Part 4: Our Solar System, Life in the Universe

Tuesday, April 11 — Reading: Chapter 15 (12th & 13th Edition of the textbook)
- Solar System: Introduction and Formation; Other Solar Systems

Thursday, April 13 — Reading: Chapter 18 (planets)
- Solar System: Jupiter, Saturn, Uranus, Neptune

Tuesday, April 18 — Reading: Chapter 18, 19
- Solar System: Outer Solar System, Pluto, Kuiper Belt, Comets, Satellites

Thursday, April 20 — Reading: Chapter 16, 17, 18, 19
- Solar System: Satellites, our Moon, Mercury, Asteroids

Tuesday, April 25 — Reading: Chapter 17
- Solar System: Mars and Venus

Thursday, April 27 — Reading: Chapter 16
- Solar System: Earth

Monday, May 1 — Help Session from 4 to 6 PM in RLM 4.102

Tuesday, May 2 — Exam 6

Thursday, May 4 — Reading: Chapter 20
- The history of life on Earth; Life in the Universe

Please stay to fill out your professor evaluations at the end of class.

Thank you!

The Earth is a miracle.

Almost all of the Universe is too hot or too cold for liquid water. Next time you are on a beach, think about the miracle that this planet is mostly covered with liquid water. It makes life possible.

The other miracle about the Earth is its oxygen atmosphere. Oxygen is very reactive. If it were not continually replenished by green plants, it would quickly be used up. Life created our oxygen atmosphere. Life keeps the Earth viable.


Lassen

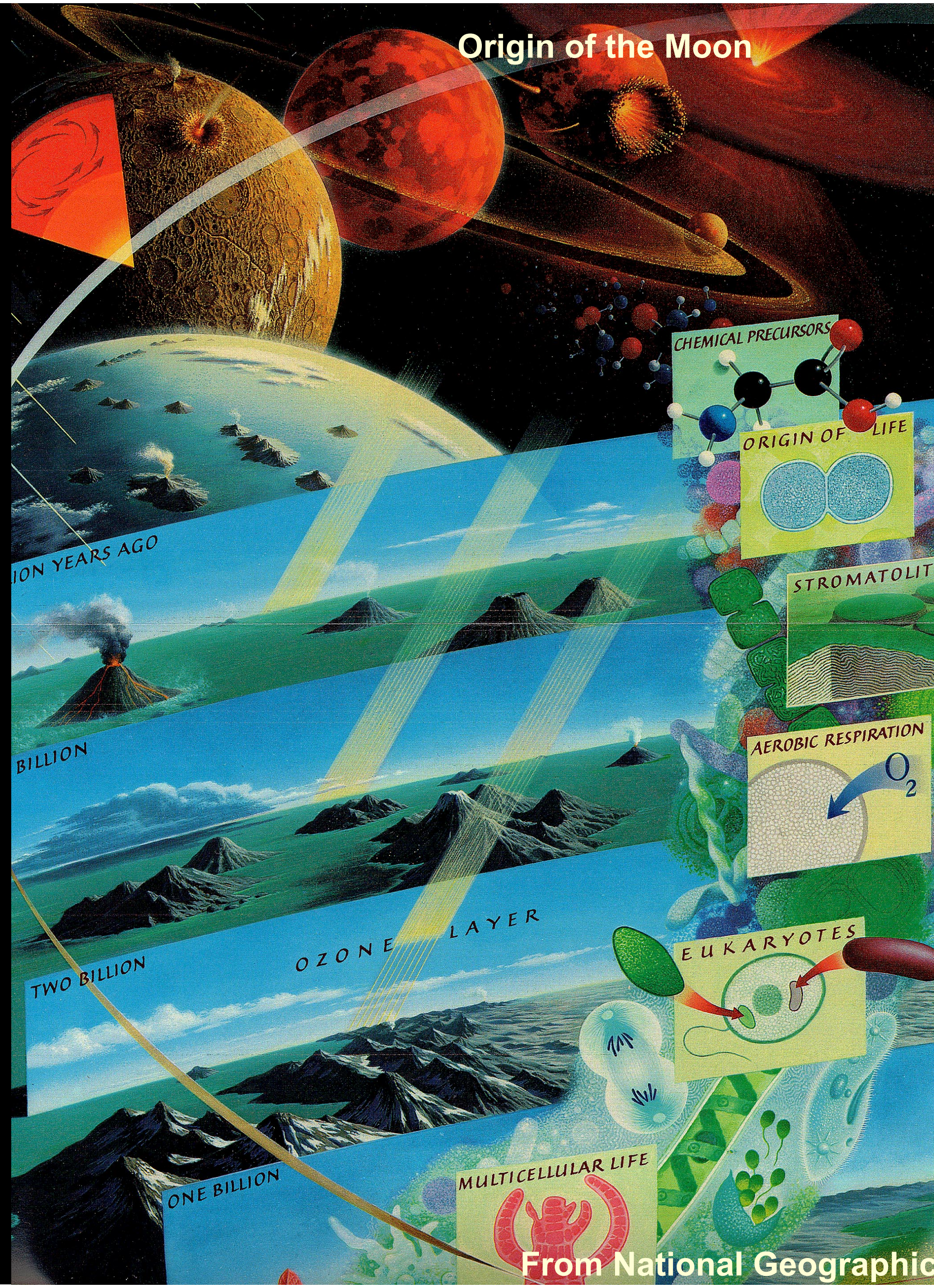
The Origin of Life on Earth

FOUR BILLION YEARS AGO
Earth's atmosphere contained N_2, CO_2, water, ammonia, methane, but no oxygen when life originated.

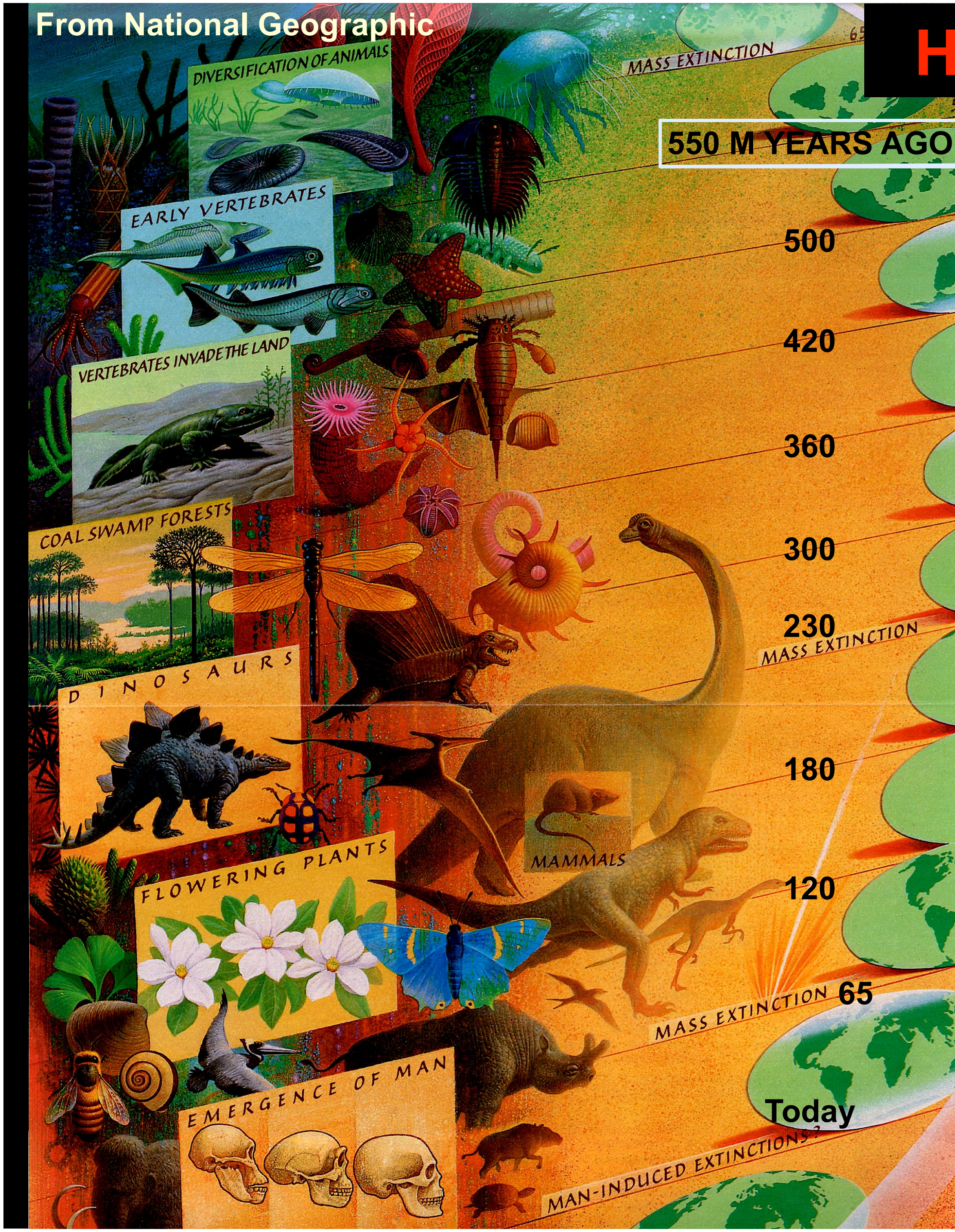
THREE BILLION YEARS AGO
Stromatolite bacterial colonies began to manufacture our oxygen atmosphere.

TWO BILLION YEARS AGO
The origin of the nucleated cells (eukaryotes) was a big step in the development of life.

ONE BILLION YEARS AGO
So was the development of multicellular life.



History of Life on Earth



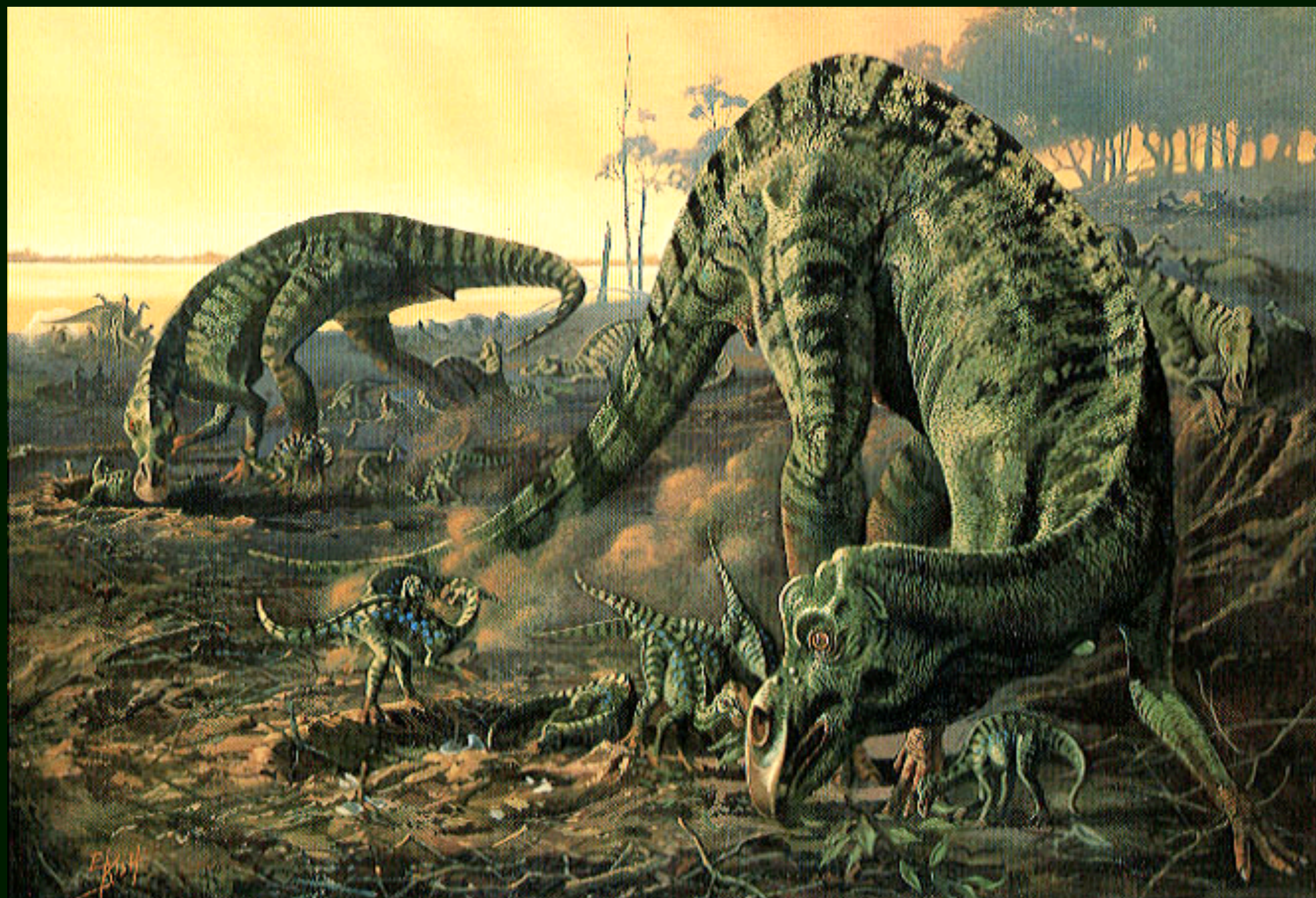
550 MILLION YEARS AGO
Biological “Big Bang” — sudden explosion in the diversity and complexity of multicellular life.

Oxygen in Earth’s atmophere reached present levels.

235 — 65 MILLION YEARS AGO
The age of dinosaurs lasted 170 million years. Dinosaurs were not clumsy hulks. Instead, they were exceedingly well adapted.

TODAY
One of the biggest mass extinctions ever is being caused now by humans.

Dinosaurs were exceedingly well adapted.



Dinosaurs were exceedingly well adapted.

Dinosaurs were able to survive in a great variety of conditions:

jungle, forests and plains, of course, but also
hot deserts,
the frigid arctic,
the oceans, and
the skies.

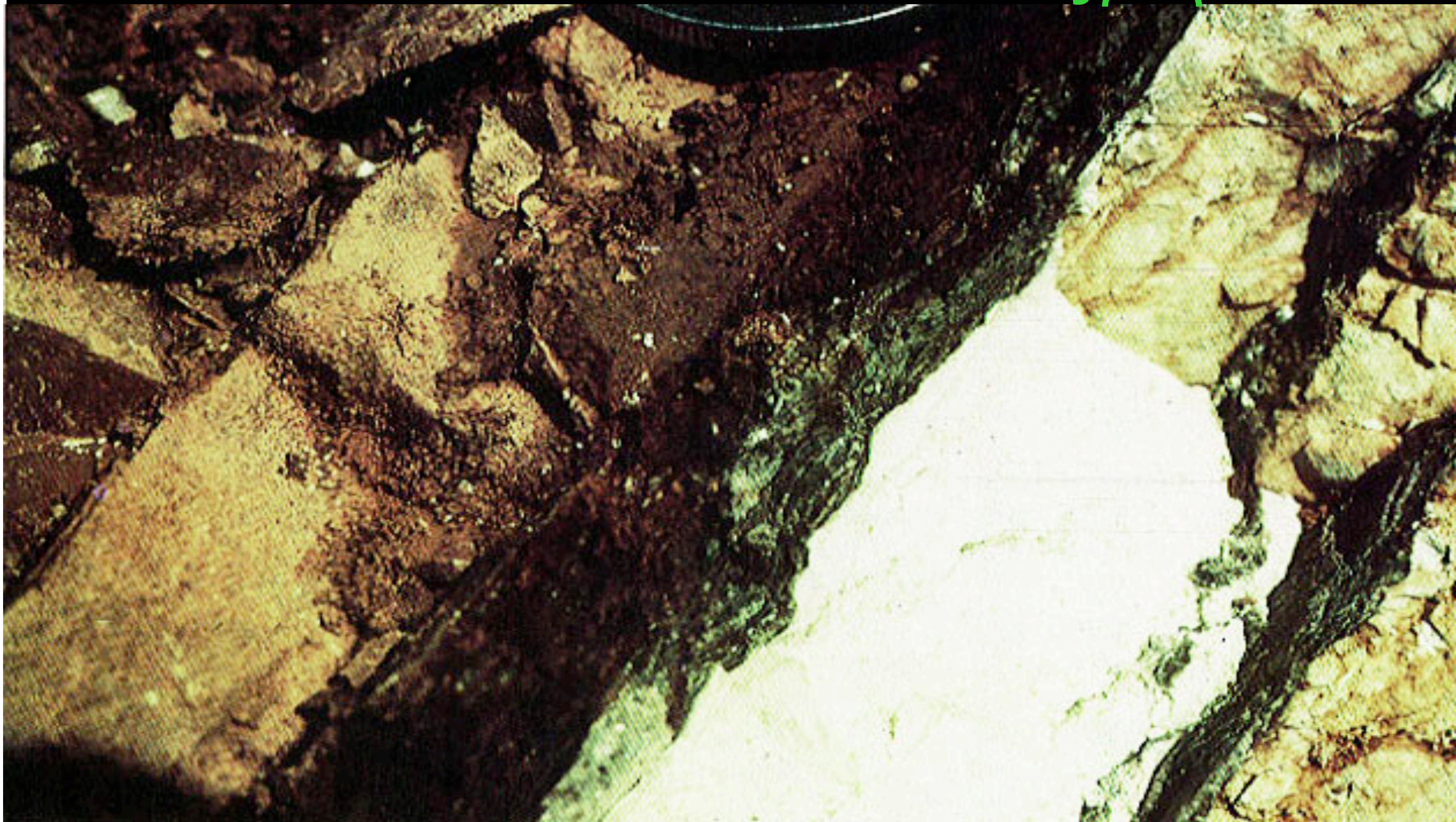
They were remarkably successful for 170 million years.

Dinosaurs did not die out because they "ran out of gas," evolutionarily.

There is now strong evidence that the dinosaurs were killed off in a mass extinction caused by the "KT asteroid impact" 65 million years ago.

We believe the KT impact injected huge amounts of water & dust into the air, making thick clouds — an effect like "nuclear winter." Much life was killed directly, but much more probably starved to death when plants froze.

The K-T Boundary



Tertiary period:
no more dinosaurs;
mammals are ascending

Gray clay
rich in iridium deposited by meteorite
impact that killed the dinosaurs

Cretaceous period:
limestone from the age of dinosaurs

Mass extinctions !

The victims and survivors

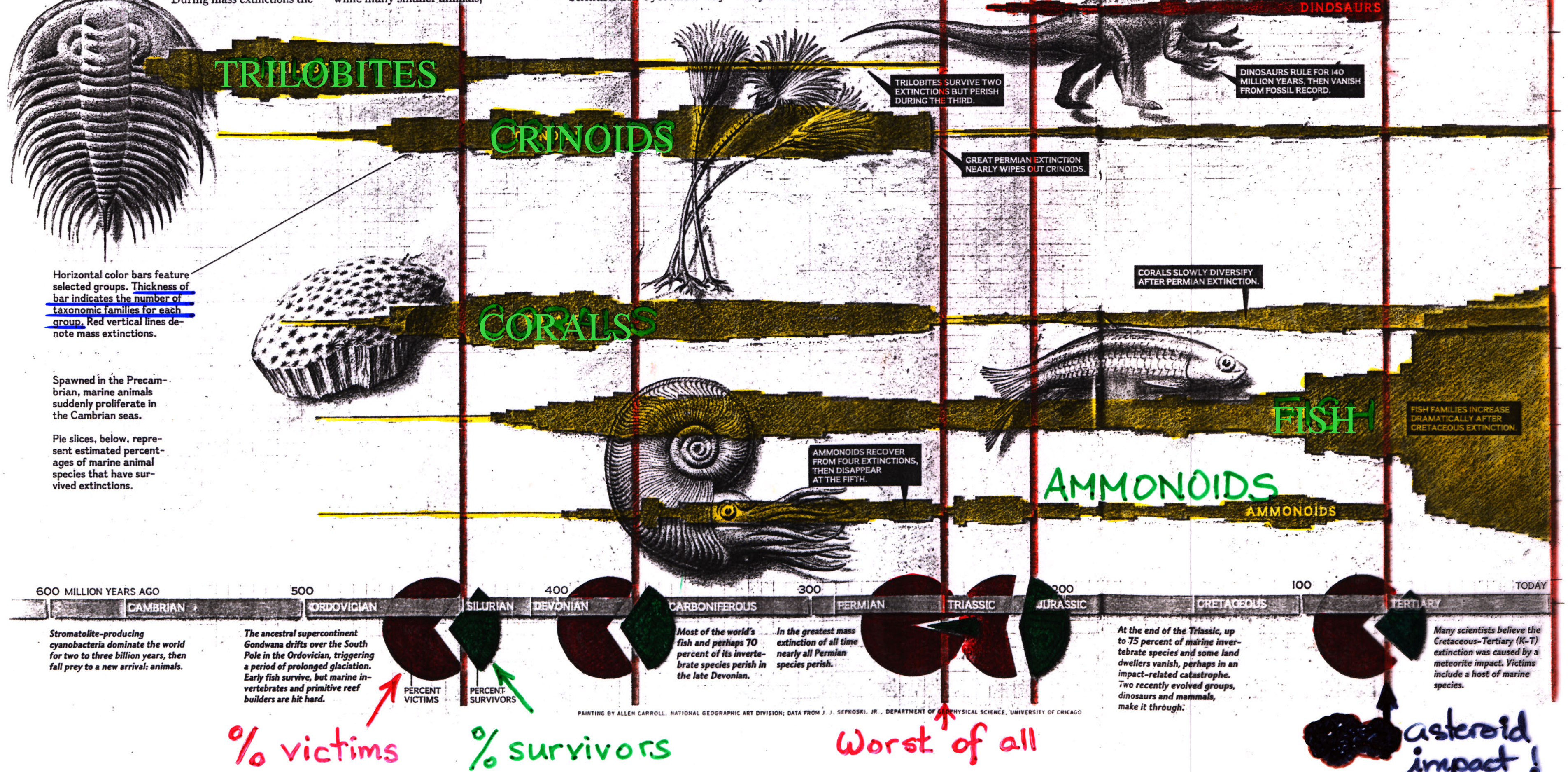
Extinction has claimed 99 percent of all species that have ever lived—many of them victims of "background" extinction, the piecemeal disappearance of species due to small-scale environmental changes. Others perished in one of earth's major mass extinctions (vertical bars) detected in the fossil record.

"During mass extinctions the rules change," says paleontologist Jack Sepkoski of the University of Chicago. "What had been advantageous may suddenly become a liability."

Tremendous size, for example, helped the dinosaurs dominate for some 140 million years. But they vanished during the great Cretaceous extinction, while many smaller animals, including mammals, survived.

In general, widespread species seem to weather mass extinctions better than those endemic to small regions. Others at high risk are those that live in tropical climates and cannot readily adapt. The ocean is no refuge—extinctions hit marine as well as land dwellers.

Scientists don't yet know why some groups (the trilobites, the ammonoids) survived several mass extinctions, then disappeared altogether—while others (the crinoids, the corals) nearly vanished, then reappeared. Or why fish and mammals have been so successful, radiating to fill vacated habitats. Says Sepkoski, "The whole thing may boil down to luck."



Stromatolite-producing cyanobacteria dominate the world for two to three billion years, then fall prey to a new arrival: animals.

The ancestral supercontinent Gondwana drifts over the South Pole in the Ordovician, triggering a period of prolonged glaciation. Early fish survive, but marine invertebrates and primitive reef builders are hit hard.

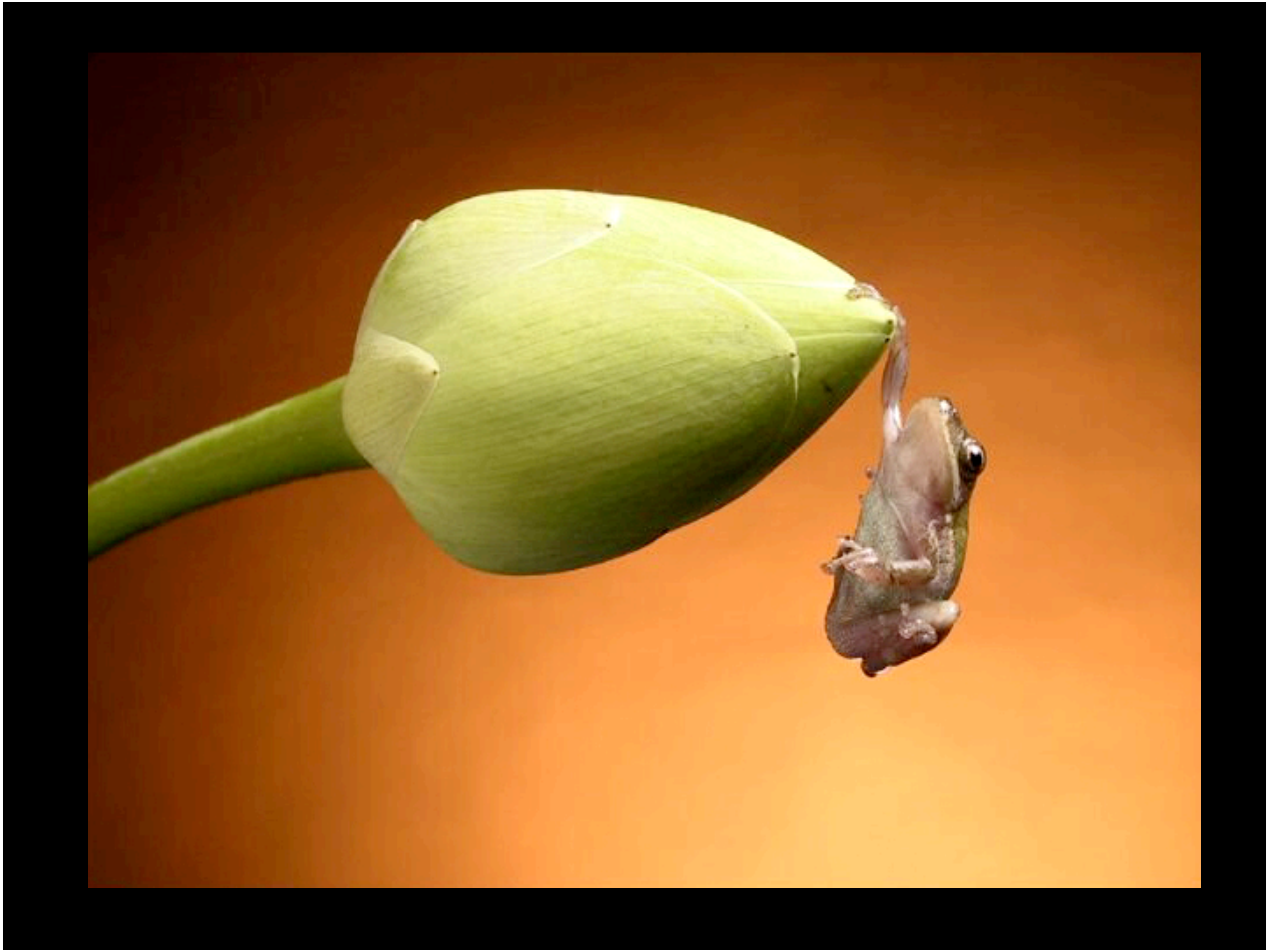
Most of the world's fish and perhaps 70 percent of its invertebrate species perish in the late Devonian.

In the greatest mass extinction of all time nearly all Permian species perish.

At the end of the Triassic, up to 75 percent of marine invertebrate species and some land dwellers vanish, perhaps in an impact-related catastrophe. Two recently evolved groups, dinosaurs and mammals, make it through.

Many scientists believe the Cretaceous–Tertiary (K–T) extinction was caused by a meteorite impact. Victims include a host of marine species.

PAINTING BY ALLEN CARROLL, NATIONAL GEOGRAPHIC ART DIVISION; DATA FROM J. J. SEPKOSKI, JR., DEPARTMENT OF GEOPHYSICAL SCIENCE, UNIVERSITY OF CHICAGO



Life on Earth: A Very Brief Summary

Life originated early in Earth's history, ~ 4 billion years ago – only ½ billion years after the planet formed – and probably before the torrent of planetesimal impacts ended. When life originated, Earth's atmosphere consisted of carbon dioxide, water, and hydrogen-rich gases like methane and ammonia. It contained no oxygen.

For most of its history, life consisted of simple bacterial colonies like stromatolites. These manufactured the present oxygen atmosphere via photosynthesis.

Life needed 3.5 billion years to invent multicellular animals. Then, at the start of the Cambrian Period (550 million years ago), there was an astonishingly rapid proliferation of animals. Maybe the enabling factor was the buildup of oxygen in the oceans and atmosphere. Ever since, evolution has made more and more complicated animals.

Intelligence is a very recent development.

Mass extinctions have occurred at least 5 times in the past 500 million years. The extinction 65 million years ago that wiped out the dinosaurs was probably caused by a large asteroid impact. It is plausible that the others were also caused by asteroids, but we don't know. The balance of conditions that allows life to flourish is delicate. People are upsetting it very badly. It may turn out that the worst mass extinction of all time is being caused right now by us.

So it is not clear that intelligence was a successful experiment.

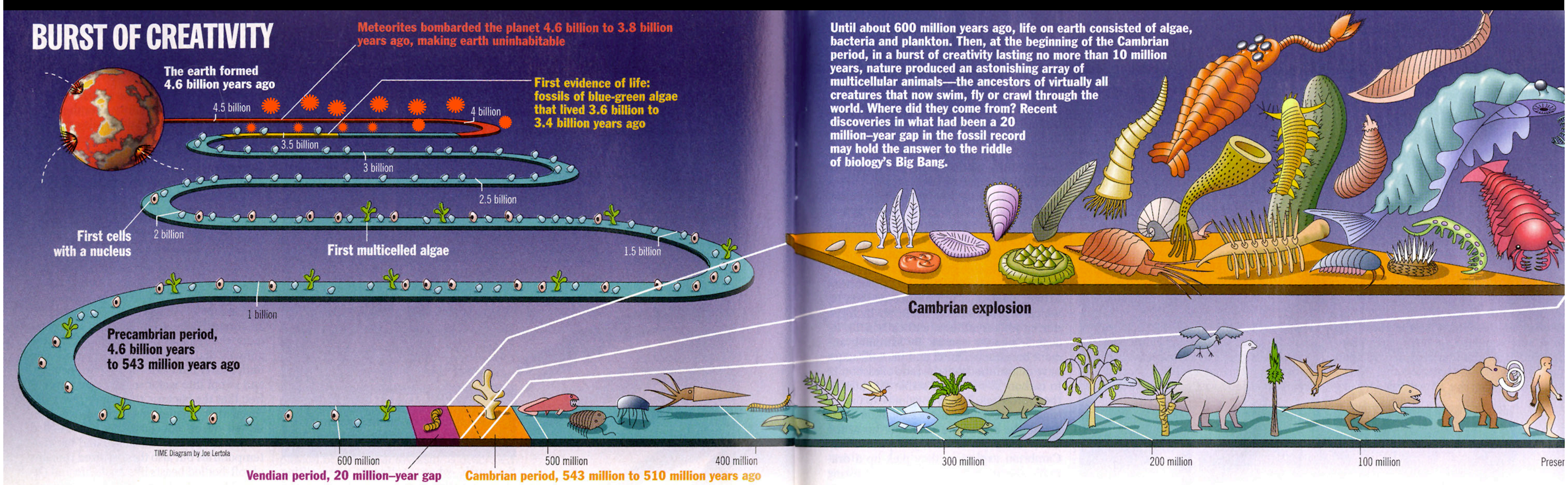
Definition of Life

Life is a self-sustained chemical system capable of reproduction*
and Darwinian evolution.†

Life extracts energy from its surroundings
to modify itself and its surroundings and to create offspring.

Life can evolve,†
i. e., it can change gradually to better adapt to its (possibly changing) surroundings.

*Reproduction $\Rightarrow$ offspring are like parents,
†but with an opportunity for “improvement.”



The Origin of Life on Earth: Study Guide

Four of the five most abundant elements in the Solar System (hydrogen, oxygen, carbon, nitrogen) make up 96 % of the human body by mass and 99.5 % of the human body by number of atoms. Life is made of the most abundant ingredients possible. (The second most abundant element in the Universe, helium, is rare on Earth because it is chemically inert and light enough to escape from Earth's atmosphere.)

Life originated early in Earth's history, ~ 4 billion years ago, only 0.5 billion years after the planet formed, and before the rain of planetesimal impacts ended. When life originated, our atmosphere contained carbon dioxide, water, and hydrogen-rich gases like methane and ammonia. It contained no oxygen.

“Organic” molecules — ones containing C and typically N, O, and H — are abundant in interstellar gas and in comets and meteorites. People wonder whether life got such an early start on Earth because precursor molecules rained down on it from the sky. But scientists do not think that this was **necessary** for the formation of life:

The Miller-Urey experiment (1952) demonstrated that complicated organic molecules could form naturally on the primitive Earth through the action of energy sources like lightning on an original atmosphere of H_2O, CO_2, N_2, NH_3, CH_4, … . The experiment duplicated these conditions and made a “primordial soup” containing amino acids. We now believe that the early atmosphere contained less NH_3 and CH_4, but the experiment nevertheless showed that organics form easily and naturally.

Several processes could concentrate the soup, promote (“catalyze”) further reactions, and make more complicated molecules. These include foaming, regular crystals in clays, and pyrite crystals.

We do not know exactly how the organic materials came to life. But Cesare Emiliani emphasizes that the Earth’s surface was an enormous laboratory, running vast numbers of chemical experiments over hundreds of millions of years. Gradually, we think, these experiments produced self-replicating structures. Gradually they discovered how to transmit their structural blueprints via a genetic code imprinted in self-replicating molecules like DNA. Foam bubble walls became cell walls designed to contain DNA, energy generation mechanisms, and other specialized inventions. Gradually organic chemicals came to life.

Composition of the Sun and of the human body

Element	Abundance (percent of total number of atoms)	Abundance (percent of total mass)
Hydrogen	91.2	71.0
Helium	8.7	27.1
Oxygen	0.078	0.97
Carbon	0.043	0.40
Nitrogen	.0088	0.096
Silicon	.0045	0.099
Magnesium	.0038	0.076
Neon	.0035	0.058
Iron	.0030	0.14
Sulfur	.0015	0.040

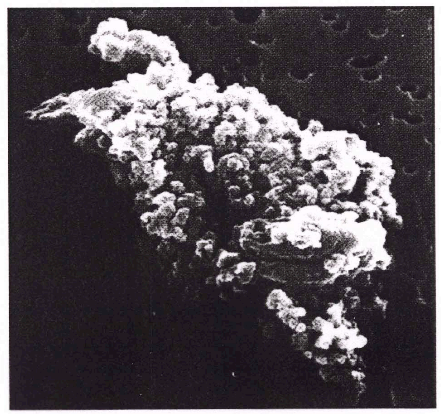
Table 19.1. Composition of the human body (cf. Table 2.1)

Element	Percentage By Mass	Percentage By Number of Atoms
O	65	25.6
C	18	9.5
H	10	63.1
N	3	1.32
Ca	1.5	1.23
P	1.0	0.20
K	0.35	0.06
S	0.25	0.05
Na	0.15	0.04
Cl	0.15	0.03
Mg	0.05	0.01
Fe	0.004	0.00045

Billions of years ago comets and asteroids delivered enormous quantities of organic matter to Earth just about the time life arose here. Coincidence — or cause and effect?

Life from the Stars?

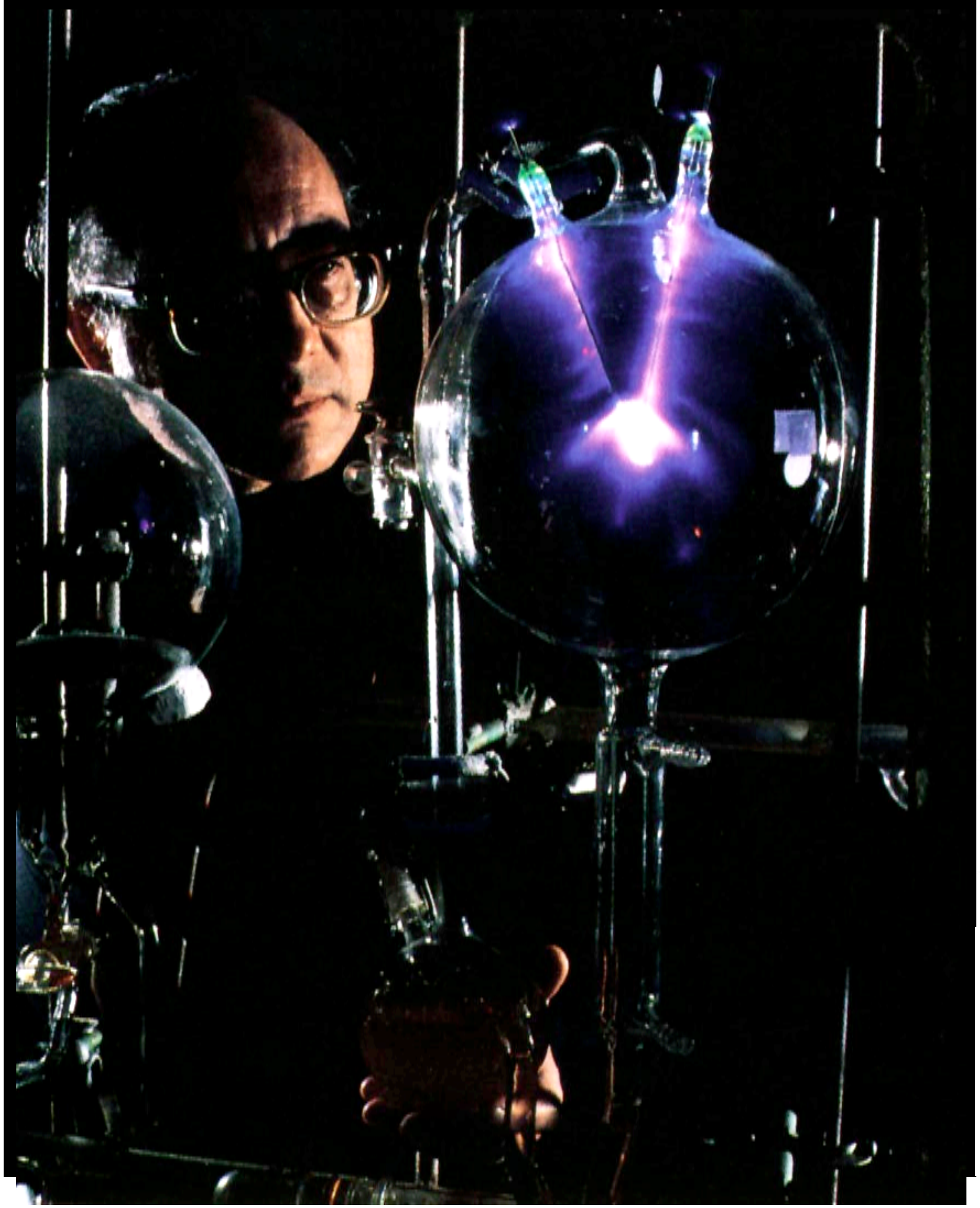
By Yvonne J. Pendleton and Dale P. Cruikshank

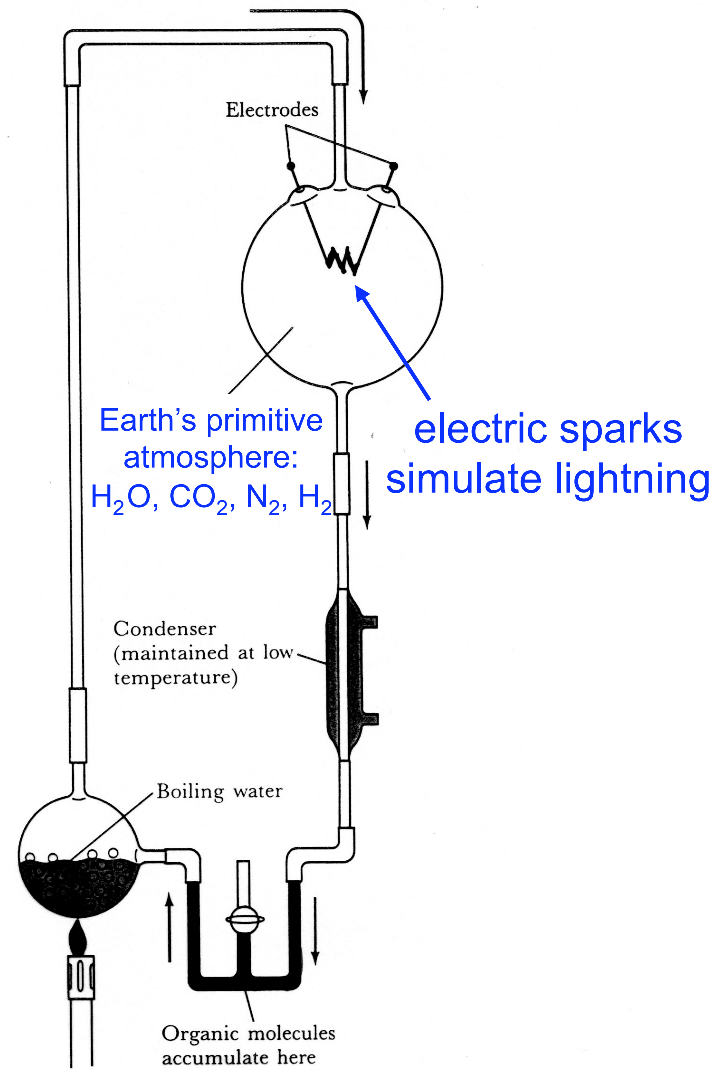


EACH YEAR 300 TONS of organic material rich in carbon-bearing molecules rain down on Earth as microscopic dust particles that come from evaporating comets and ground-up asteroids. As if to punctuate this steady infall, meteorites sometimes deliver a ton or more of these compounds directly to our planet's surface. The inescapable conclusion is that organic molecules from space have found their way, in colossal quantities, to an environment in which life, the most complex self-replicating chemistry known, has thrived for 3½ billion years.

Could organic molecules from space have contributed significantly to life's origin?

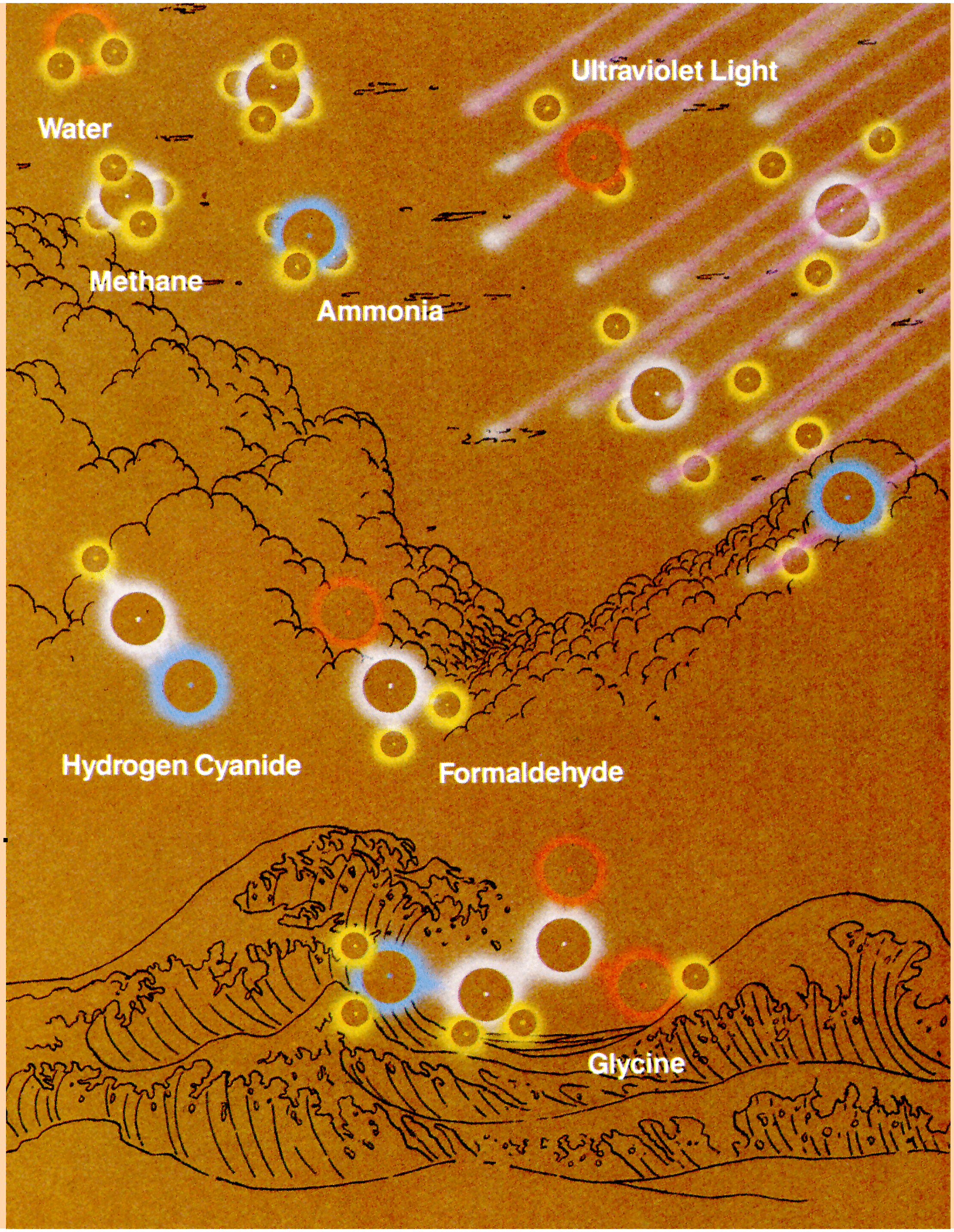
How did life originate?





The Miller-Urey experiment (1952) produced amino acids out of water, carbon dioxide, nitrogen, and hydrogen gas.

Earth's primordial atmosphere contained water, methane, and ammonia…



…which were broken up into fragments by ultraviolet light from the Sun and by lightning. Then...

…the fragments recombined into (among others) hydrogen cyanide and formaldehyde.

These more complicated molecules reacted with ammoniated water to make amino acids.

Figure E–3
The simple solution of organic material in the oceans, from which life may have arisen, is informally known as "primordial soup."

Primordial Soup Was Very Dilute

From Cesare Emiliani, “Planet Earth”:

“For organic compounds in the primordial soup to interact, concentration was necessary.

An efficient way to concentrate organics is foaming.

There was lots of foam in the primitive ocean.

The step from foam containing a mixture of organics to a living cell is an enormous leap. The biochemistry of even the simplest bacterium is so complex that it would seem impossible to believe that it happened by random steps. But:

Three facts :

1. Earth’s surface was an enormous laboratory compared to the sizes of molecular experiments.
2. There was an enormous amount of time available — millions to hundreds of millions of years, possibly half a billion.
3. Molecular experiments are fast — enzymes can process thousands of molecules per second. Catalase holds the record of 100,000 molecules per second in the reduction of H_2O_2 to H_2O.

It is to be expected that anything that could happen did happen and that life eventually emerged.”

The transition from “almost alive” to “alive” is not sharp (e. g., viruses).

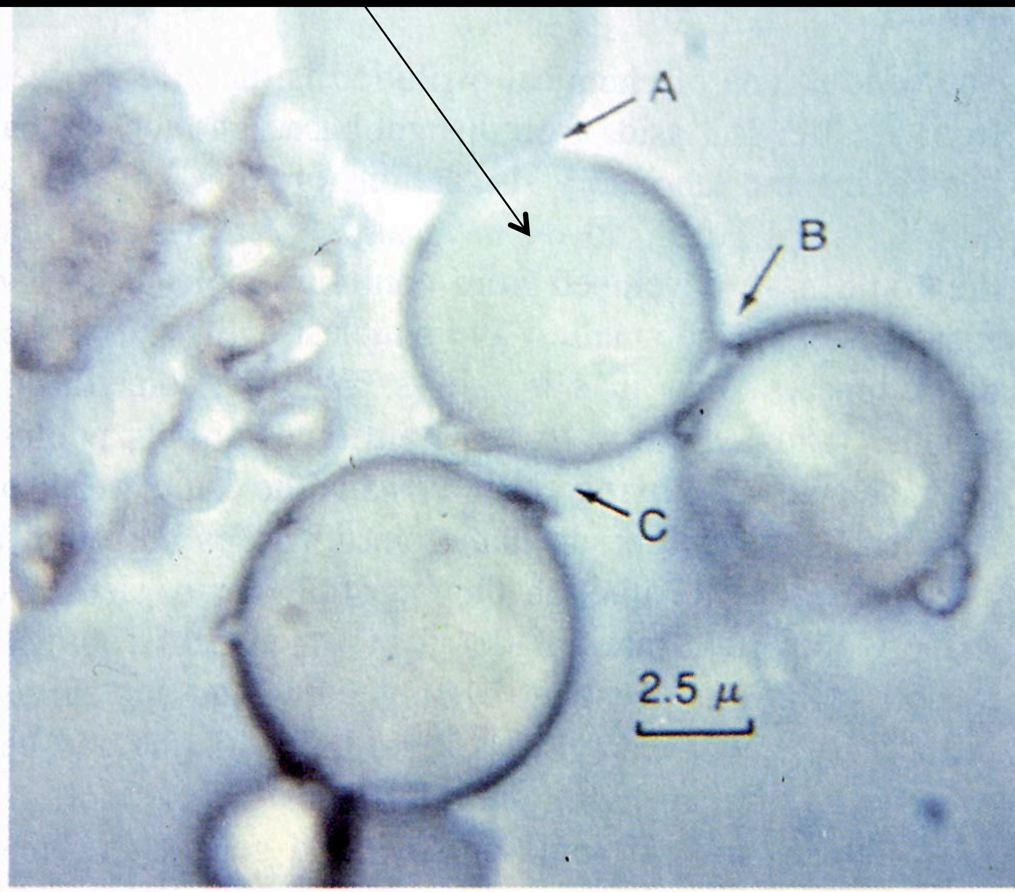


__Figure 30.9__ These carbon-rich, proteinlike droplets display the clustering of as many as a billion amino-acid molecules in a liquid. Droplets can ''grow,'' and parts of droplets can separate from the ''parent'' to become new individual droplets.

In these droplets, no genetic code transmits information from one generation to the next, ensuring that offspring are like parents. These droplets are not alive.

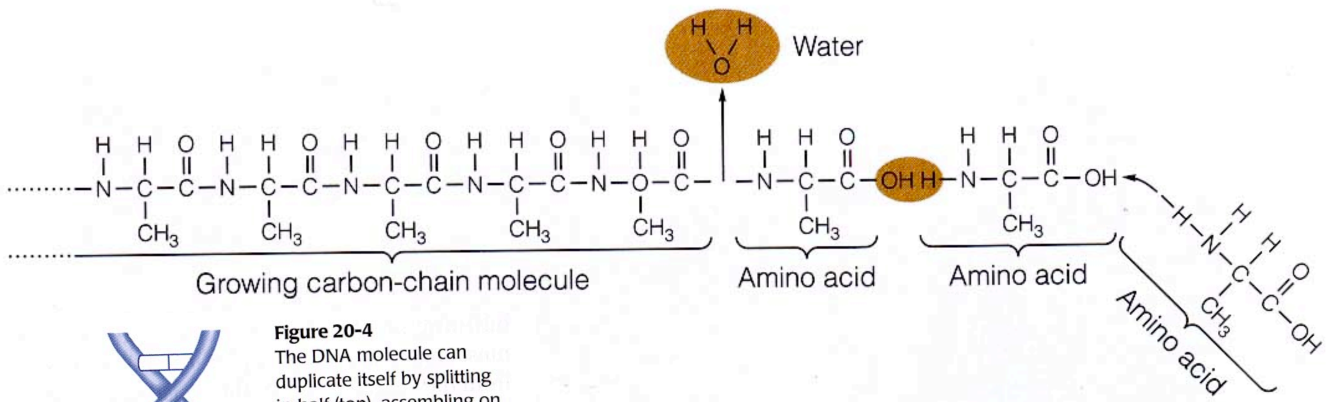


Figure 20-8
Amino acids can link together through the release of a water molecule to form long carbon-chain molecules. The amino acid in this hypothetical example is alanine, one of the simplest.

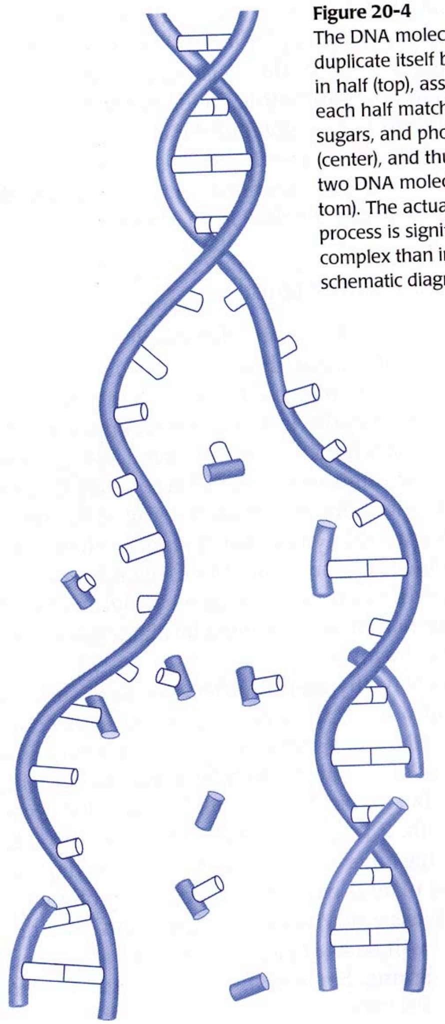


Figure 20-4
The DNA molecule can duplicate itself by splitting in half (top), assembling on each half matching bases, sugars, and phosphates (center), and thus producing two DNA molecules (bottom). The actual duplication process is significantly more complex than in this schematic diagram.

Biggest Step = Creation of DNA

The blueprint of life on Earth — the genetic code made of amino acids that tells offspring how to grow — is contained in DNA (deoxyribonucleic acid)

Scientists Have Manufactured Polio Virus From Scratch.

"Using genetic code as the recipe and carbon-containing chemicals as ingredients, researchers have made infective polio virus 'from scratch'. This is the first time that life has been manufactured using chemistry alone.

The team claims that this demonstrates the risk that viruses could be created from their genetic code by bioterrorists.

Polio virus is relatively easy to build. It has a very short and simple genome."

Reference

Cello, J., Paul, A.V. & Wimmer, E.
Chemical synthesis of poliovirus cDNA:
Generation of infectious virus in the absence of natural template.
Science published online 10.1126/science.1072266 (2002).

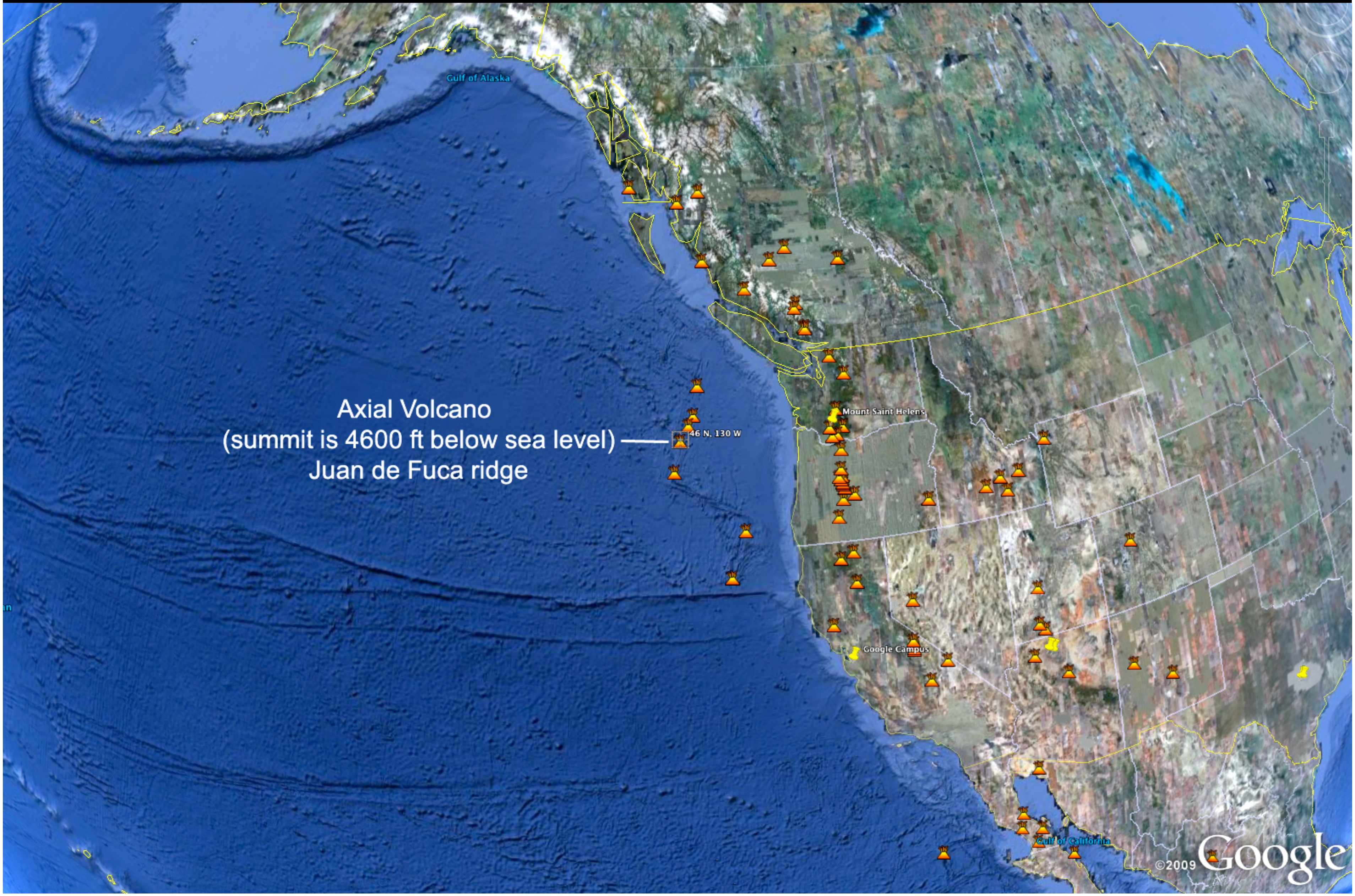
Where Did Life Start?

In Darwin’s “warm little pond” containing organic compounds?

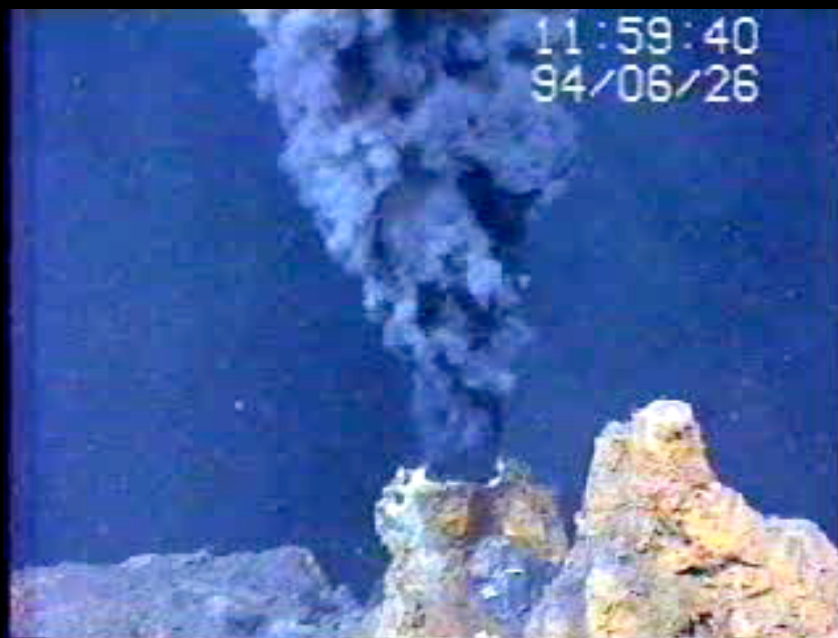
In ocean foam?
There was a lot of foam,
and it can concentrate materials that are essential to life.

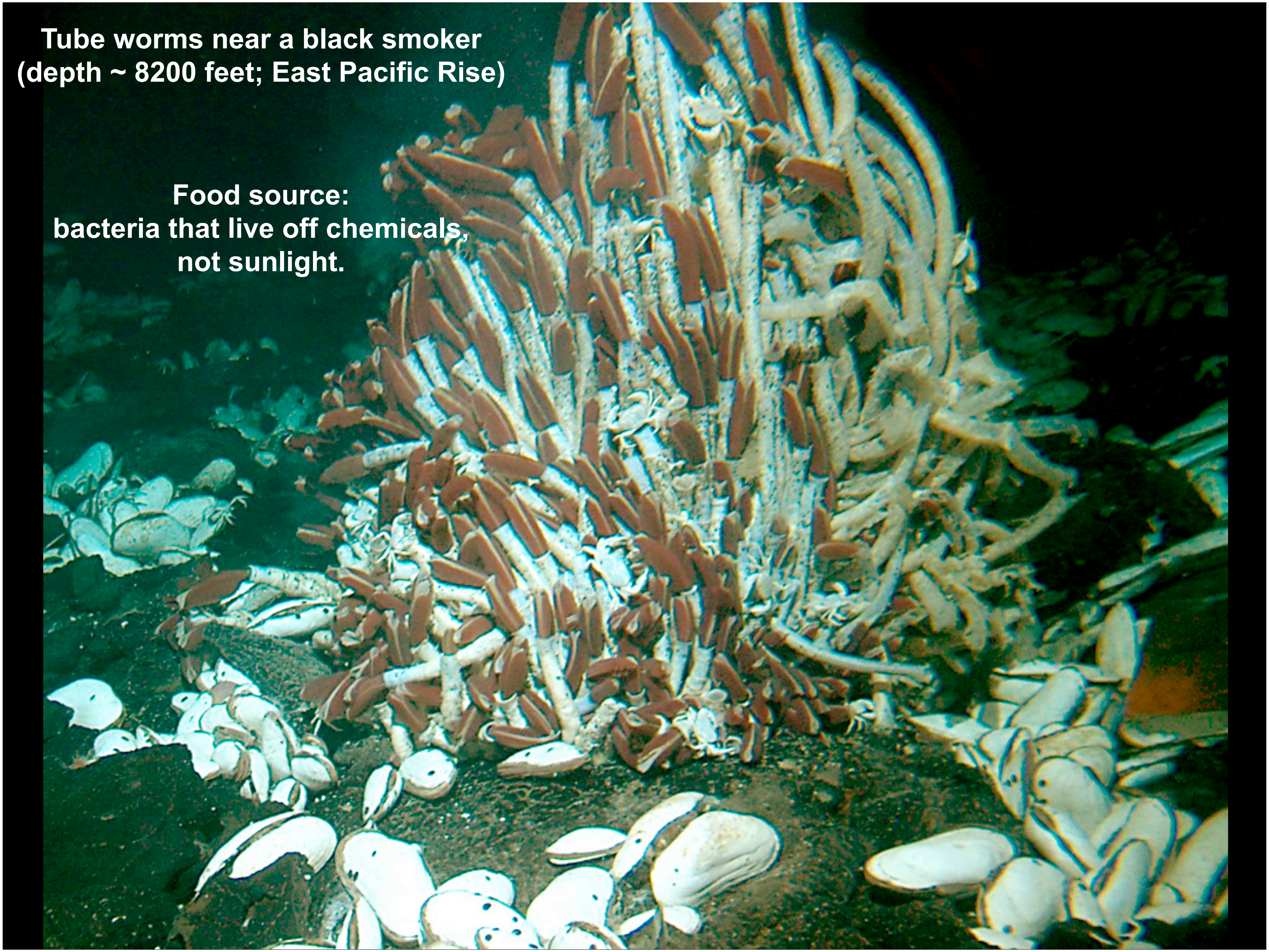
Near hydrothermal vents on the ocean floor?
Some of Earth’s most archaic creatures still live there.
Note: The deep ocean is relatively safe from asteroid impact.

Axial Volcano



Black Smoker atop 30-foot chimney (342° C)




Tube worms near a black smoker
(depth ~ 8200 feet; East Pacific Rise)
Food source:
bacteria that live off chemicals,
not sunlight.

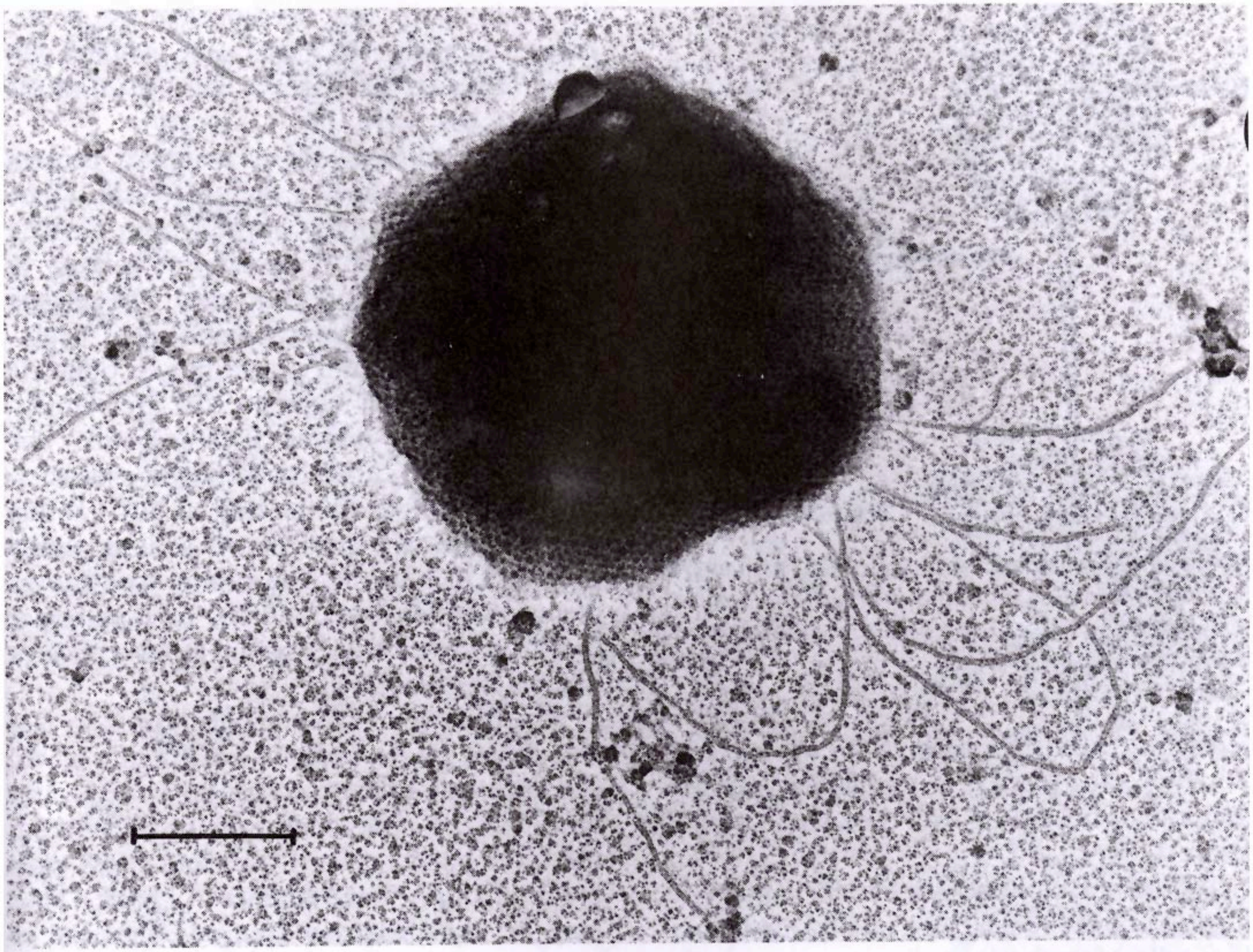


Figure 19.11. The archaebacterium *Hyperthermus butylicus*, found in a salty fumarole on the coast of the island of São Miguel, Azores (length of bar = 0.5 μm); where the salinity is about 17%, and temperatures range up to 112°C. *H. butylicus* grows best at temperatures between 95°C and 106°C. It derives its energy from the fermentation of peptides and by converting elemental sulfur and molecular hydrogen to H_2S. In the primitive Earth, the peptides may have formed abiotically in the fumarole itself. (Courtesy Wolfram Zillig, Max-Planck-Institut für Biochemie, Martinread Germany.)

Why does Earth have oxygen in its atmosphere?

When life originated, Earth's atmosphere contained
carbon dioxide, nitrogen, water,
and a bit of methane and ammonia.
It contained no oxygen.

For most of its history,
life consisted of simple bacterial colonies like stomatolites.
They manufactured the present oxygen atmosphere via
photosynthesis.

Chemical processes kept the oxygen concentration low until
about 2.3 billion years ago. Then it began to rise rapidly.
Oxygen reached its present concentration ~ 500 million yr ago.

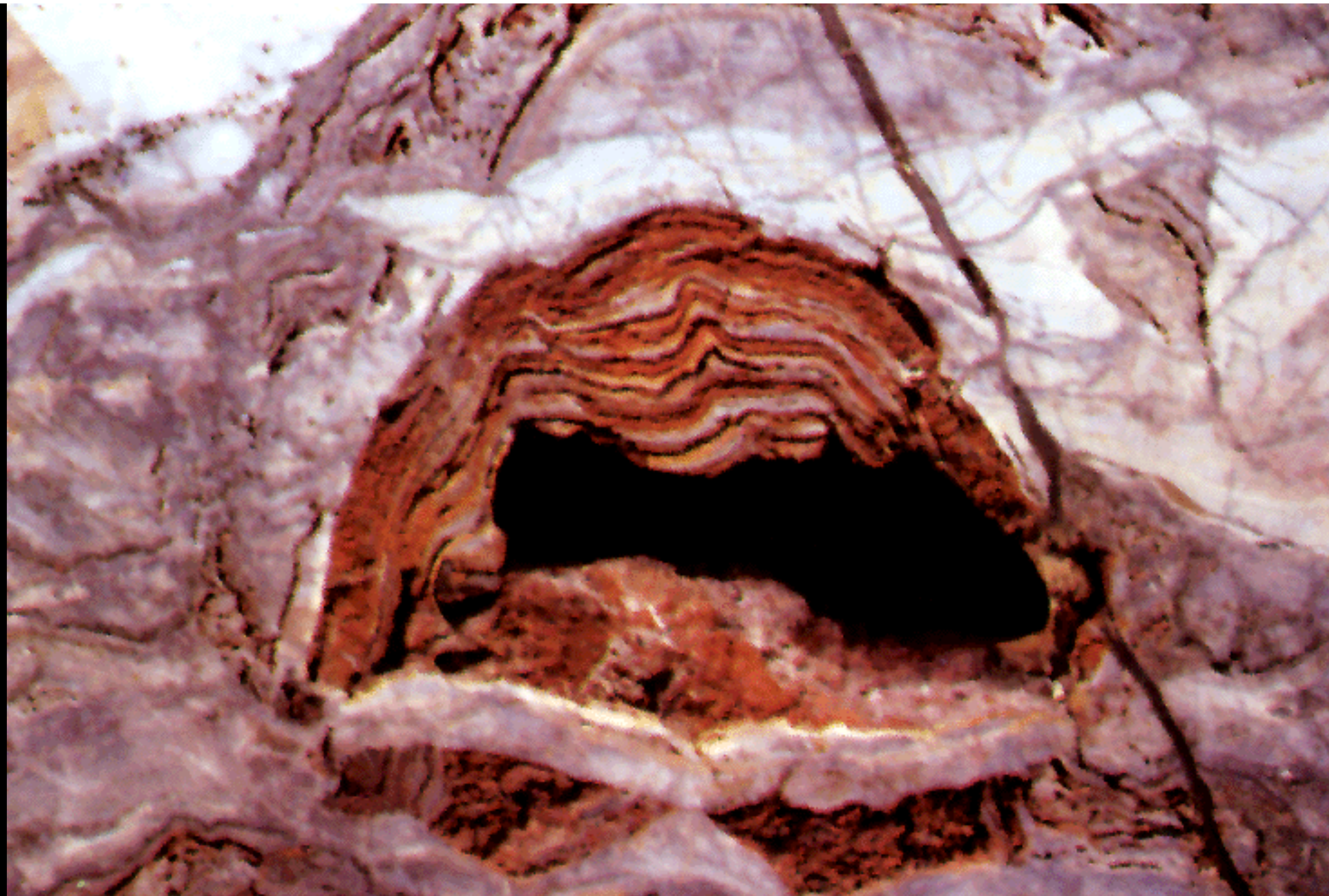
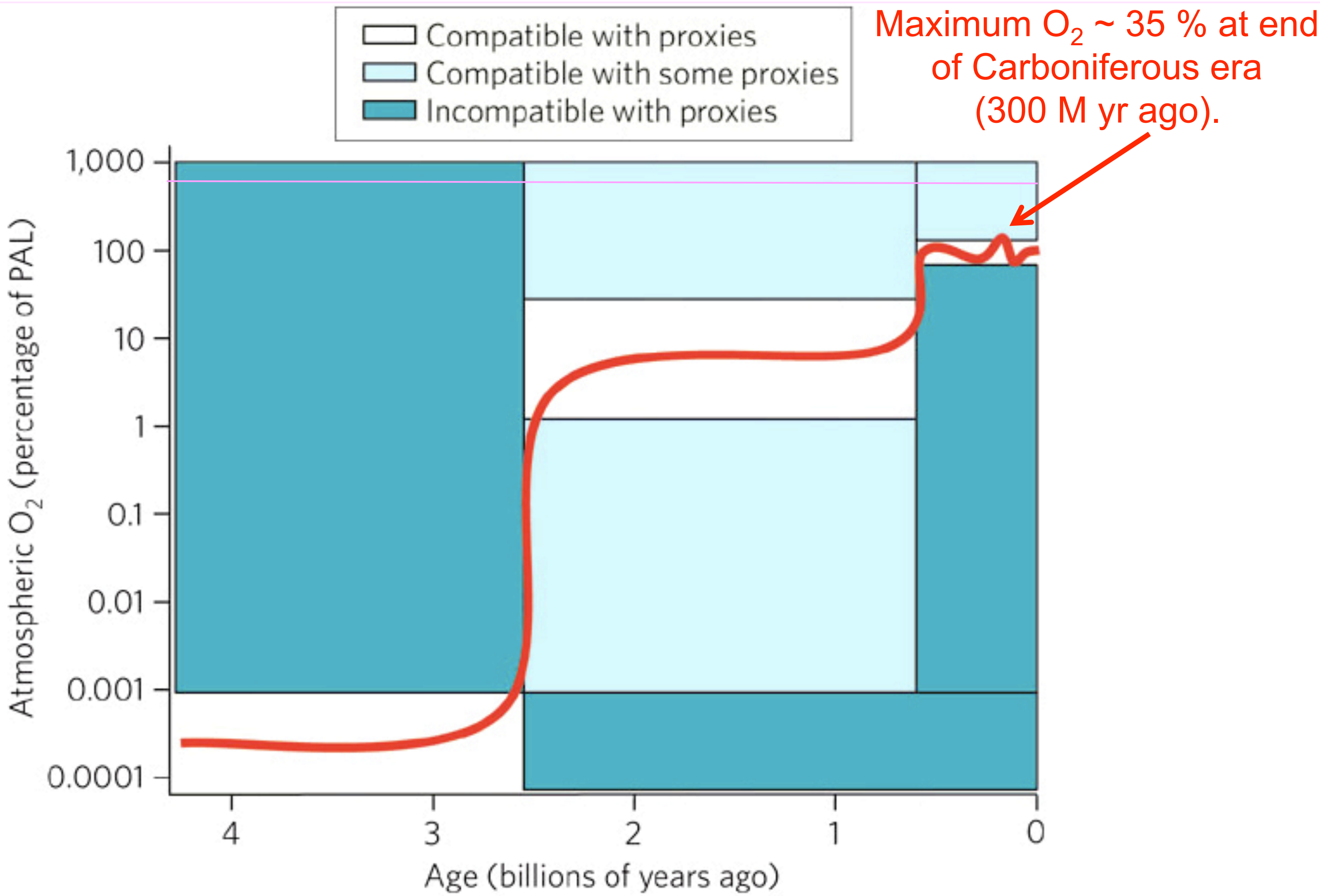


Figure 20-11 A 3.5-billion-year-old fossil stromatolite from western Australia is one of the oldest known fossils (above). Stromatolites were formed, layer by layer, by mats of blue-green algae or bacteria living in shallow water. Such algae may have been common in shallow seas when Earth was young (top). Stromatolites are still being formed today in similar environments. (Mural by Peter Sawyer; photos courtesy Chip Clark, National Museum of Natural History)

Life Created Earth's Oxygen Atmosphere



The red line shows the inferred level of atmospheric oxygen bounded by the constraints imposed by the proxy record of atmospheric oxygen variation over Earth's history[2, 20]. The signature of mass-independent sulphur-isotope behaviour sets an upper limit for oxygen levels before 2.45 billion years ago and a lower limit after that time. The record of oxidative weathering after 2.45 billion years ago sets a lower limit for oxygen levels at 1% of PAL, whereas an upper limit of 40% of PAL is inferred from the evidence for anoxic oceans during the Proterozoic. The tighter bounds on atmospheric oxygen from 420 million years ago to the present is set by the fairly continuous record of charcoal accumulation[19]: flames cannot be sustained below an oxygen level of 60% of PAL, and above about 160% of PAL the persistence of forest ecosystems would be unlikely because of the frequency and vigour of wildfires[21].

The Origin of Life on Earth

We have reproduced a few of the steps in the laboratory, including production of self-replicating foam bubbles. We have not produced true life. But it is important to note:

The definition of life is elusive. Are viruses alive? They are inert molecules in the absence of a host. They are in the conceptually gray area between nonliving and living. They teach us that the dividing line between nonliving and living is not sharp. This implies that **protolife did not at any stage have to make a huge evolutionary leap to change from organic chemicals to living beings. This is very important**, because gradual evolution is much easier and therefore much more likely. It is sufficient.

It is possible that life began — or began independently — in hydrothermal vents on the ocean floor. Primitive bacteria still thrive in hydrothermal vents, supporting a complicated food chain that is completely independent of other life. In particular, it is independent of the Sun. Such an origin for life has the advantage that the ocean floor is relatively safe from asteroid bombardment.

For most of its history, life consisted of simple bacterial colonies like stromatolites. These manufactured the present oxygen atmosphere via photosynthesis.

Life needed 3.5 billion years to invent multicellular animals. Then, at the start of the Cambrian Period (550 million years ago), there was an astonishingly rapid proliferation of animals. Ever since, evolution has made more and more complicated animals.

Mass extinctions have occurred at least 5 times in the past 500 million years. The extinction 65 million years ago that wiped out the dinosaurs was probably caused by a large asteroid impact. It is plausible that the others were also caused by asteroids, but this has not been proved. After all, the balance of conditions that allows life to flourish is delicate. People are upsetting it badly. It may turn out that the greatest mass extinction of all time is being caused right now by us.

Intelligence is a very recent development. It is not clear that intelligence is a successful experiment.

Intelligence
is a very recent development.

We have not demonstrated
that it is a successful experiment
… if “success” is measured
in longevity.

Life in the Universe

Prospects for life elsewhere in the Universe

The search for life in the Universe

Our future in space

Prospects for Life Elsewhere in the Universe

Most scientists believe that life developed on many planets. Reasons :

Life is made of the most abundant ingredients in the Universe.   Organic molecules are common in the gas and dust that makes solar systems.   Solar systems form naturally around stars, and we are finding thousands of planets. Nonvariable stars like the Sun that do not have unsuitable stellar companions have a zone around them where conditions on Earthlike planets are likely to favor life.

Life originated early in Earth's history.   In the rain of deadly planetesimals, it may have originated several times.   This suggests that life forms easily.   Everything that we know about the origin of life suggests that it is natural & inevitable on planets that are suitable.

Life on Earth is astonishingly varied and robust. It survives inside Antarctic rocks, in the driest places on Earth, and at temperatures like those on Mars.   It lives off of hydrogen sulfide in "black smokers" at the bottoms of the oceans, where the pressure is > 400 atmospheres and where the temperature is > 200^{o} F.   It lives off of oil that seeps through the ocean floor.   Life thrives in conditions that would instantly kill you and me. Life is endlessly inventive.   Given time, it can adapt to unbelievably hostile conditions. So:

It would be no surprise if life developed on Mars and still survives inside rocks or caves in the warmest and wettest places. It would be no surprise to find life in the atmospheres of Jovian planets – the right ingredients are plentiful, and so are energy sources like lightning. It would be no surprise to find life in an interior ocean of Europa or Enceladus.

Life is probably common in the Universe.   If it were not common, this would be a surprise.

Intelligence has existed for 0.001 % of the history of life on Earth.   We don't know if it will survive.   It hard to estimate whether intelligent life exists elsewhere in the Universe.

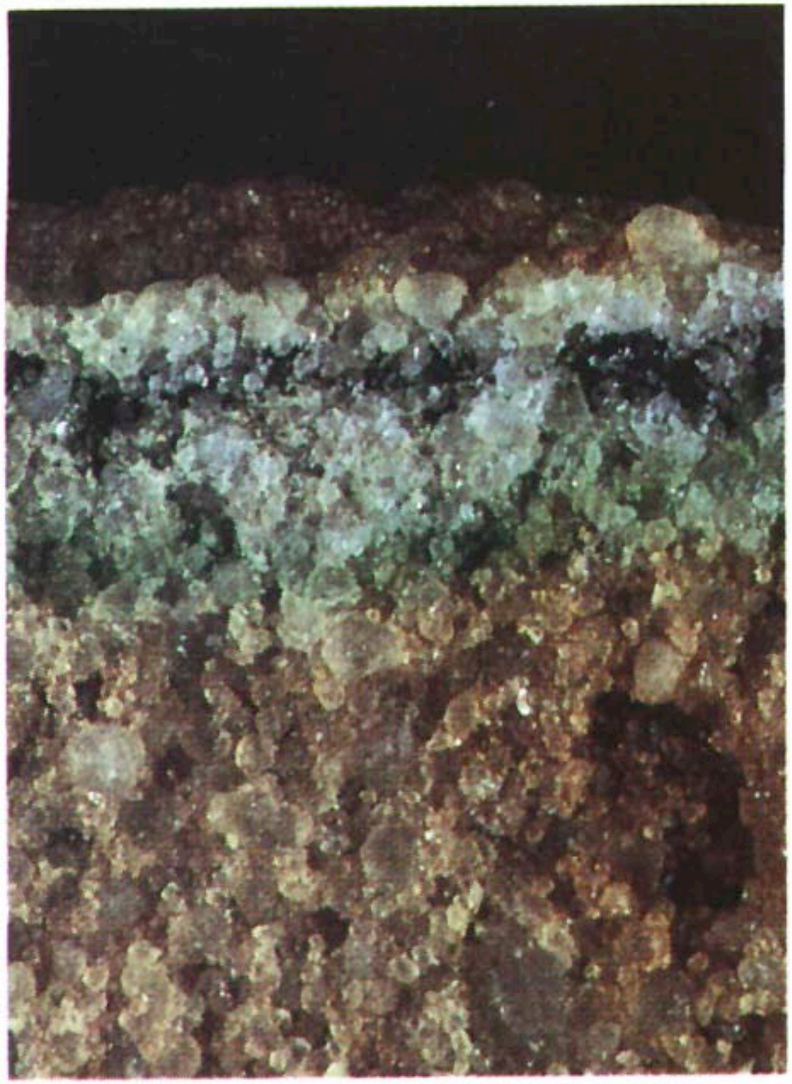
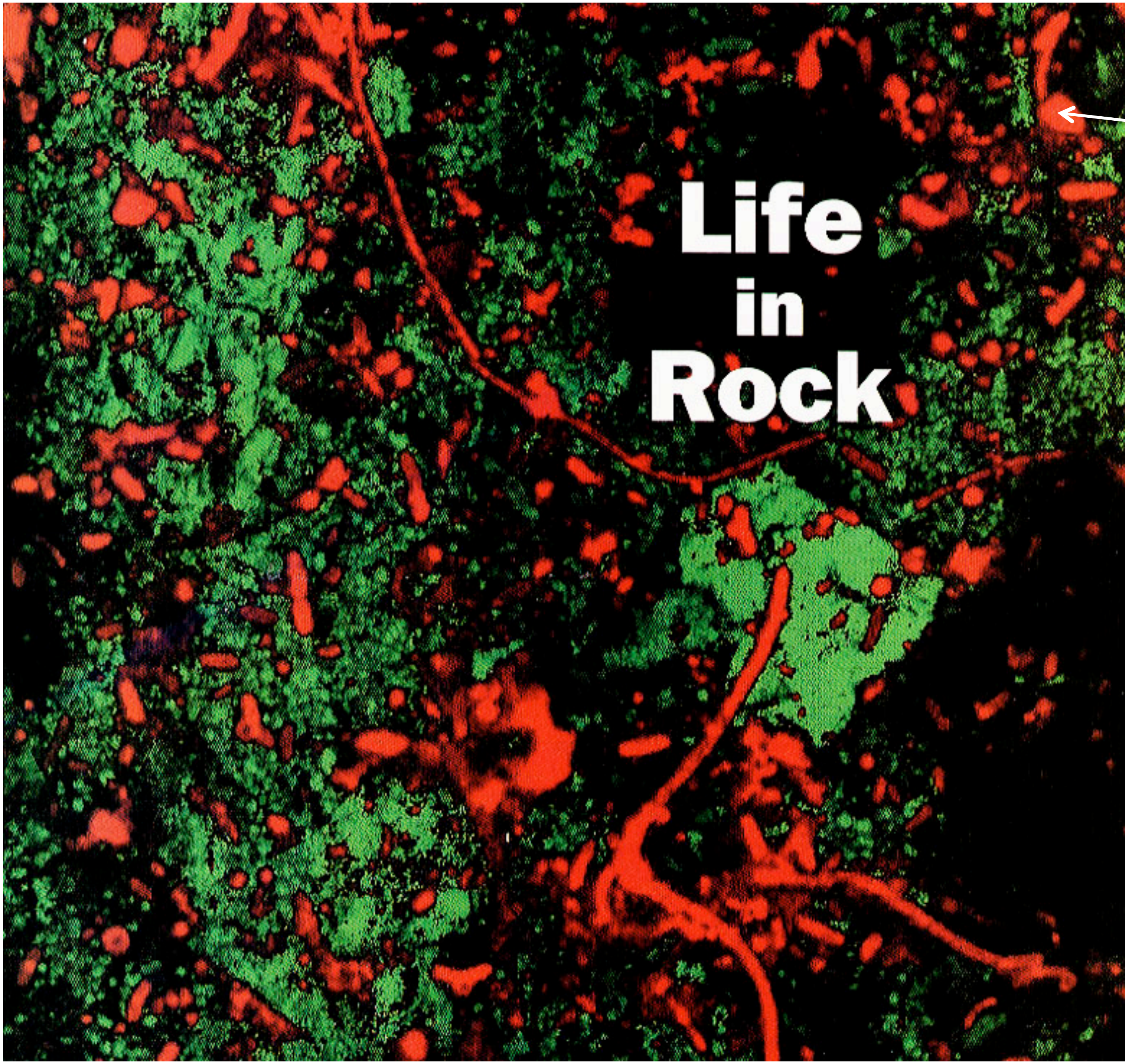


Figure E–5
We see the inside of an Antarctic rock, with a lichen growing safely insulated from the external cold.



These bacteria live in rocks at least 1.6 miles underground and at temperatures up to 113^{o} C.

They are completely independent of the Sun's energy and of surface life.

They live off of rocks and water.

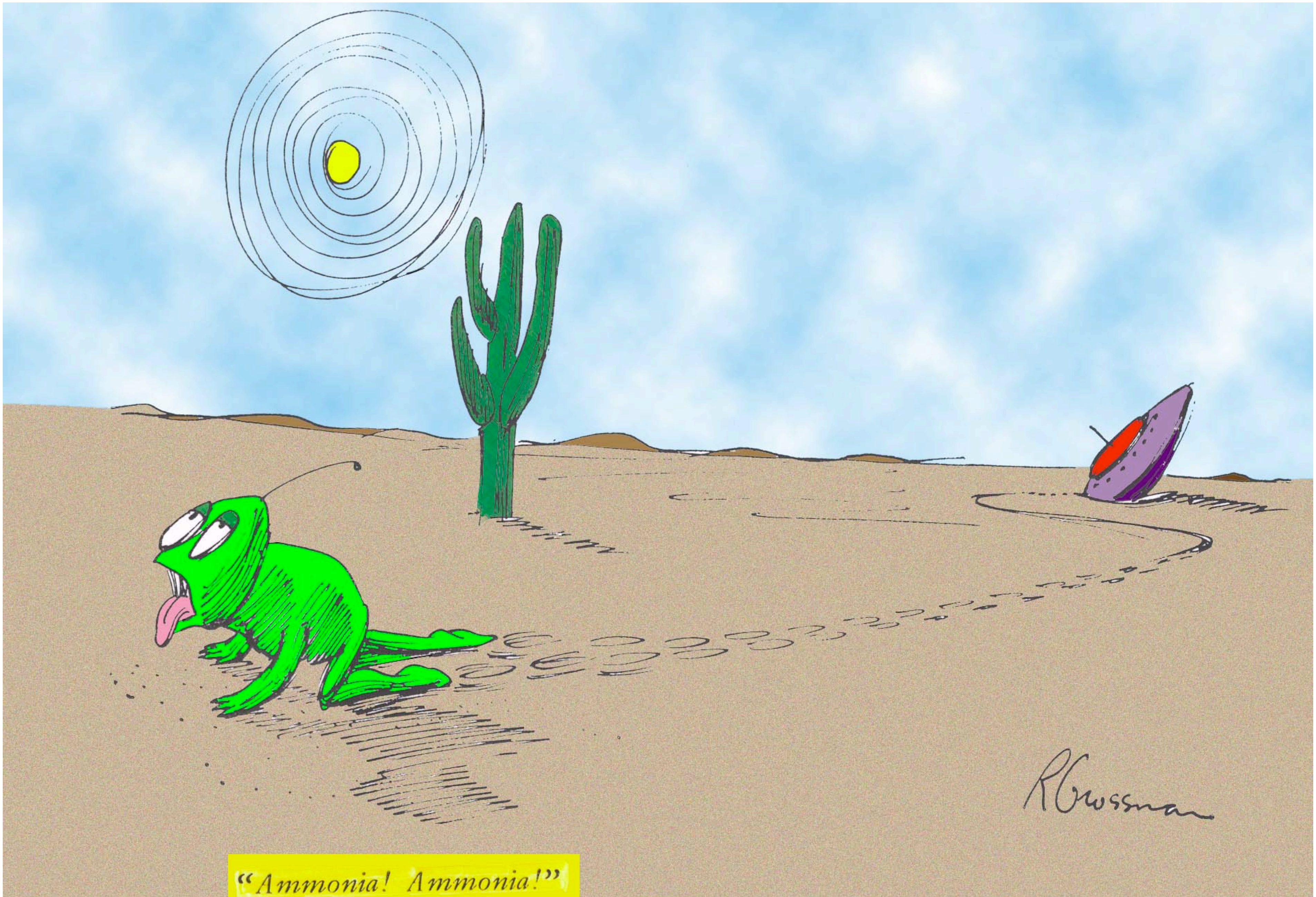
Life is unbelievably, miraculously adaptable.

Bacteria live in hot springs in Yellowstone National Park.

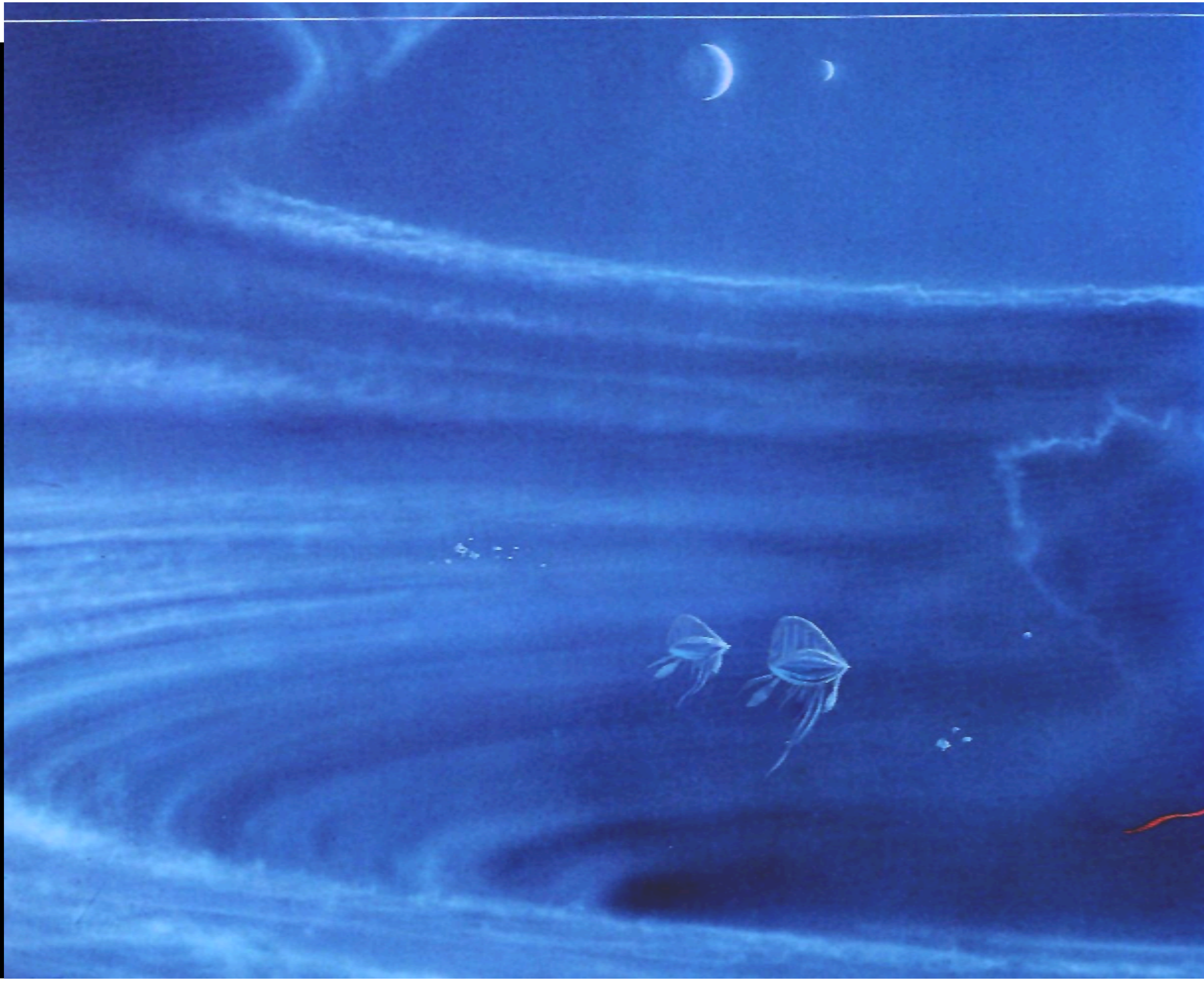
Orange-colored cyanobacteria live in water that has cooled below 163 degrees F. The green chlorophylls in these photosynthetic bacteria are masked by orange carotenoid pigments.

Warmer, whitish areas of the ponds contain nonphotosynthetic bacteria that live at temperatures up to 176 degrees F.   Bacteria near mid-ocean hydrothermal vents easily tolerate temperatures up to ~ 213 degrees F.

Life is unbelievably, miraculously adaptable.



Problem: We can't even imagine life that is very different from our own. Our viewpoints — and this slide — are too anthropocentric.



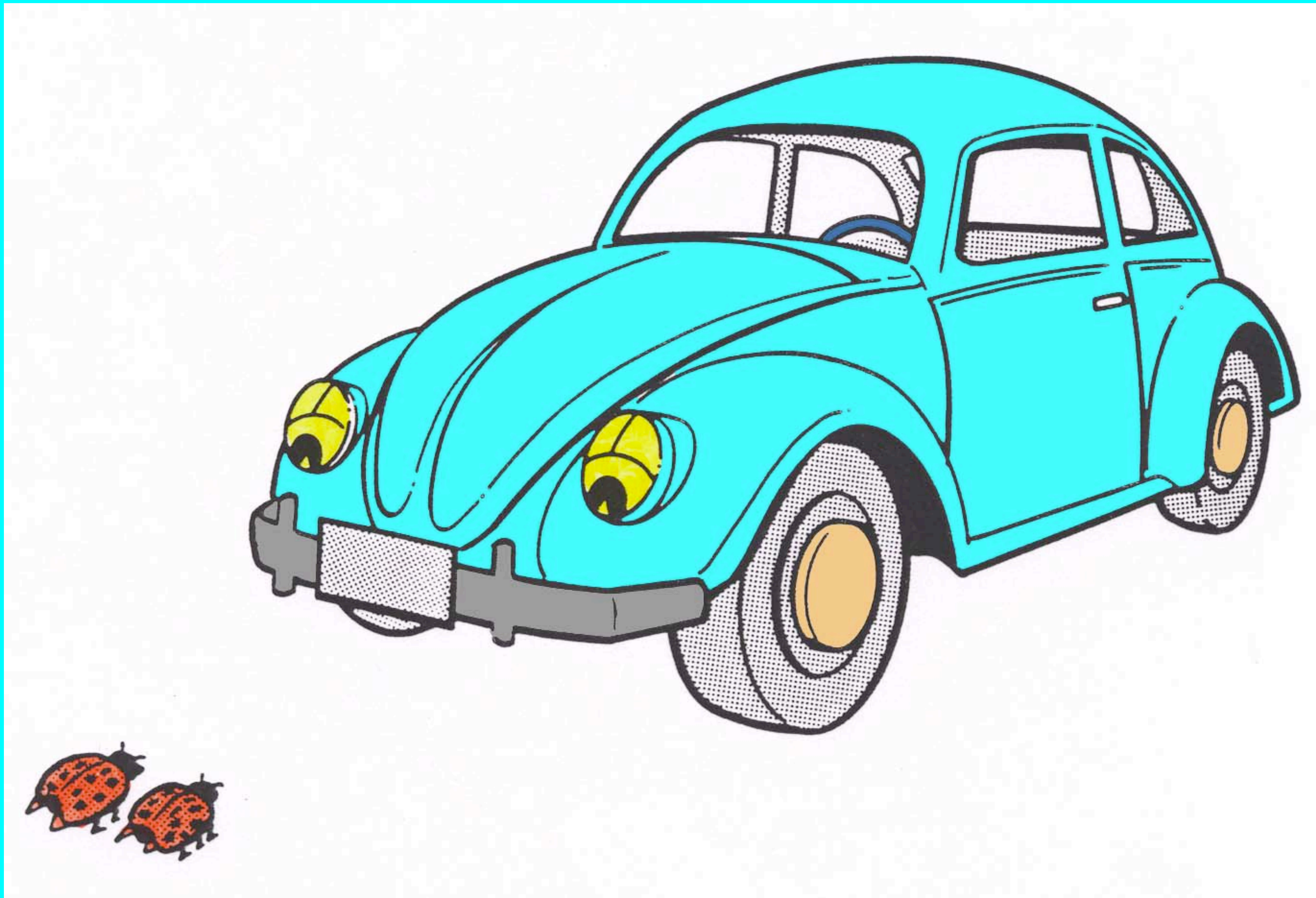
Where is Everybody ?

Enrico Fermi

If intelligent life developed elsewhere and if it spread successfully out of its home solar system, then there has been lots of time for it to spread widely. Why has it not contacted us?

Does this mean that the above has not happened?

Would we be able to understand the signals of a truly advanced being?



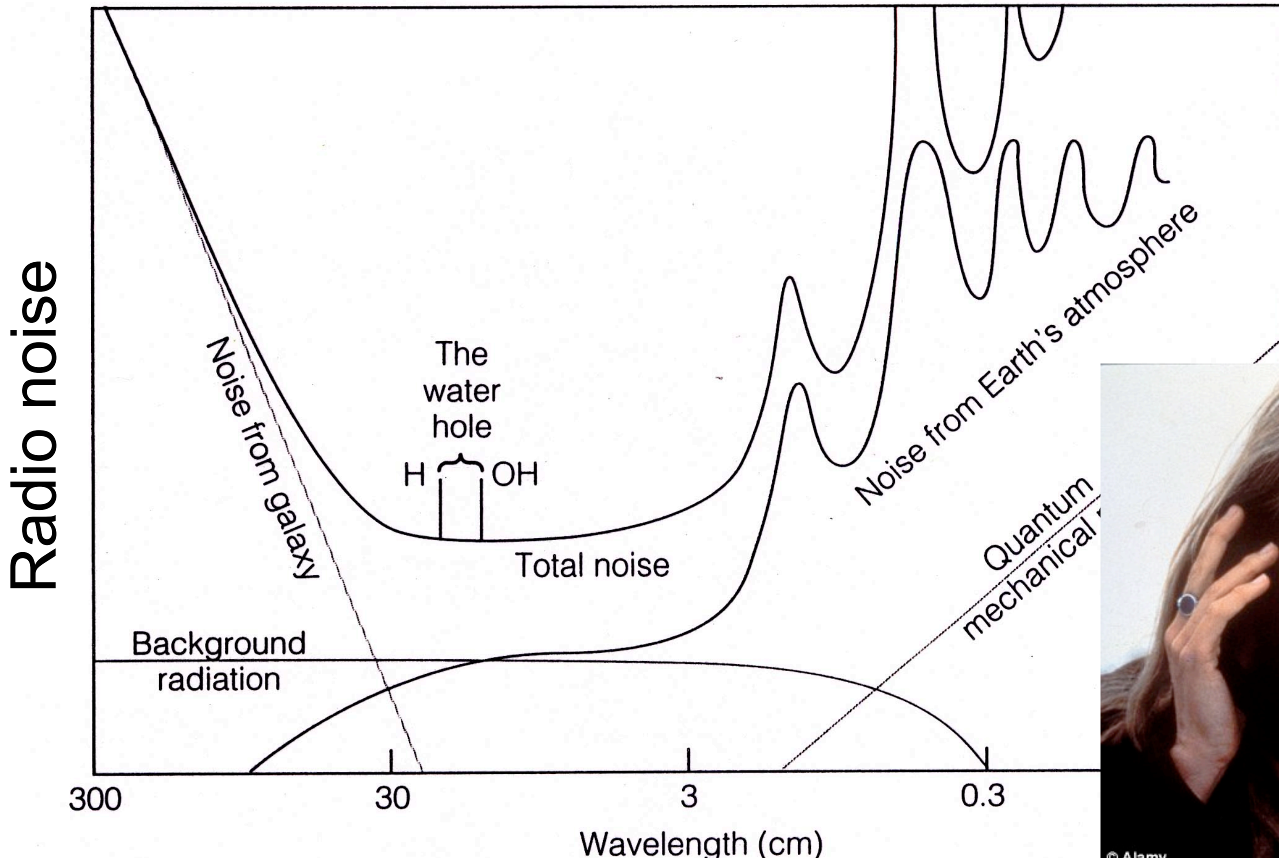

SOMETIMES I THINK THE SUREST SIGN THAT INTELLIGENT LIFE EXISTS ELSEWHERE IN THE UNIVERSE IS THAT NONE OF IT HAS TRIED TO CONTACT US.
WATTERSON

Consider: Would it be a good thing to detect intelligent life elsewhere?

Should we worry whether it is hostile?

Should we worry that we might deprive ourselves of our chance to develop in our own way?

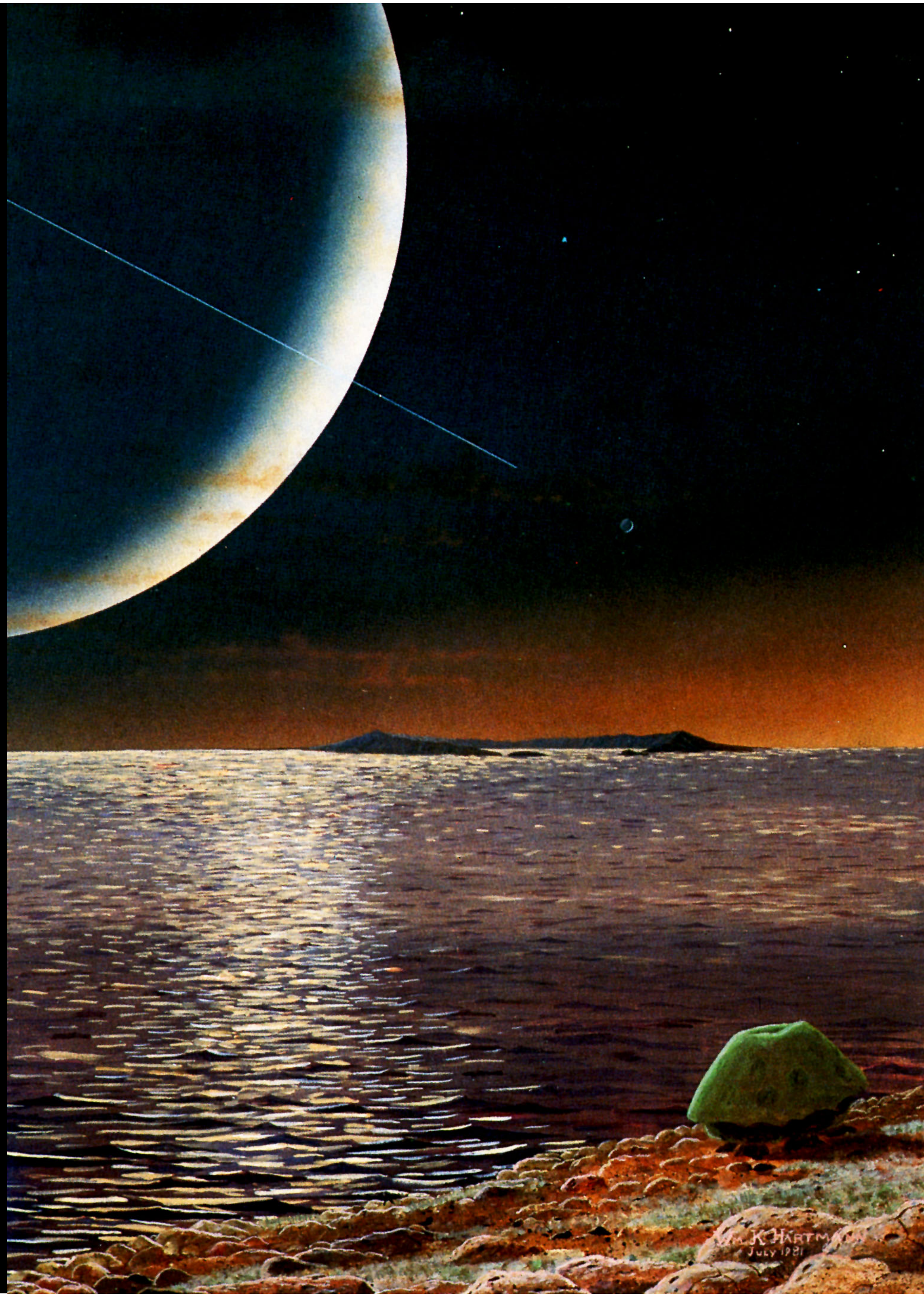
Should we worry that we may not be able to cope with what we learn? After all, we are already good at mass destruction.



Jodie Foster in "Contact"

As funding allows, we listen for artificial patterns in radio noise from nearby stars. So far we have found nothing.

Meanwhile, the oldest episodes of "I Love Lucy" are now more than 50 light years from Earth and still going and going . . .


July 1981

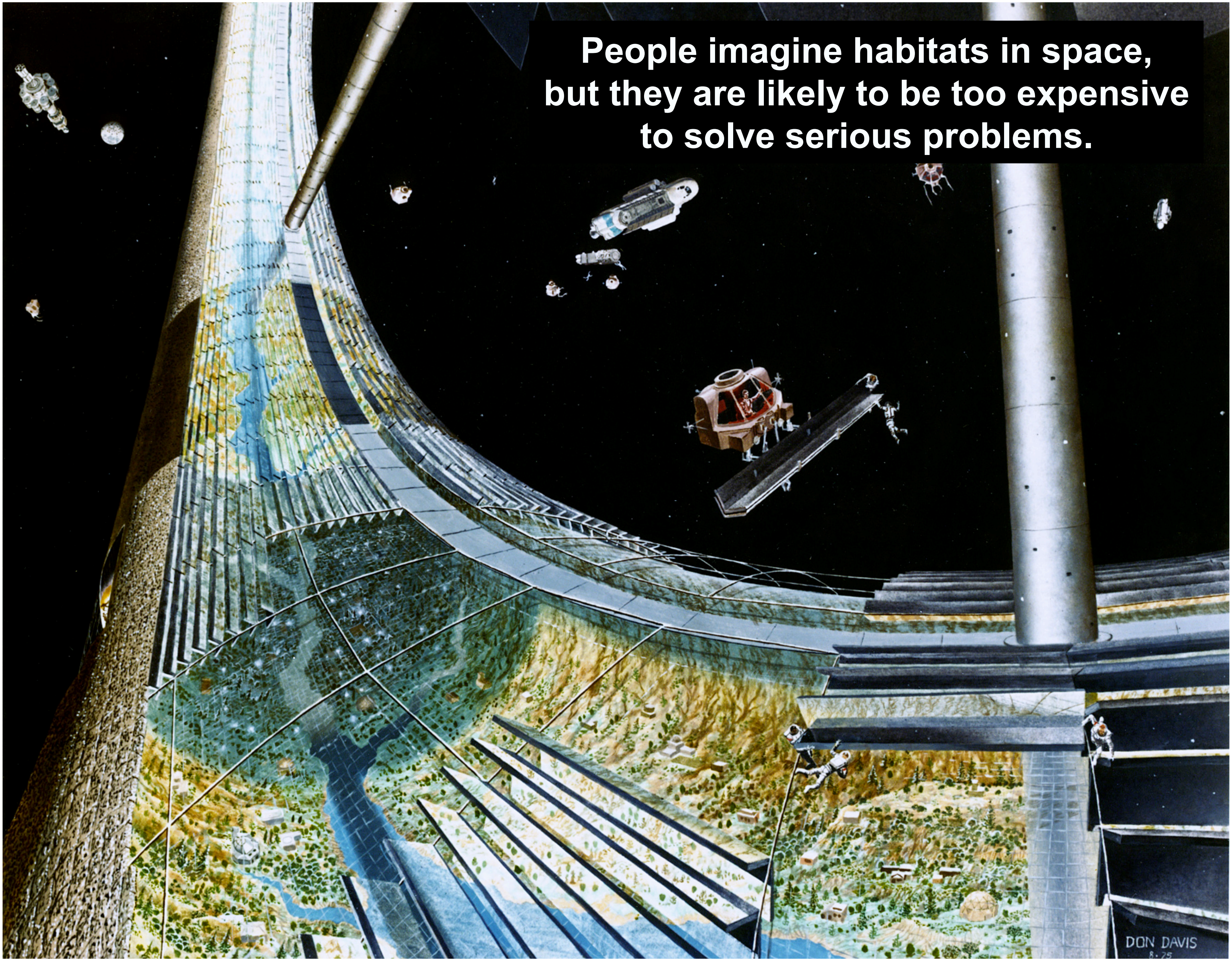
There is a good chance that extraterrestrial life will be discovered in our lifetimes.

Expect that "exolife" will be strange and mysterious.

Our Future in Space

**Population pressure,
commercial prospects,
insurance for our survival,
and our curiosity and sense of adventure
may take us into space in the foreseeable future.**

**What we accomplish
is limited more by politics and by our collective will
than by technology.**



People imagine habitats in space, but they are likely to be too expensive to solve serious problems.

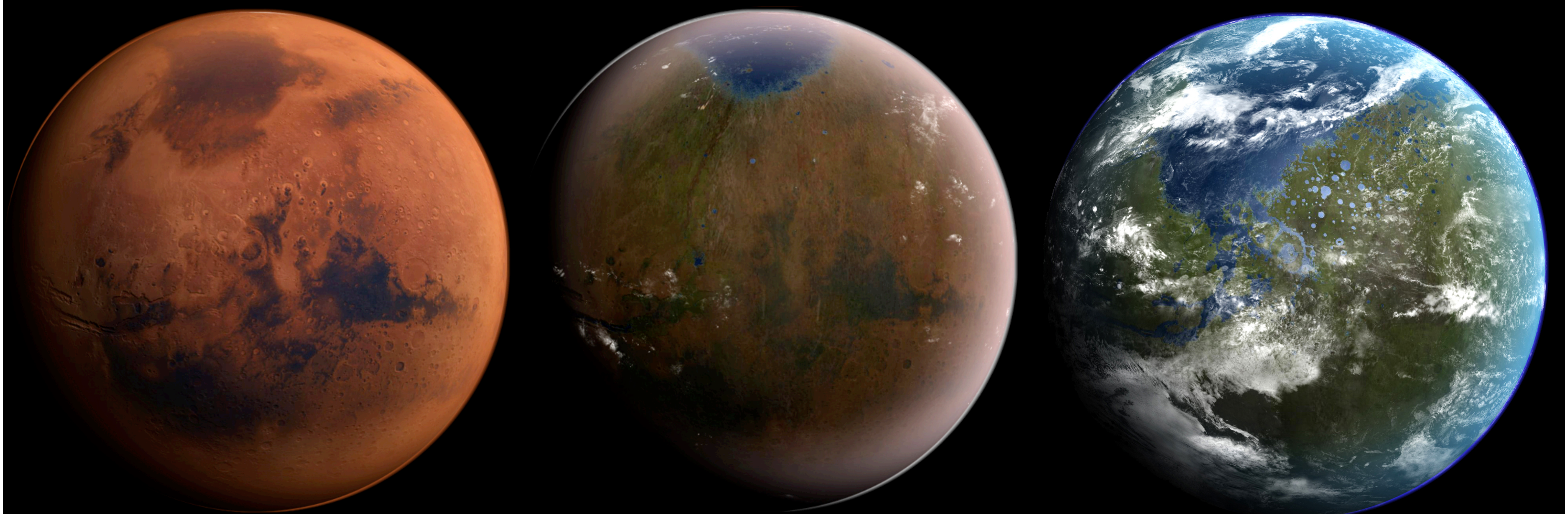
Colonizing Mars is feasible but expensive.

Terraforming Mars

Mars could be terraformed using processes that we already know.

It would take hundreds to thousands of years.

There are ethical questions involved,
especially if there is indigenous life.



If you think that this is science fiction — You’re right!

If you think that it is impossible,
consider what 200 years ago we would have thought about
flying
TV
modern medicine,
etc.

Our Future in Space

Efficient travel to other stars is not possible unless our understanding of physics is very wrong.

Sending "generation ships" that carry a few colonists to spread our civilization to other solar systems may be possible but would require an exceedingly heroic effort.

Terraforming Mars may be possible but would require an exceedingly heroic effort.

Both of the above enterprises would require many generations of effort and would take many generations to bear fruit. Political entities are likely to undertake such efforts only in response to extreme crisis. It is not clear that sufficient resources would be available in such a crisis. Humanity has a very bad history of how it responds to extreme crisis.

Constructing modest colonies in space — on planets, on satellites, inside asteroids, or as free-floating "space stations" — is possible. It would require major efforts, but much less heroic efforts than terraforming or than travel outside our Solar System.

So it is feasible for us to spread out enough in the Solar System to protect ourselves from civilization-threatening disasters like war, epidemic illness, or asteroid impact.

Whether governments will decide that any of this is cost-effective is not clear. Much depends on capricious political, social, and technical developments.

The good news is this: If we can make space travel economically feasible, then we will go into space in a major way. Signs are that this is in progress (e. g., "Virgin Galactic").

Our future is in our own hands.

The greatest adventures of the human spirit can still be before us if we have the will to make them happen.