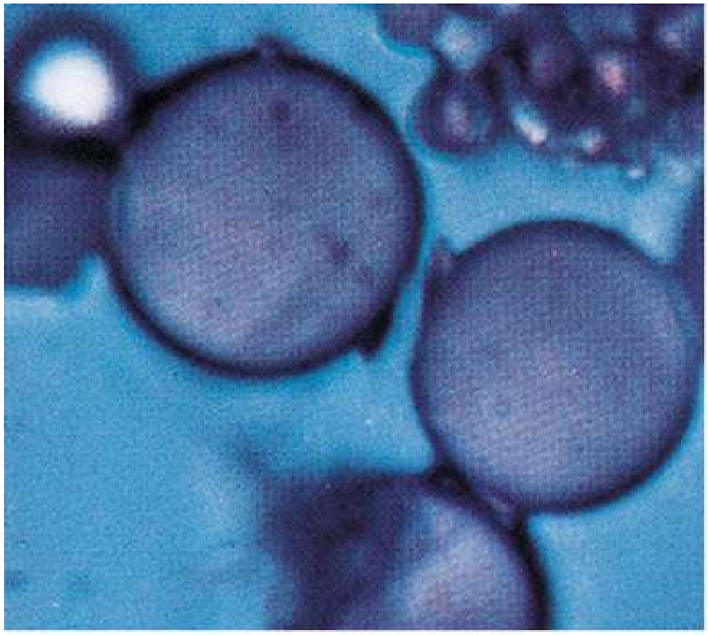
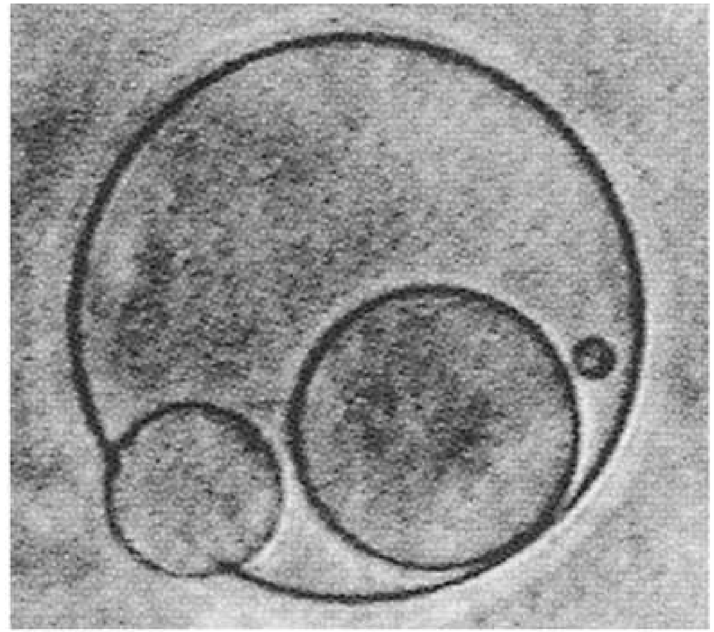


Laboratory experiments allow us to investigate possible pathways to the origin of life.



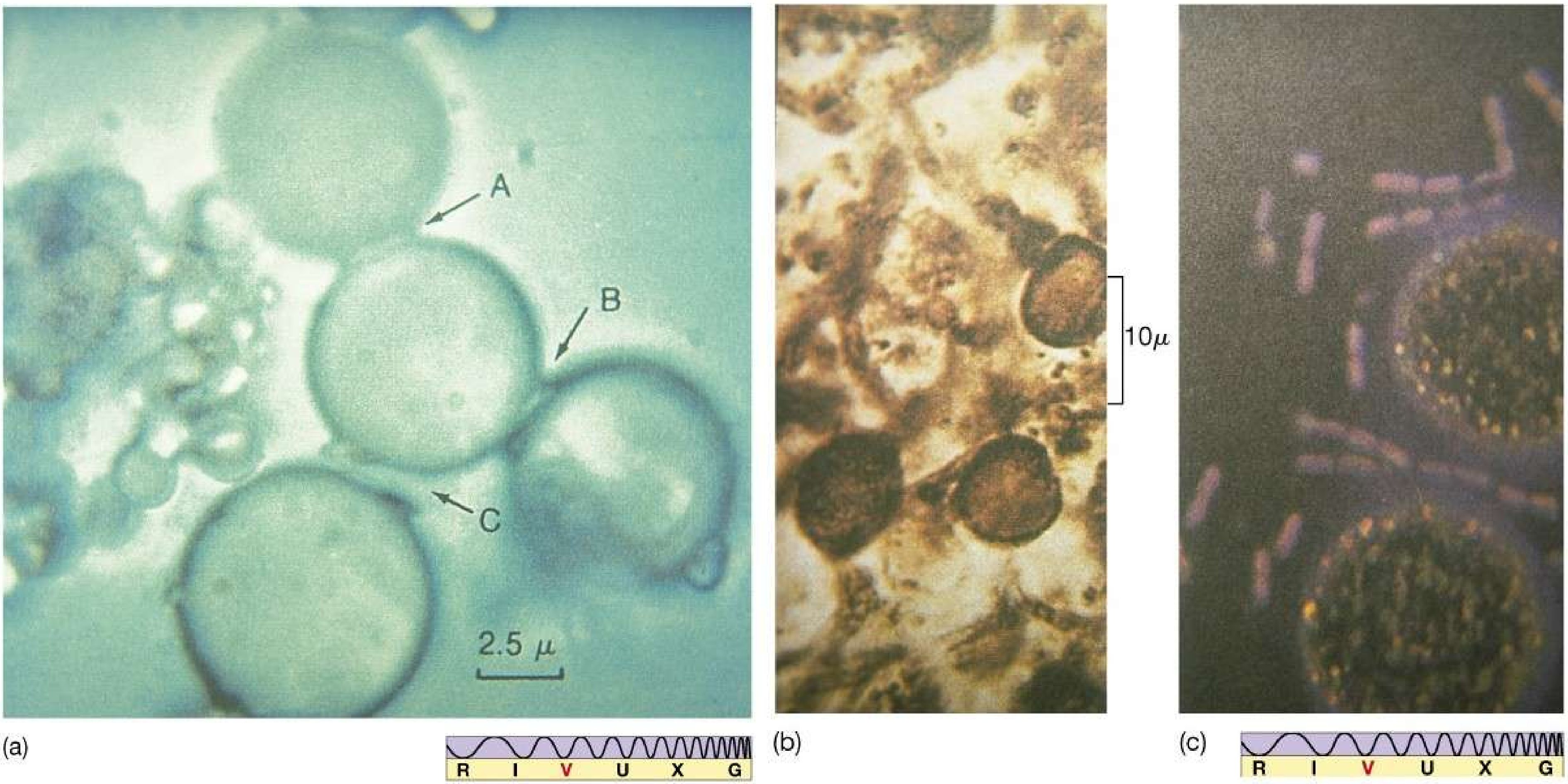
Miller-Urey experiment (and more recent experiments):

- Building blocks of life form easily and spontaneously under conditions which might resemble early Earth.

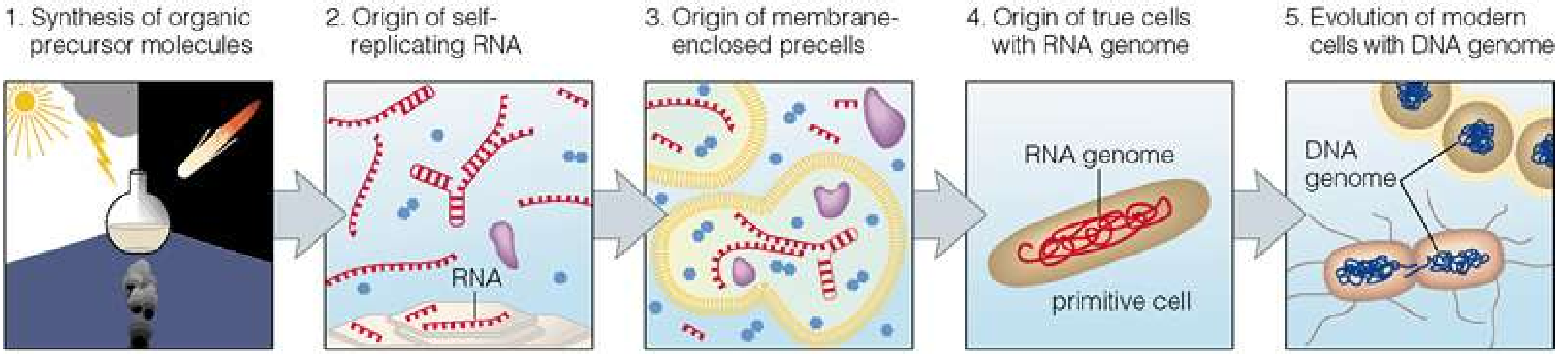



Microscopic, enclosed membranes or "pre-cells" have been created in the lab.

Chemical Evolution: [a] these droplets show how amino acids cluster in liquid. [b] This microscopic photograph shows a fossilized organism found in sediments radioactively dated to be 2 billion years old. [c] For comparison with [b], this photo shows modern blue-green algae on the same scale.



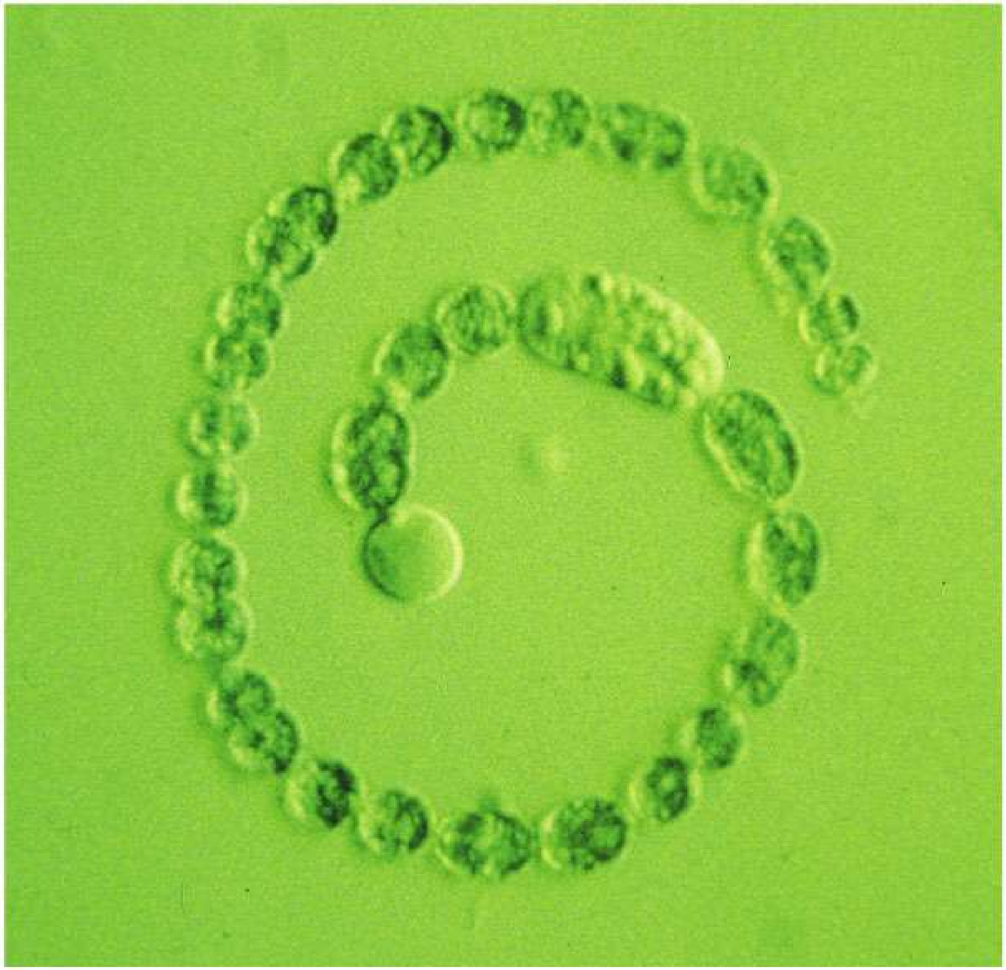
Chemicals to Life?



Maybe this is how it happened...

Given how long it took for complex life to evolve on Earth, we should look for signs of complex life only around stars with masses less than or equal to the Sun's mass.

Origin of Earth's atmospheric oxygen



- Cyanobacteria paved the way for more complicated life forms by releasing oxygen into the atmosphere via photosynthesis.
- Oxygen poisonous to some bacteria!
- Eventually organisms learned to use oxygen as an energy source

What are the necessities of life?

- Nutrient source
- Energy (sunlight, chemical reactions, internal heat)
- Liquid water (or possibly some other liquid)

Hardest to find on other planets

18.2 Life in the Solar System

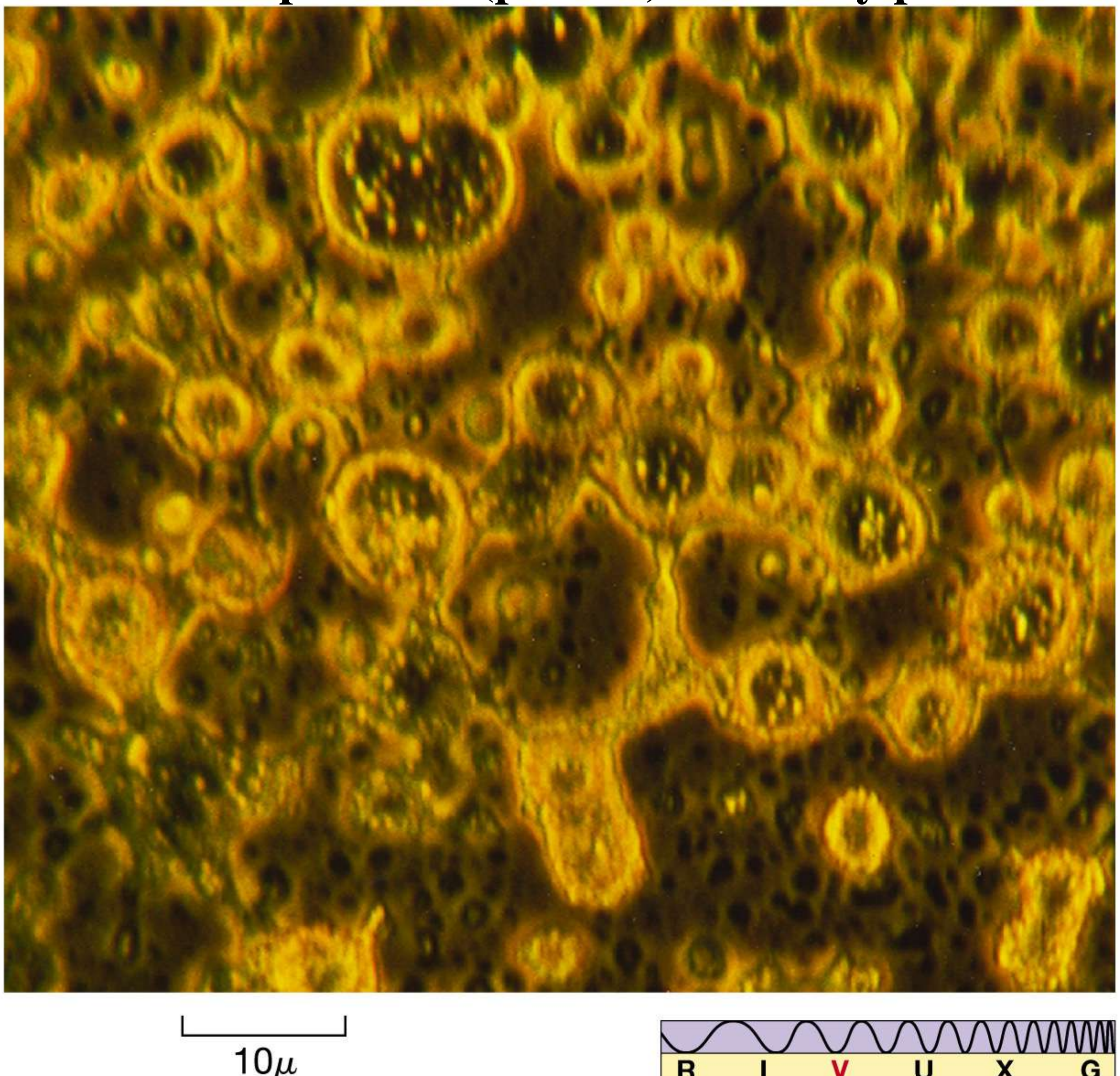
Our goals for learning

- Could there be life on Mars?
- Could there be life on Europa or other jovian moons?

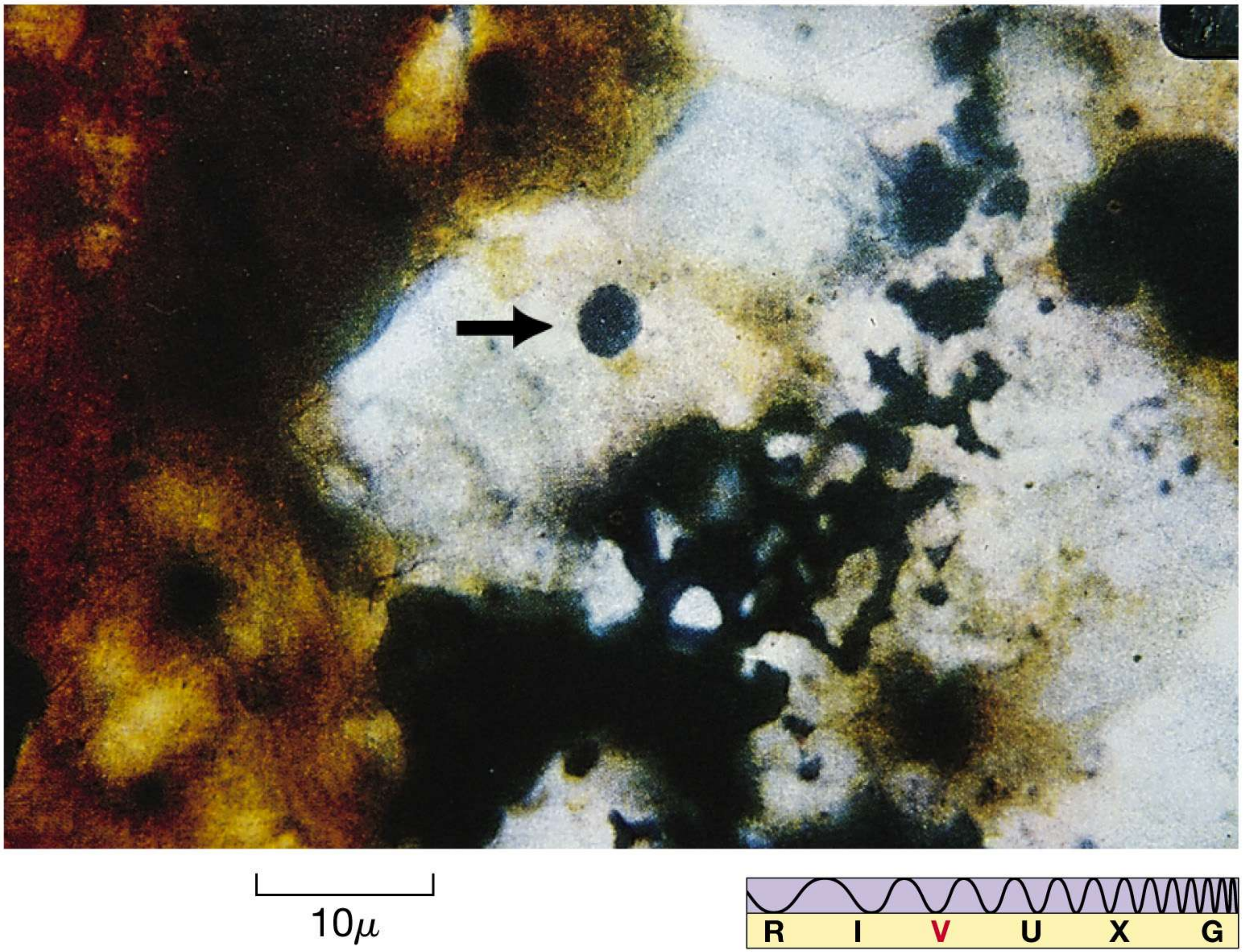
Could life have migrated to Earth?

- Venus, Earth, Mars have exchanged tons of rock (blasted into orbit by impacts)
- Some microbes can survive years in space...

Interstellar Globules: droplets rich in organic molecules made by exposing ice, methanol, ammonia & carbon monoxide to UV radiation. Although they are not alive, they illustrate the prebiotic (pre-life) chemistry possible in outer space.

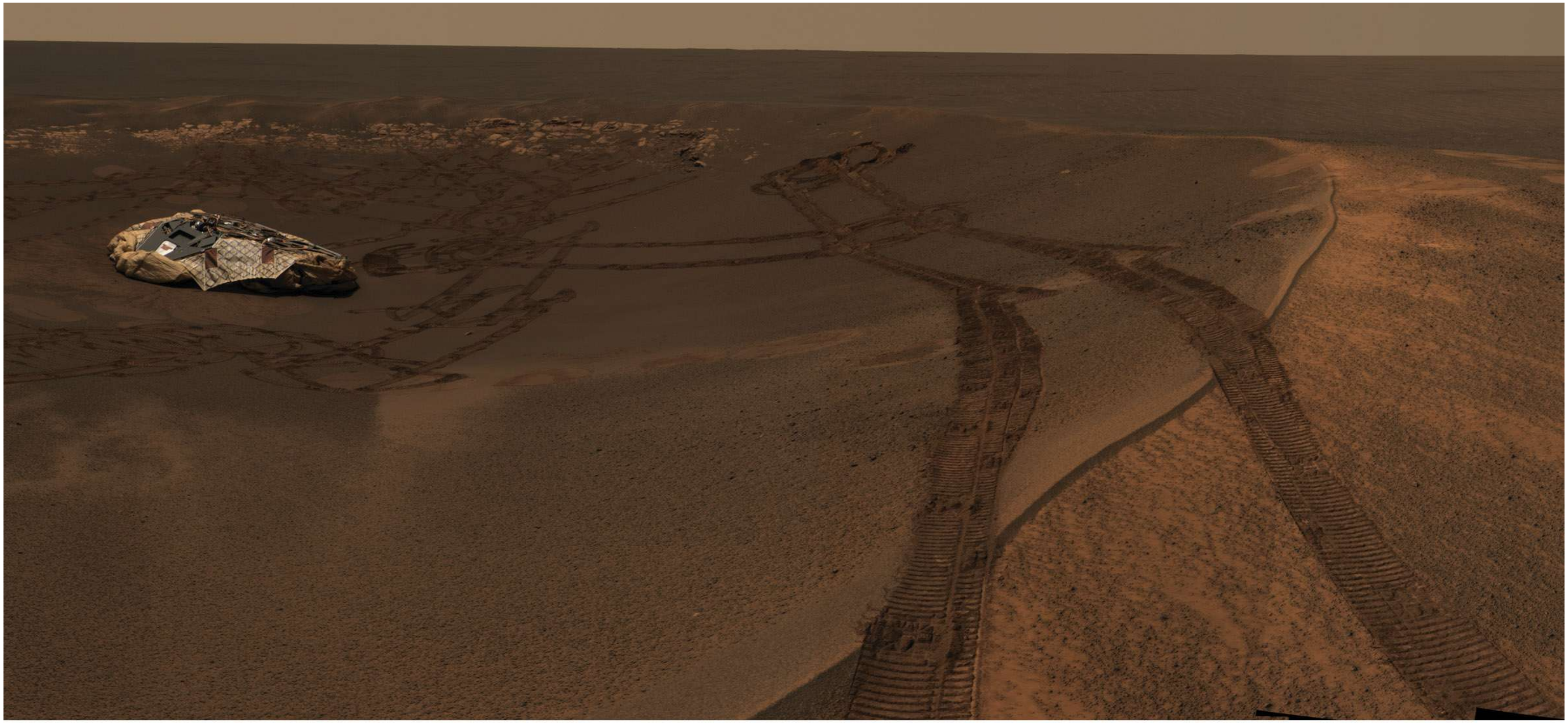


Murchison Meteorite (amino acids)

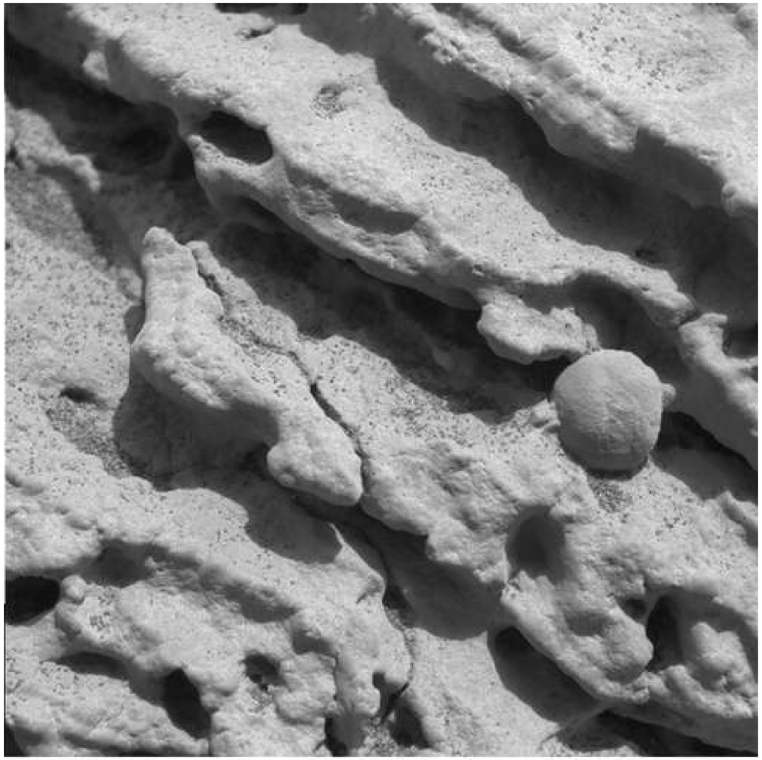


Could there be life on Mars?

- Mars had liquid water in the distant past
- Still has lots of subsurface ice; possibly subsurface water near sources of volcanic heat.



In 2004, NASA Spirit and Opportunity Rovers sent home new mineral evidence of past liquid water on Mars.



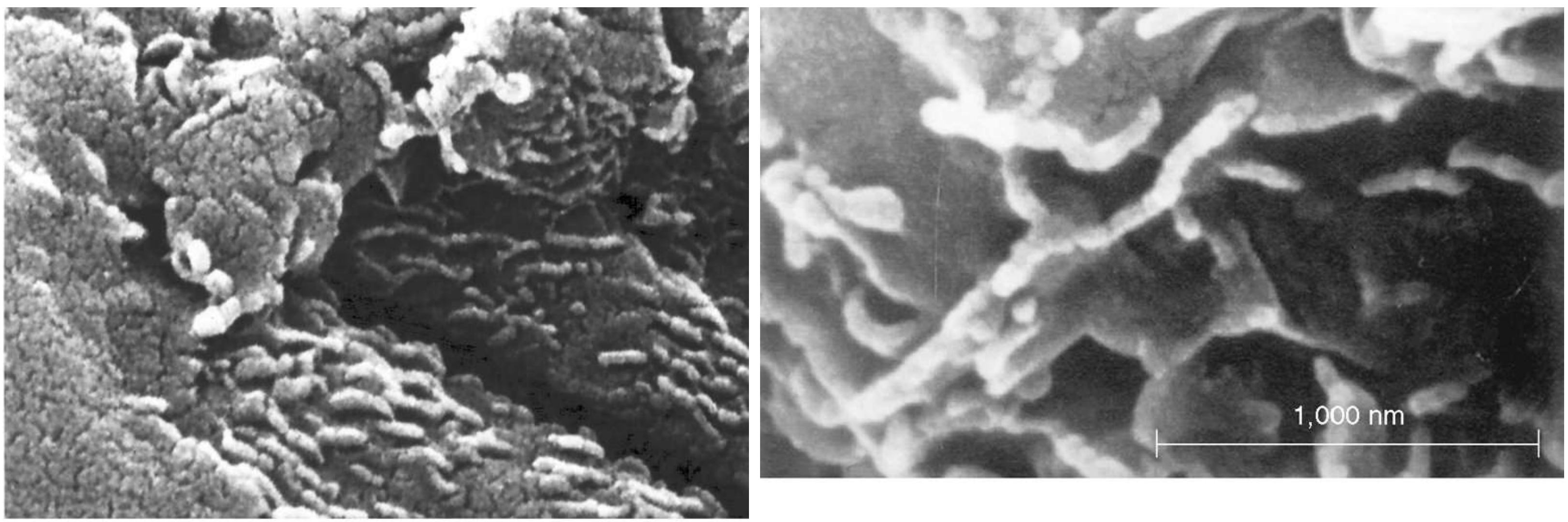
Close-up view of round pebble apparently formed in water on Mars.

The Martian Meteorite debate

composition indicates origin on Mars.

- 1984: meteorite ALH84001 found in Antarctica
- 13,000 years ago: fell to Earth in Antarctica
- 16 million years ago: blasted from surface of Mars
- 4.5 billion years ago: rock formed on Mars

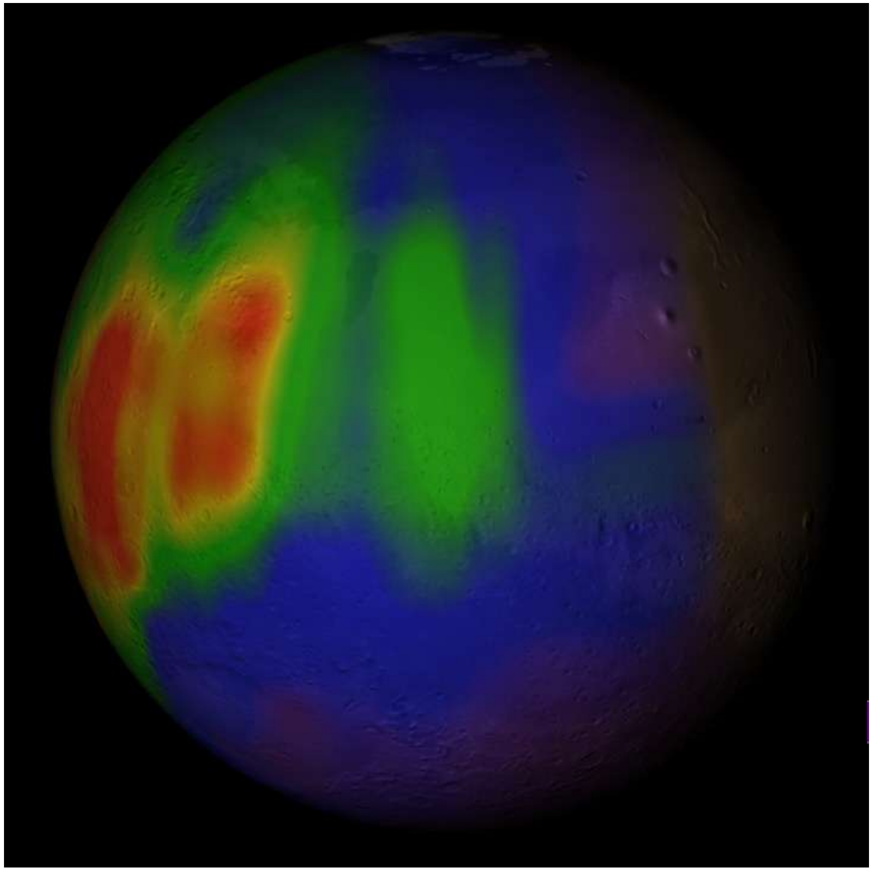
- Does the meteorite contain fossil evidence of life on Mars? (left: Mars; right: Earth)



… most scientists not convinced; investigations are continuing.

Methane in the Martian Atmosphere

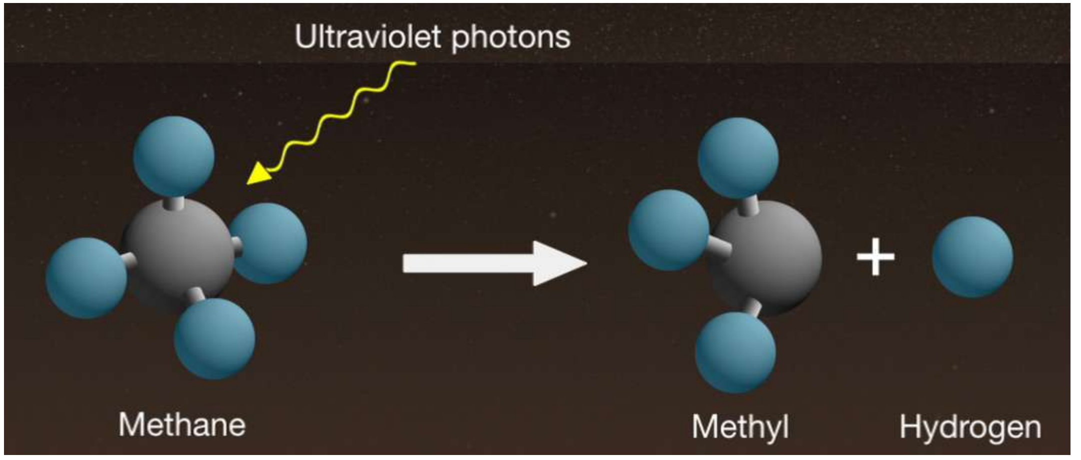
- Methane gas was recently detected in Mars' atmosphere using ground-based telescopes
- The methane gas distribution is patchy and changes with time
- Most methane in Earth's atmosphere is produced by life, raising questions about its origin on Mars



View of Mars colored according to the methane concentration observed in the atmosphere. Warm colors depict high concentrations.

Recent Release of Methane on Mars

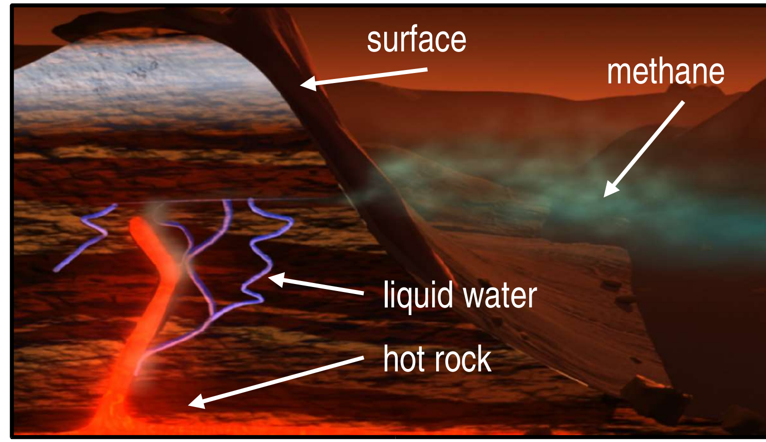
- **Methane in the Martian atmosphere should be destroyed by ultraviolet light within a few hundred years**
- **Therefore, methane observed now must have been produced recently**
- **Variations in space and time suggest that it was recently released from the subsurface in localized areas, rather than from everywhere on the planet**

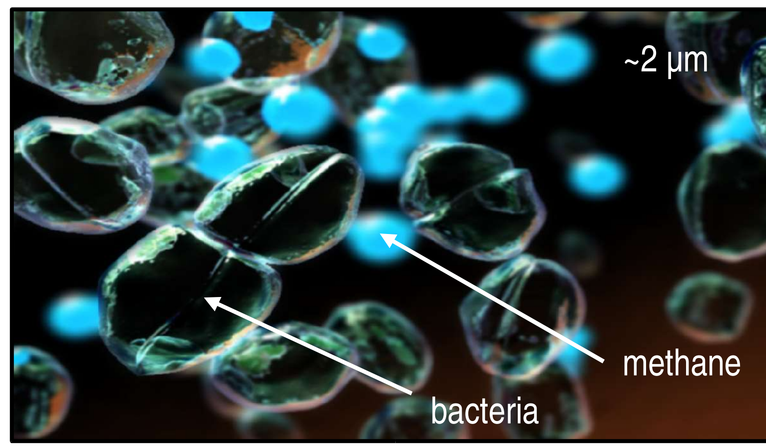


Ultraviolet photons have enough energy to break molecules apart

Where does Mars' atmosphere get its methane?

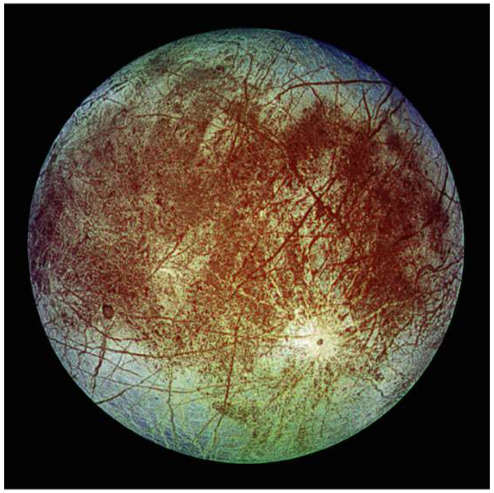
- By analogy with Earth, there are two leading theories for the origin of subsurface methane on Mars:
  - Methane is produced by water-rock interactions
  - Methane is produced by bacteria, in regions where liquid water is found
- Either theory implies that the Martian subsurface is dynamic, not unchanging
- Future observations can test for trace chemicals associated with each process

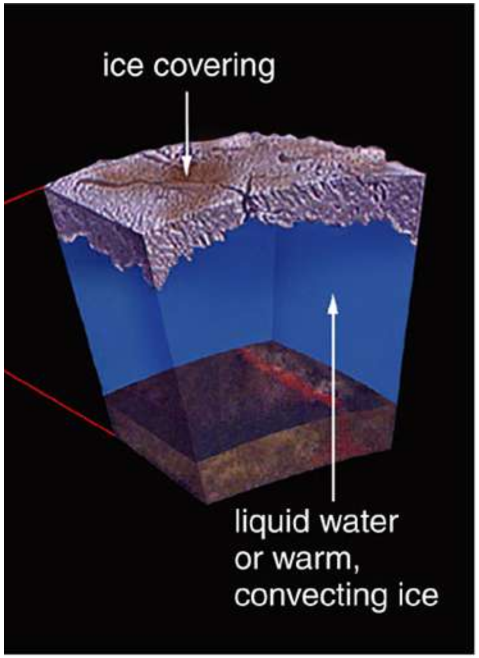


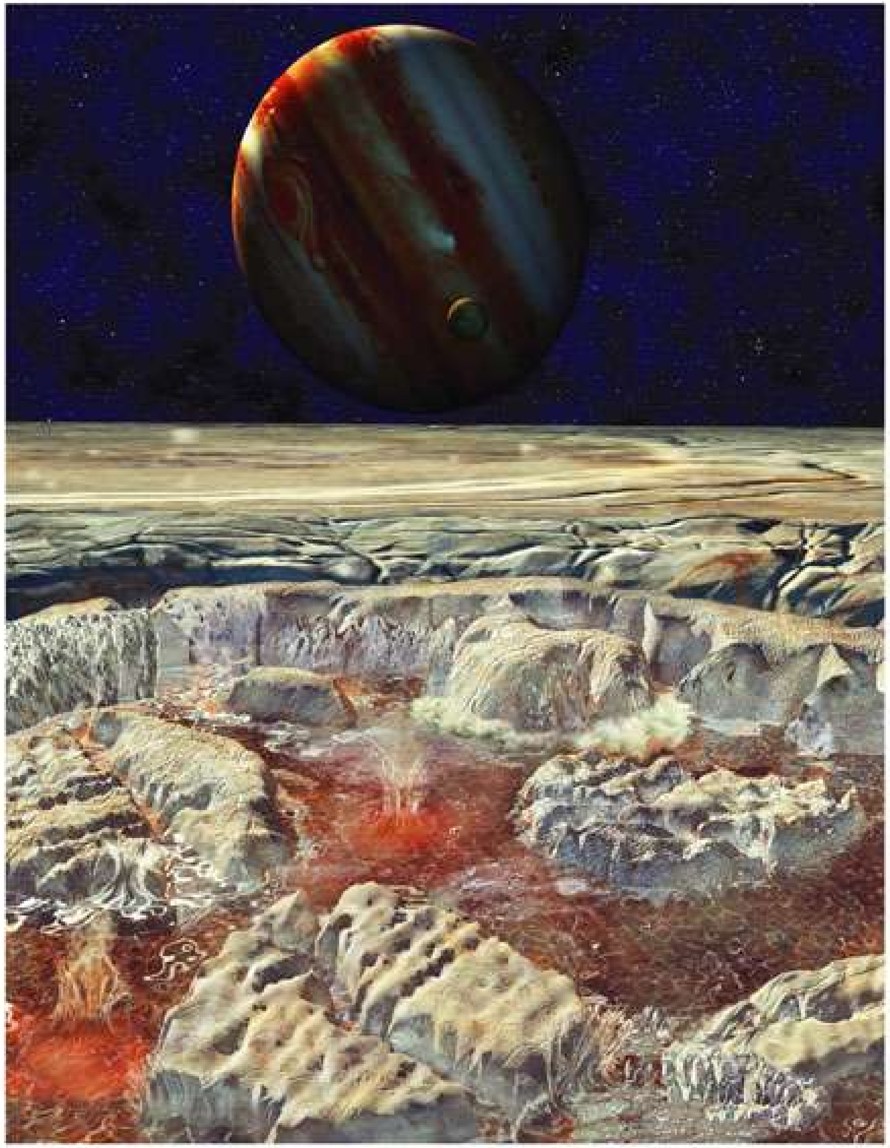


Methane on Mars could be produced chemically through liquid/rock interactions (top) or biologically (bottom)

Could there be life on **Europa** or other jovian moons?





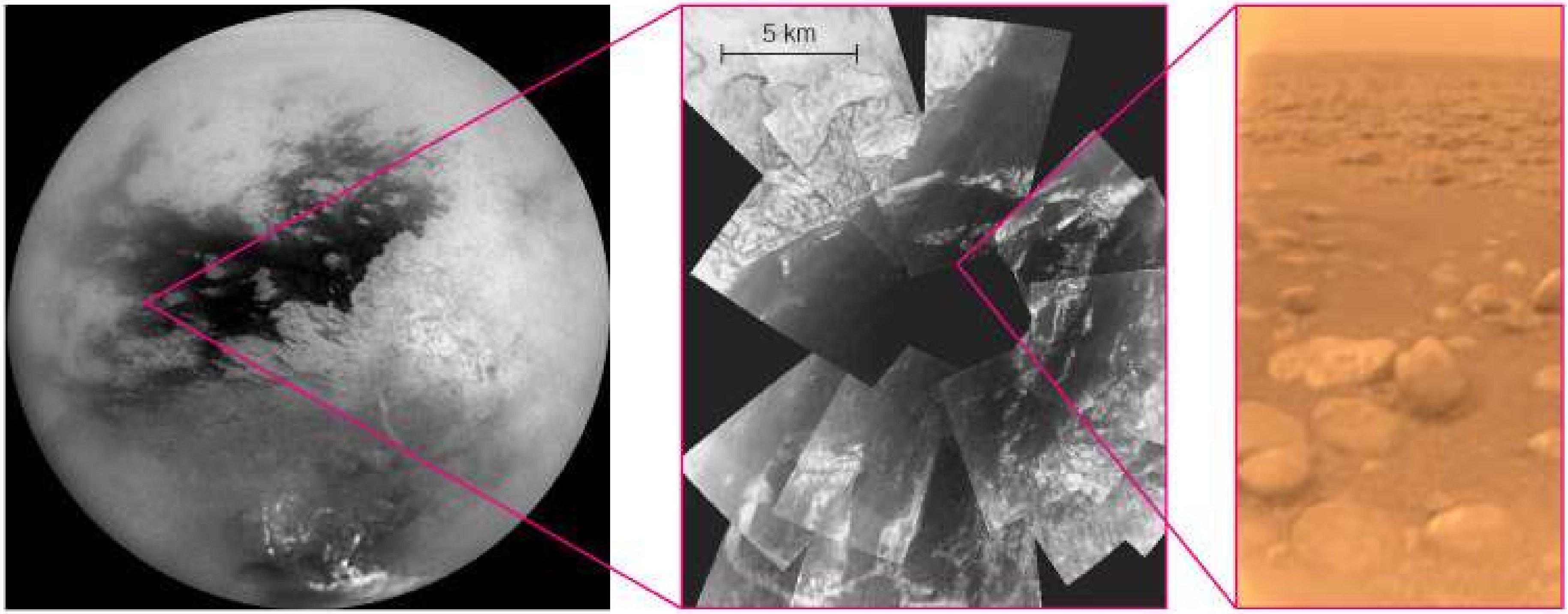


- Europa, Ganymede, Callisto all show at least some evidence for subsurface oceans.
- Relatively little energy available for any life there
- Nonetheless, intriguing prospect of THREE potential homes for life around Jupiter alone.

Ganymede

Callisto

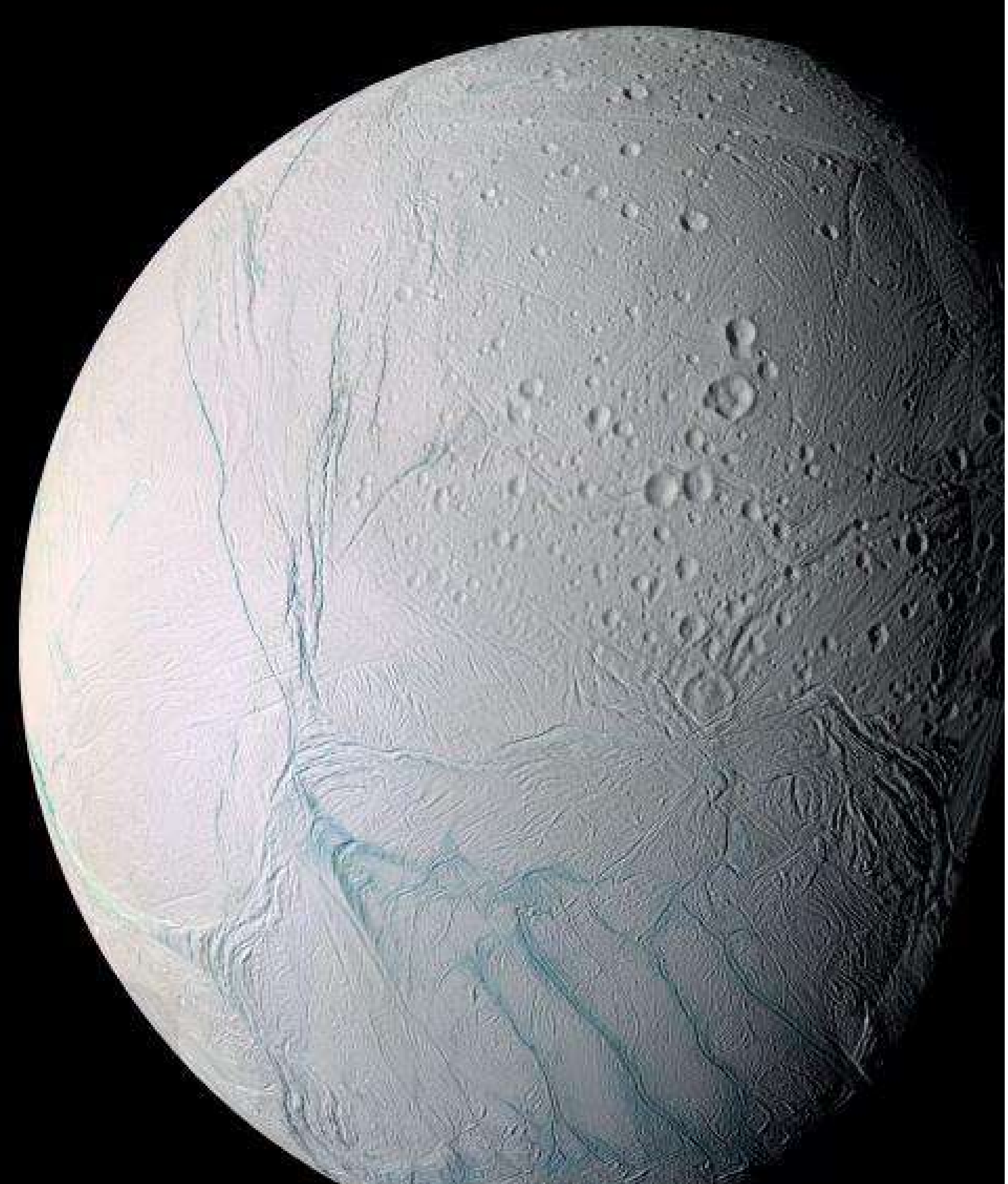
Titan



- Surface too cold for liquid water (but deep underground?)
- Liquid ethane/methane in places on the surface

 ...but not at Huygens probe landing site, Jan. 2005

No evidence for surface life (if any, probably quite alien)



Enceladus: ice moon, ocean moon?

An Ocean Below Enceladus' Icy Crust?

- **NASA's Cassini spacecraft has observed plumes of material escaping from Saturn's small icy moon, Enceladus**
- **The plume is mostly water vapor, with tiny ice particles and other gaseous molecules mixed in (e.g. carbon dioxide, methane, ammonia, ethane)**
- **The plume supplies ice particles to Saturn's E ring**
- **Some ice particles contain salt, which may indicate they originate in an ocean deep below the icy crust**

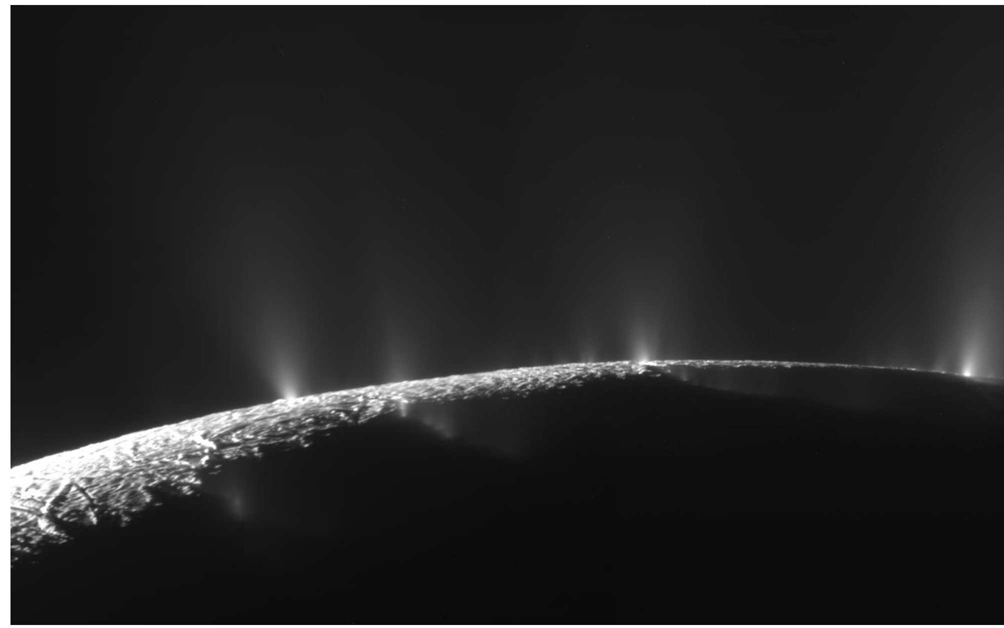
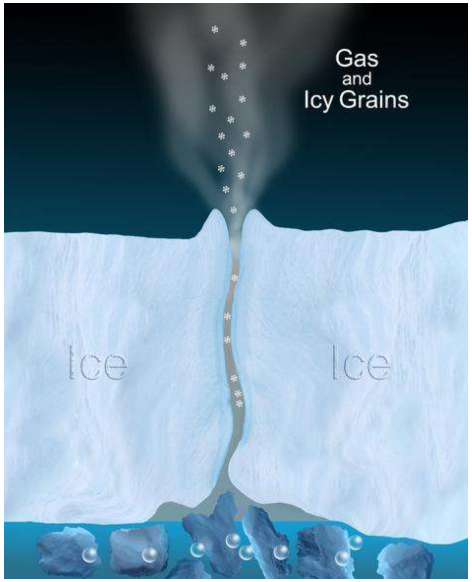
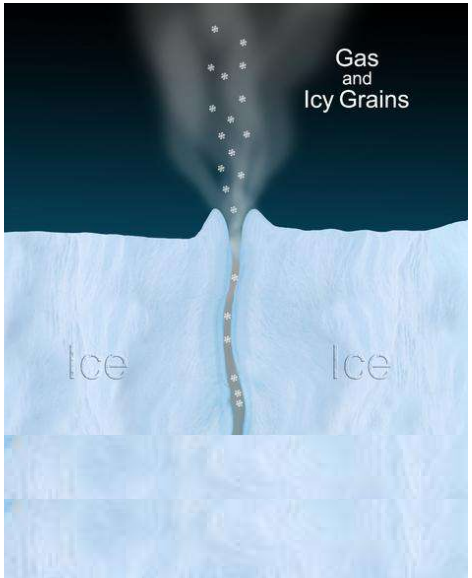


Image mosaic of Enceladus taken by Cassini, showing individual plumes of gas and ice escaping from the surface. The plumes extend hundreds of km into space from the ~500 km diameter moon.

What Creates the Plumes?

- **Plumes may be material escaping through surface cracks from internal salty and carbonated ocean(s) or lake(s)**
- **Alternatively, ice along cracks may sublime or melt, followed by escape of water vapor and icy particles**
- **Most scientists find the ocean model most convincing, but others favor combinations of alternative explanations**





Left: Enceladus may have a salty subsurface ocean that releases material to space through cracks in the moon's icy shell. Right: The walls of icy cracks in the surface may melt or sublime, venting gas and icy particles to space.

The Big Picture

- Enceladus is surprisingly active for such a small body - likely a consequence of both tidal heating and decay of radioactive isotopes inside Enceladus

- Future flybys of Enceladus by Cassini may help to resolve whether Enceladus has a subsurface ocean

- If Enceladus has an ocean, then it contains all of the ‘ingredients’ known to be important for life: liquid water, molecular building blocks, and energy

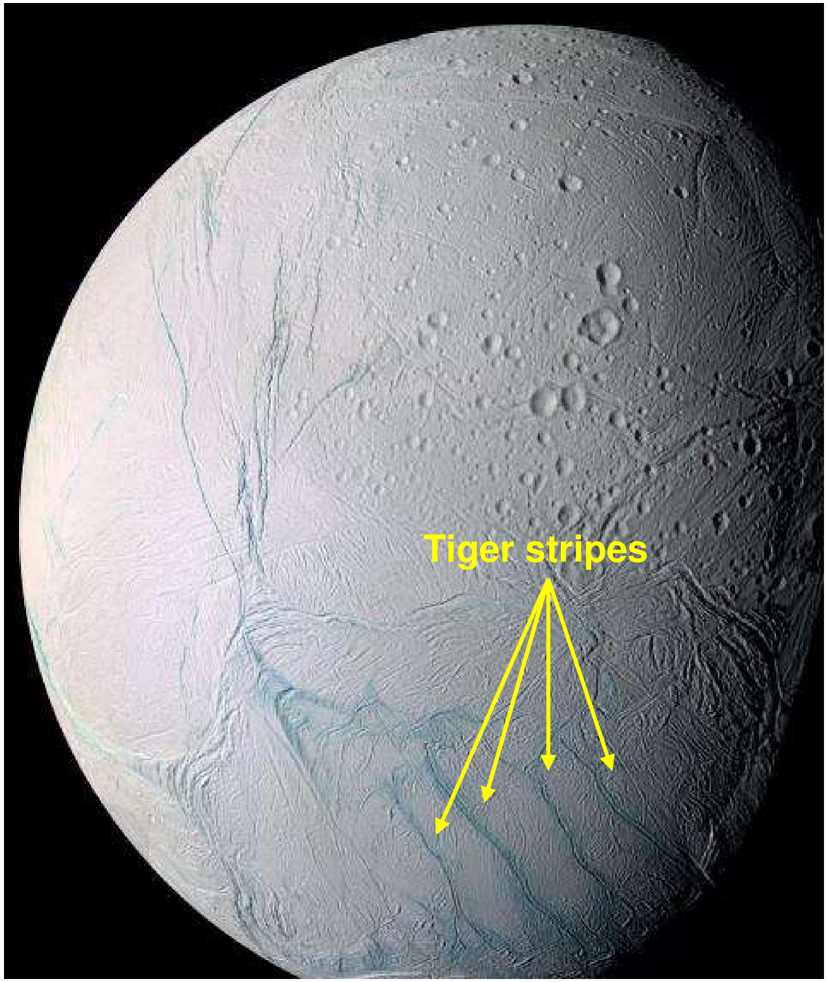


Image of Enceladus showing the ‘tiger stripes’ region in the southern hemisphere, where the plumes originate

What have we learned?

- **When did life arise on Earth?**
- Fossil evidence puts the origin of life at least 3.5 billion years ago, and carbon isotope evidence pushes this date to more than 3.85 billion years ago. Thus, life arose within a few hundred million years after the last major impact of the heavy bombardment, and possibly in a much shorter time.

What have we learned?

- **How did life arise on Earth?**
- Genetic evidence suggests that all life on Earth evolved from a common ancestor, and this ancestor was probably similar to microbes that live today in hot water near undersea volcanic vents or hot springs. We do not know how this first organism arose, but laboratory experiments suggest that it may have been the result of natural chemical processes on the early Earth.

What have we learned?

- **What are the necessities of life?**
- Life on Earth thrives in a wide range of environments, and in general seems to require only three things: a source of nutrients, a source of energy, and liquid water.

What have we learned?

- **Could there be life on Mars?**
- Mars once had conditions that may have been conducive to an origin of life. If life arose, it might still survive in pockets of liquid water underground.

What have we learned?

- **Could there be life on Europa or other moons of Jupiter or Saturn?**
- Europa probably has a subsurface ocean of liquid water, and may have undersea volcanoes on its ocean floor. If so, it has conditions much like those in which life on Earth probably arose, making it a good candidate for life beyond Earth. Ganymede and Callisto might have oceans as well. Titan may have other liquids on its surface, though it is too cold for liquid water. Perhaps life can survive in these other liquids, or perhaps Titan has liquid water deep underground. Enceladus may have subsurface water, or it may just have slush.