Alles Introductory Biology: Illustrated Lecture Presentations

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Part Three: The Integration of Biological Knowledge

Major Events in The Proterozoic Eon

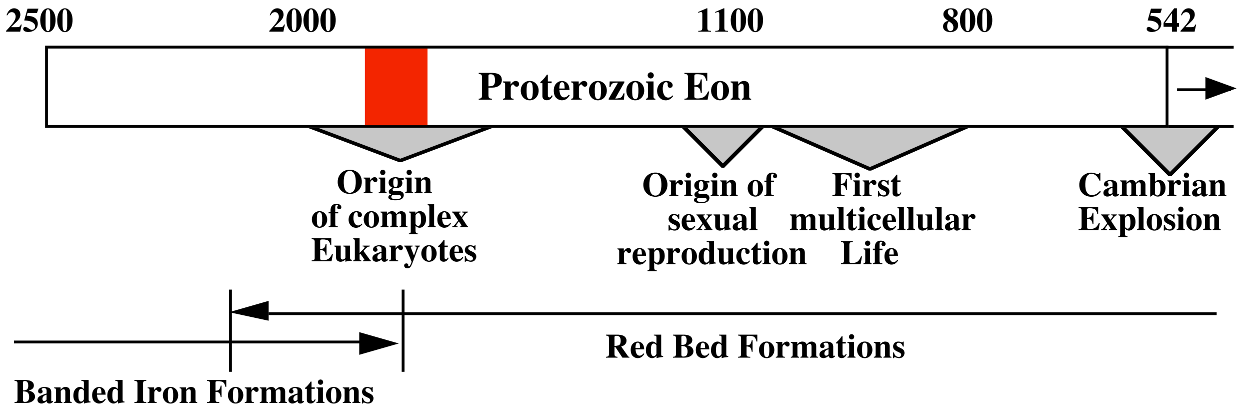
and

Adaptive Radiations & Mass Extinctions

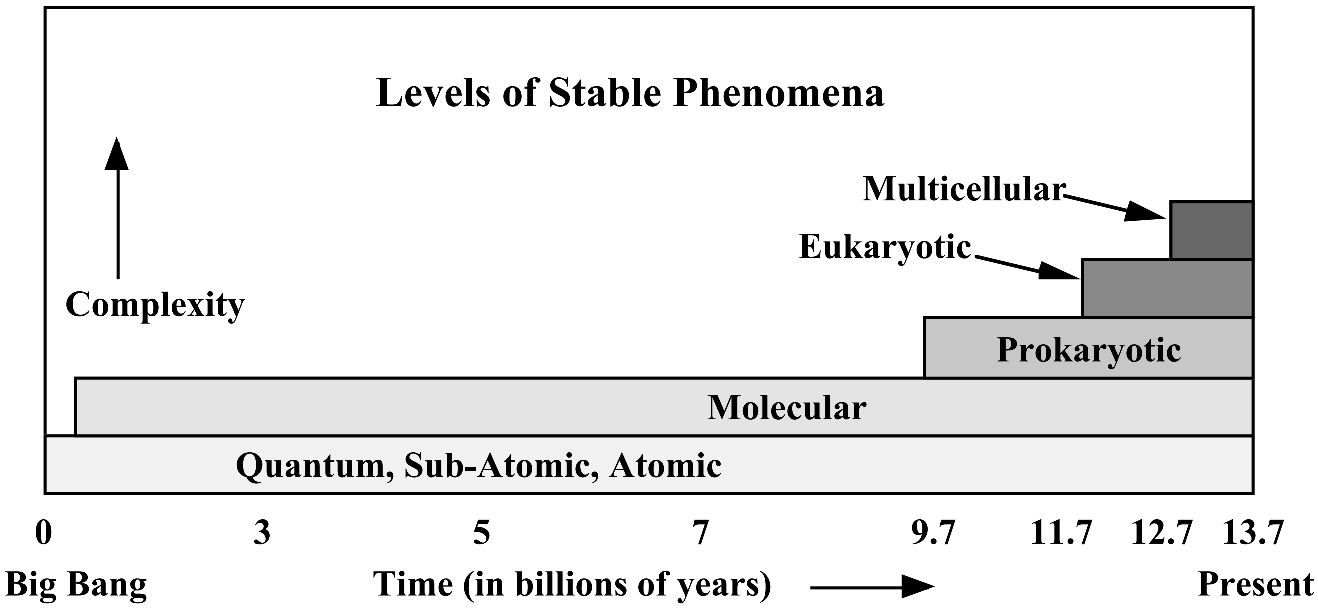
Major Events in The Proterozoic Eon

2500 to 542 m.y.a.

- **The evolution of complex eukaryotes**
- The evolution of sexual reproduction
- The evolution of multicellular life forms



"Organic walled fossils demonstrably made by eukaryotes occur in rocks as old as 1.8 to 1.6 billion years ..."—Falkowski, et al, 2004



The Eukaryotic Level (origin ~ 2000 million years ago)

1) Scale in size—1×10^{-5} to 1×10^{-4} meter or ten to a hundred times larger than the prokaryotic

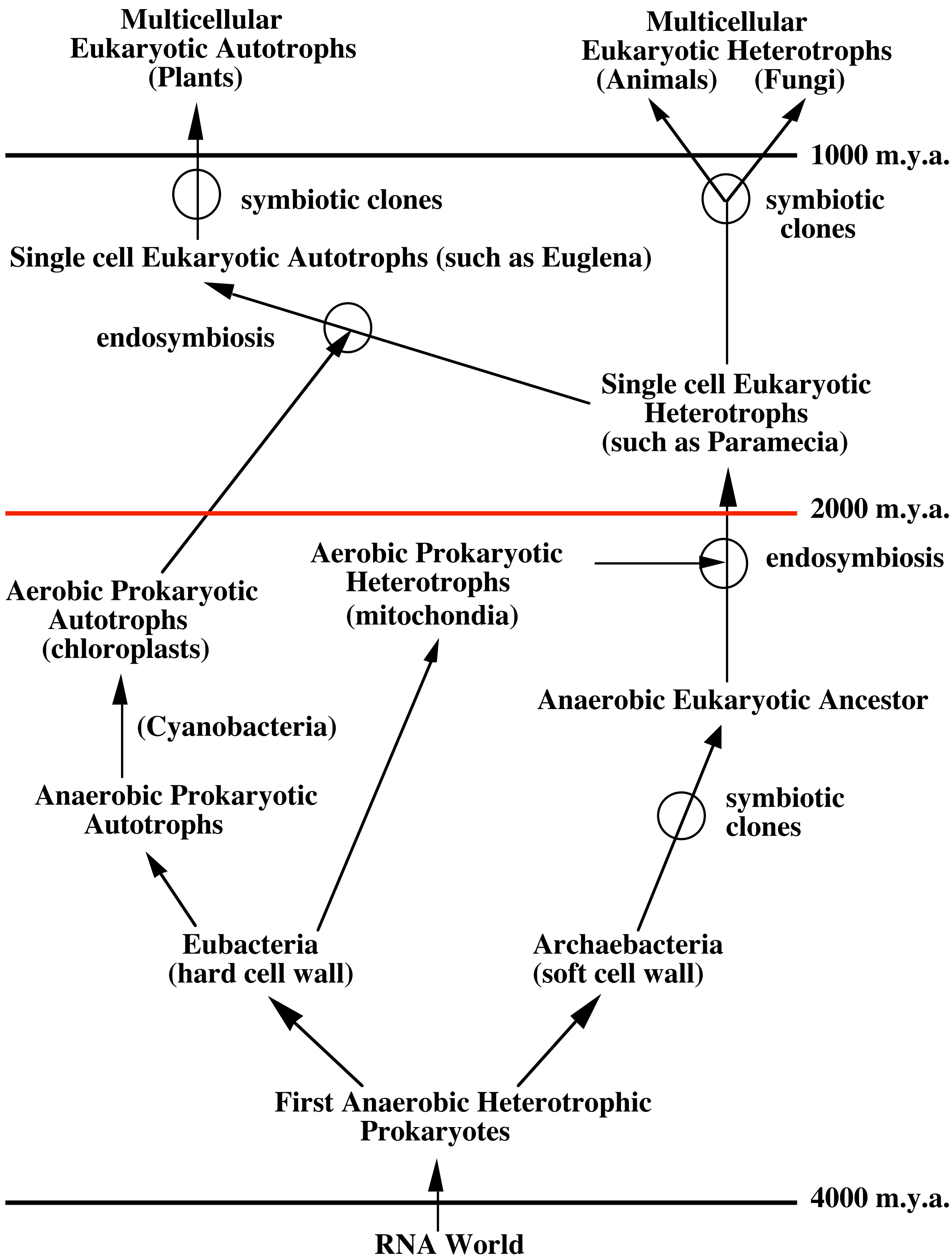
2) Self Organization—endosymbiotic mutualism of primitive eukaryotes and prokaryotic bacteria to form true eukaryotic cells

3) Emergent Properties & Processes—endosymbiotic mutualism; origin of Kingdom *Protista*; evolution of sexual reproduction (origin ~ 1100 million years ago)

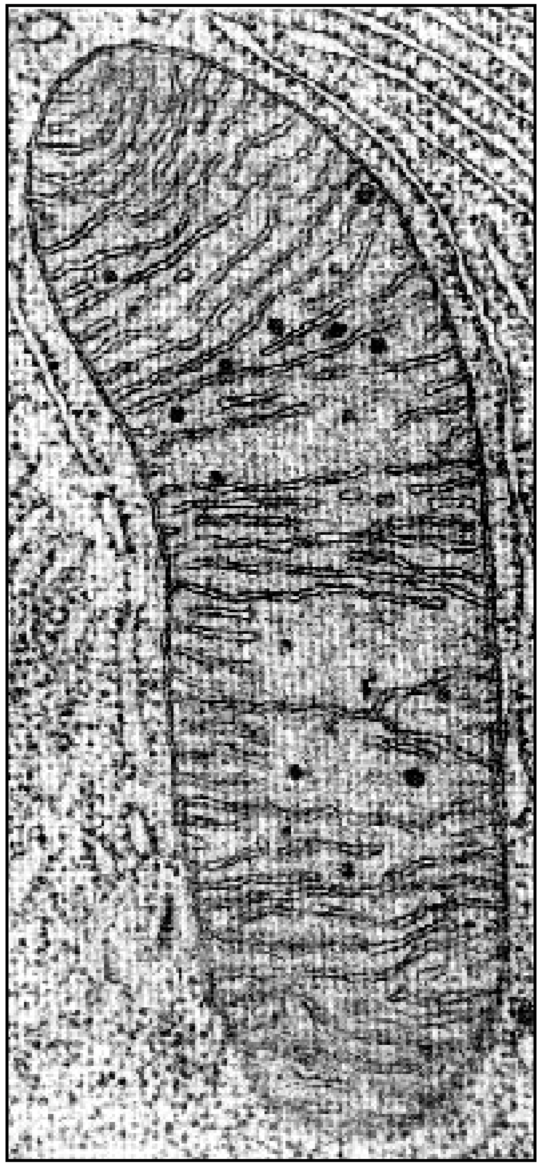
Paramecia, Domain *Eukarya*, Kingdom *Protista*

(Photograph by Dennis Kunkel courtesy of Microbeworld)

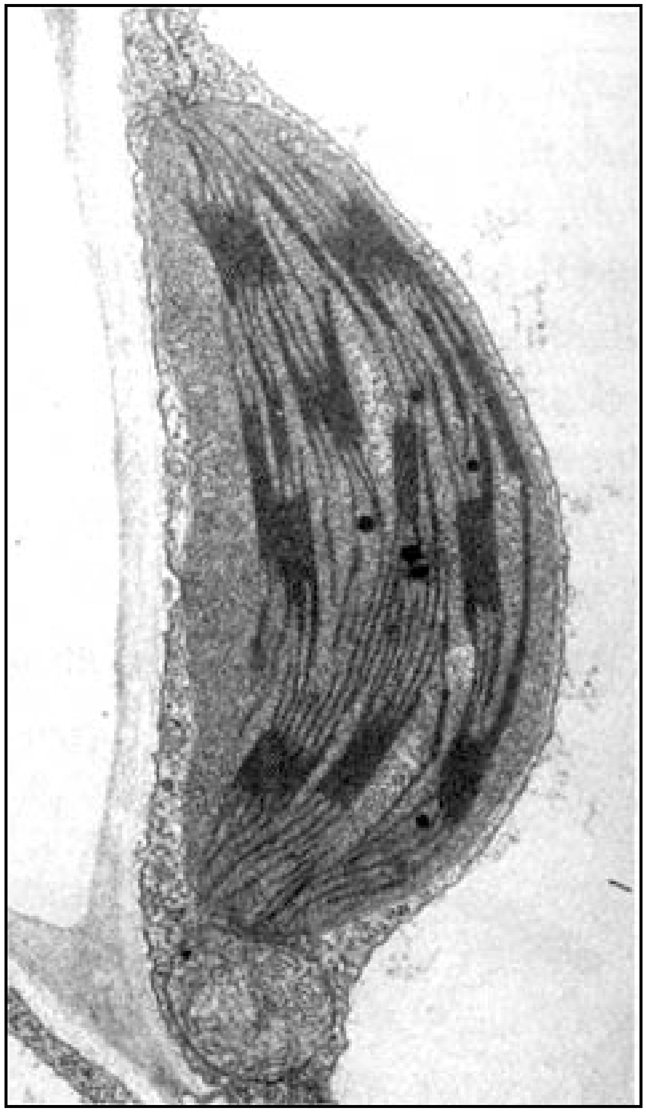
Endosymbiosis & Eukaryotic Cells



Dr. Lynn Margulis, Distinguished Professor at the University of Massachusetts at Amherst, in the 1960's was the first to propose the endosymbiotic theory of eukaryote evolution. Although now a widely accepted theory, both she and her theory were ridiculed by mainstream biologists for a number of years. Thanks to her persistence, biology can now offer a plausible explanation for the evolution of eukaryotes.



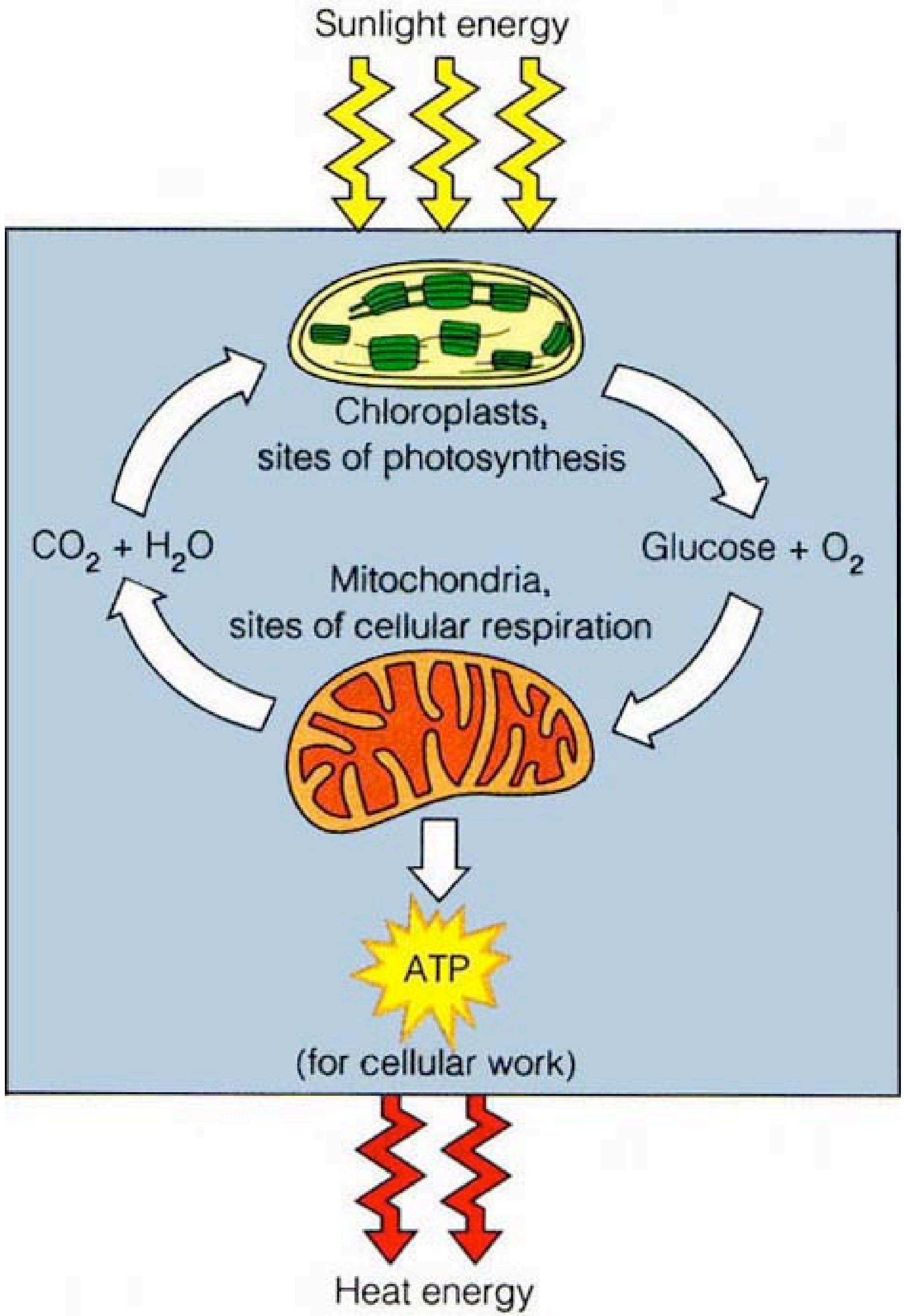
Mitochondria, the descendents of free living aerobic prokaryotes, contain their own DNA and reproduce independent of their host cell.

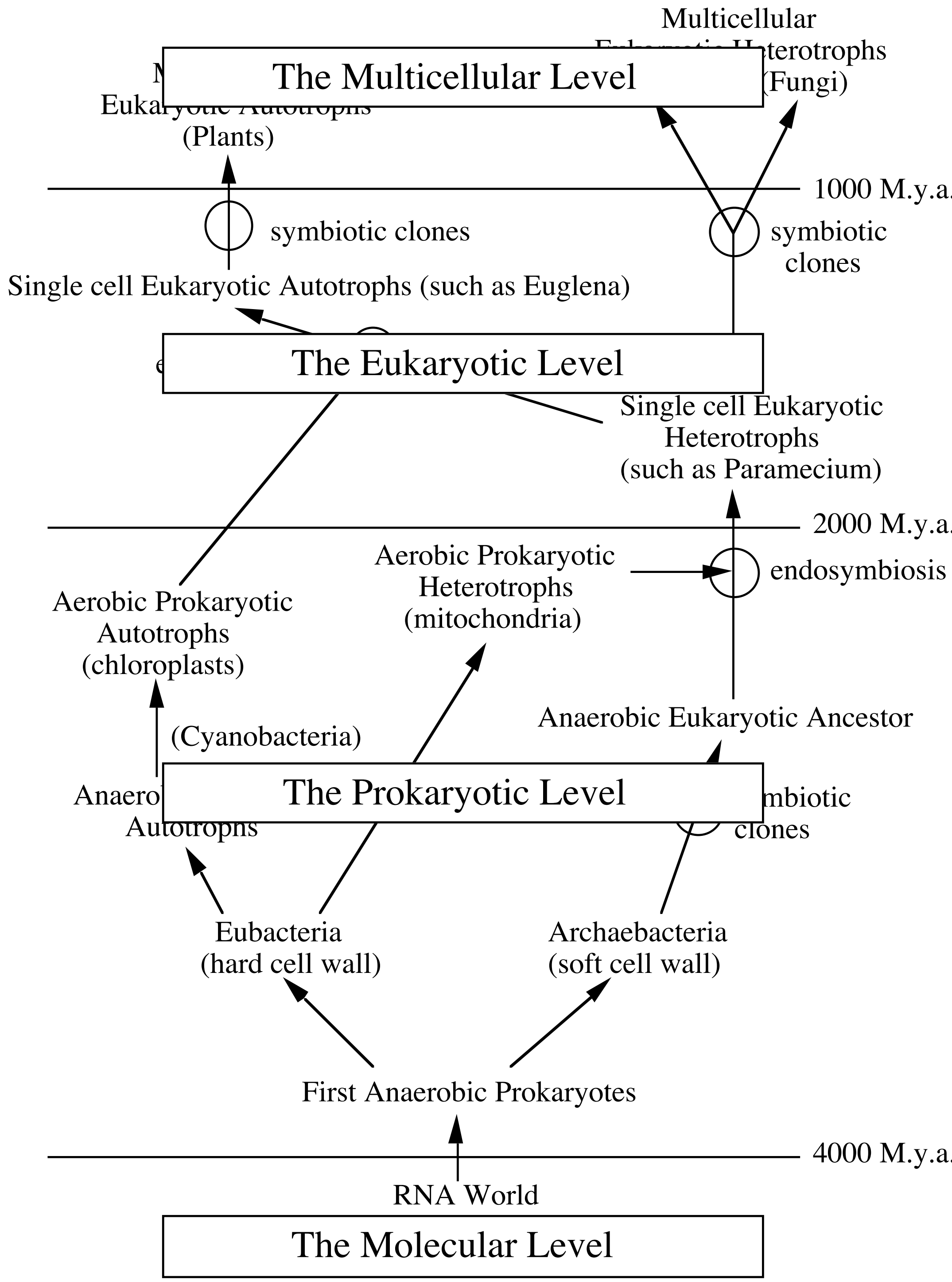


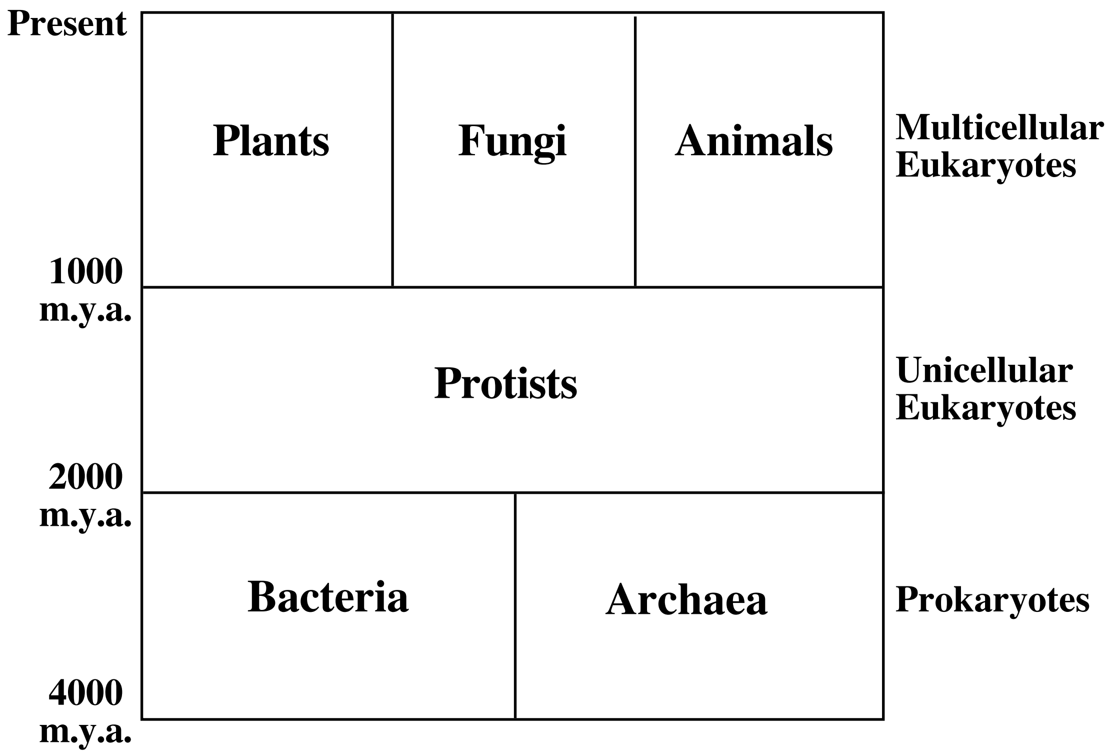
Chloroplasts, the descendents of free living cyanobacteria, also contain their own DNA and reproduce independent of their host cell.

Paramecia, a single cell heterotrophic protist, contains mitochondria.

Euglena, a single cell photoautotrophic protist, contains both mitochondria and chloroplasts.


Sunlight energy
Chloroplasts, sites of photosynthesis
$CO_2 + H_2O$
Glucose + O_2
Mitochondria, sites of cellular respiration
ATP
(for cellular work)
Heat energy


Multicellular
The Multicellular Level
(Fungi)
(Plants)
1000 M.y.a.
symbiotic clones
symbiotic
clones
Single cell Eukaryotic Autotrophs (such as Euglena)
The Eukaryotic Level
Single cell Eukaryotic
Heterotrophs
(such as Paramecium)
2000 M.y.a.
Aerobic Prokaryotic
Heterotrophs
(mitochondria)
endosymbiosis
Aerobic Prokaryotic
Autotrophs
(chloroplasts)
(Cyanobacteria)
Anaerobic Eukaryotic Ancestor
The Prokaryotic Level
Eubacteria
(hard cell wall)
Archaebacteria
(soft cell wall)
First Anaerobic Prokaryotes
4000 M.y.a.
RNA World
The Molecular Level



Classification in Modern Taxonomy: Domains or Kingdoms

The last ten years have seen a revolution in how biologists classify organisms. So much has changed, because of our growing knowledge of the genetic relationships between species, that some of the traditional schemes for classifying life on Earth have become meaningless.

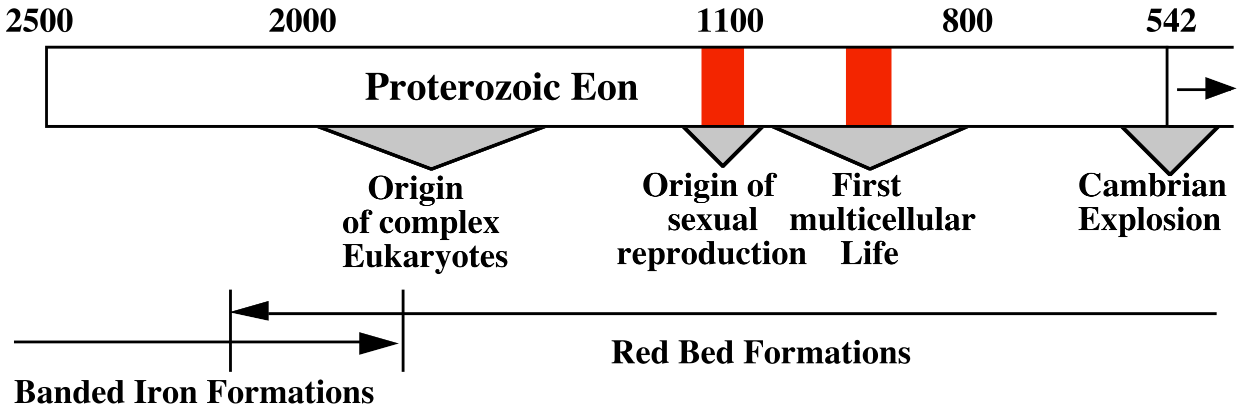
The current state of systematics, as taxonomy is known today, divides all of life into three fundamental groups called domains, Domain *Bacteria*, Domain *Archaea*, and Domain *Eukarya*. But it is also useful to recognize the subdivision of the Domain *Eukarya* into Kingdoms for Protists, Fungi, Animals, and Plants. This gives six basic divisions for life on Earth into which all species can be placed.

Web Reference
http://www.fossilmuseum.net/Tree_of_Life/tree_of_life_main_page.htm

Major Events in The Proterozoic Eon

2500 to 542 m.y.a.

- The evolution of complex eukaryotes
- **The evolution of sexual reproduction**
- **The evolution of multicellular life forms**



2500
2000
1100
800
542
Proterozoic Eon
Origin of complex Eukaryotes
Origin of sexual reproduction
First multicellular Life
Cambrian Explosion
Red Bed Formations
Banded Iron Formations

Binary Fission in Bacteria

Human Egg and Sperm at the Moment of Fertilization

Sex and the Evolution of Death

Why Sex?

For slowly reproducing eukaryotic protists (compared to prokaryotes), sexual reproduction by meiosis has the advantage of rapid genetic mixing of existing genetic variation (Barton & Charlesworth, 1998).

Why Death?

There are two issues concerning death:

1. Death and Uniqueness: In asexual reproduction, such as binary fission in prokaryotes, "offspring" are genetic clones of "parents". It is therefore impossible to tell which is "parent" and which is "offspring". Because of this, prokaryotic life is essentially immortal. As Lewis Thomas puts it in his essay *Death in the Open*,

"There are some creatures that do not seem to die at all; they simply vanish totally into their own progeny. Single cells do this. The cell becomes two, then four, and so on, and after a while the last trace is gone. It cannot be seen as death; barring mutation, the descendants are simply the first cell, living all over again."
—Thomas, 1974

In sexual reproduction, however, because of the nature of cellular division by meiosis, offspring are always genetically different from their parents. For every sexually reproducing organism, each individual is genetically unique at the level of alleles. This genetic uniqueness of individual organisms, along with the division between body cells and reproductive cells in multicellular organisms, is what has given rise to our concept of death.

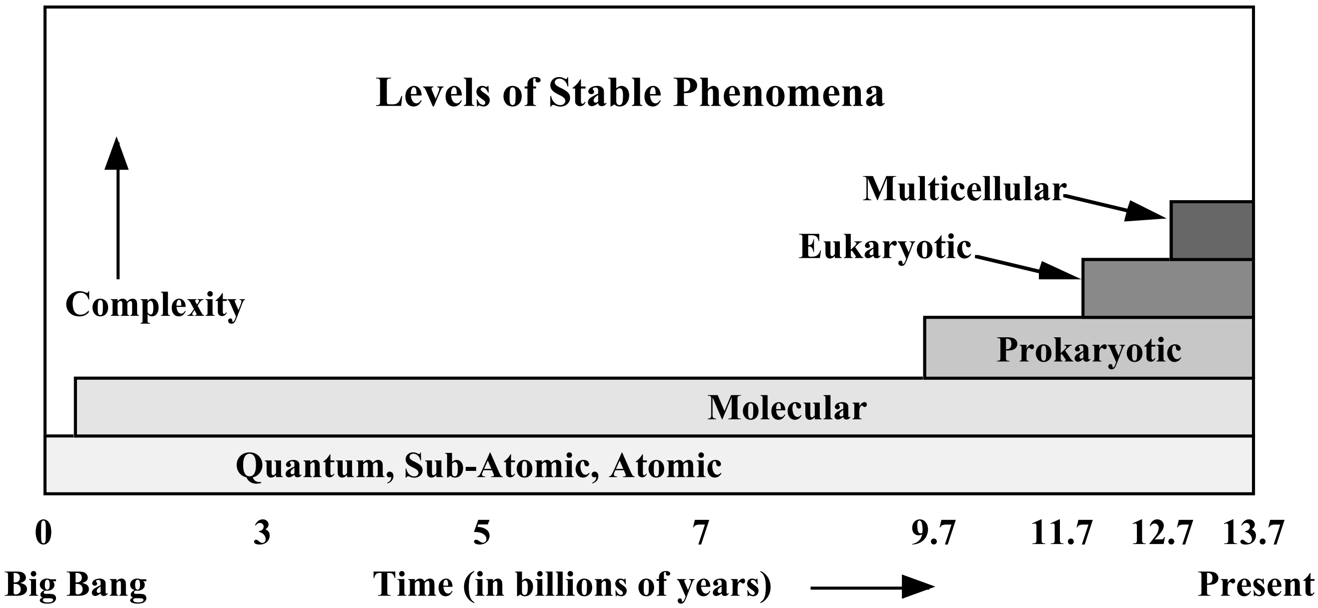
2. Why don't individuals live forever? Why do we grow old?

"In evolution that would not be stable, because eternal youth does not abolish mortality. Sooner or later something will get you: an accident, a new epidemic, and attack by terrorists, or whatever. A mutation that would confer some slight advantage in our early child bearing years that allowed us to leave more offspring might well be favored even if it causes us to drop dead at an older age."—George C. Williams in Roes, 1998

The Evolution of Multicellular Animals

"Before there were single-celled or multicellular eukaryotic consumers, the Earth's ecosystem was relatively simple. Because the primary photosynthetic producers—cyanobacteria and eukaryotic algae—did not suffer predation, they multiplied in aquatic settings to an extent that was limited only by the supply of nutrients essential to their growth. Seas and lakes were, in effect, saturated with algae—a situation that may have slowed evolution by leaving very little room for the origin of new species.

Although the first organisms to feed on algae must have been animal protists, today these forms are feeble in this role in comparison to the multicellular animals, which because of their size can consume algae rapidly. Thus, the origin of eukaryotic consumers, especially multicellular animals, added a new trophic level to many aquatic ecosystems."—Stanley, 1989



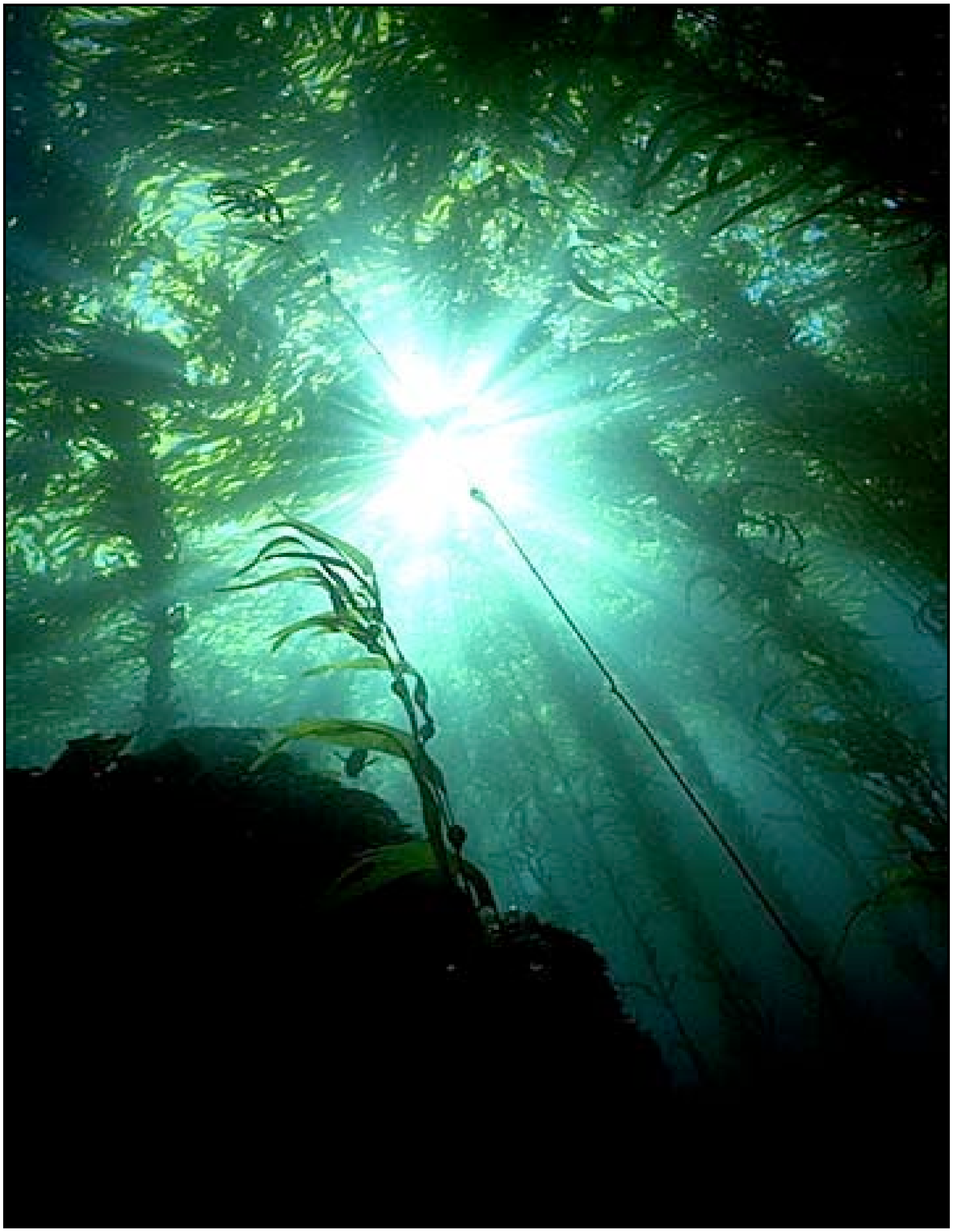
The Multicellular Level (origin ~1000 to 600 million years ago)

1) Scale in size—one thousandth of human scale to human scale or 1×10^{-3} to 1 meter

2) Self Organization—multicellular organization by cell types into tissues and organs, to whole organisms

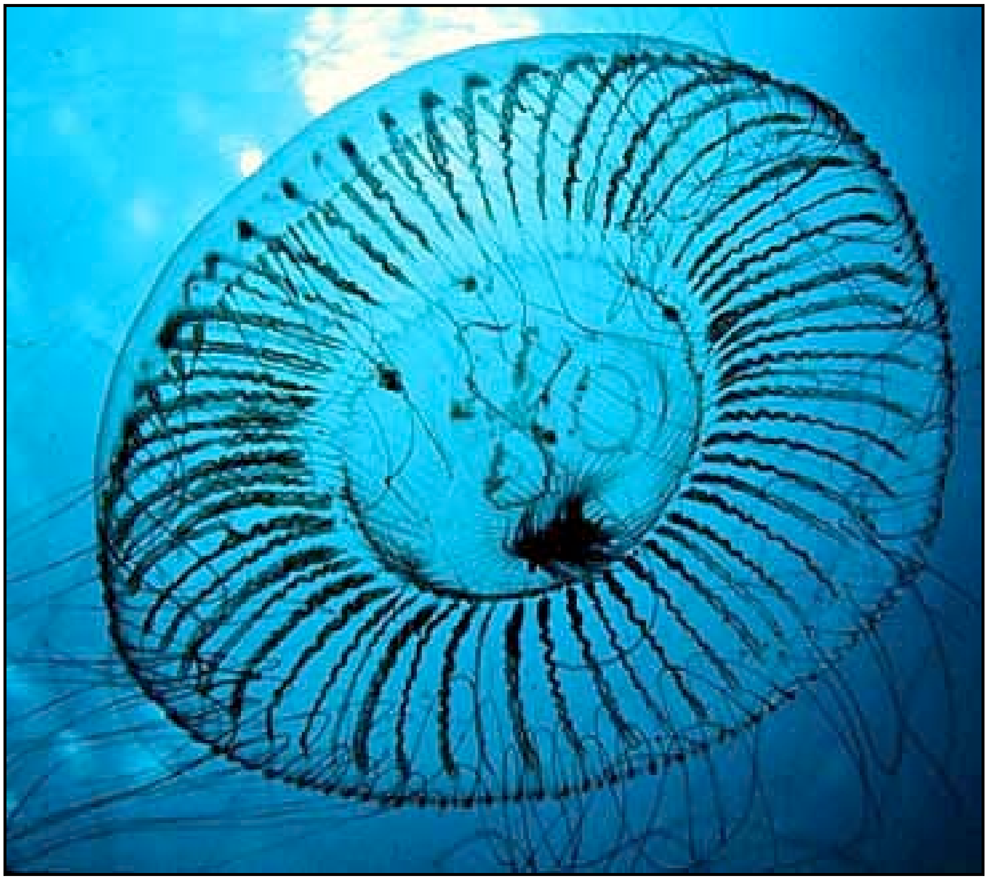
3) Emergent Properties & Processes—cell specialization; emergence of large life forms; origin of Kingdoms *Fungi*, *Plantae*, and *Animalia*; social behavior; language

A 5000 Cell Colony of Volvox Algae, Kingdom *Protista*



An Underwater Forest of Multicellular Brown Algae

Commonly known as kelp these primitive multicellular organisms can grow to over 100 feet (30 meters) long. Giant Kelp, pictured above, is one of the key species in the kelp forests that stretch from Northern California to Alaska.



Aequorea victoria* (a jellyfish), Kingdom *Animalia

Animals first appear in the fossil record around 600 million years ago as frond-like forms, jellyfish-like imprints, and trace fossils. These fossils appear simultaneously on all continents, except Antarctica, and each assemblage contains roughly the same kinds. At the end of the Proterozoic about 550 million years ago, all of the modern phyla of animals appear in the fossil record.

(Photograph by David Wrobel)

Web Reference

http://www.ucmp.berkeley.edu/vendian/vendian.html

The Evolution of Life and Energy

• From the evolution of photosynthesis that led to increasing oxygen in the atmosphere;

• to the evolution of aerobic respiration in heterotrophic prokaryotes —like mitochondria—that could consume the carbohydrates produced by autotrophic prokaryotes;

• to the evolution of eukaryotic life with its abundant energy from mitochondria;

• to the evolution of sexual reproduction that provided genetic mixing for large, complex and slowly reproducing eukaryotes;

• to the evolution of heterotrophic multicellular life that could effectively consume abundant autotrophic eukaryotic life;

• we see life evolving mechanisms to take advantage of new sources of energy.

Relative Time

• On the order of 2000 million years elapsed between the origin of life on Earth and the evolution of the first complex eukaryotic protists. This represents two billion years of prokaryotic evolution, half of the history of life.

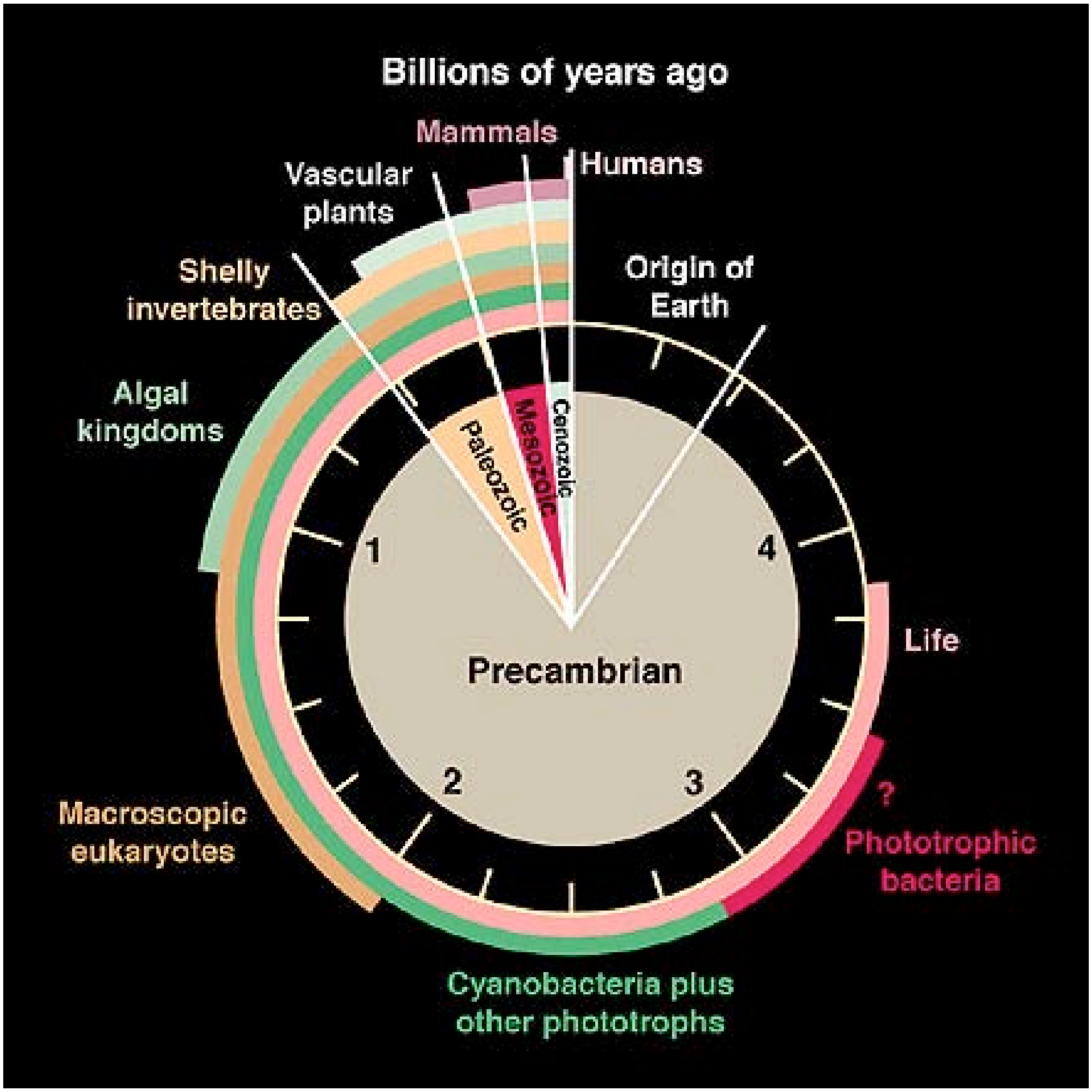
• Almost 1000 million years elapsed between the origin of complex eukaryotes and the first evidence of sexual reproduction.

• It was then only from 100 to 400 million years between the evolution of sexual reproduction and the evolution of the first multicellular organisms—creatures like ourselves.

• So for approximately 3000 million years of the history of life on Earth all life-forms were single cell. This is 75% of the total history of life.

• And fully 4000 million years elapsed between the formation of the Earth and the beginning of the Phanerozoic eon 542 m.y.a.—the eon of multicellar life.

• In stark contrast, all of recorded human history occupies only 0.005 million years. That is 0.00000125 of the history of life on Earth.



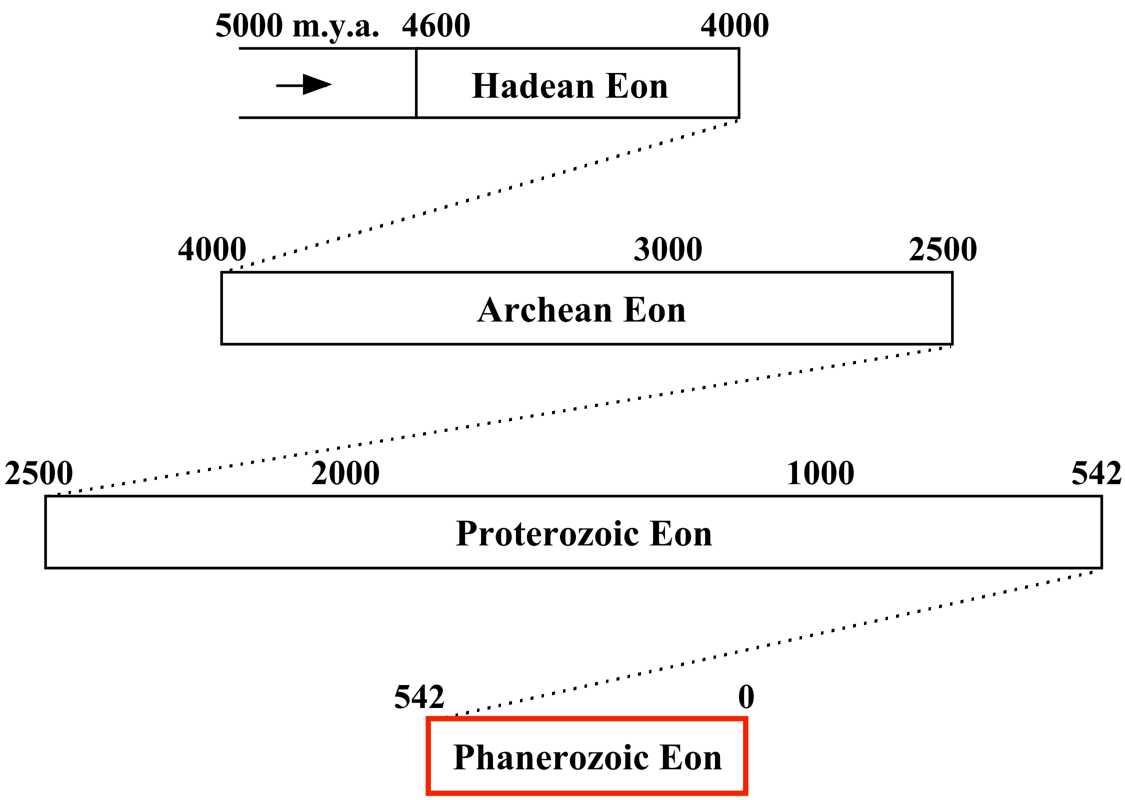
The History of the Earth and Life over 5 Billion Years

(Figure from Des Marais, 2000)

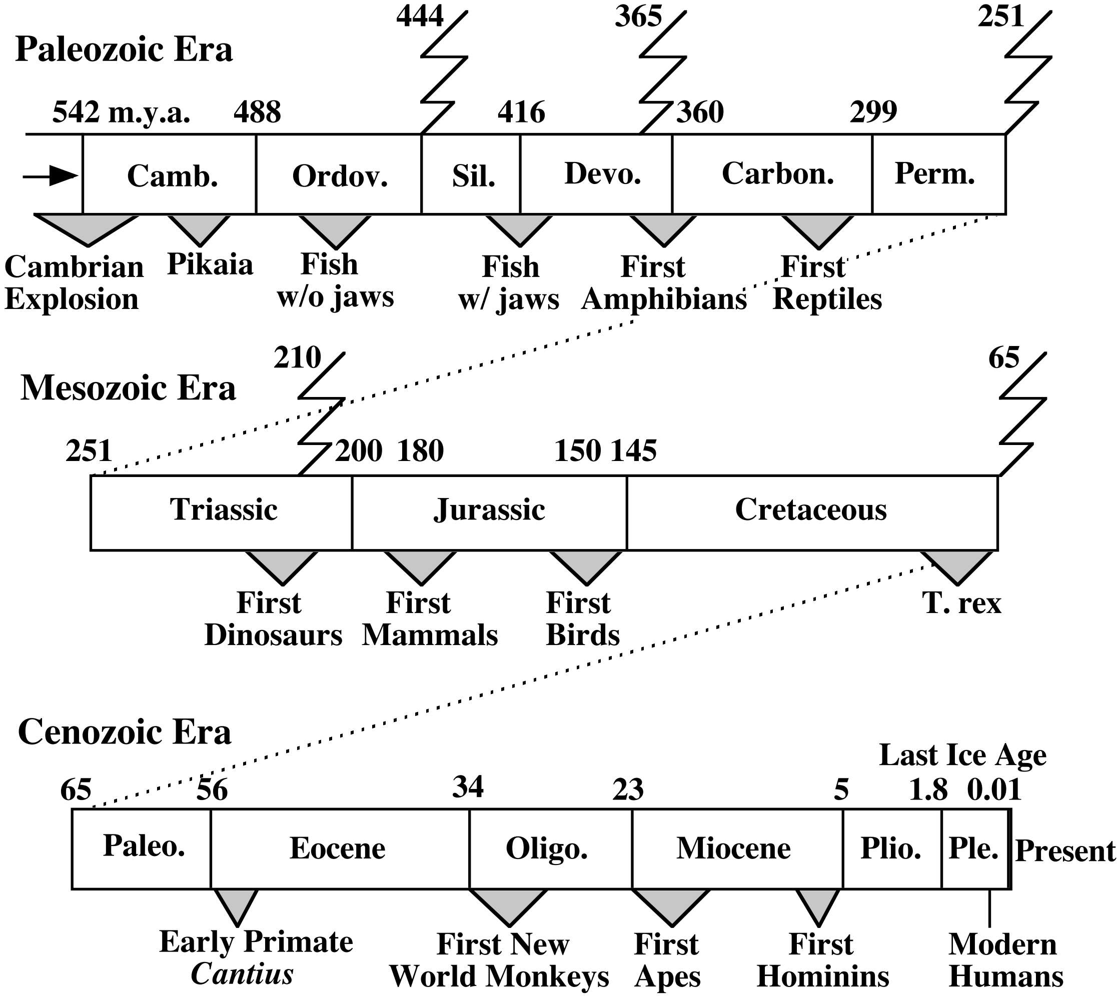
Part Three: The Integration of Biological Knowledge

Adaptive Radiations & Mass Extinctions

Geologic Timeline



The Phanerozoic Eon



Major Events in the Phanerozoic Eon

1. the Cambrian adaptive radiation—the evolution of all of the basic body plans of animals including the evolution of the notochord
2. the mass extinction event at the end of the Ordovician
3. the colonization of land by plants and then insects in the Silurian
4. the adaptive radiation of fish in the Devonian
5. the mass extinction event during the late Devonian
6. the evolution of the first land vertebrates, the amphibians, during the late Devonian
7. the evolution of internal fertilization and the amniotic egg with the first reptiles in the Carboniferous
8. the mass extinction event at the end of the Permian
9. the adaptive radiation of the dinosaurs in the Mesozoic
10. the mass extinction event during the late Triassic
11. the evolution of the first true mammals in the early Jurassic
12. the mass extinction event at the end of the Cretaceous
13. the adaptive radiation of mammals, including primates, in the Cenozoic

The Five Mass Extinction Events of the Phanerozoic Eon
(after Benton, 2003)

1. End Ordovician ~ 444 m.y.a. with a loss of at least 50% percent of species.

2. Late Devonian 370 to 360 m.y.a. with a loss of at least 50% percent of species.

3. End Permian 251* m.y.a. with a loss of 80 to 95 percent of species.

4. Late Triassic ~ 210 m.y.a with a loss of at least 50% percent of species.

5. End Cretaceous 65* m.y.a. with a loss of at least 50% percent of species.

Three things happened in all the mass extinctions of the Phanerozoic.

A. many species became extinct, generally more that 50%.

B. the extinct forms span a broad range of ecologies, and they typically include marine and non-marine forms, plants and animals, microscopic and large forms

C. the extinctions all happened within a short time, and hence relate to a single cause, or cluster of interlinked causes.

*These mass extinctions have been dated to a very short or instantaneous period of time and have, therefore, very precise dates.

Adaptive Radiations and Mass Extinctions

A new evolutionary adaptation may lead to a new level of evolutionary stability that, because of its inherent potential to provide new opportunities for life, gives rise to an adaptive radiation of new species. Multicellularity was such an evolutionary adaptation, and it gave rise to the explosive radiation of animal evolution known as the Cambrian Explosion.

The history of the Phanerozoic Eon is marked by such adaptive radiations of species. The events that have driven these bursts of rapid evolution follow a pattern of abiotic change that leads to mass extinction events that, in turn, set the stage for a new round of adaptive radiation by a new group of species. The major abiotic causes for such mass extinctions are associated with **plate tectonics** and **meteorite impacts**.

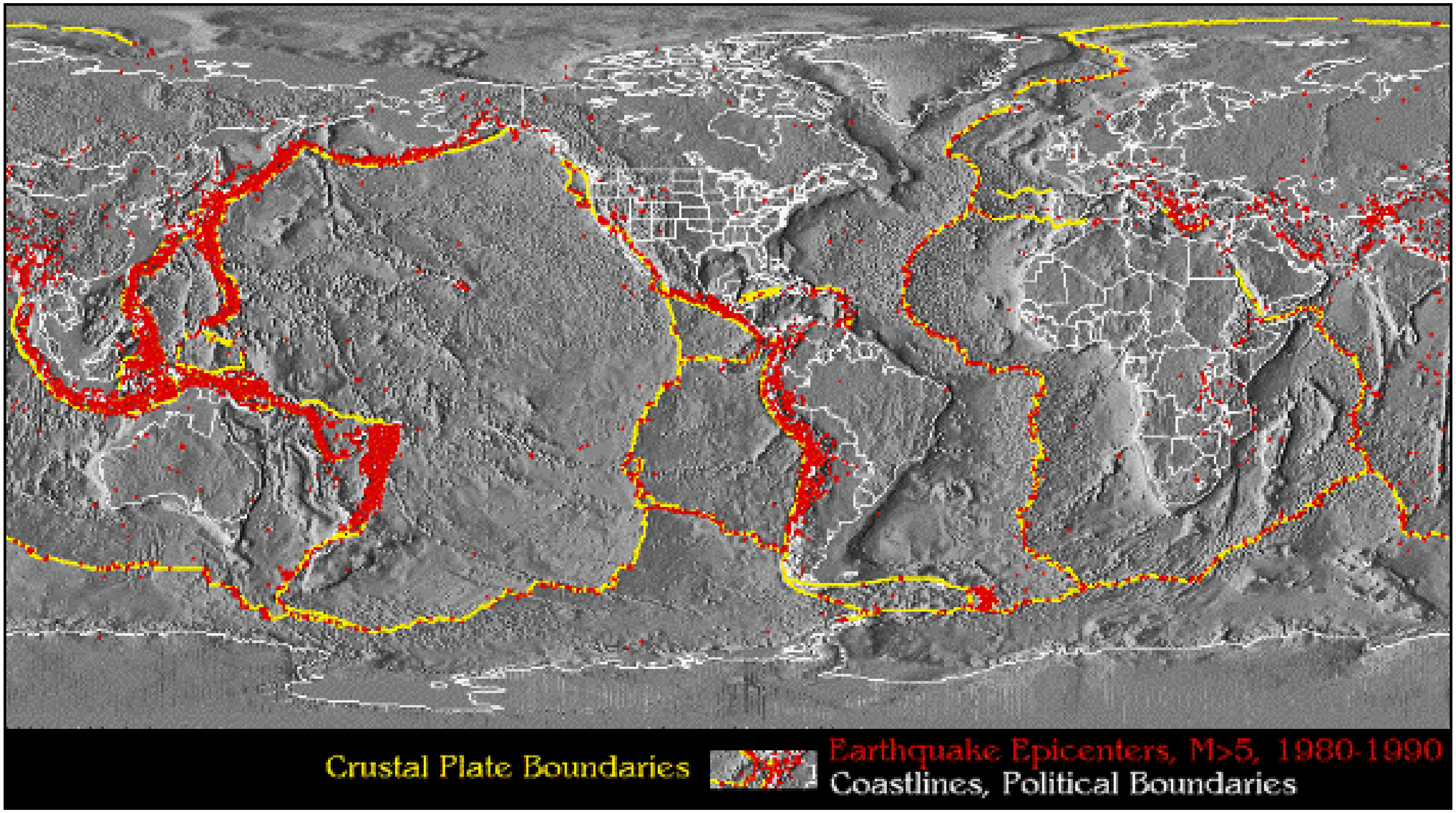


Plate Tectonics

Web Reference
http://pubs.usgs.gov/publications/text/dynamic.html

Barringer Meteorite Crater

The Barringer Meteorite Crater is a gigantic hole in the middle of the arid sandstone desert 20 miles outside Winslow, Arizona. A rim of smashed and jumbled boulders, some of them the size of small houses, rises 50 meters above the surrounding plain. The crater itself is nearly a 1500 meters wide and 180 meters deep. When Europeans first discovered the crater, the plain around it was covered with chunks of meteoritic iron—over 30 tons of it—scattered over an area 12 kilometers to 15 kilometers in diameter. Scientists now believe that the crater was created approximately 50,000 years ago. The meteorite itself was composed almost entirely of nickel-iron, suggesting that it may have originated in the interior of a small planet. It was 50 meters across, weighed roughly 300,000 tons, and traveled at a speed of 65,000 kilometers per hour.

(Photograph by Louis Maher http://www.geology.wisc.edu/~maher/air.html)

Essay—The Effects of Meteorite Impacts

"The effects of an impact on life depend in a qualitative way on the impact energy. The smallest space debris to hit Earth's atmosphere is slowed to benign speeds by gas drag or vaporized before it hits the ground. The largest impactors can melt a planet's crust and eliminated life entirely. Strong iron impactors ranging in size from that of a car to that of a house may hit the ground at high velocity, killing living beings in their path. The rocky bolide that exploded over Tonguska, Siberia, in 1908 was about the size of a football field; it produced a blast wave that knocked over trees tens of kilometers away.

An impactor a few kilometers in size would throw enough dust into the upper atmosphere to substantially darken the sky for much of a growing season. The threat of such an impactor to human food supplies has led NASA to initiate a program to detect all near-Earth asteroids (NEAs) larger than about 1 km.

Mass extinctions (such as that at the K/T boundary) result from even larger impacts, which load the atmosphere with dust and chemicals (from vapor and pulverized matter originating in both the impactor and the crater ejecta). Radiation from high-velocity ejecta re-entering the atmosphere may cause global fires. Even larger impacts fill the atmosphere with enough hot ejecta and greenhouse gases to vaporize part or all of the planet's oceans."
—Lissauer, 1999

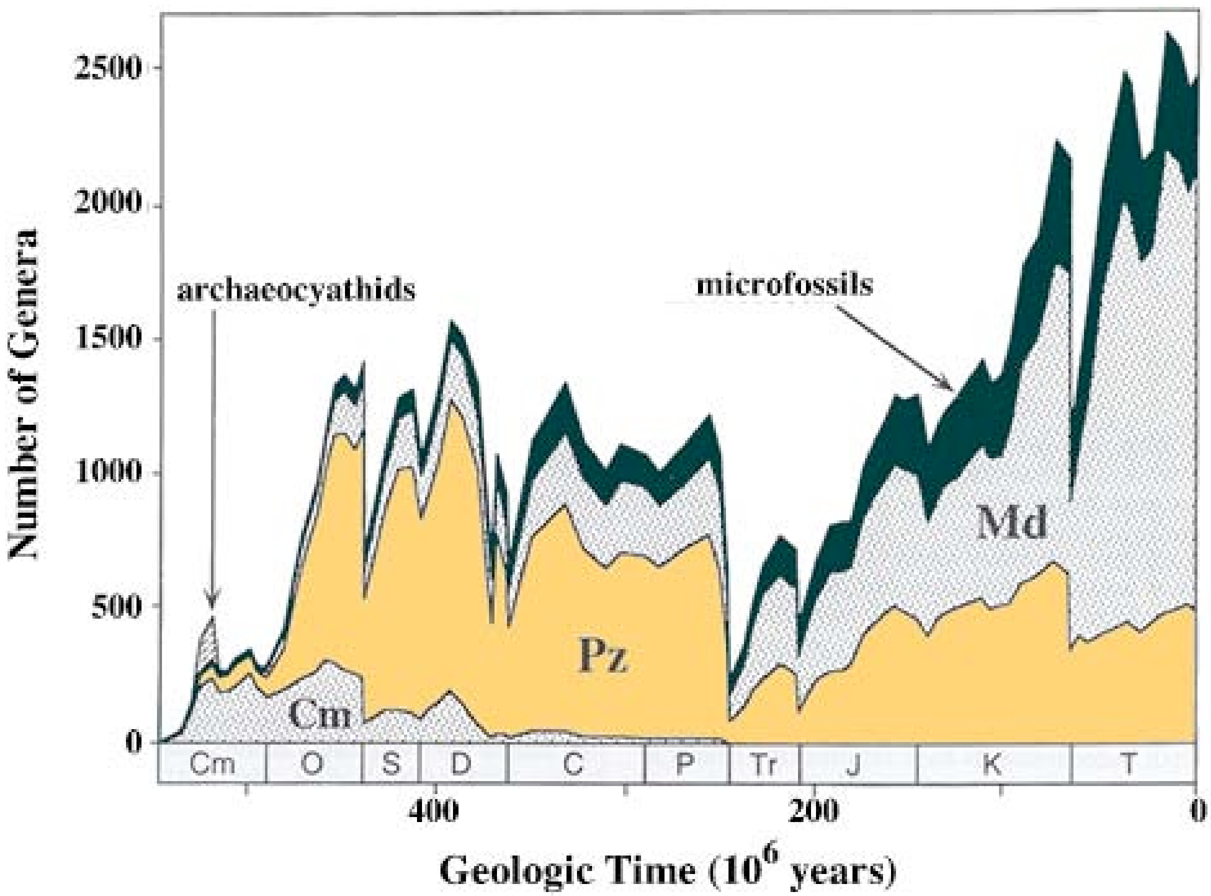
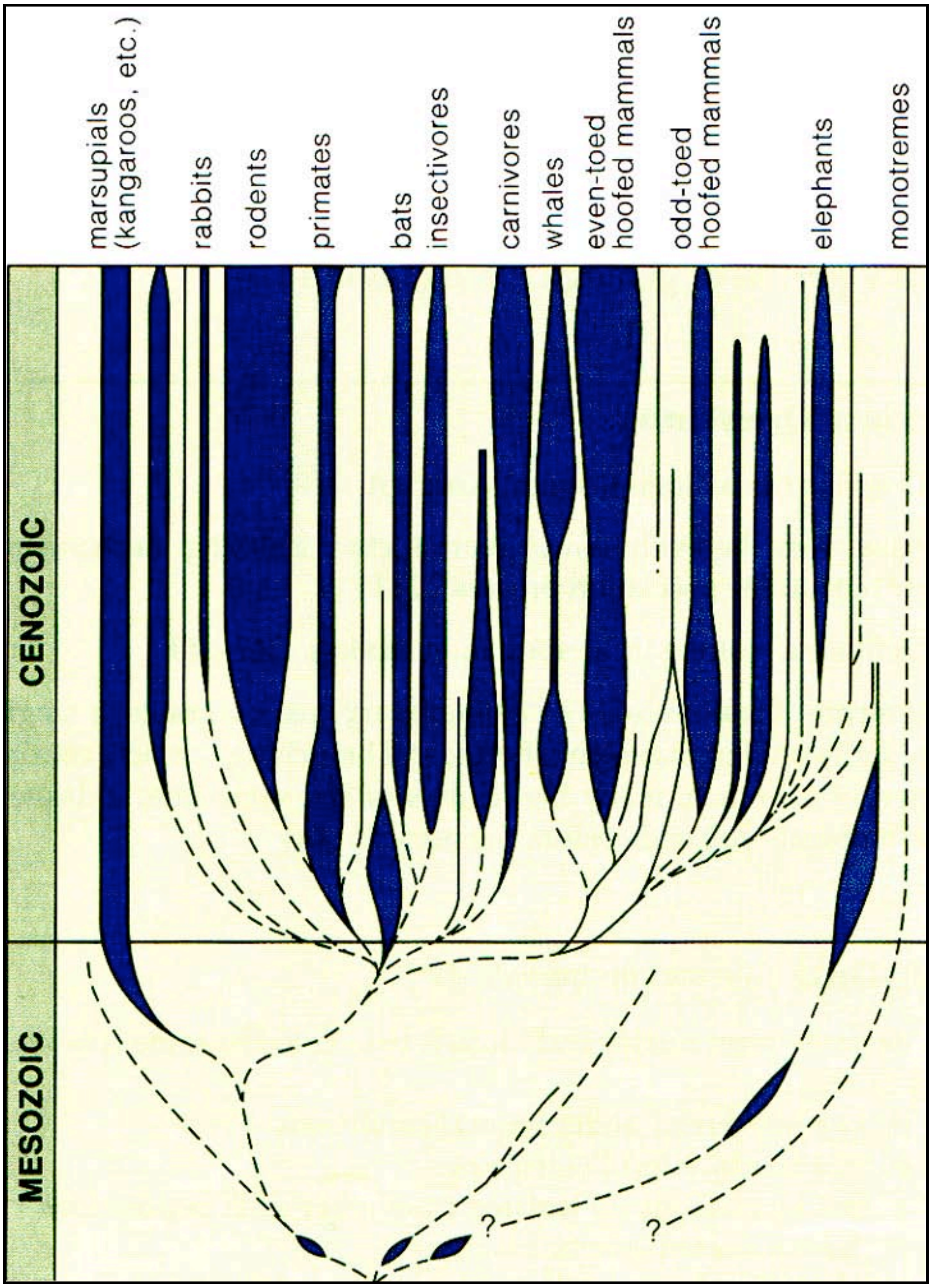


Chart of Biodiversity in the Phanerozoic Eon

This chart is from the work of paleontologist J. John Sepkoski Jr., originally published in 1984 and revised in 1993. This work has been called into question over the last two years with claims of bias in sampling the fossil record. David Jablonski has recently shown (Jablonski, et al., 2003) that these claims of bias are greatly over stated (by a factor of 10) and that Sepkoski's work is still a viable portray of the increase in biodiversity in the Phanerozoic Eon and the effects of mass extinctions. Sepkoski died in 1999.



The Adaptive Radiation of Mammals

Adaptive radiations characteristically follow mass extinction events as shown in this chart of the adaptive radiation of mammals following the mass extinction of the dinosaurs 65 million years ago.

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