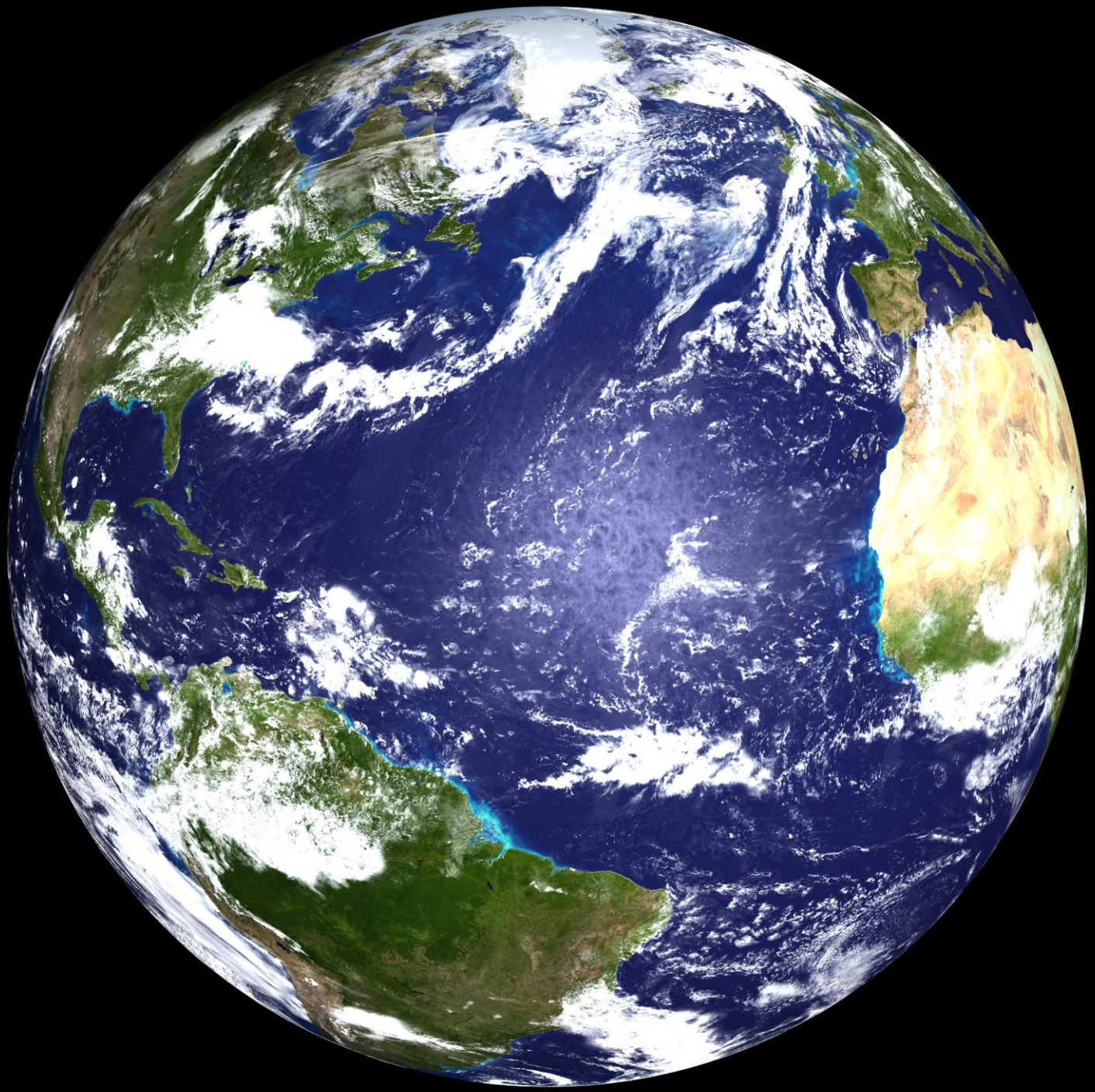
A Brief History of Earth

(and the rest of the universe)

Daniel I. Carey



How Old is the Earth?

350 years ago, Europeans thought the earth was less than 6,000 years old.

Bishop Ussher, Primate of Ireland in 1650 used the Bible to determine that Earth was created on October 23, 4004 b.c.

Scientists have now determined that the earth is not 6,000 but 4,600,000,000 years old.

The Structure of Scientific Revolutions, by Thomas S. Kuhn.

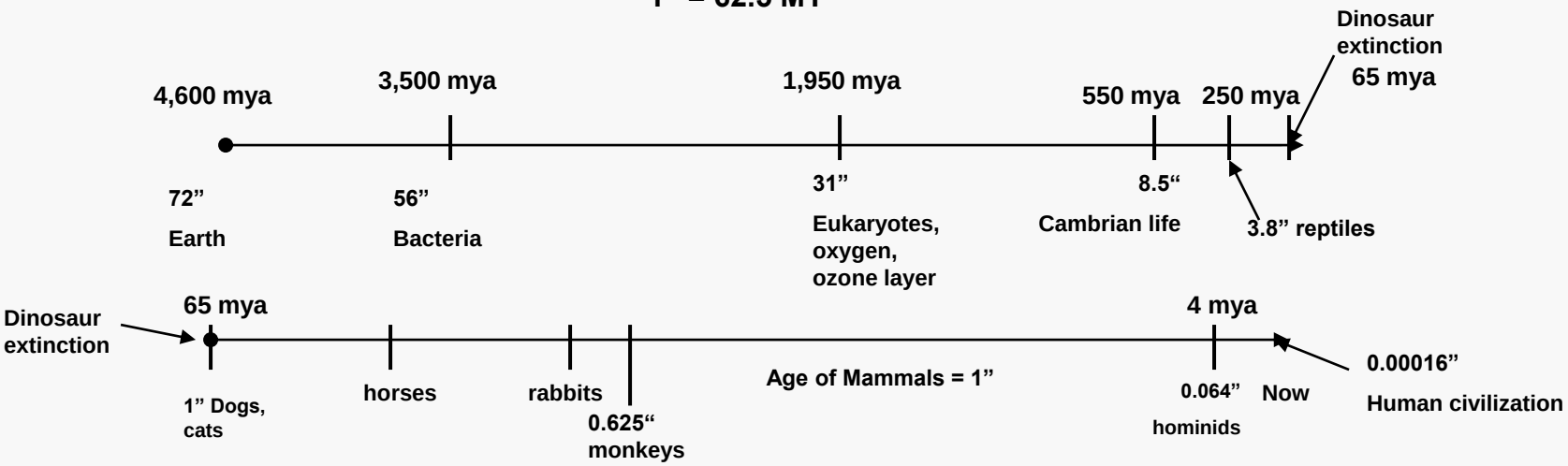
The Garden of Eden—Painting by Patricia Melvin

Timeline of Earth History

Age of Earth = 6’

750 MY = 12”

1” = 62.5 MY



Annals of a Former World, John McPhee

At 4.6 billion years, the earth is 750,000 times older than Bishop Ussher calculated. If we measure the earth’s age with a 6 foot ruler, the emergence of life as we know It has occurred only a few inches from the end; mammals arising about 1 inch from the end. The length of time of human civilization Is less than the thickness of a human hair on the end of the ruler.

Earth Clock

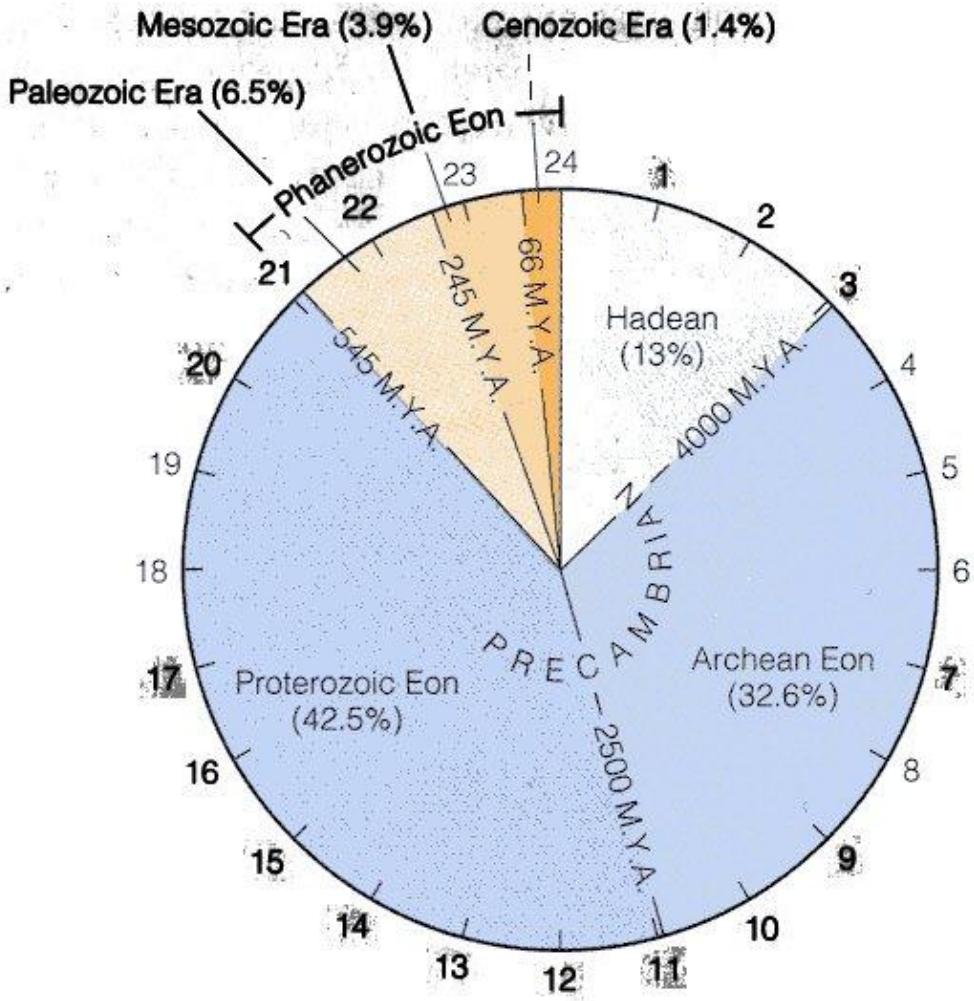


FIGURE 8.2 Geologic time represented on a 24-hour clock. Precambrian time includes more than 21 hours on this clock, or more than 88% of all geologic time.

Hominids--1.5 minutes

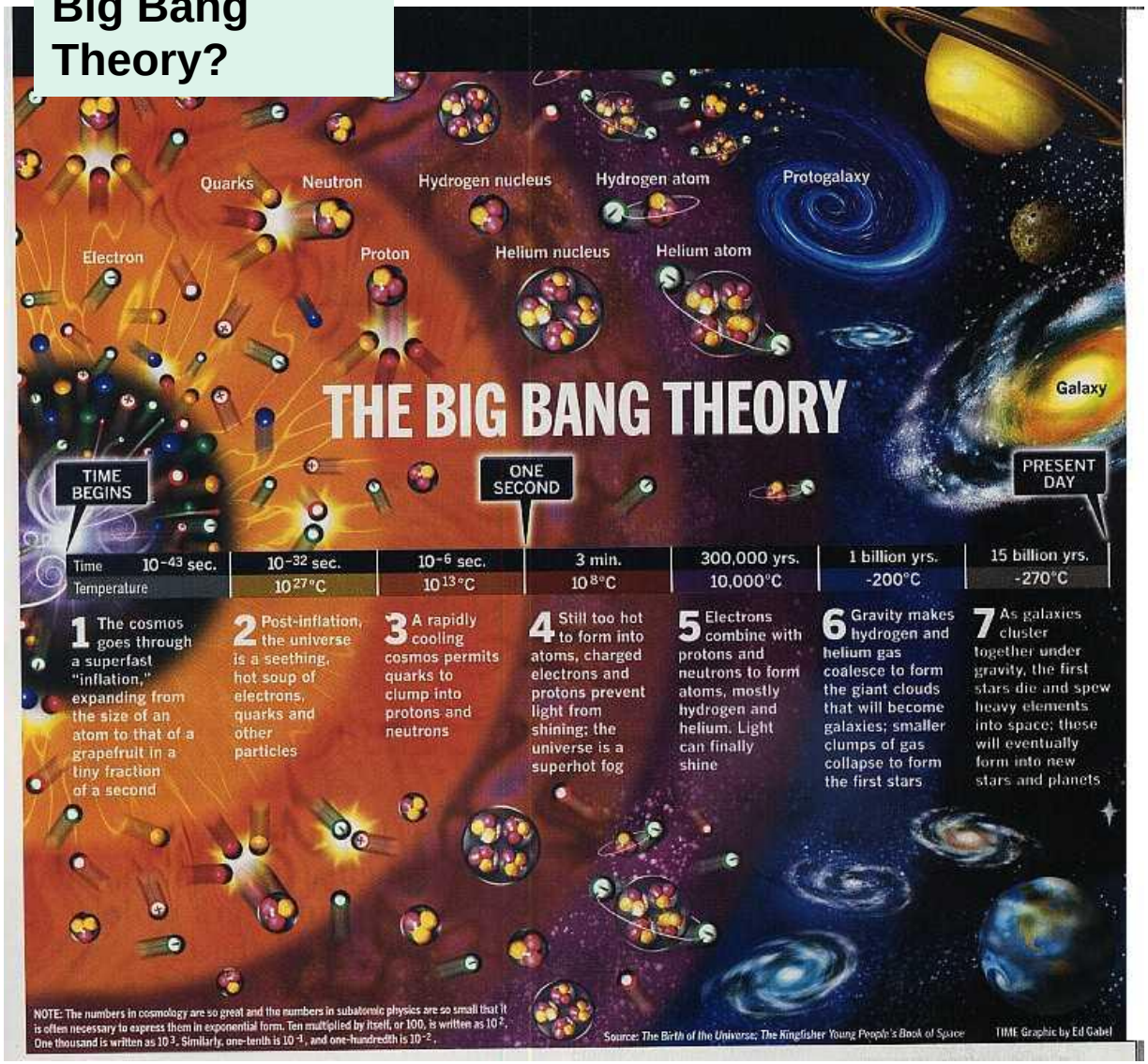
Homo Sapiens--10 seconds

If history is represented by a 24-hour clock, humans have been on earth for 10 seconds.

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

What evidence supports the Big Bang Theory?

The Big Bang



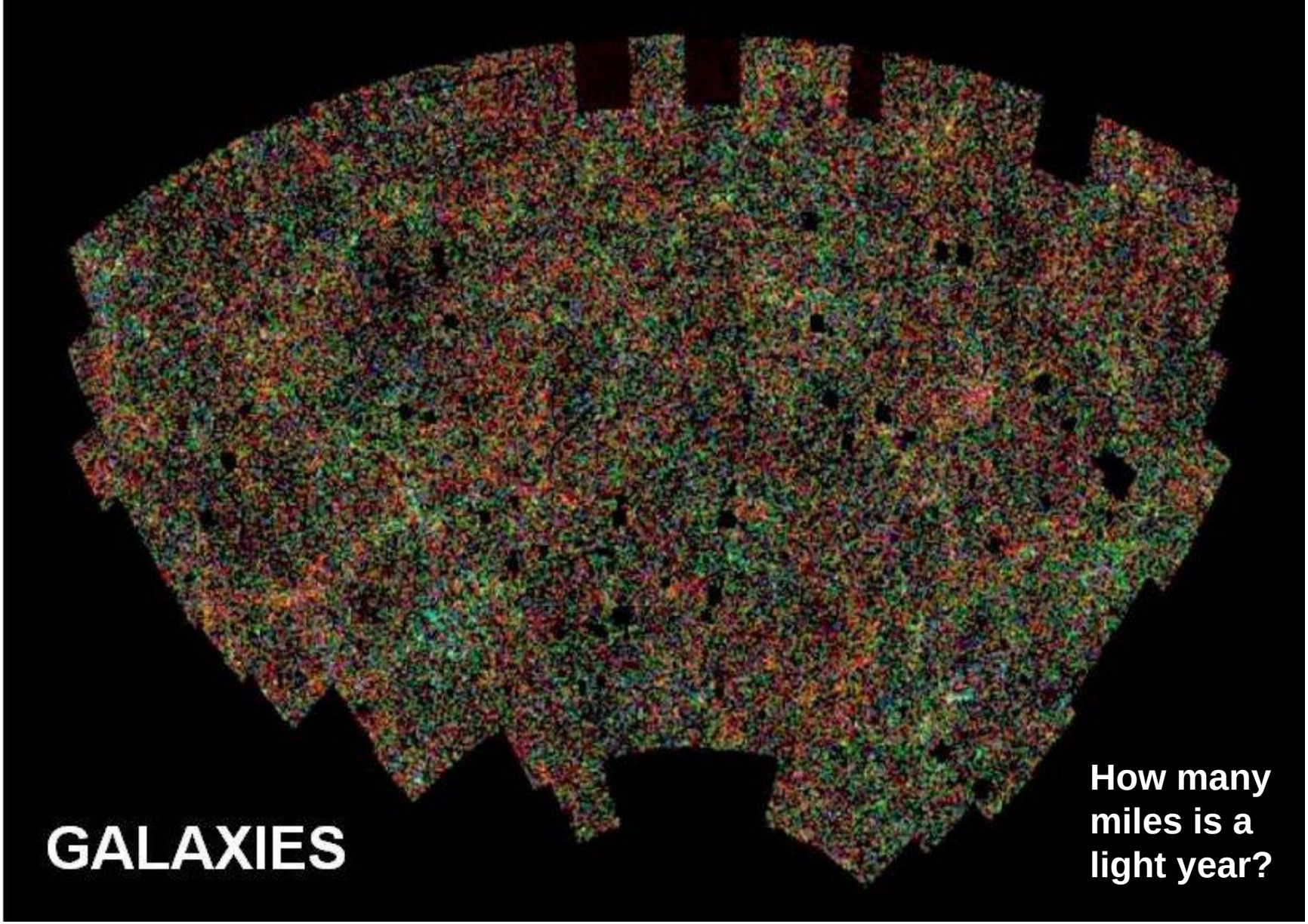
Some of the best minds of our generation have spent their lives studying the heavens and the Earth. They have concluded that the universe came into being 13.7 billion years ago with a massive, explosive expansion of pure energy, the Big Bang.

Within minutes, they tell us, the energy began to differentiate into atomic particles: quarks, electrons, protons and neutrons. Nuclear and electromagnetic forces arranged those particles into the lighter elements, hydrogen and helium.

Gravitational forces brought the newly created matter together into galaxies of stars. The stars began to burn with nuclear fire, and there was light. Heavier elements were cooked in the stellar ovens, and as the first stars burned out and died, they exploded, strewing across space the building blocks for the next generation of stars.

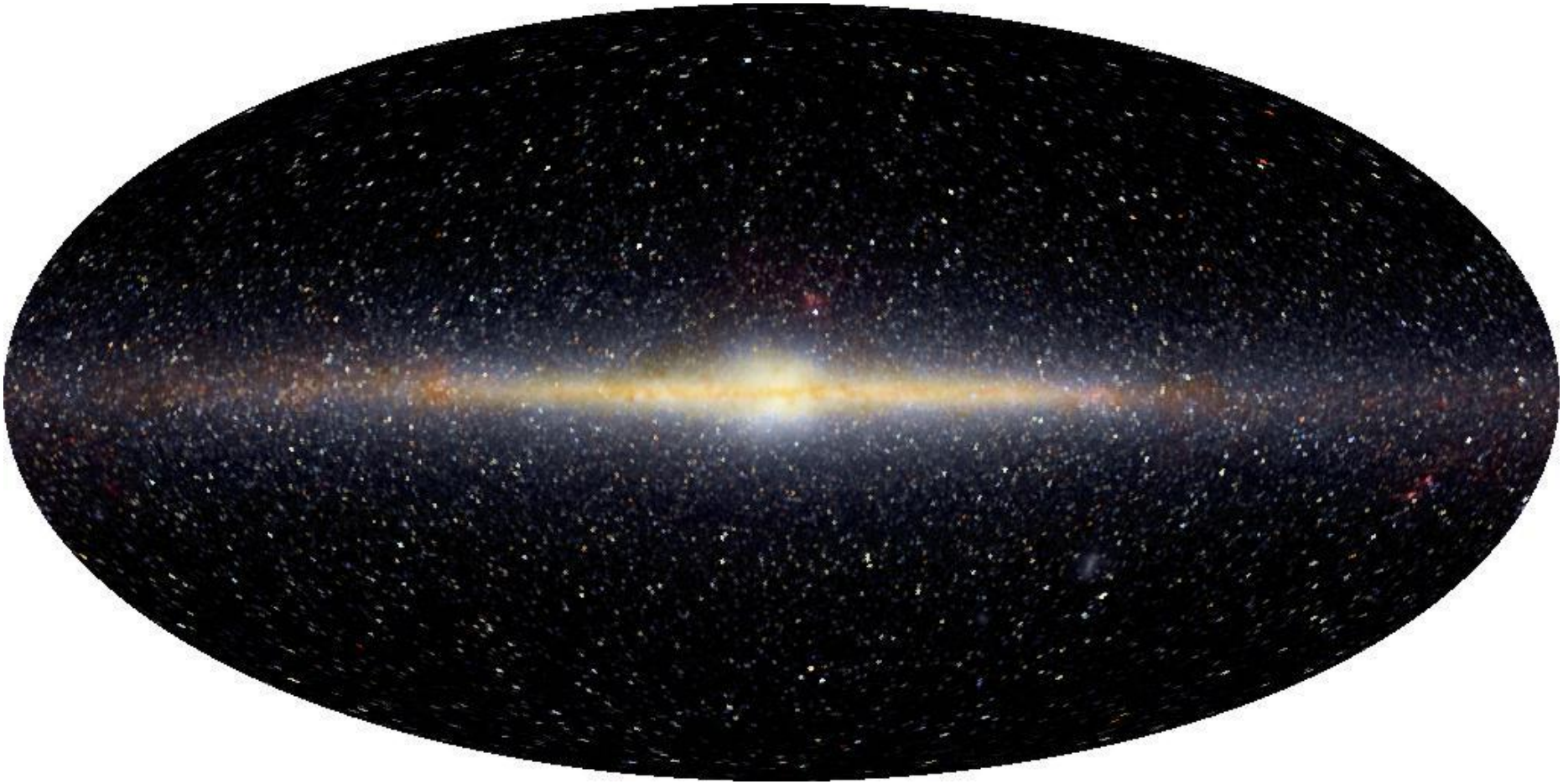
The Big Bang – 13.7 BYA

Where We Come From



Survey picture of a large part of the sky, about 30 degrees across, showing almost a million galaxies out to a distance of about 2 billion light years.

Distance across universe ~ 1 million, billion, billion miles
Stars in the universe ~ 125 billion x 100 billion = 12,500 billion billion



The Milky Way

The Milky Way is a gravitationally bound collection of roughly a hundred billion stars. Our Sun is one of these stars and is located roughly 24,000 light years (or 8000 parsecs) from the center of our the Milky Way.

NASA Our Universe

What is a parsec?

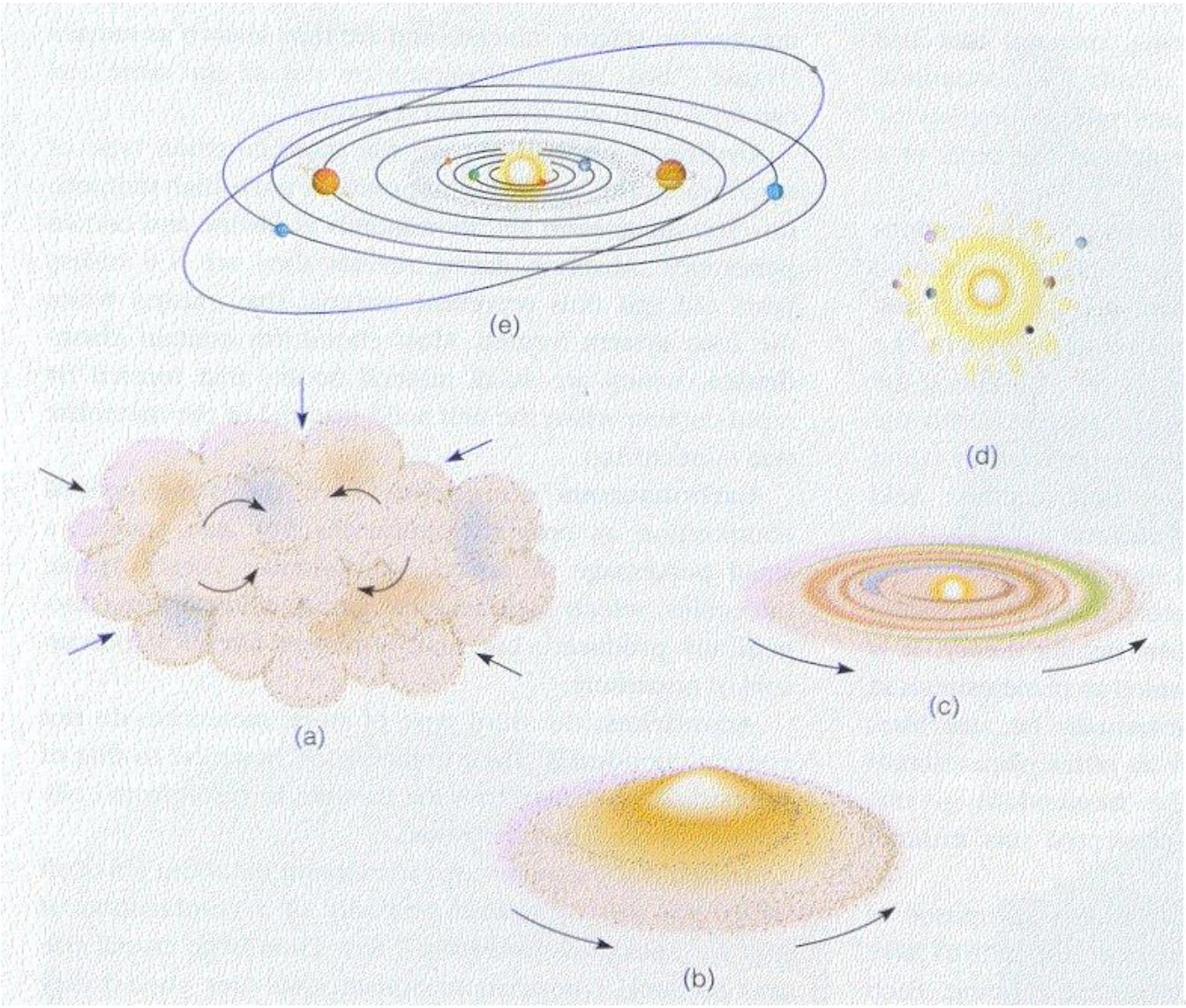
Image of "Star Birth" Clouds in M16 Galaxy

Heavy elements cooked up in early stars and released in supernovae provide the stuff of solar systems

Our own sun and planetary system was built by gravitational forces from the remnants of earlier stars.

Life and death of a star

Solar System Genesis



The currently accepted theory for the origin of our solar system involves (a) a huge nebula condensing under its own gravitational attraction, then (b) contracting, rotating, and (c) flattening into a disk, with the Sun forming in the center and eddies gathering up material to form planets. As the sun contracted and began to visibly shine, (d) intense solar radiation blew away unaccreted gas and dust until finally, (e) the Sun began burning hydrogen and the planets completed their formation.

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

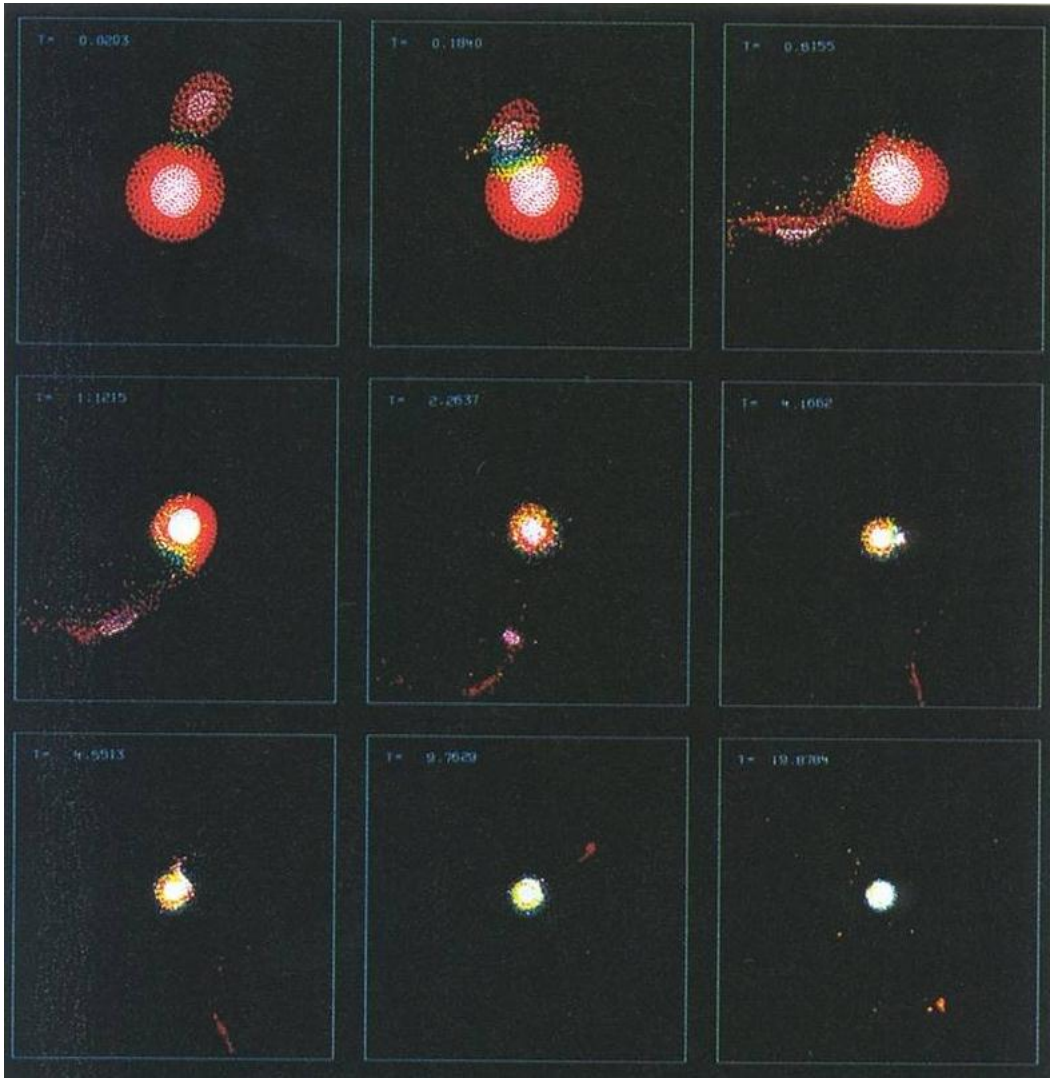
Early Solar System

At the stage of development shown here, planetesimals have formed in the inner solar system, and large eddies of gas and dust remain at great distances from the protosun.

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

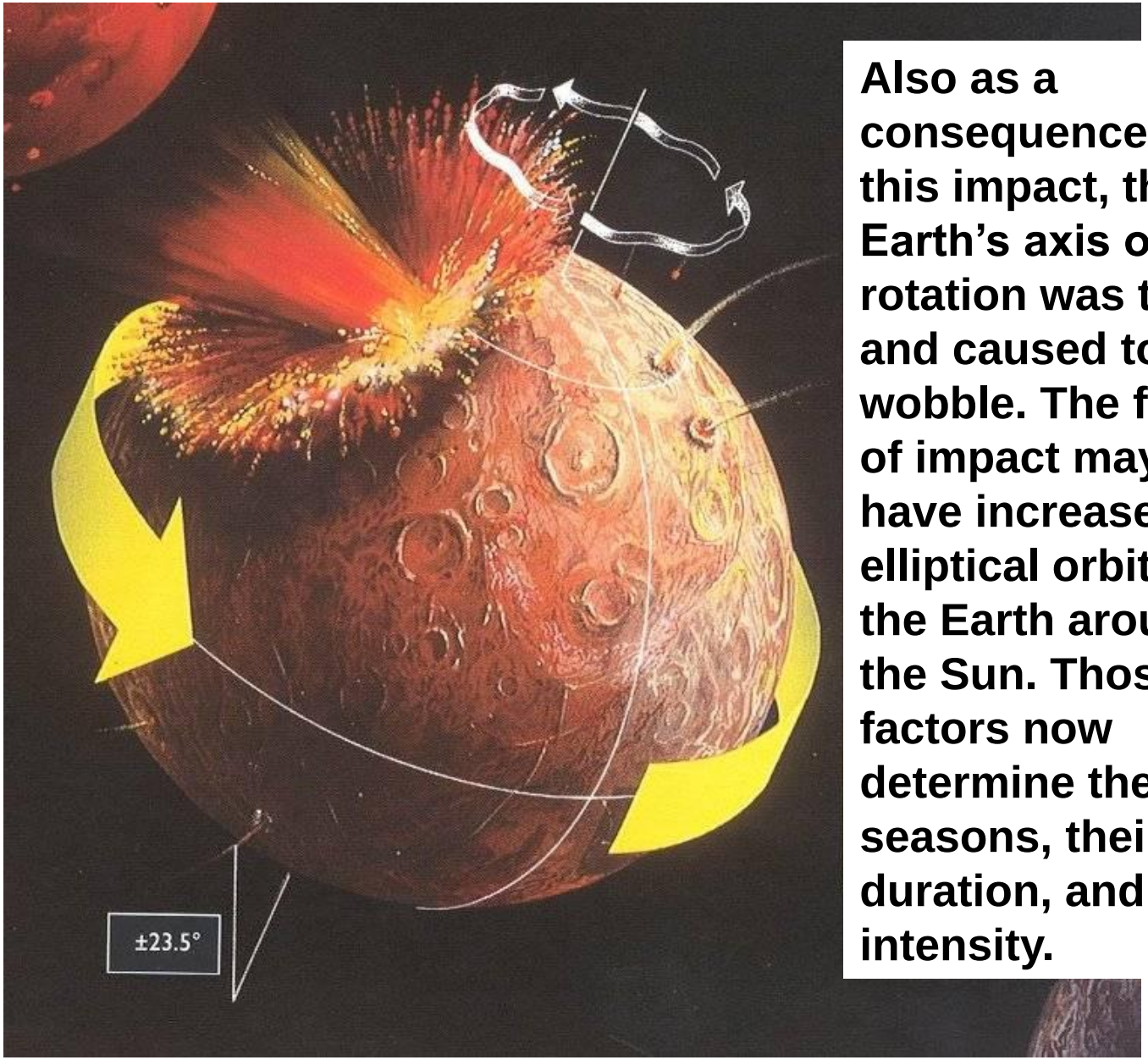
Moon Genesis Simulation

According to one hypothesis for the origin of the Moon, a large planetesimal the size of Mars crashed into the earth 4.6 to 4.4 billion years ago, causing the ejection of a mass of hot material that formed the Moon. This computer simulation shows the formation of the Moon as result of an Earth-planetesimal collision.



Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

Earth’s Tilt, Wobble, and Seasons



Also as a consequence of this impact, the Earth’s axis of rotation was tilted and caused to wobble. The force of impact may also have increased the elliptical orbit of the Earth around the Sun. Those factors now determine the seasons, their duration, and their intensity.

Origins: The Evolution of Oceans, Continents, and Life. RonRedfern, U. Okla. Press, 2001.

Longer Days

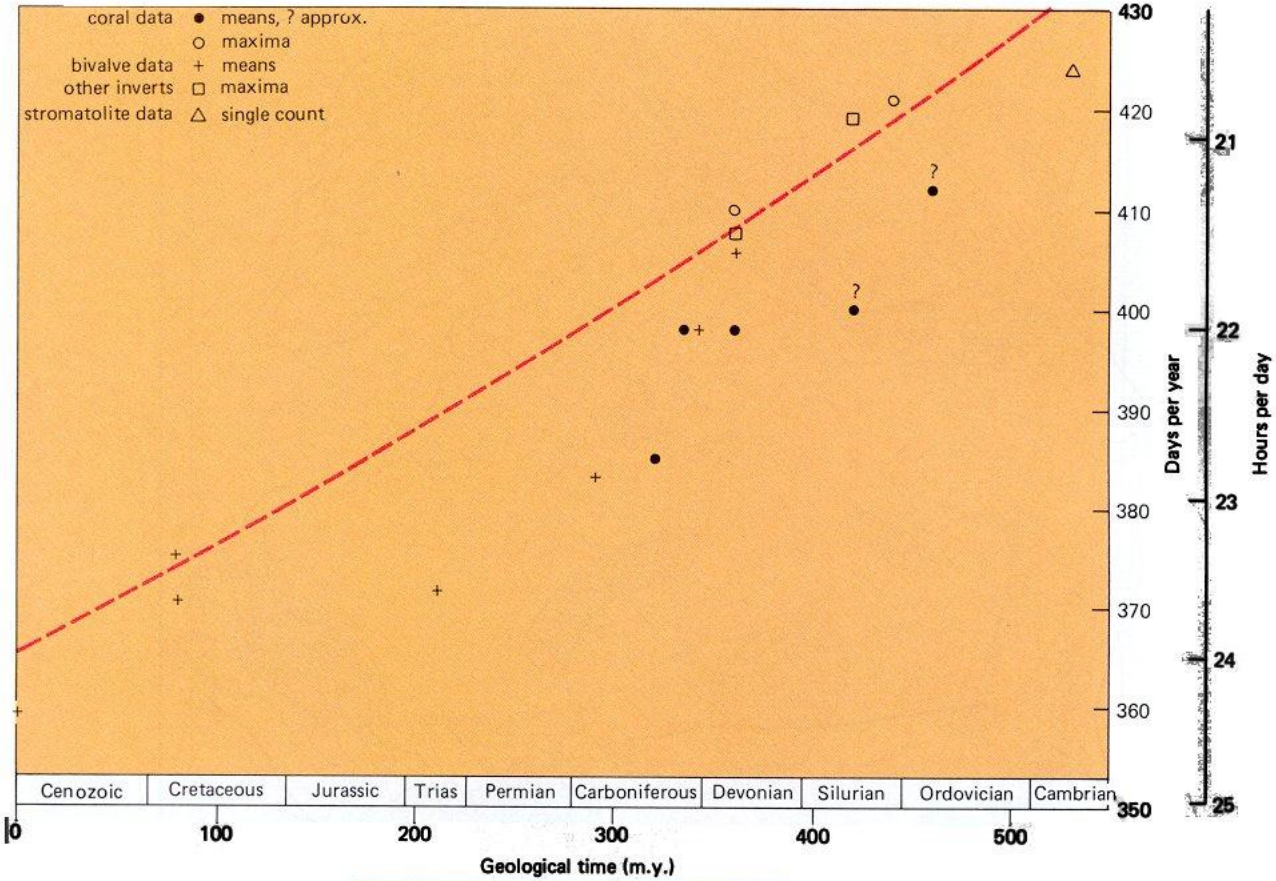
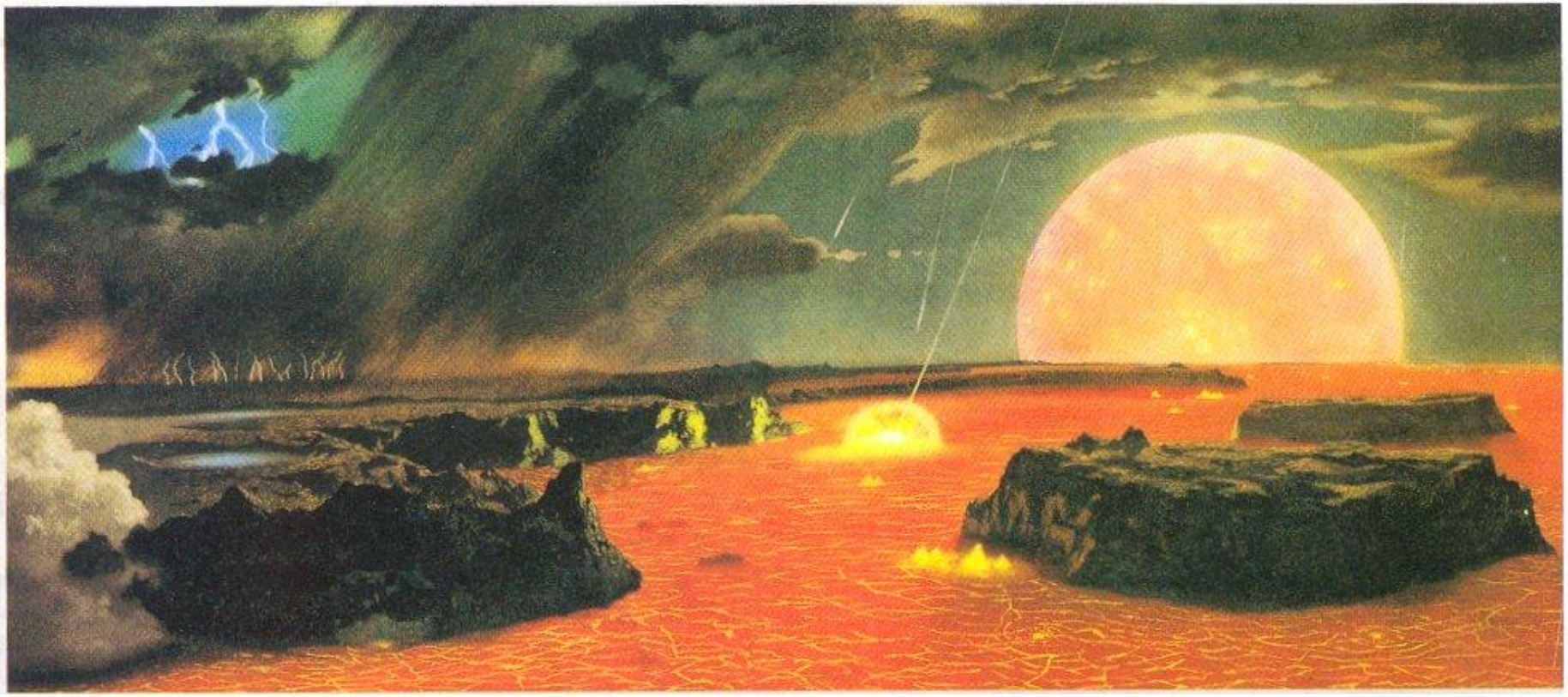


FIGURE 12.16 Changing length of day through Phanerozoic time based upon data gathered from corals, stromatolites, bivalves, and other invertebrates. The dashed line shows the gradual lengthening of the day and is based on a constant of 2 milliseconds per century. (*Muller and Stephenson, 1975.*)

The moon's gravitational attraction produces the tides and also acts to slow the rotation of the earth. Over hundreds of millions of years, the day has lengthened from 21 to 24 hours, and the number of days in a year has gone from 430 to 365.

Evolution of the Earth. Donald R. Prothero and Robert H. Dott, Jr., McGraw-Hill, 2002.

HADEAN EON



Earth as it is thought to have appeared about 4.6 billion years ago.

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

Precambrian Era

- Formation of the earth's crust, 4,600 million years old

  The earth's interior is divided into layers of different density

  Chemical fractionation of the molten earth:

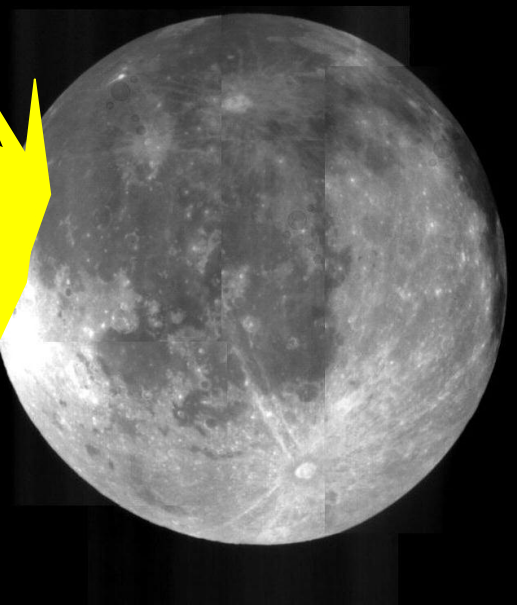
  Silica and light crust materials rose to the surface

  Nickel and iron are heavier elements fell to the core

- Primordial earth had no atmosphere. It was a big, cooling rock, revolving around a sun in space. What happens to a planet with no atmosphere?

  Think about the moon.

  In the early evolution of the earth, our planet was bombarded by meteorites and comets.

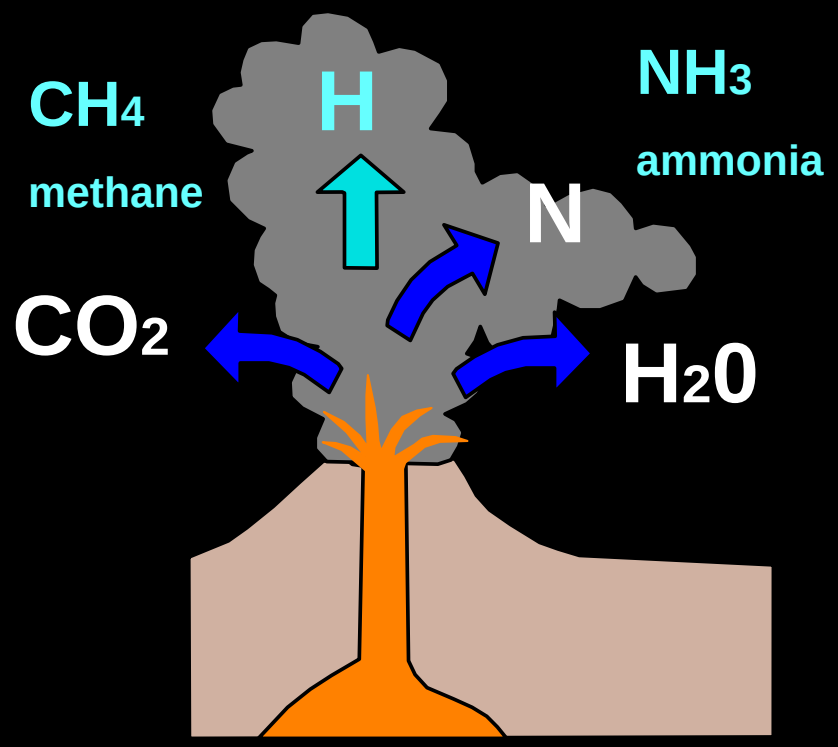


http://nssdc.gsfc.nasa.gov/

Precambrian atmosphere

- The oldest rocks found on Earth are 4,200,000,000 to 3,900,000,000 years old. So by at least that time, the Earth had cooled. But when and how did the Earth's atmosphere form?

- Presently, the most accepted theory is that as the Earth cooled, an atmosphere formed through the process of **outgassing**



Present atmosphere:

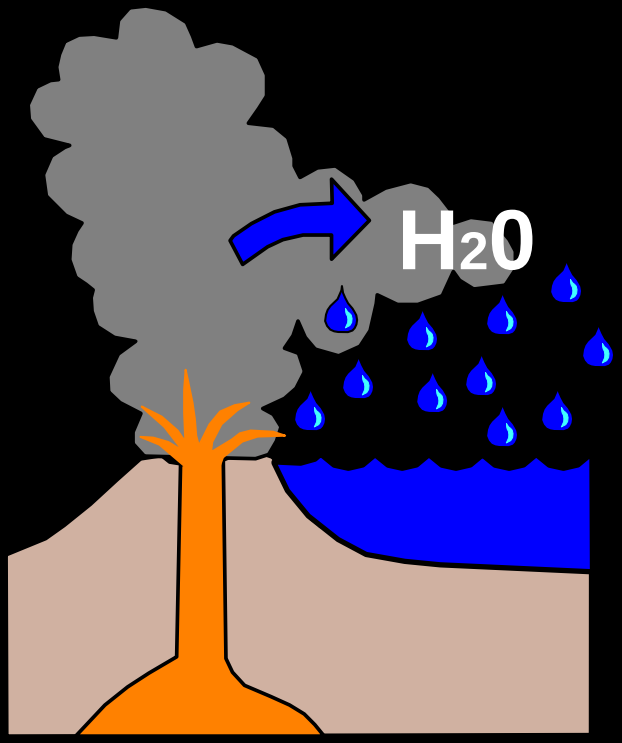
78% Nitrogen

? 21% Oxygen (where did all the oxygen come from?)

>1% CO_2, H_2O, Argon, etc.

Where did the oceans come from ?

- As water vapor cooled in the air it precipitated as rain. For millions of years it rained, and rained, and rained.



Hence, formation of the earth's oceans is also tied to the production of salts and minerals below the ground

Salts are minerals. Salt water is formed by the combination of salt and water. Salts in the world's oceans were weathered from new-formed continental crust, outgassing, and precipitated in the ocean

Did water also come from the Oort ice comet cloud ?

Water was critical for life to begin

The rise of Precambrian life

- Where did the organic materials and compounds essential for life come from?

(1) Volcanic outgassing

(2) Comets

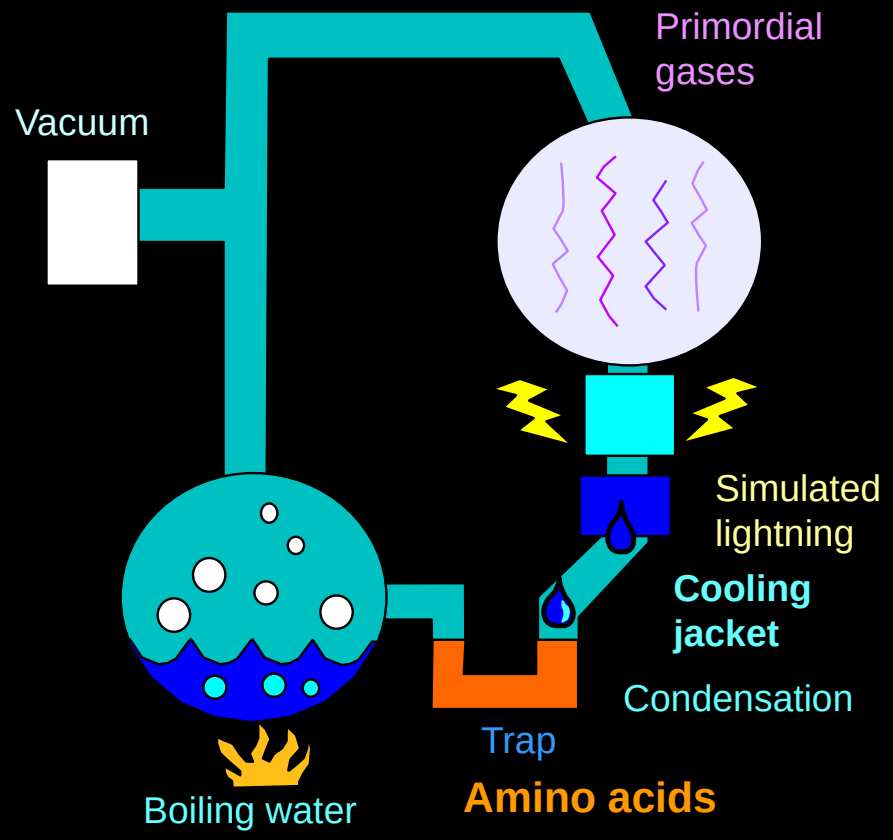
(3) Deep-sea vents in the crust

(4) Geysers

The rise of Precambrian life

…from outgassing

- In the 1950's, Stanley Miller and Harold Urey replicated an early earth atmosphere with abundant methane and ammonia. Sparks from electrodes simulated lightning. Within a week, the lower flask contained a "soup" of organic compounds, including amino acids: the building blocks of proteins, and life



The experiment showed you could theoretically form the building blocks of life from non-living materials under natural processes.

The rise of Precambrian life

…from comets

- **In 1986, when Halley's comet passed close to earth, several spacecraft were launched to analyze the chemical makeup of the comet.**

- **Results from those missions and others indicate that comets contain carbon, hydrogen, oxygen, and nitrogen…. Organic elements. Not life, or even the compounds of life (amino acids), but the raw materials.**

- **A growing number of scientists believe that the steady bombardment of the primordial earth during the early Precambrian may have seeded the earth with organic elements and water.**

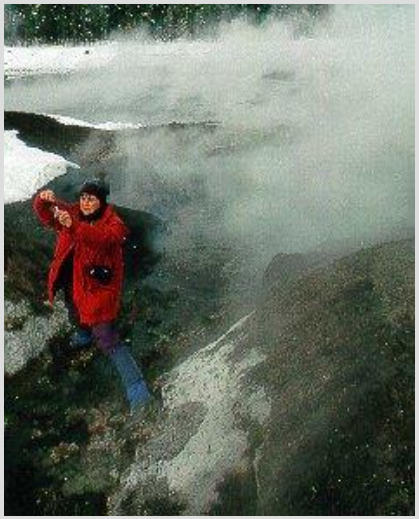
…from deep-sea vents

Images from American Museum of Natural History, http://www.amnhonline.org/expeditions/blacksmokers/smoker1.html

- Amino acids have also been documented along hydrothermal vents called "black smokers." These vents occur along the mid-ocean ridges where hot water and minerals escape from hot magma below.

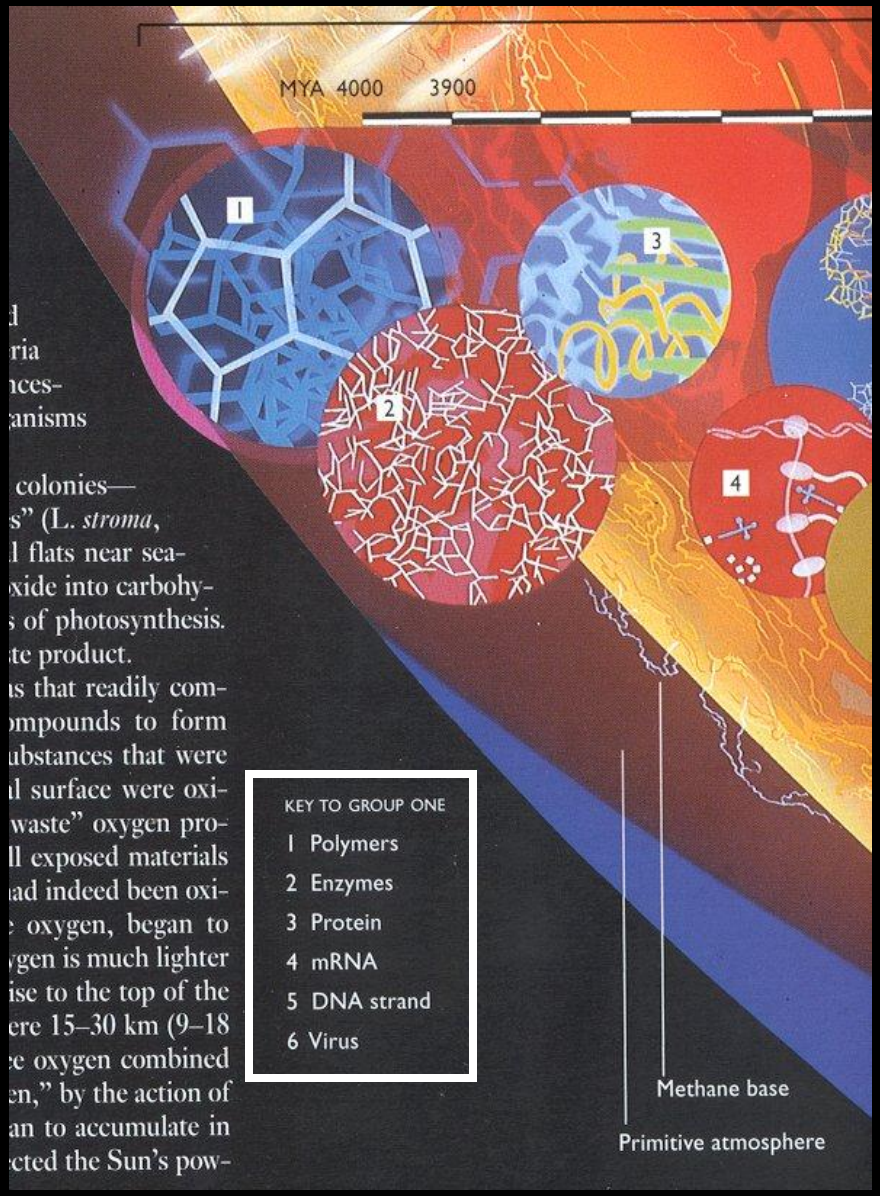
- Primitive bacteria live along vents. They don't need oxygen. They get their energy from heat in the vent and through digesting sulfur compounds. These life forms get their energy from heat and minerals of the vent, rather than sunlight.

…from geysers



- New research in modern geysers at Yellowstone National Park has shown that the super-heated water (heated by underlying magma) contains single-celled bacteria (without nuclei). A type of life that some biologists call thermophiles. They live on the heat and minerals in the water. They do not eat organic matter, but rather, consume sulfur and iron minerals in the water.

From Monastersky, W.R., 1998, The Rise of Life on Earth, National Geographic, v. 193, no. 3,



The beginnings of life on Earth

Molecular forces provided the mechanism by which many of the earliest forms– polymers, enzymes, proteins, mRNA (messenger RNA), DNA, and viruses– could reproduce.

Replication templates

The Sacred Depths of Nature, Ursula Goodenough, Oxford U. Press, 1998

Origins: The Evolution of Oceans, Continents, and Life. RonRedfern, U. Okla. Press, 2001

The rise of Precambrian life – fossils

- **There are several possible microscopic fossils that date from 3, 800 to 3, 500 million years ago, but the evidence for each is not definitive.**

- **In 1996, scientists using an electron microscope found evidence of rod-shaped bacteria, less than 1 micron in length, in 3, 500 million years ago chert from South Africa. The chert was deposited next to a geyser. This is the oldest fossil on earth.**

(from Lamb, S., and Sington, D., 1998, Earth Story: Prineton University Press, p. 178)

Geysers are formed where hot water (heated by magma below) erupts to the surface. It carries minerals with it. Heat and water were probably essential to early life

Bacteria are cells without a nucleus = prokaryotes

Life needs energy to live. In the earliest forms, energy came from simple molecules, then fermentation (energy production without oxygen), then photosynthesis.

Prokaryotes, bacteria and archaea, (Greek pro- before + karyon- nut or kernel) have no nucleus. Prokaryotes are everywhere. They can live where it is hotter than boiling water, in acids, under pressures of 1,000 atmospheres, and other extreme conditions. They have been found alive in 250,000-year-old salt crystals. They may live on space dust and seed planets. Your body contains about 60 trillion prokaryotes. The 5,000 billion, billion, billion estimated to live on Earth weigh as much as all the plants in the world—about a gigaton.

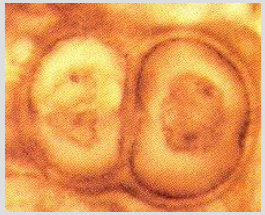
More about prokaryotes

A 3.86 billion year old carbon sphere from Greenland is shown above. Is it organic? If so, it's oldest evidence of life.

From Monastersky, W.R., 1998, The Rise of Life on Earth, National Geographic, v. 193, no. 3,

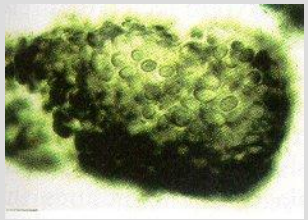
Precambrian Era

Cyanobacteria, also called blue-green algae (but not really algae) occur as fossils in rocks as old as 3, 500 million years.



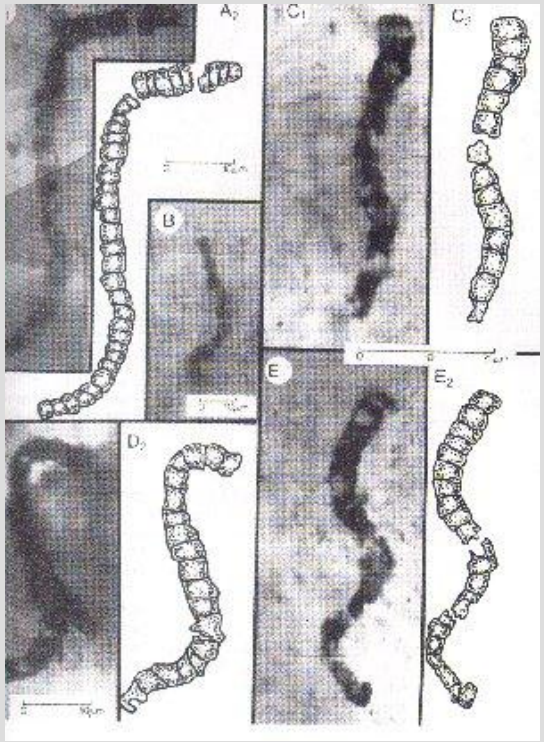
Fossil, 1.55 by from the Urals

Living



Fossil, 2.15 by from Canada

Living



Fossil filaments of cyanobacteria, 3.46 billion years ago from Australia

Cyanobacteria are prokaryote cells that have chlorophyll. They can photo-synthesize for energy. Don't need energy from hot springs or mineral vents.

(modified from Dott, R.H., Jr., and Prothero, D.R., 1994, Evolution of the Earth: McGraw-Hill, Inc. p. 203)

Cyanobacteria and Stromatolites

Cyanobacteria still live today and can form visible mounds called stromatolites. Stromatolites are the most common fossil from Precambrian rocks. They are the only megascopic (large enough to be seen) fossil found in rocks of ages from 3, 500 million years ago to 700 million years ago.

(modified from Dott, R.H., Jr., and Prothero, D.R., 1994, Evolution of the Earth: McGraw-Hill, Inc. p. 194)

For more than 2.5 billion years, stromatolites ruled. They photo-synthesized, taking in CO_2, and expelling O_2. This process created an oxygen-rich atmosphere in which life could flourish on earth.

Present atmosphere:

78% Nitrogen

21% Oxygen

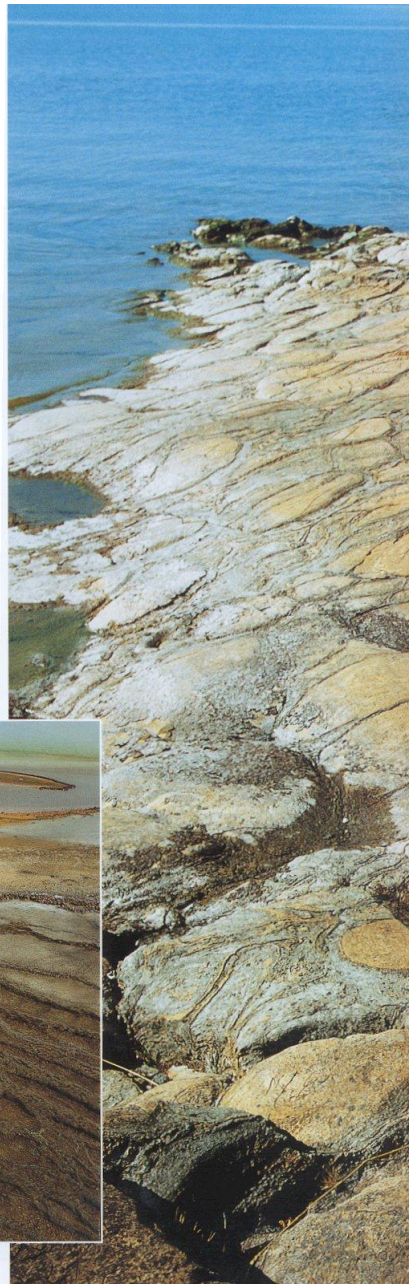
>1% CO_2, H_2O, Argon, etc.

Photosynthesis, a chemical process of living organisms, is responsible for most of the present atmospheric oxygen

The First Life

Each stromatolite, a mat-like structure, was formed by a colony of single-celled unnucleated bacteria, micro-organisms that replicated perfect clones of themselves. Such "prokaryotes" (once known as blue-green algae but now called "cyanobacteria"), converted the carbon dioxide-based atmosphere into carbohydrates by photosynthesis: the lived on carbohydrates and exhaled oxygen as a waste product. These bacterial reefs became so prolific worldwide that over many millions of years they contributed to the conversion of the Earth's atmosphere. The proportion of carbon dioxide was vastly reduced and that of the oxygen greatly increased—a development that caused gradual and increasing environmental stress on the world's stromatolite community. Oxygen was poisonous to most early forms of life. The gradual adaptation of micro-organisms to an oxygen-based atmosphere was a key step in the evolution of the nucleated cell—the "eukaryotic" cell. This led to the evolution of the multicellular macro-organisms and an explosion of new forms of life on Earth.

The main picture shows part of a fossilized stromatolite reef dated 1,950 million years ago. The inset picture of Prismatic Spring depicts an even earlier stage in life's evolution—the kind of "warm little pond" (Charles Darwin's phrase) in which the origin of life is thought to have taken place around 3.5 billion years ago.



Bacterial growth, Prismatic Spring, Yellowstone National Park, Wyoming

Origins: The Evolution of Oceans, Continents, and Life. RonRedfern, U. Okla. Press, 2001.

Precambrian Era

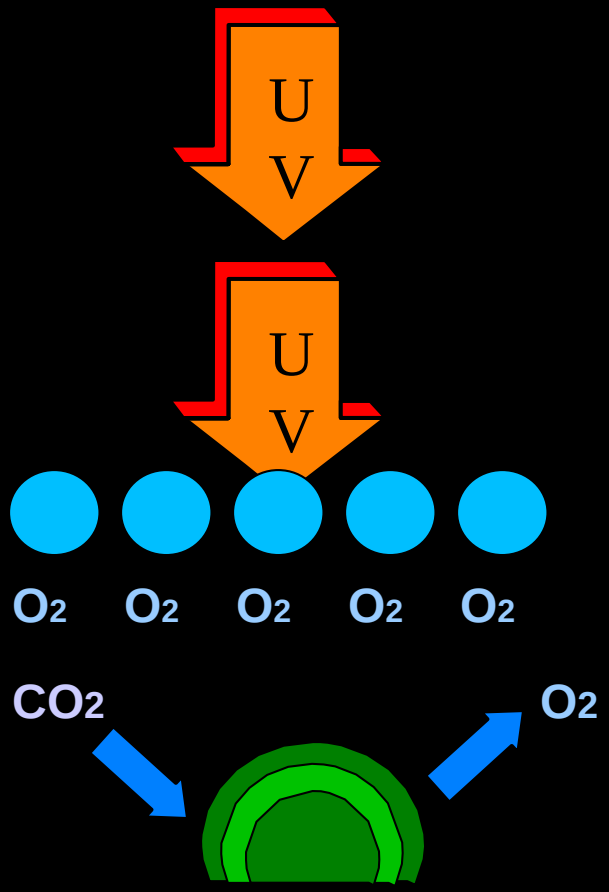
The ozone layer

Prior to development of the ozone, ultraviolet radiation bombarded the earth. This would have been lethal to life as we know it today.

Ultraviolet radiation may have been first contributor to the ozone by splitting water molecules into hydrogen and oxygen.

But stromatolites were the key to the ozone layer. Photosynthesis and the release of free oxygen to the atmosphere was also important in the creation of an ozone layer.

Hence, life modified the chemistry of the atmosphere, and subsequently set the stage for later life.



Gaia: a new look at life on earth, James Lovelock

Oxygen in the Atmosphere

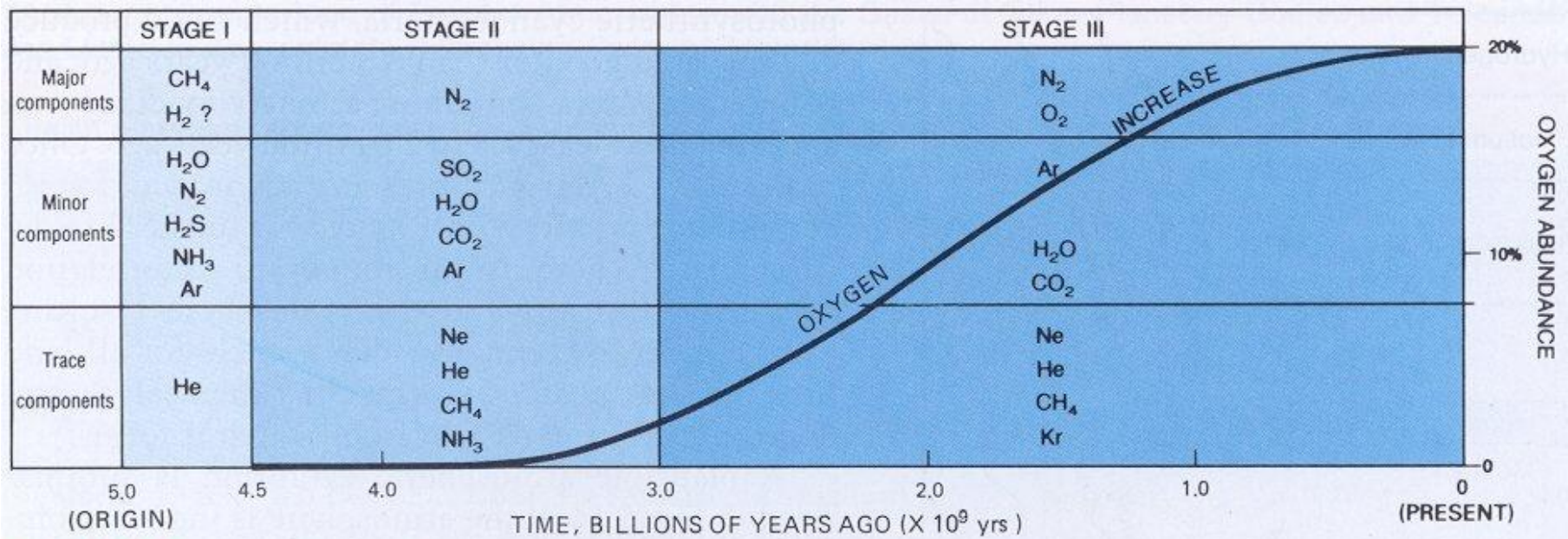
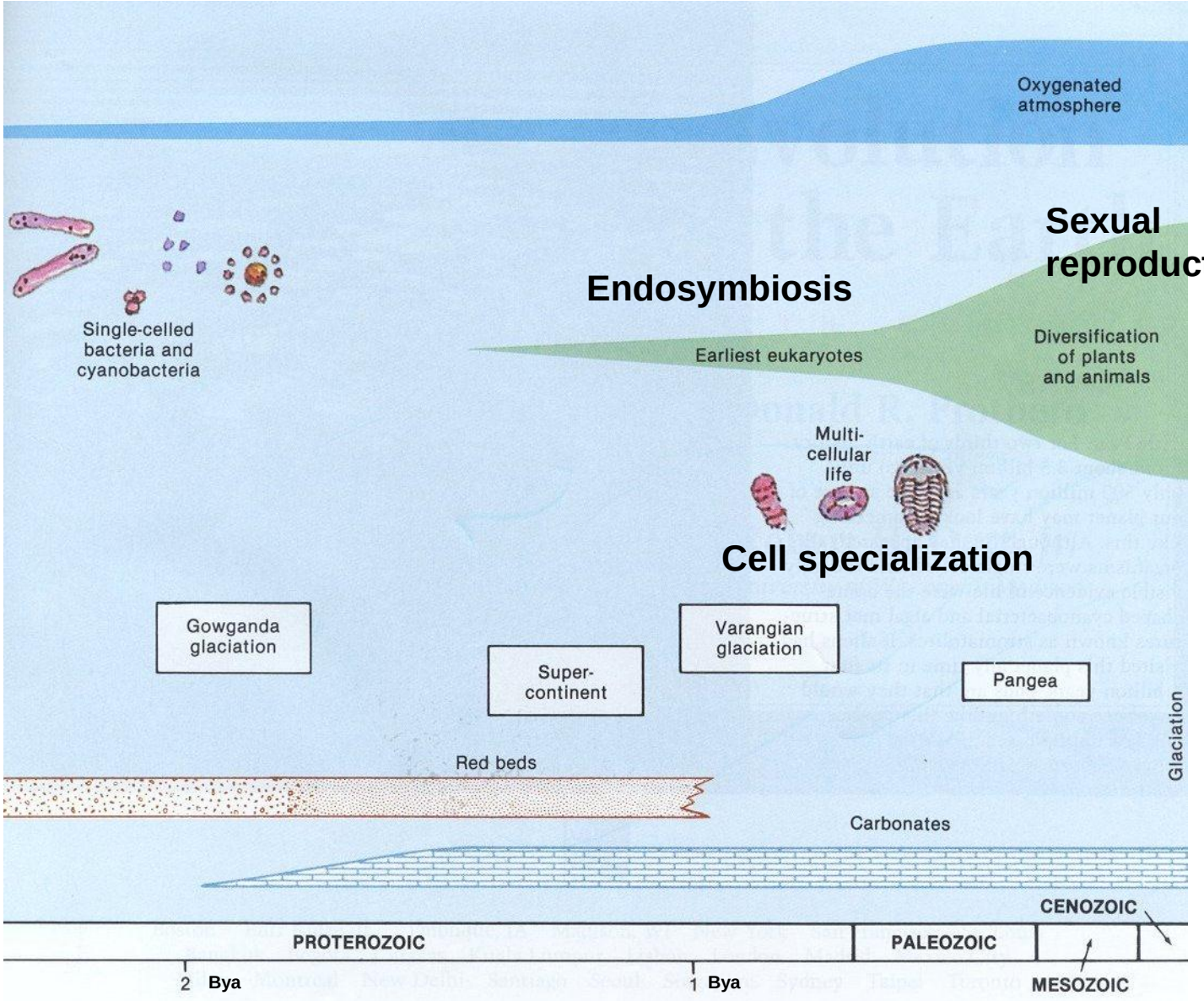


FIGURE 6.14 **Probable evolution of composition of the earth's atmosphere.** (***Adapted from H. D. Holland, 1964, in The origin of the atmosphere and oceans; by permission of John Wiley & Sons, Inc.***)

It took approximately half of earth history for the evolution of an oxygen-rich atmosphere and the evolution of complex life.

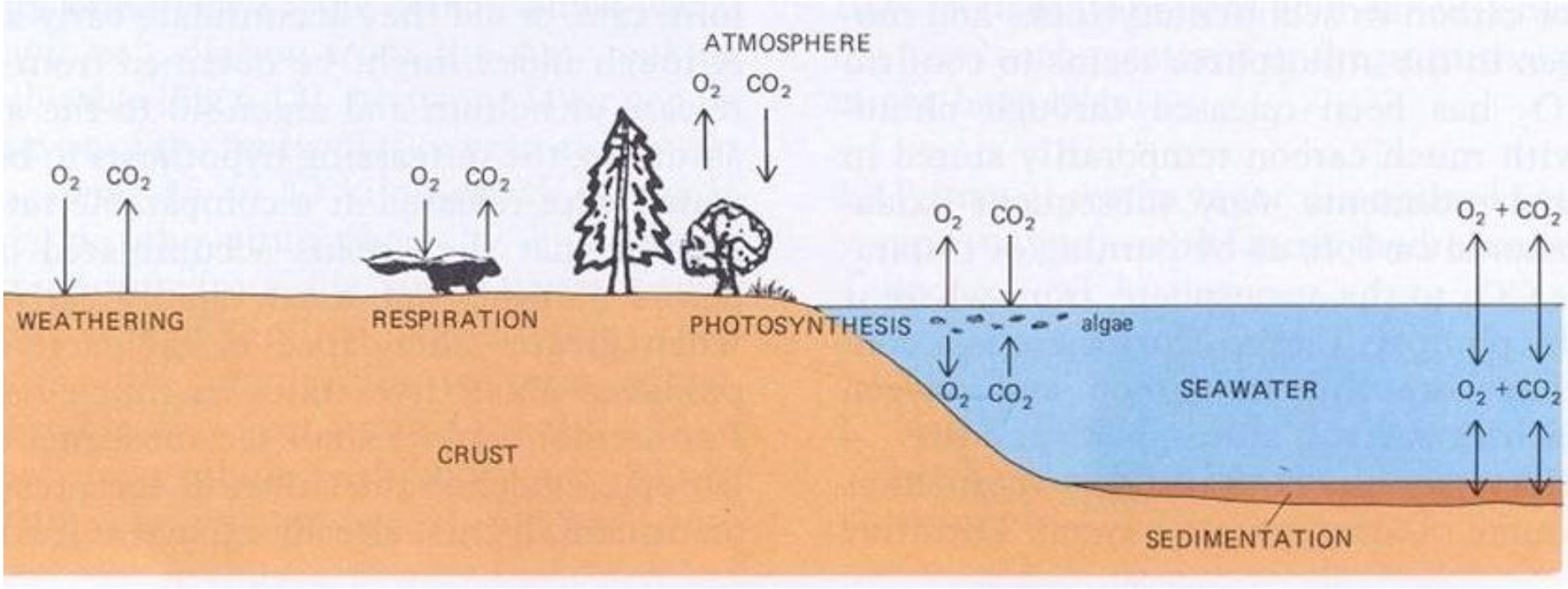
Evolution of the Earth. Donald R. Prothero and Robert H. Dott, Jr., McGraw-Hill, 2002.

Our oxygen-rich atmosphere and the ozone layer was created and is maintained by the life on Earth.



Evolution of the Earth. Donald R. Prothero and Robert H. Dott, Jr., McGraw-Hill, 2002.

The Oxygen Cycle

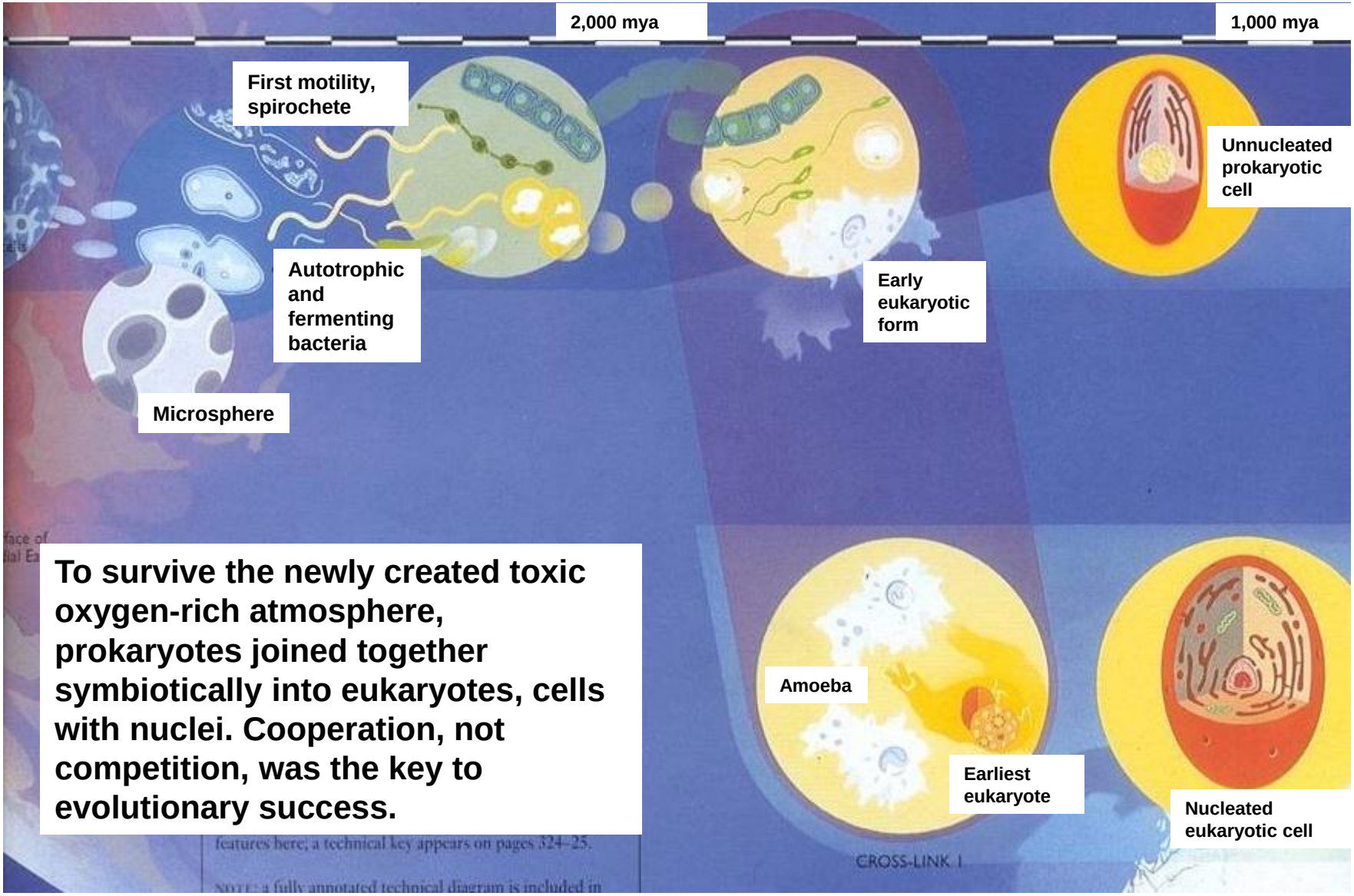


PLANTS -- SOLAR ENERGY + CO_2 $\longrightarrow$ carbohydrates + O_2

ANIMALS -- carbohydrates + O_2 $\longrightarrow$ ENERGY + CO_2

Evolution of the Earth. Donald R. Prothero and Robert H. Dott, Jr., McGraw-Hill, 2002.

Adaptive Complexity

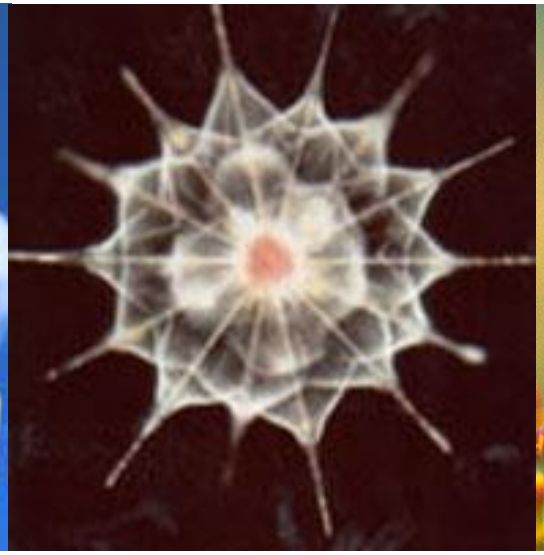


To survive the newly created toxic oxygen-rich atmosphere, prokaryotes joined together symbiotically into eukaryotes, cells with nuclei. Cooperation, not competition, was the key to evolutionary success.

Illustration adapted from, Origins: The Evolution of Oceans, Continents, and Life. RonRedfern, U. Okla. Press, 2001.

For more, see The Blind Watchmaker, Richard Dawkins, Norton, 1986.

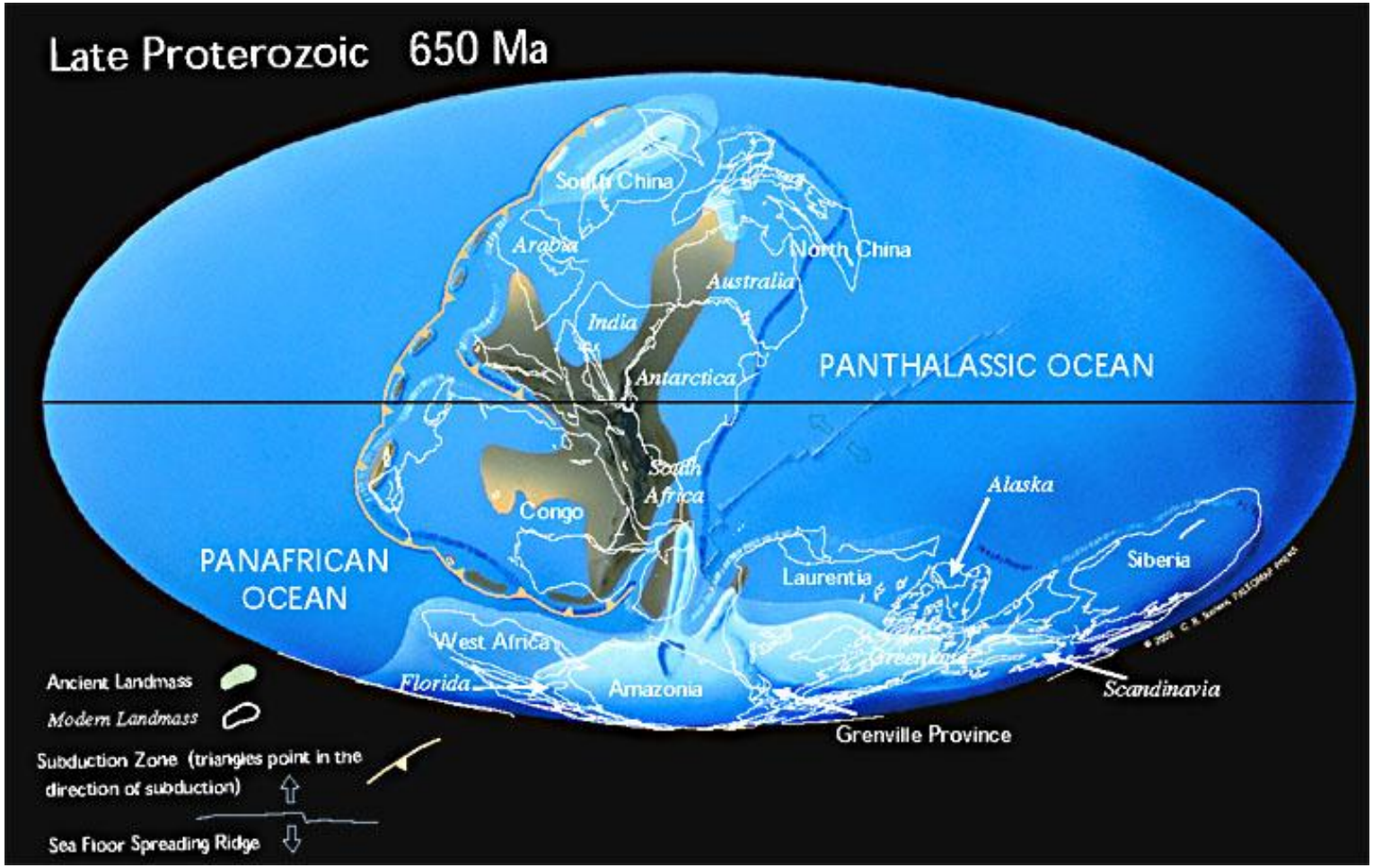
Eukaryotes



The eukaryotes include ourselves, other animals, plants and fungi and a rich variety of micro-organisms (protists). Eukaryotes visibly influence the nature of our world. Our concepts of beauty, logic and spirit are arguably derived from our observations of the eukaryotes.

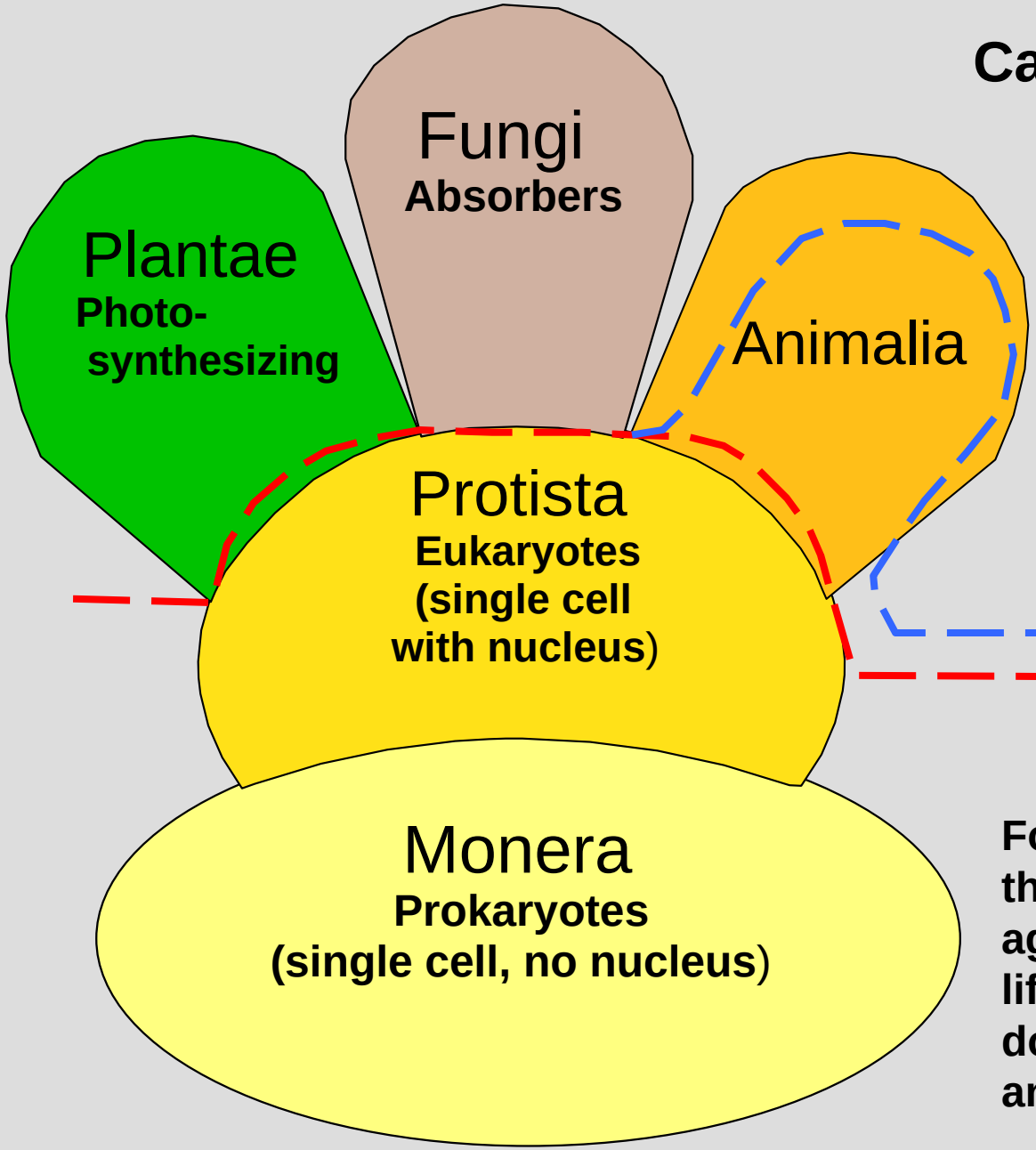
The Tree of Life web project

The World 650 Million Years Ago



This map illustrates the break-up of the supercontinent, Rodinia, which formed 1,100 million years ago. The Late Precambrian was an "Ice House" World, much like the present day.

From PALEMAP Project, Christopher R. Scotese

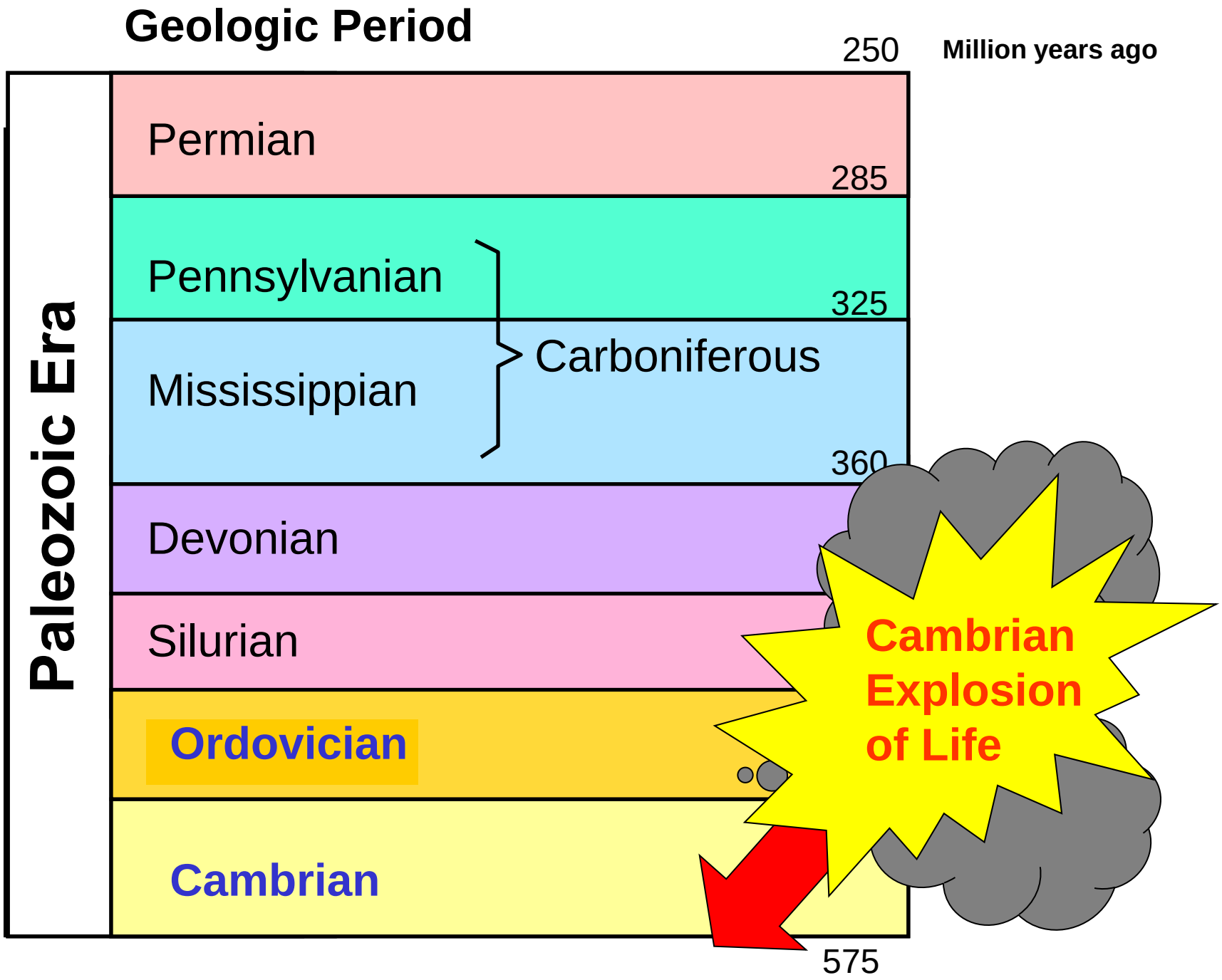


Cambrian Explosion

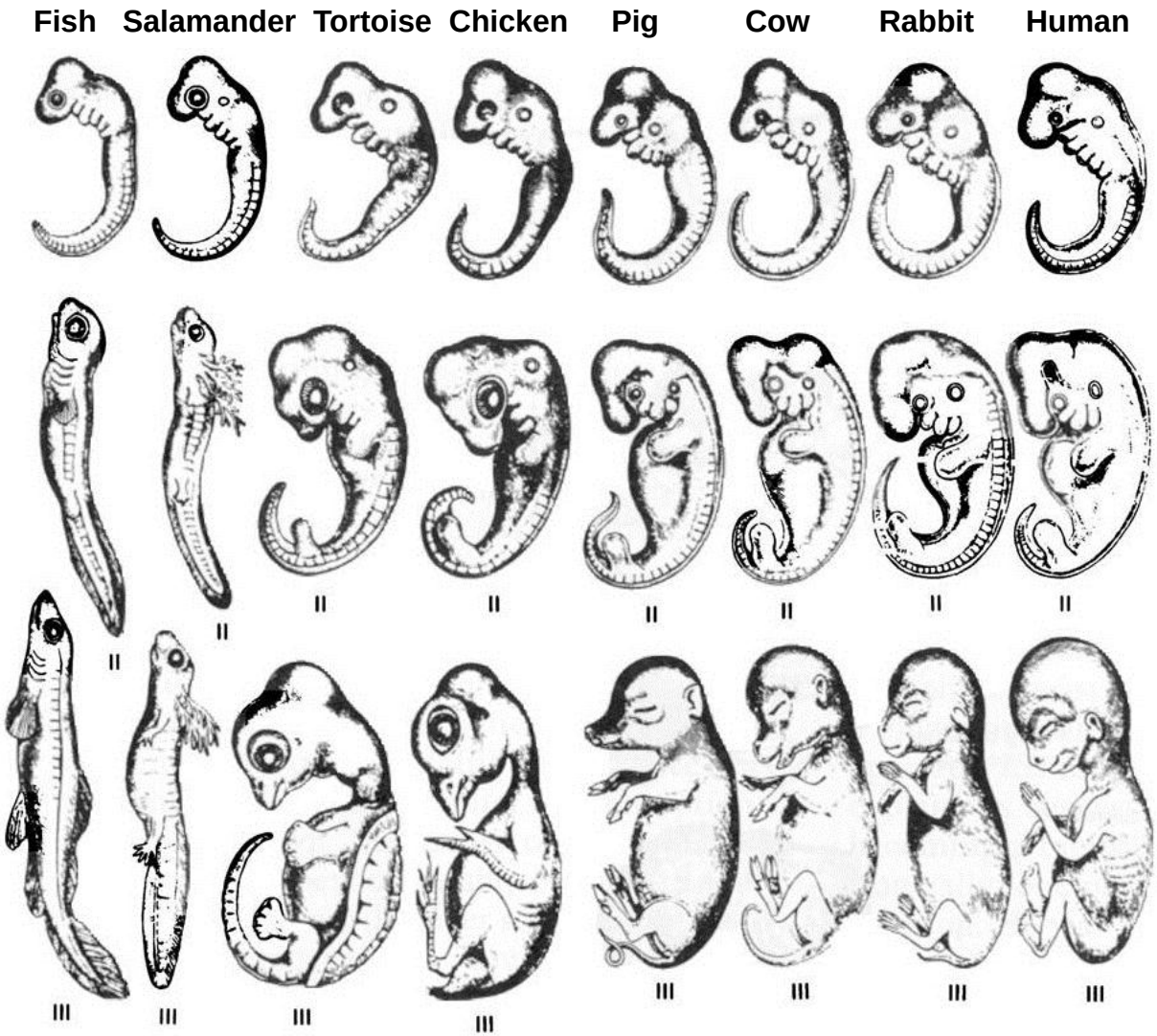
About 570 million years ago there was an explosion of life on the planet with most of the known invertebrate animal families suddenly appearing throughout the world.

Pre-Cambrian

Fossil evidence indicates that from 3,500 million years ago to 700 million years ago life on the planet was dominated by prokaryotes and eukaryotes


Geologic Period
250
Million years ago
Paleozoic Era
Permian
285
Pennsylvanian
325
Mississippian
Carboniferous
360
Devonian
Silurian
Ordovician
Cambrian
575
Cambrian Explosion of Life

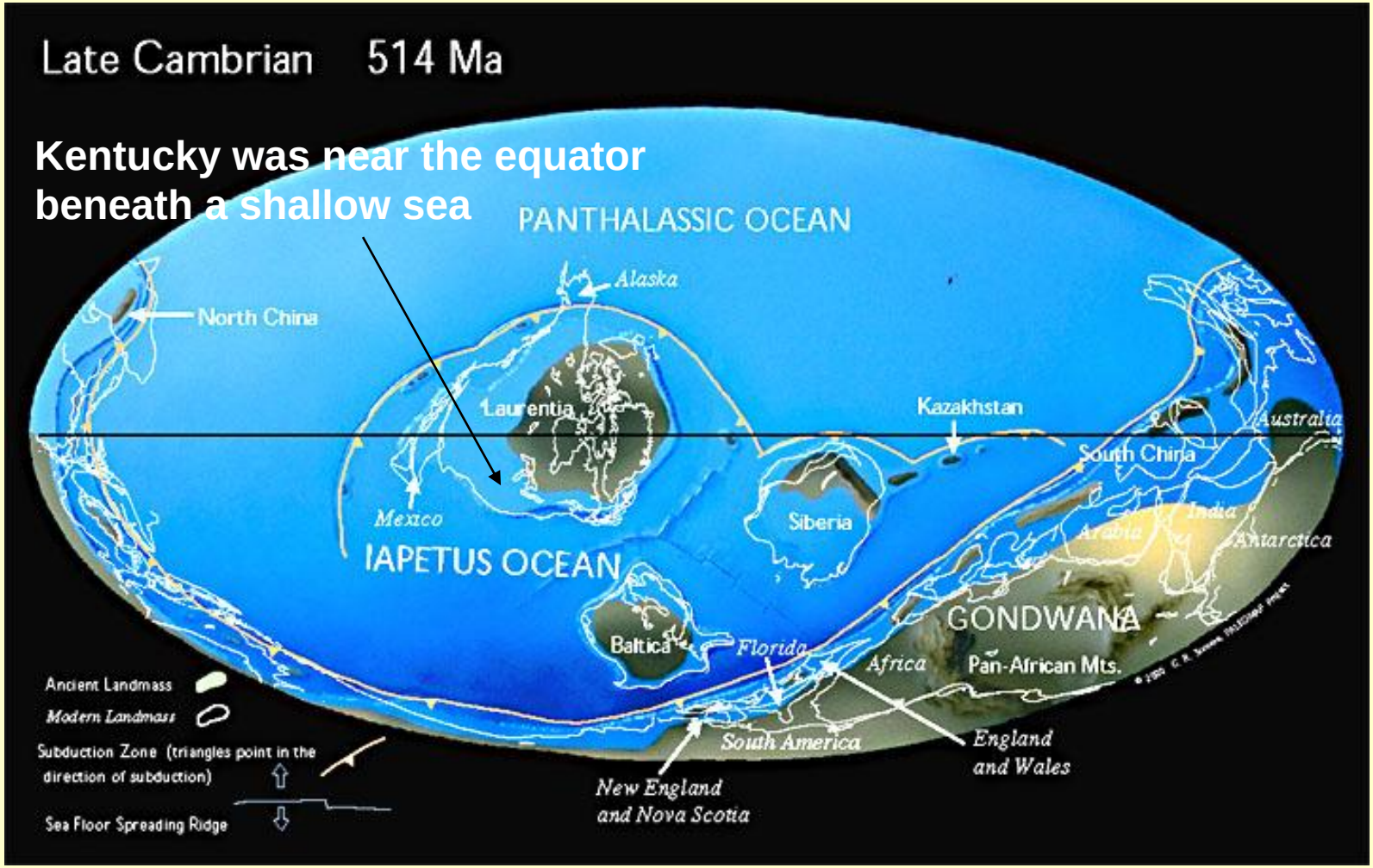
Same Basic Plan



Embroyos of different vertebrates at comparable stages of development. The earlier stages of development (top row) are strikingly similar in every group, regardless of the adult anatomy. Note that each embryo begins with a similar number of gill arches (pouches below the head) and a similar vertebral column. In later stages of development, these structures are modified to yield different adult forms. (From G.J. Romanes, 1910, Darwin and after Darwin, Open Court, Chicago.)

Evolution of the Earth. Donald R. Prothero and Robert H. Dott, Jr., McGraw-Hill, 2002.

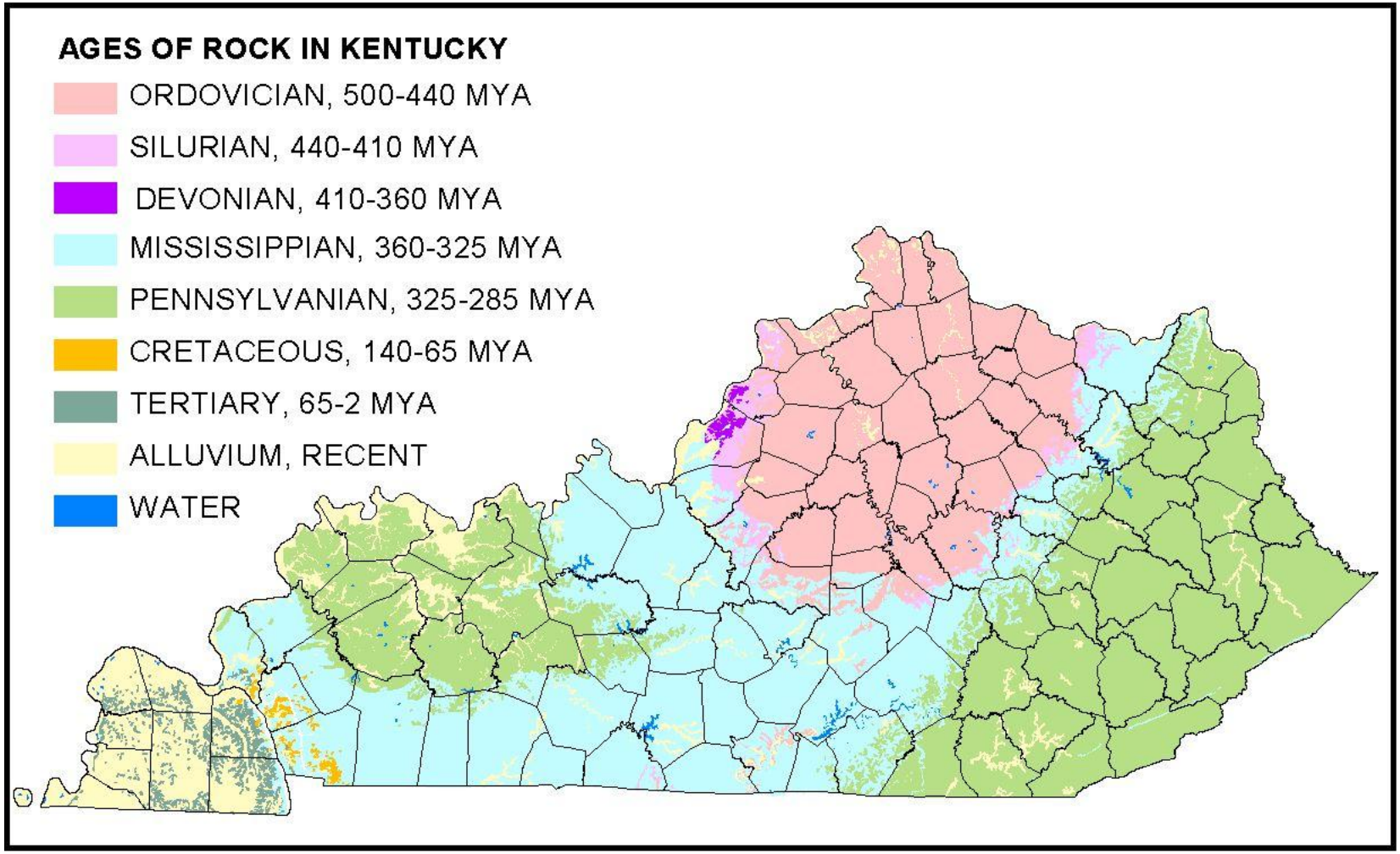
The Cambrian Period, 545 to 495 Million Years Ago



Animals with hard-shells appeared in great numbers for the first time during the Cambrian. The continents were flooded by shallow seas. The supercontinent of Gondwana had just formed and was located near the South Pole.

From PALEMAP Project, Christopher R. Scotese

Ages of Rock in Kentucky



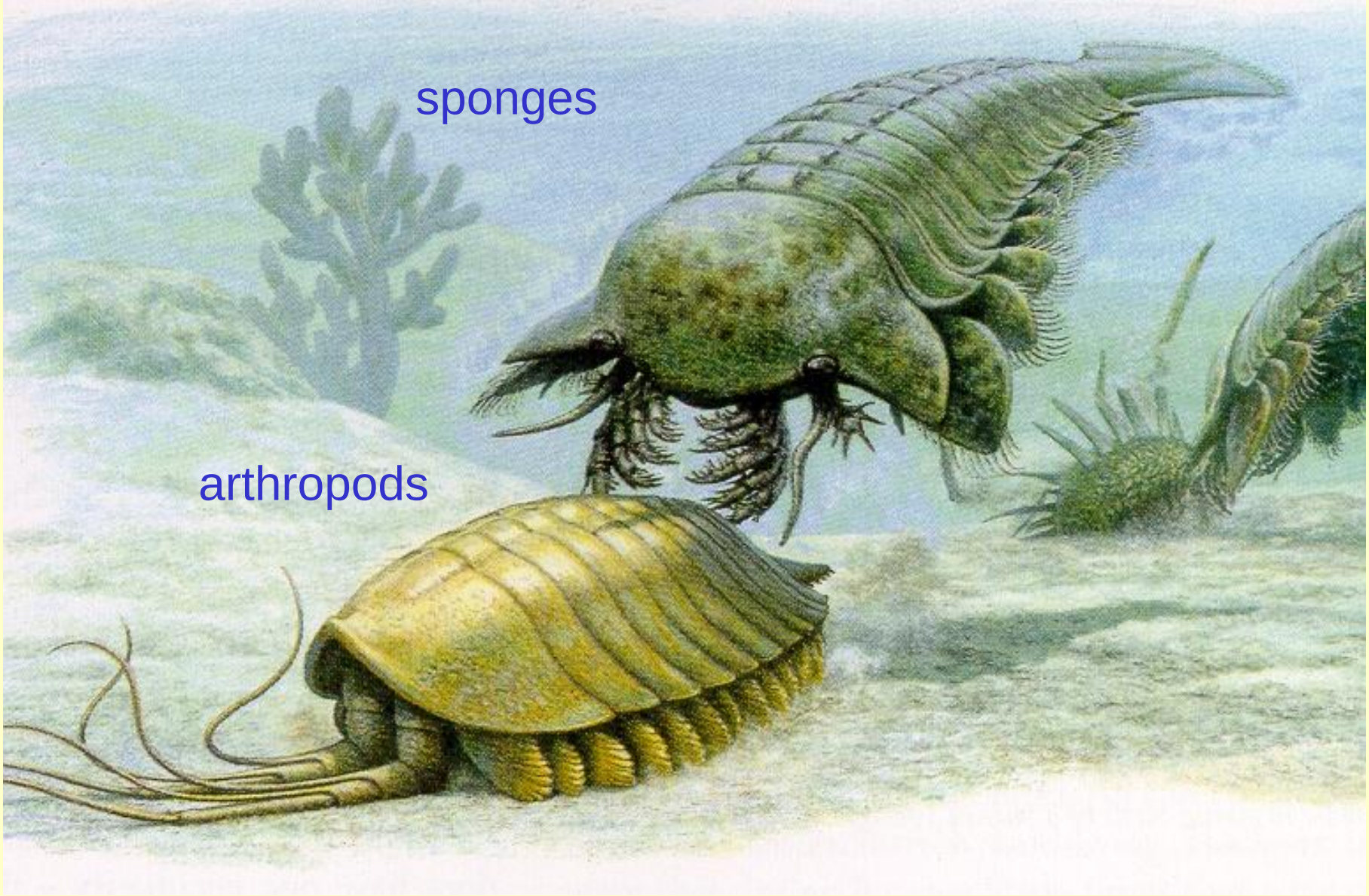
The different regions of Kentucky are defined by the underlying rock: Eastern and Western Coal Fields—Pennsylvanian; Bluegrass—Ordovician, Silurian, and Devonian; Pennyrile—Mississippian; and Jackson Purchase—Tertiary and Cretaceous.

The First Fossils

The Burgess Shale in British Columbia, Canada

- **The locality is special because of the soft-bodied preservation of a wide diversity of fossil invertebrate animals, representative of the "Cambrian explosion of life."**
- **Discovered in 1909 by Charles Walcott**
- **A World Heritage Site.**
- **Good reviews of types of fossils found can be read in "Explosion of Life—The Cambrian Period" in National Geographic, v. 184, 1993, p. 120-136, and "Wonderful Life," by Steven J. Gould, 1989.**

More about the Burgess Shale

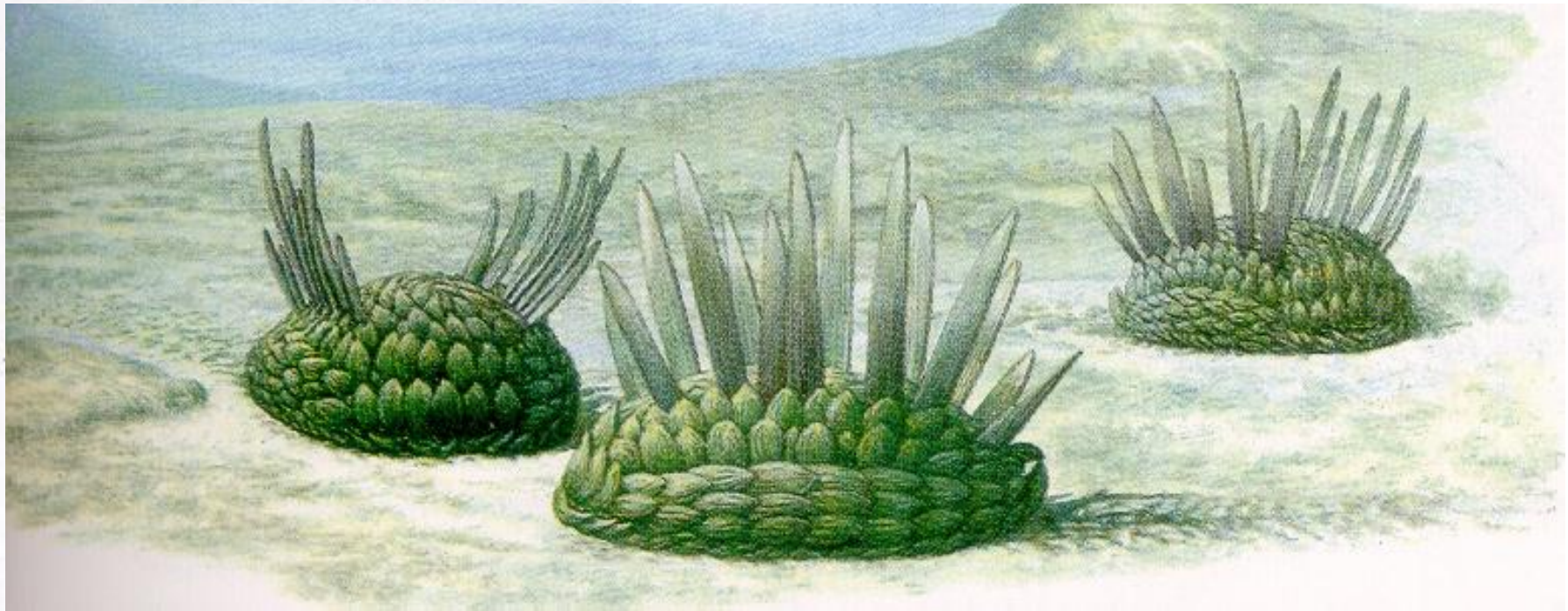


Many of the fossils from the Burgess Shale are easily recognizable **(image from Norman, D.,1994, Prehistoric Life: Macmillan Publishing, p.46**

Some of the fossils are less recognizable

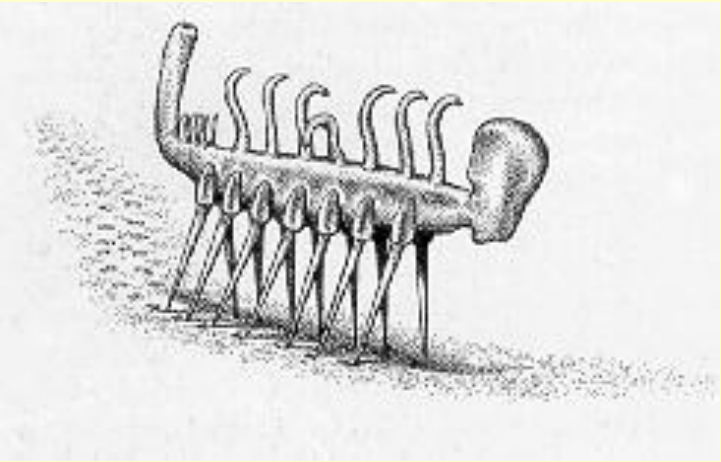
This is *Wiwaxia*, a possible spiny mollusc

(photo from Gore, R., Explosion of Life: national Geographic, v. 184, p. 131 and drawing from Norman, D.,1994, Prehistoric Life: Macmillan Publishing, p.47) .



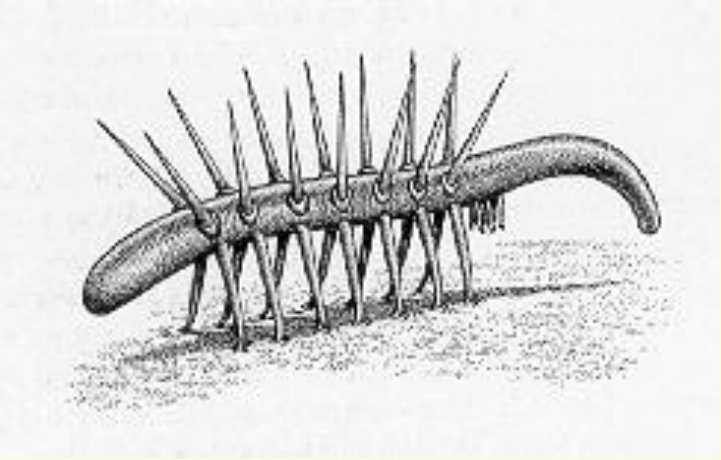
Opabinia-A predator, but anyone's guess as to what type

(Image from Norman, D.,1994, Prehistoric Life: Macmillan Publishing, p.47)



Legs down?

Or spines down?

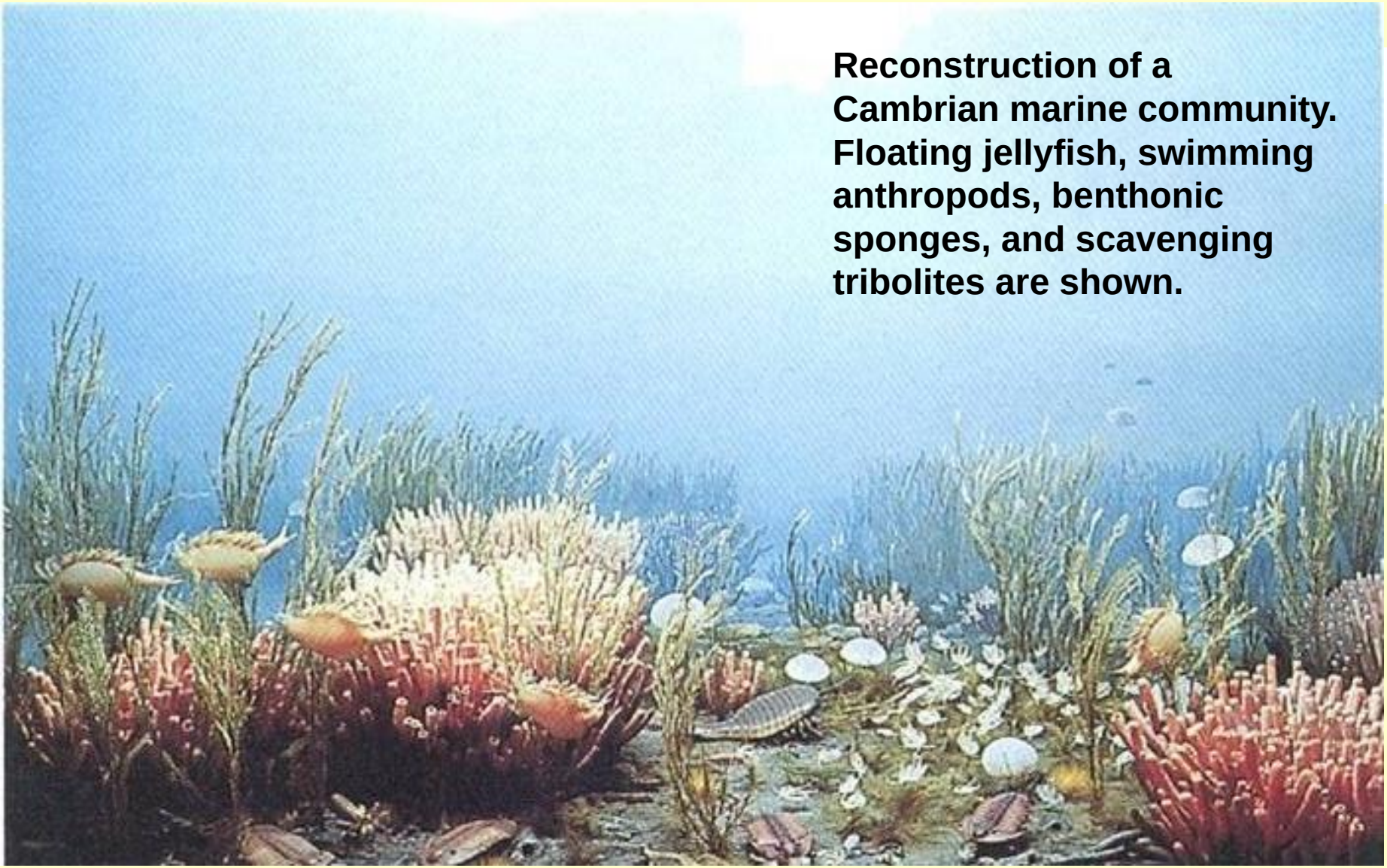


Hallucigenia-another strange creature

(photo from Gore, R., Explosion of Life: national Geographic, v. 184, p. 127

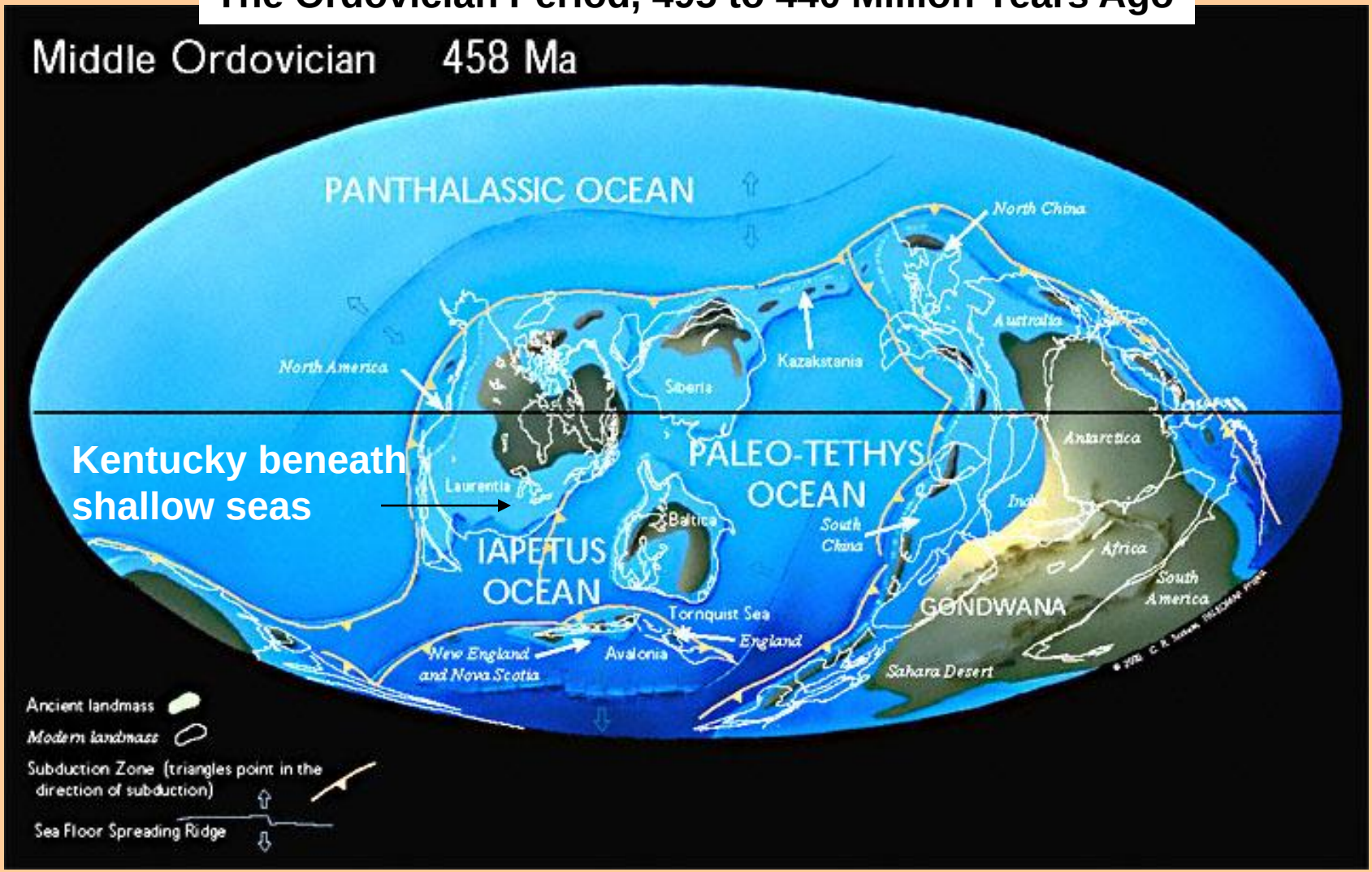
(Image from Norman, D.,1994, Prehistoric Life: Macmillan Publishing, p.44)

Cambrian Seas



Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

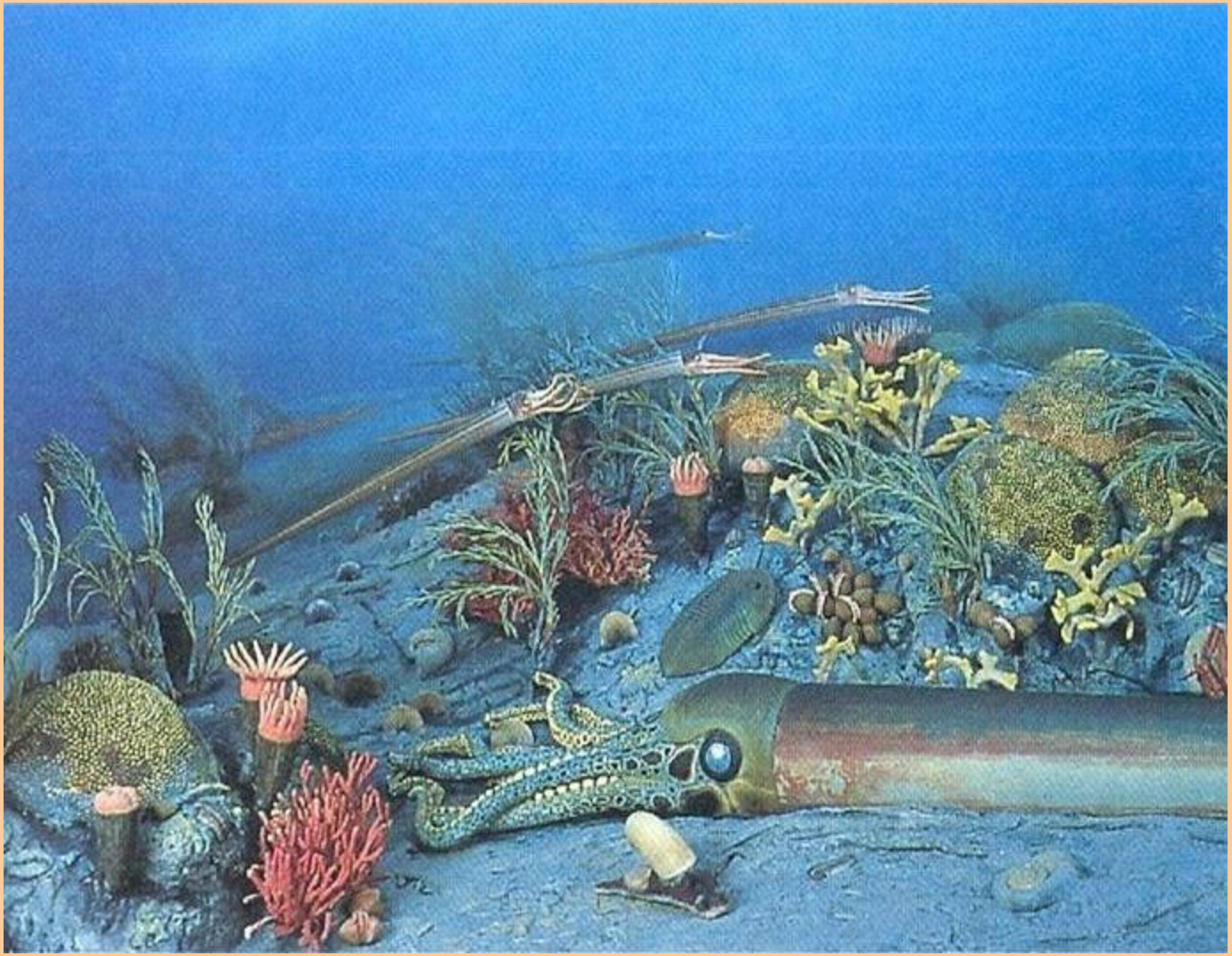
The Ordovician Period, 495 to 440 Million Years Ago



During the Ordovician ancient oceans separated the barren continents of Laurentia, Baltica, Siberia and Gondwana. The end of the Ordovician was one of the coldest times in Earth history. Ice covered much of the southern region of Gondwana.

From PALEMAP Project, Christopher R. Scotese

Ordovician Seas, ~475 million years ago

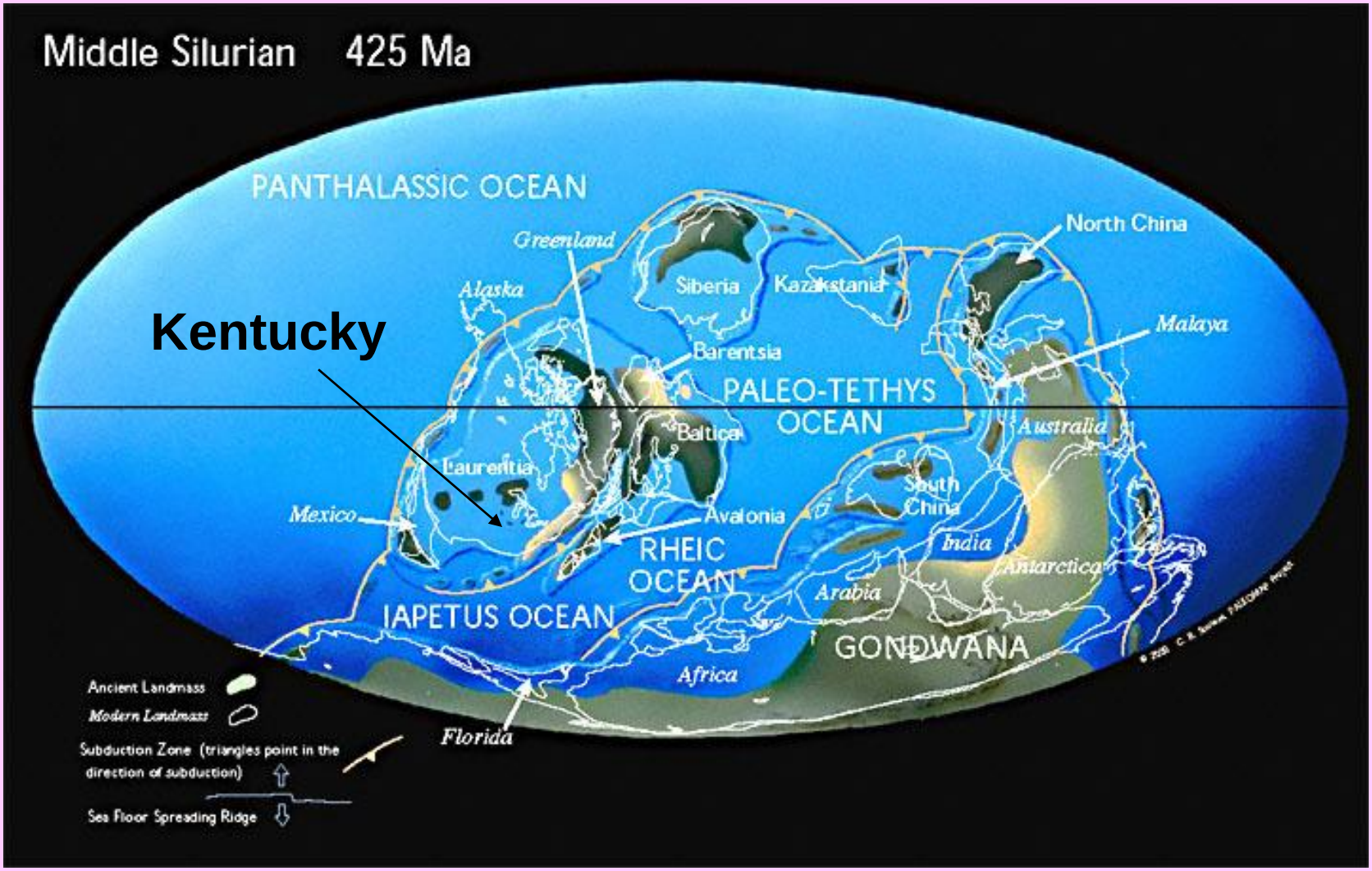


During the Ordovician, the first fish appeared, and we have fossils of land plants from the period.

Recreation of Middle Ordovician seafloor fauna: cephalopods, crinoids, colonial corals, graptolites, trilobites, and brachiopods are shown.

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

The Silurian Period, 440 to 415 Million Years Ago



Laurentia collides with Baltica closing the northern branch of the Iapetus Ocean and forming the "Old Red Sandstone" continent. Coral reefs expand and land plants begin to colonize the barren continents.

From PALEMAP Project, Christopher R. Scotese

Silurian Seas, ~425 million years ago

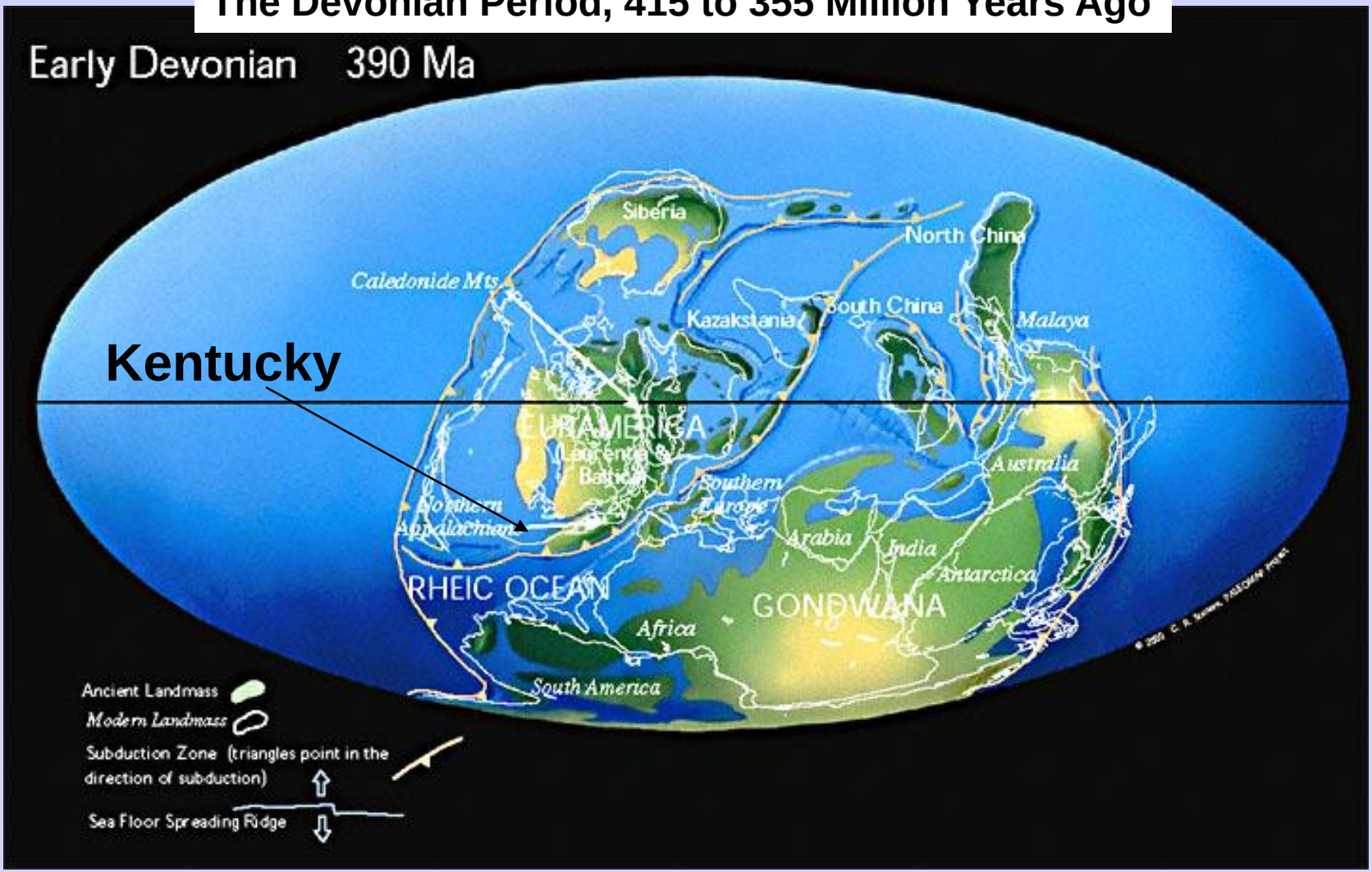
Restoration of a Silurian brackish marine bottom scene near Buffalo, New York. Shown are algae, eurypterids, worms, and shrimp

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

Plants Appear on the Land

Silurian --Seedless vascular plants, ~430 MYA

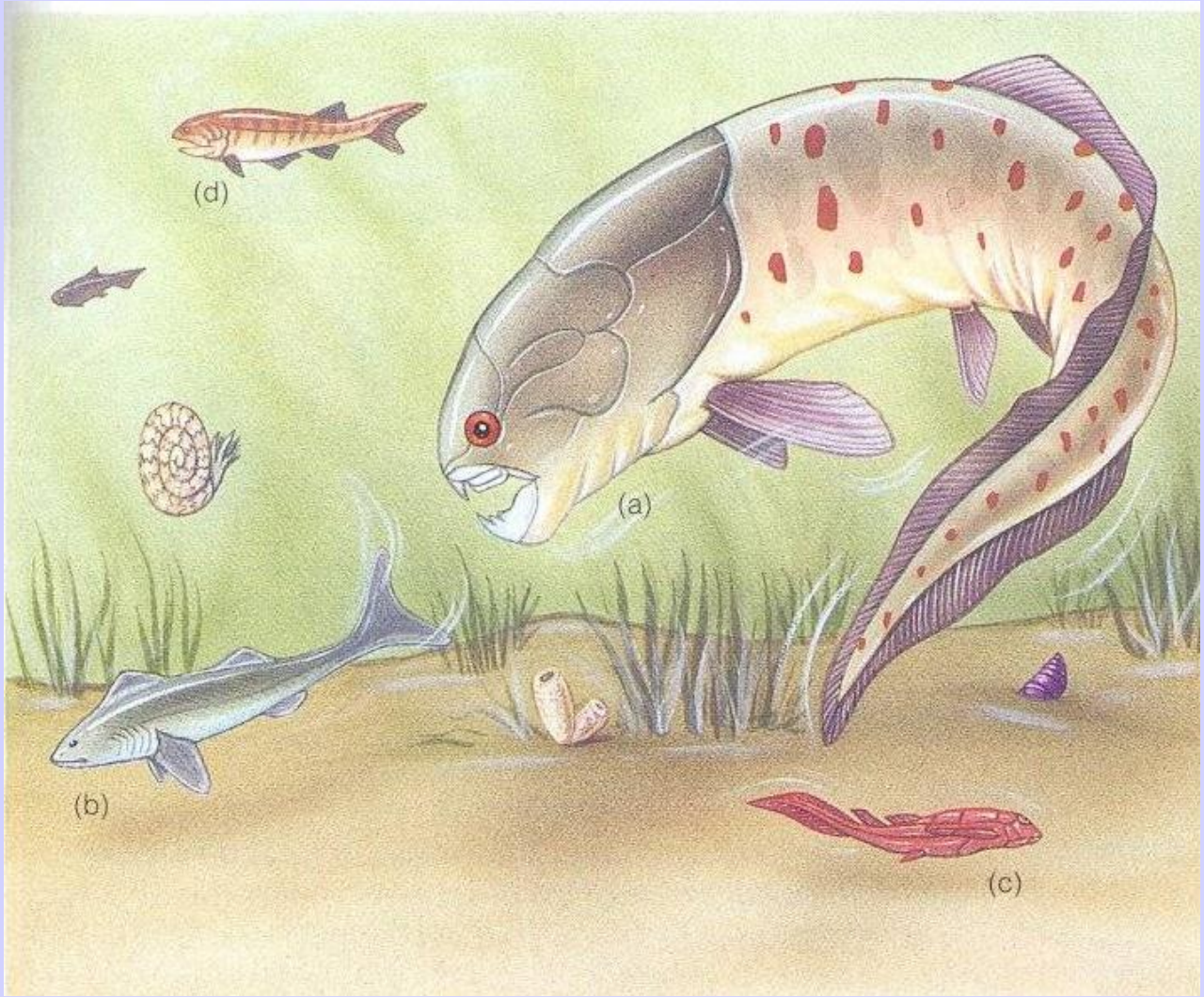
The Devonian Period, 415 to 355 Million Years Ago



By the Devonian the early Paleozoic oceans were closing, forming a "pre-Pangea". Freshwater fish were able to migrate from the southern hemisphere continents to North America and Europe. Forests grew for the first time in the equatorial regions of Artic Canada.

From PALEMAP Project, Christopher R. Scotese

Devonian Seas, ~370 million years ago



First sharks

A late Devonian marine scene from the midcontinent of North America. (a) The giant placoderm *Dunkleosteus,* 40 feet long, is pursuing (b) the shark *Cladoselache,* 4 feet long. Also shown are (c) the bottom-dwelling placoderm *Bothriolepsis* and (d) the swimming ray-finned fish *Cheirolepsis*, both of which attained a length of 16-20 inches.

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

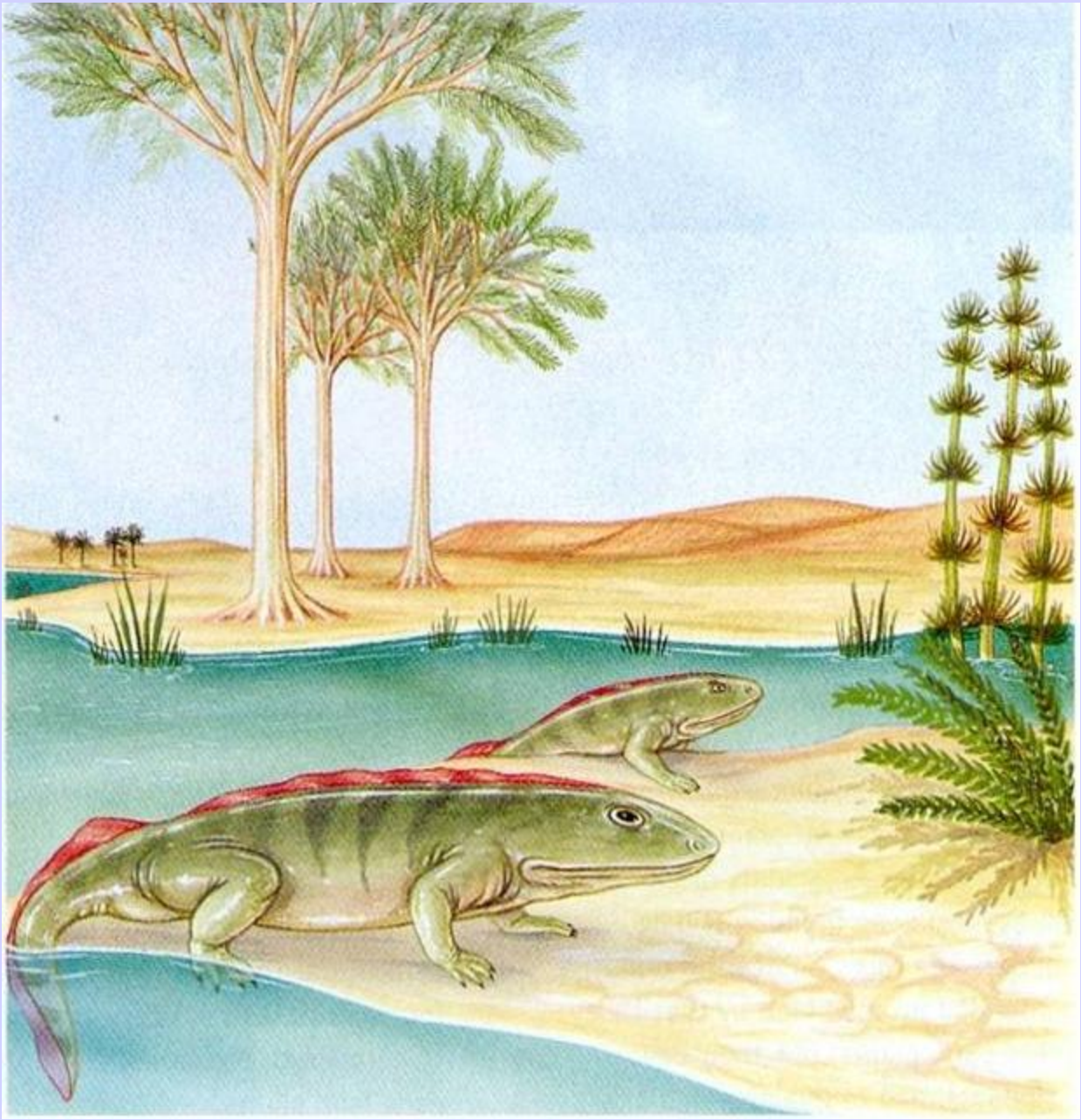
Devonian Landscape, ~370 million years ago (MYA)

Oldest fossil evidence of mosses, ~408 MYA

First insects, scorpions, and centipedes, ~385 MYA

First lobe-finned fish, ~380 MYA

First land animals (amphibians), ~375 MYA



A late Devonian landscape in the eastern part of Greenland. Shown is *Ichthyostega,* an amphibian that grew to a length of about 3 feet. The flora of the time was diverse, consisting of a variety of small and large seedless vascular plants.

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

Late Devonian -- Seed plants (gymnosperms), ~365 MYA

Silurian and Devonian, 440-360 MYA

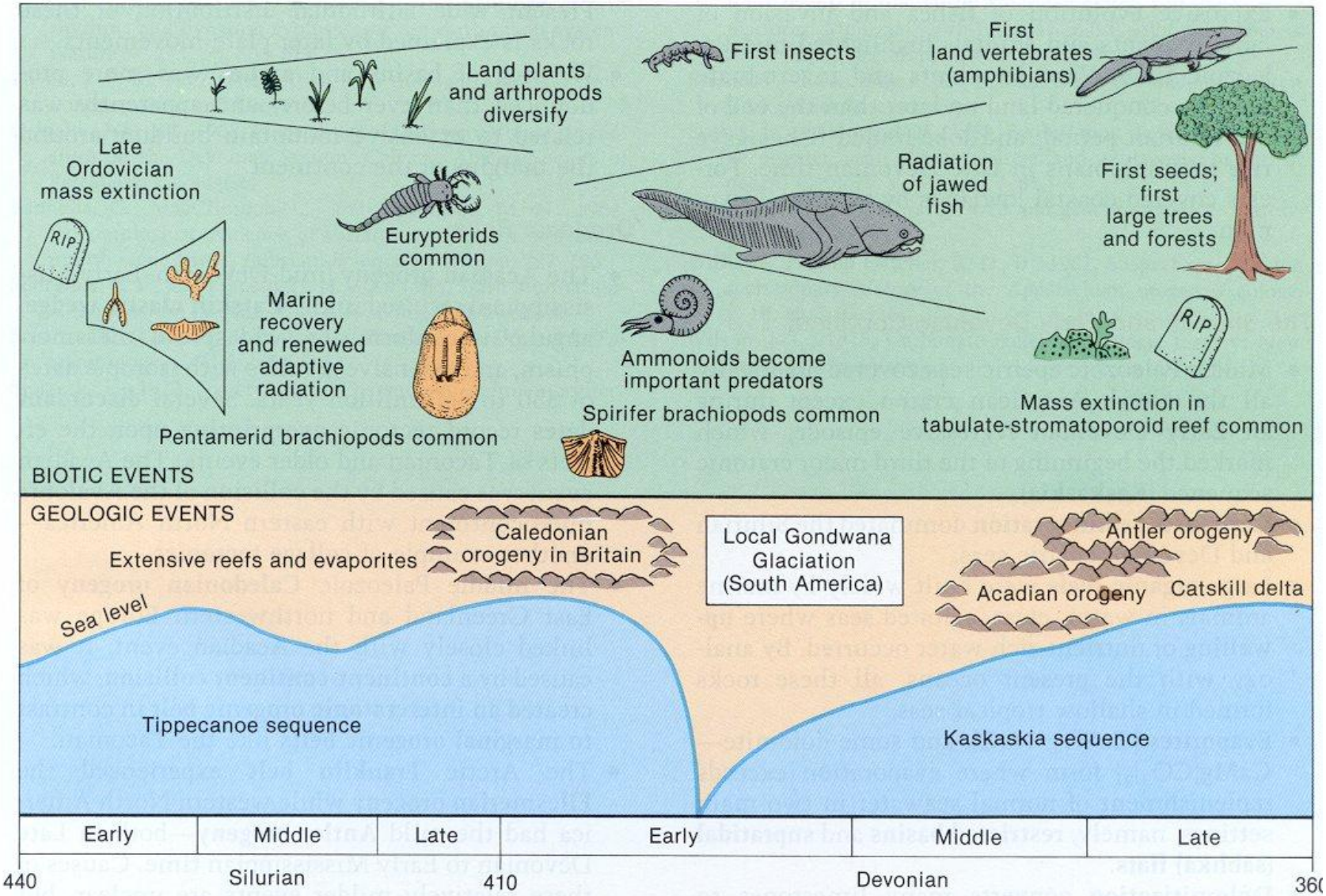
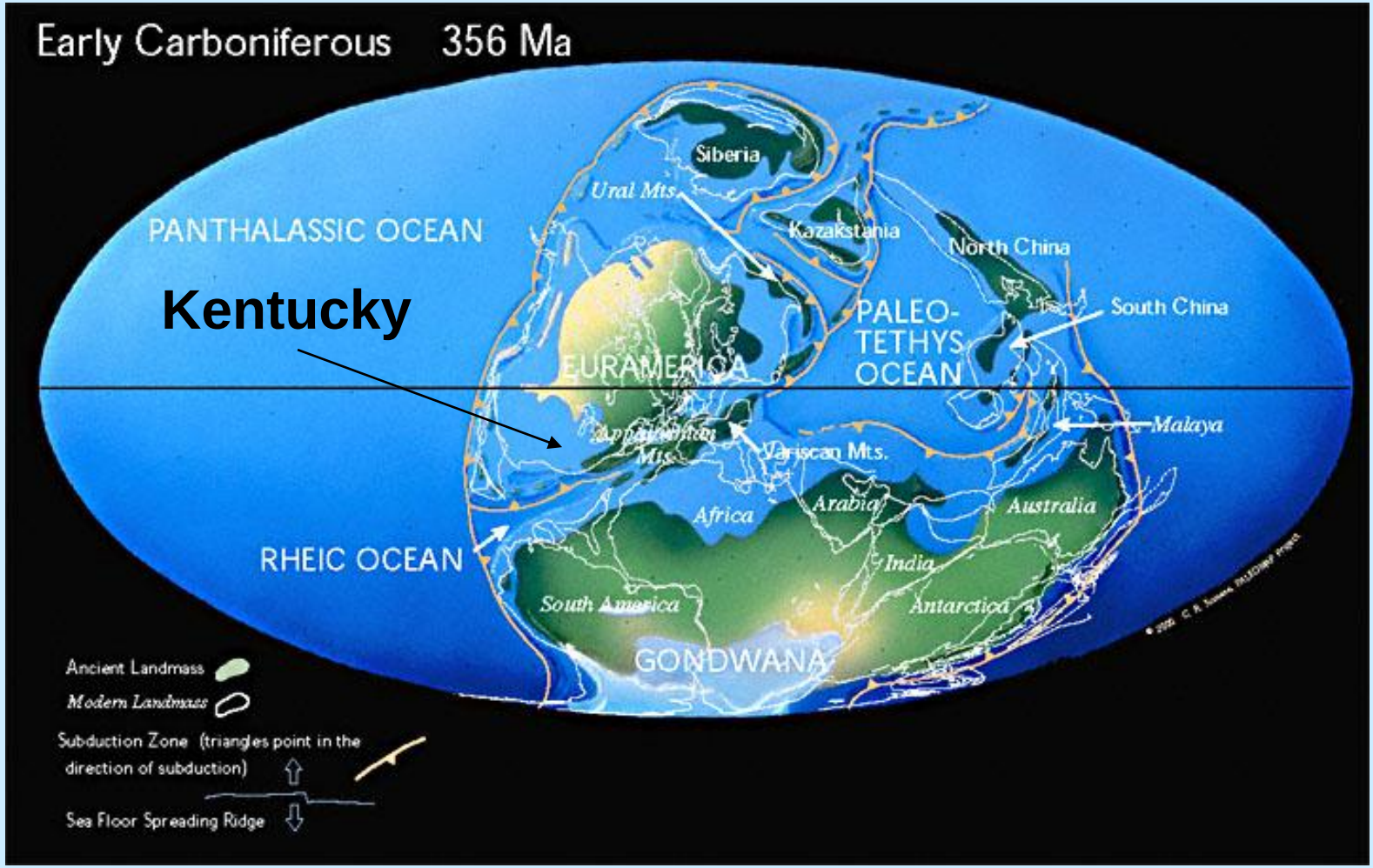


FIGURE 12.50 Summary time line of events of the Silurian and Devonian.

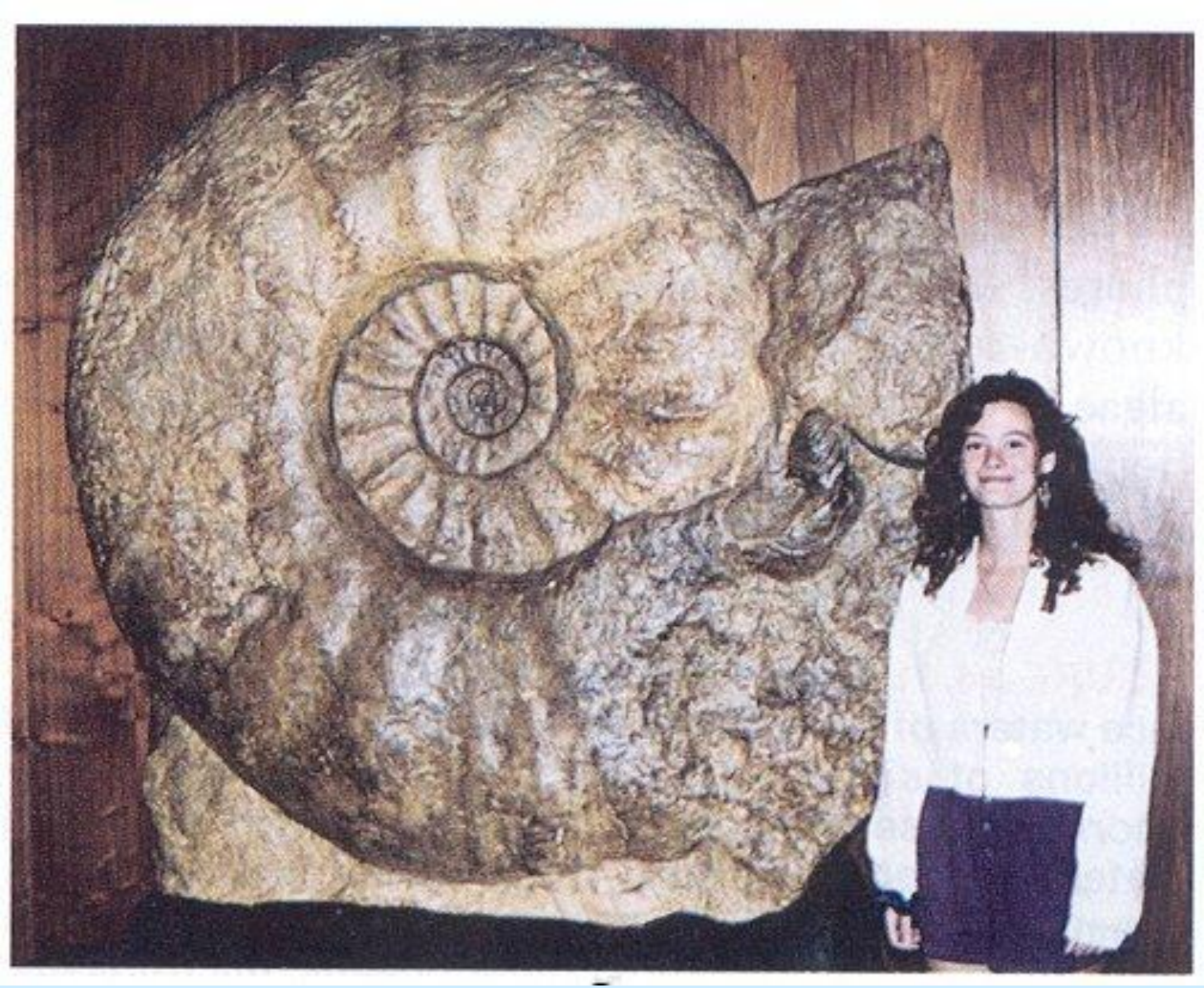
Evolution of the Earth. Donald R. Prothero and Robert H. Dott, Jr., McGraw-Hill, 2002.

Early Carboniferous (Mississippian), 355 to 325 Million Years Ago



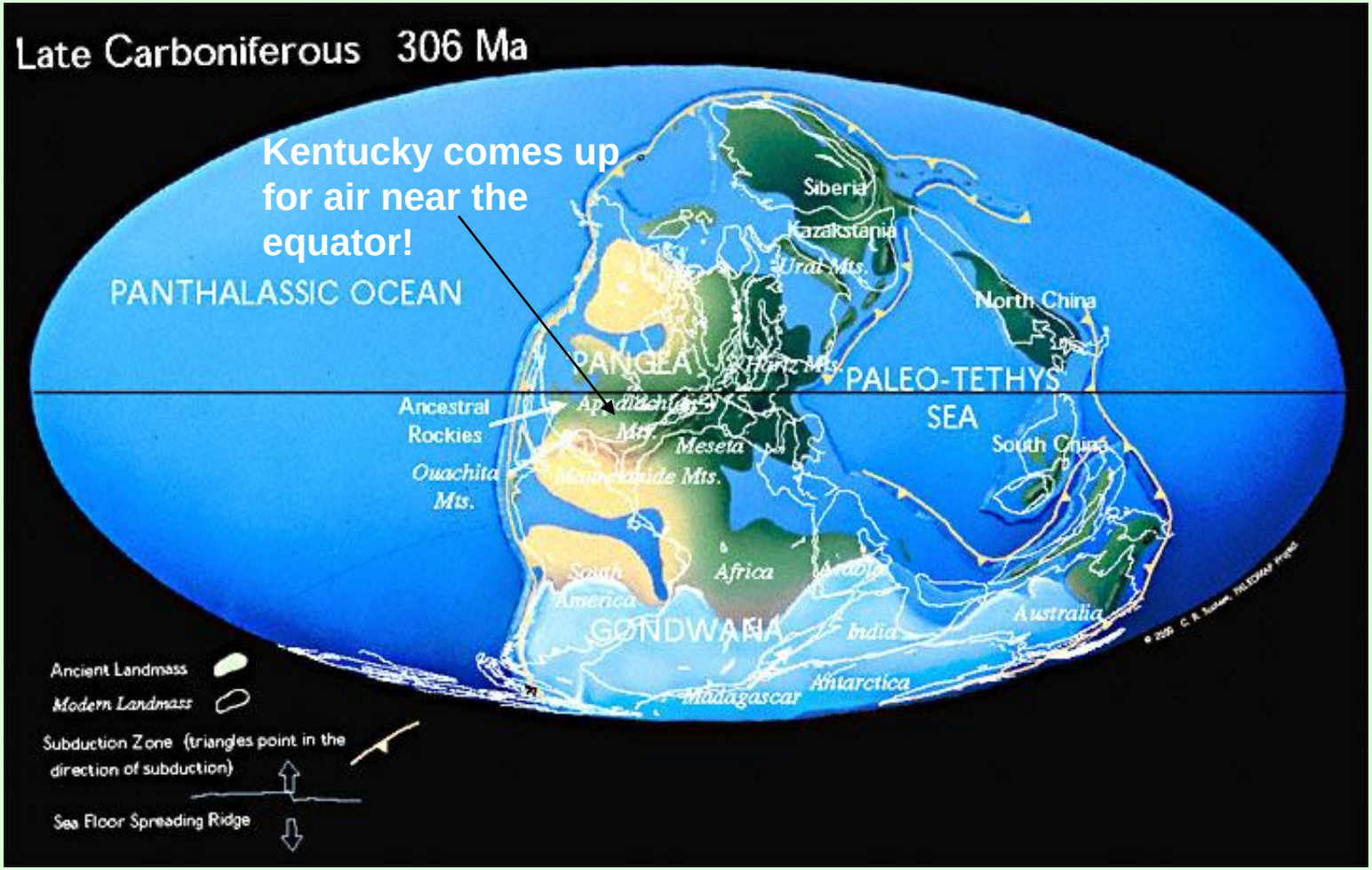
During the Early Carboniferous the Paleozoic oceans between Euramerica and Gondwana began to close, forming the Appalachian and Variscan mountains. An ice cap grew at the South Pole as four-legged vertebrates evolved in the coal swamps near the Equator.

From PALEMAP Project, Christopher R. Scotese



Mississippian Era Ammonite -- Young lady for scale

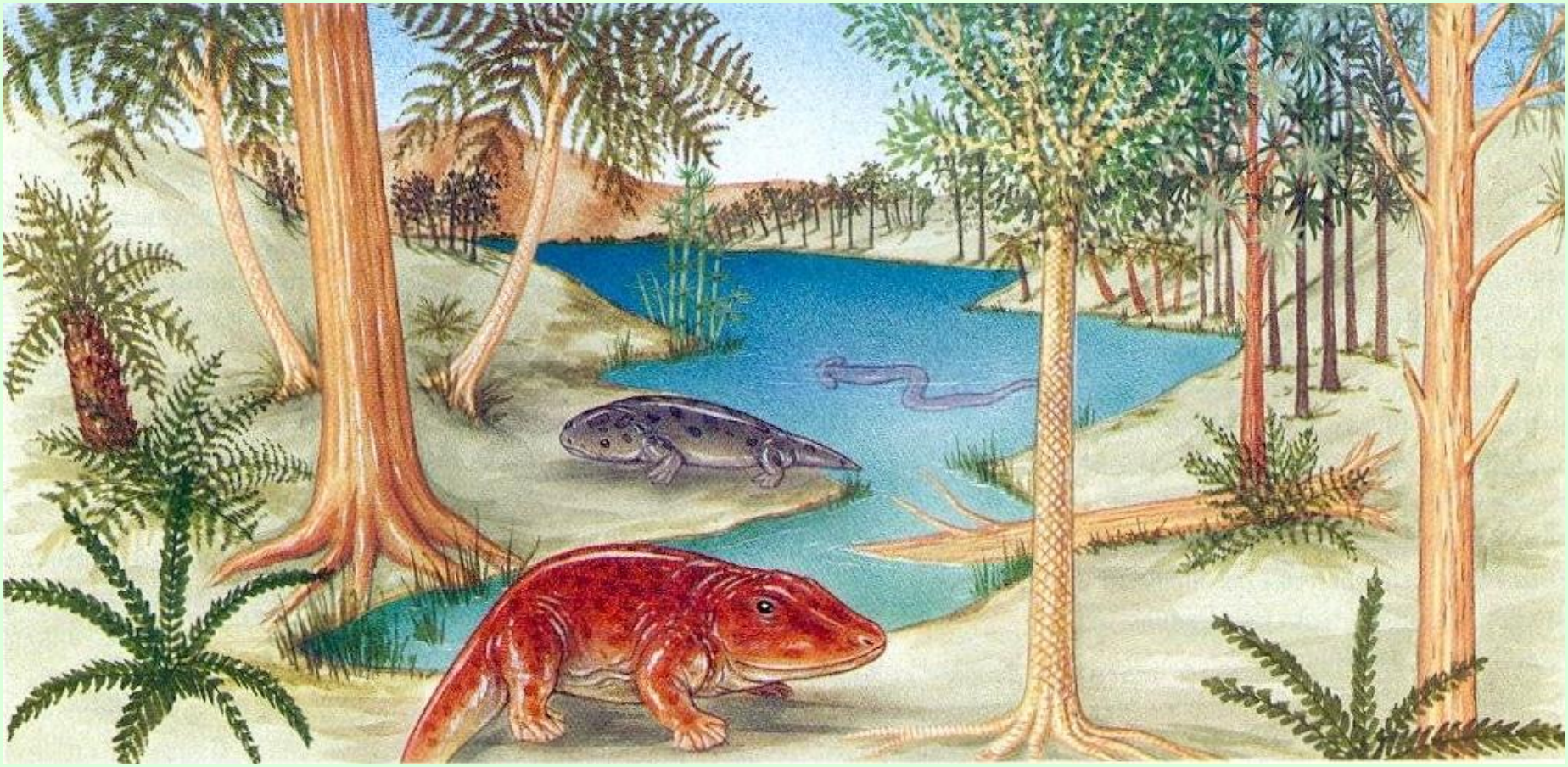
Late Carboniferous (Pennsylvanian), 325 to 290 Million Years Ago



By the Late Carboniferous the continents that make up modern North America and Europe had collided with the southern continents of Gondwana to form the western half of Pangea. Ice covered much of the southern hemisphere and vast coal swamps formed along the equator.

From PALEMAP Project, Christopher R. Scotese

Carboniferous Coal Swamp



Reconstruction of a Carboniferous coal swamp. The varied amphibian fauna of the time is shown, including the large labyrinthodont amphibian *Eryops (foreground)* and the sepentlike *Dolichosoma (background).*

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

Coal Formation

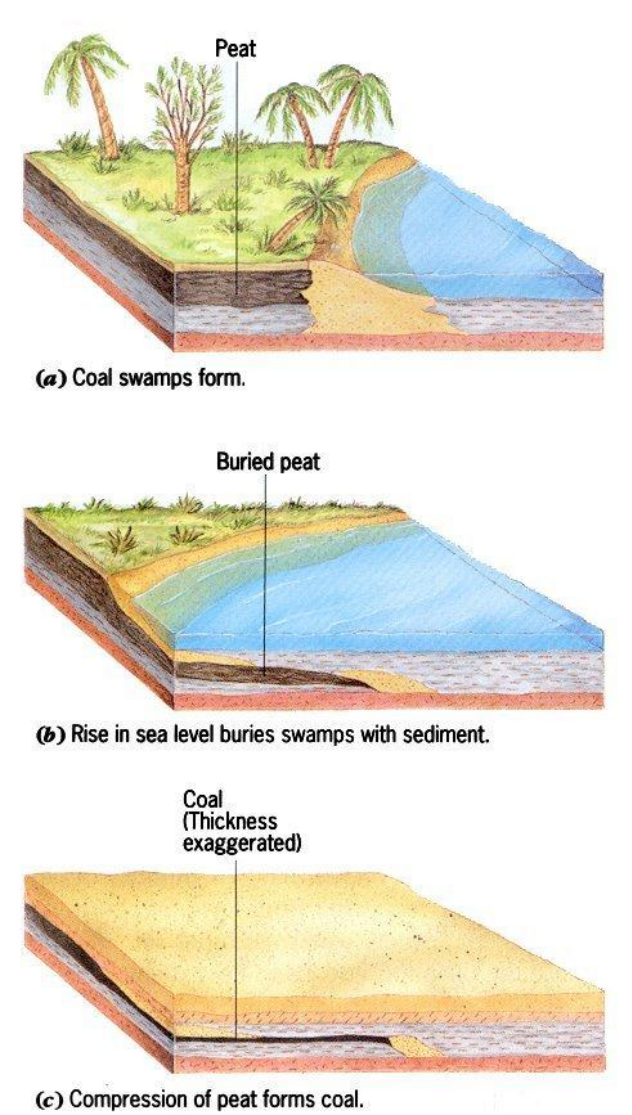


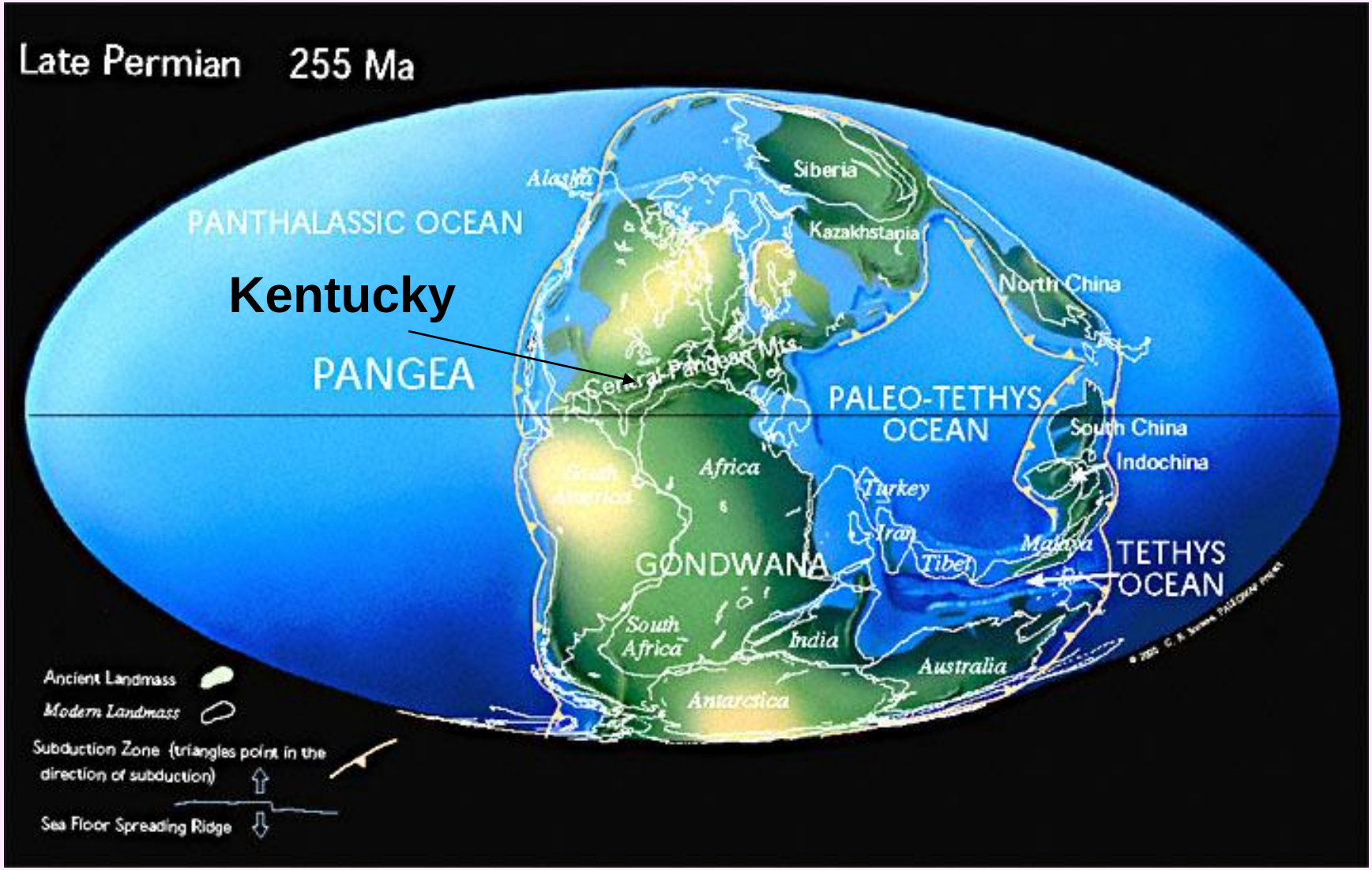
FIGURE 16.6 Processes by which buried plant debris (peat) is transformed into coal.

When partially decomposed vegetation is buried deeply in a sedimentary environment, it may be slowly transformed into coal.

From Environmental Science, Botkin Daniel B. and Edward A. Keller, 3rd ed., 2000.

Pennsylvanian dragon fly -- 2 foot wingspan, ~300 MYA

The Permian Period, 290 to 245 Million Years Ago



At the end of the Permian was Greatest Extinction of All Time

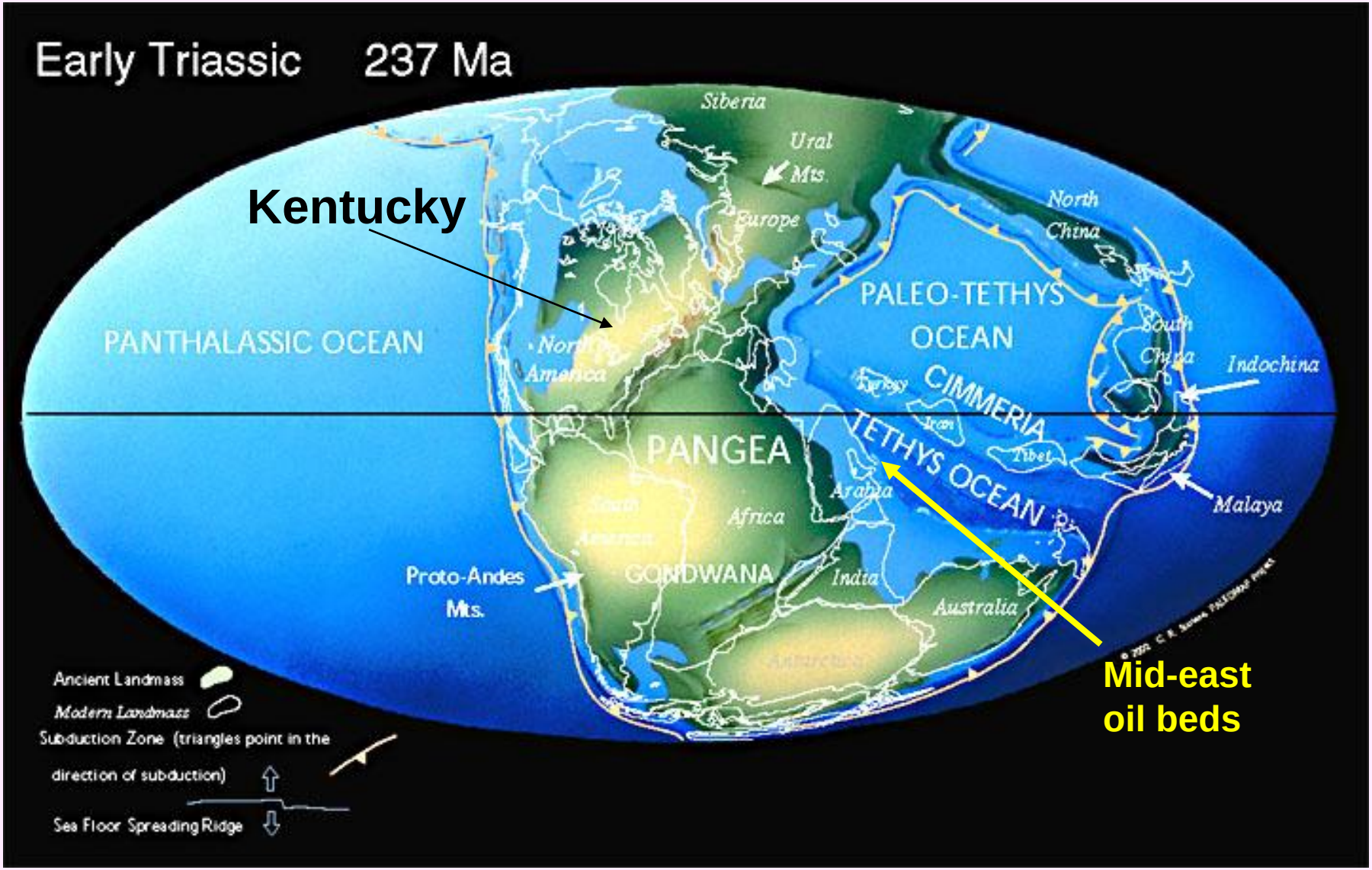
From PALEMAP Project, Christopher R. Scotese

Permian Era amphibian, ~260 MYA

Permian landscape, ~260 MYA

Permian reptile -- Dimetrodon, 5 ft long, ~260 MYA

The Triassic Period, 245 to 205 Million Years Ago



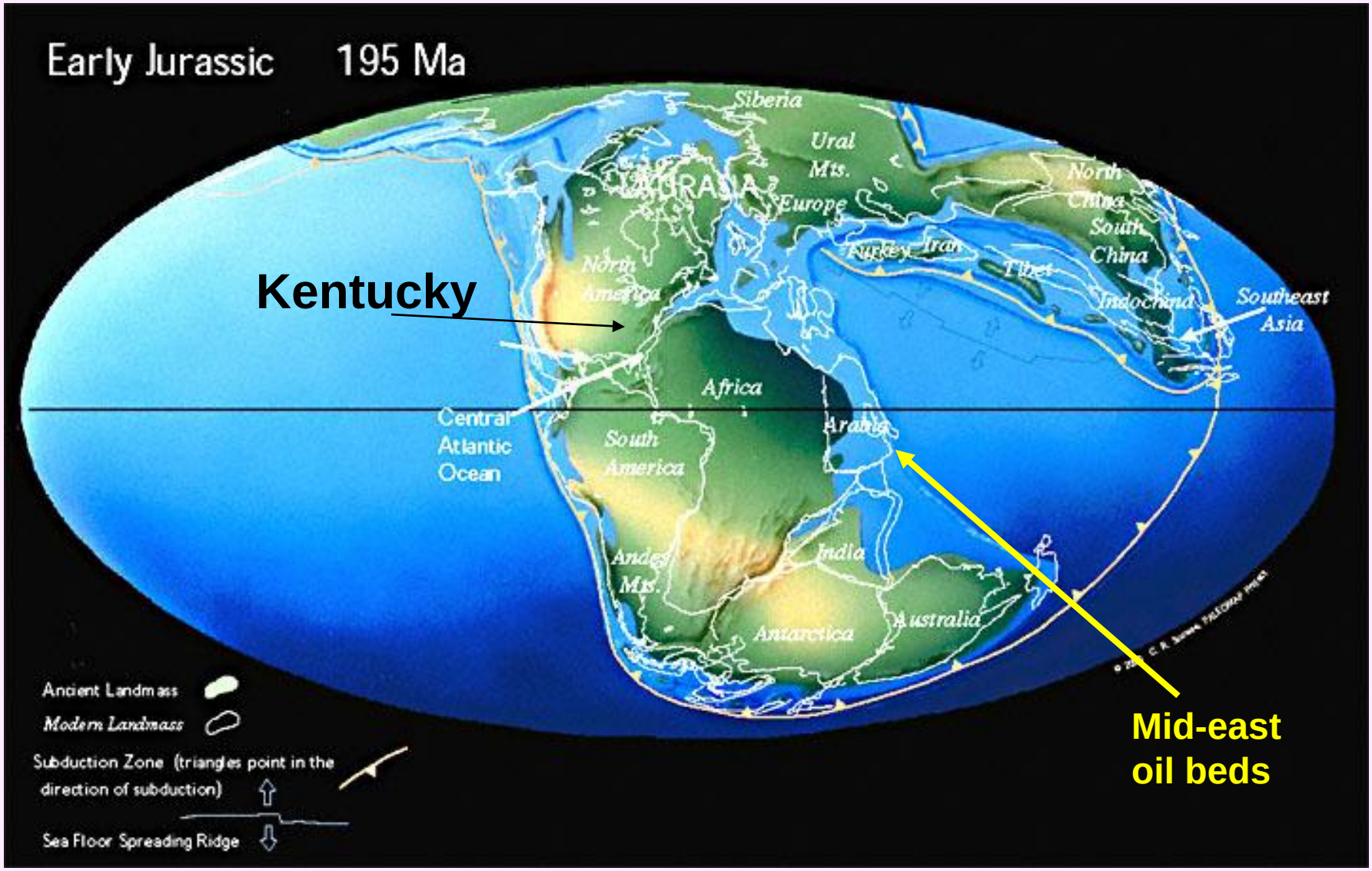
Oil that now supplies the world's energy was formed in shallow seas of the Early Triassic in what is now the Middle East.

From PALEMAP Project, Christopher R. Scotese

Triassic landscape, ~225 MYA

Triassic -- Yaleosaurus, 5 foot carnivores

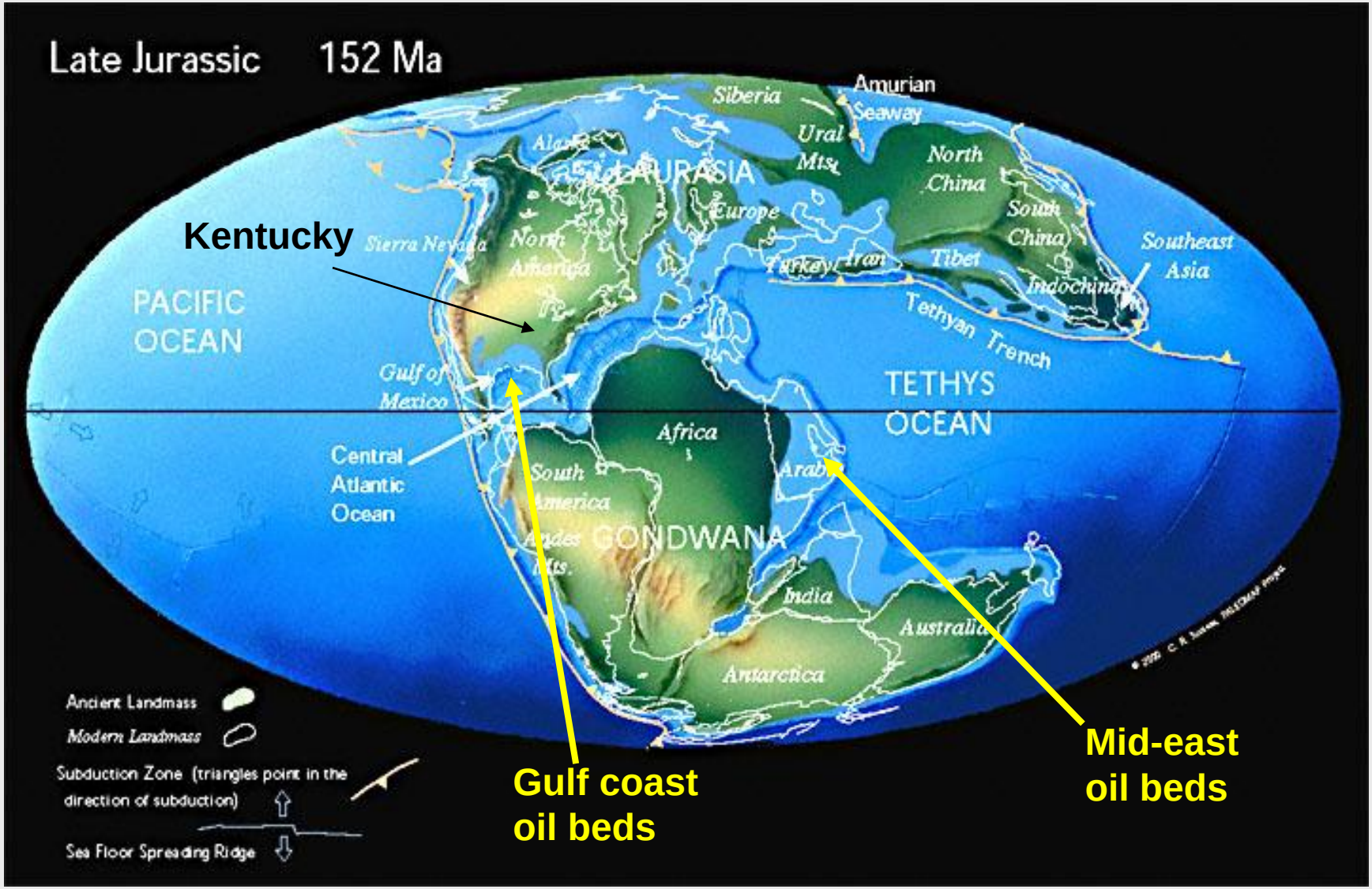
The Early Jurassic Period, 205 to 175 Million Years Ago



The Dinosaurs spread across Pangaea

From PALEMAP Project, Christopher R. Scotese

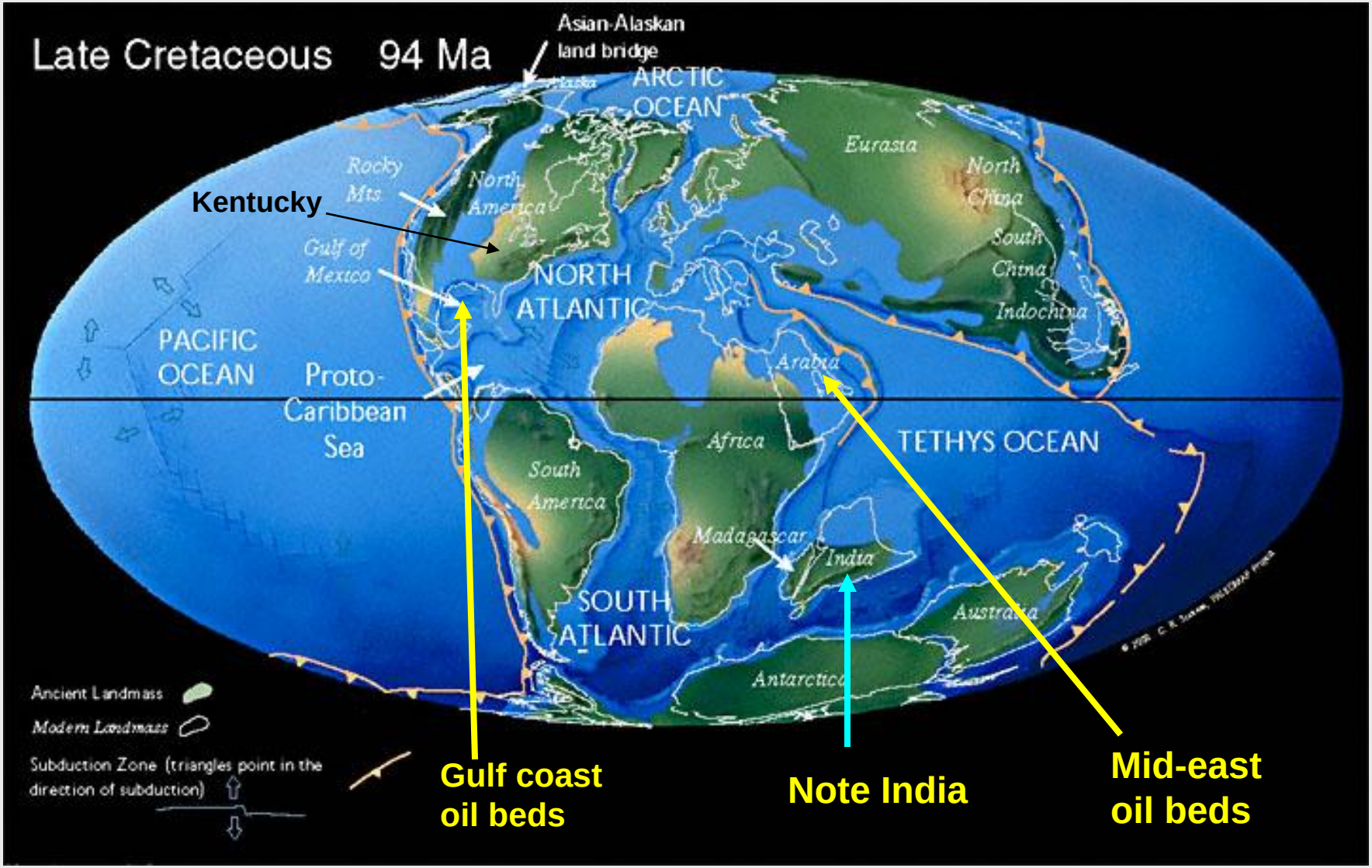
The Late Jurassic Period, 175 to 140 Million Years Ago



Pangea Begins to Rift Apart, Atlantic Ocean Grows, Sierra Nevadas

From PALEMAP Project, Christopher R. Scotese

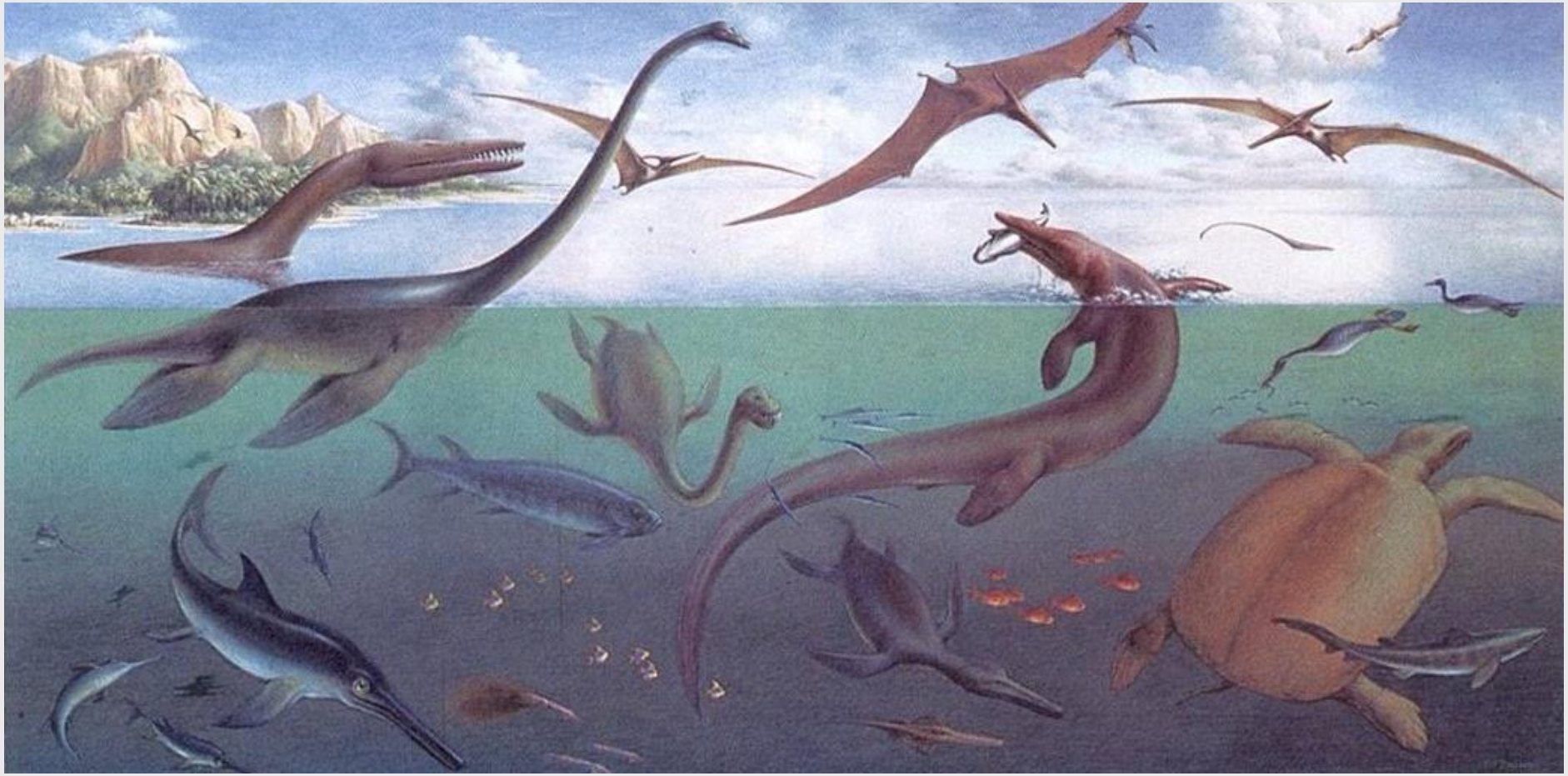
The Cretaceous Period, 140-65 Million Years Ago



Alaskan Land Bridge, Rocky Mountains

From PALEMAP Project, Christopher R. Scotese

Life in the Cretaceous



The Cretaceous seas swarmed with an immense variety of swimming animals. In addition to the squidlike belemnites (bottom), there were many different kinds of marine vertebrates. There was a great variety of advanced teleost fishes, including the giant *Xiphactinus* (largest fish in the diorama). Preying upon these were many kinds of marine reptiles, including the huge sea turtle *Archelon* (right), the long-necked paddling plesiosaurs (three examples in the upper left), the fishlike ichthyosaurs (lower left), and the marine lizards known as mosasaurs (at sea surface on right). The giant pterodactyl *Pteranodon* flew overhead, and there was even a primitive flightless toothed bird, *Hesperornis*, that was adapted for a marine existence (at sea surface on extreme right). (Painting by R. Zallinger, courtesy of Yale Peabody Museum.

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

Flowers March Across the Cretaceous Landscape

Flowering plants (angiosperms), ~115 MYA

How flowers changed the world,
***The Immense Journey*, Loren Eisley**

Encyclopedia of plants

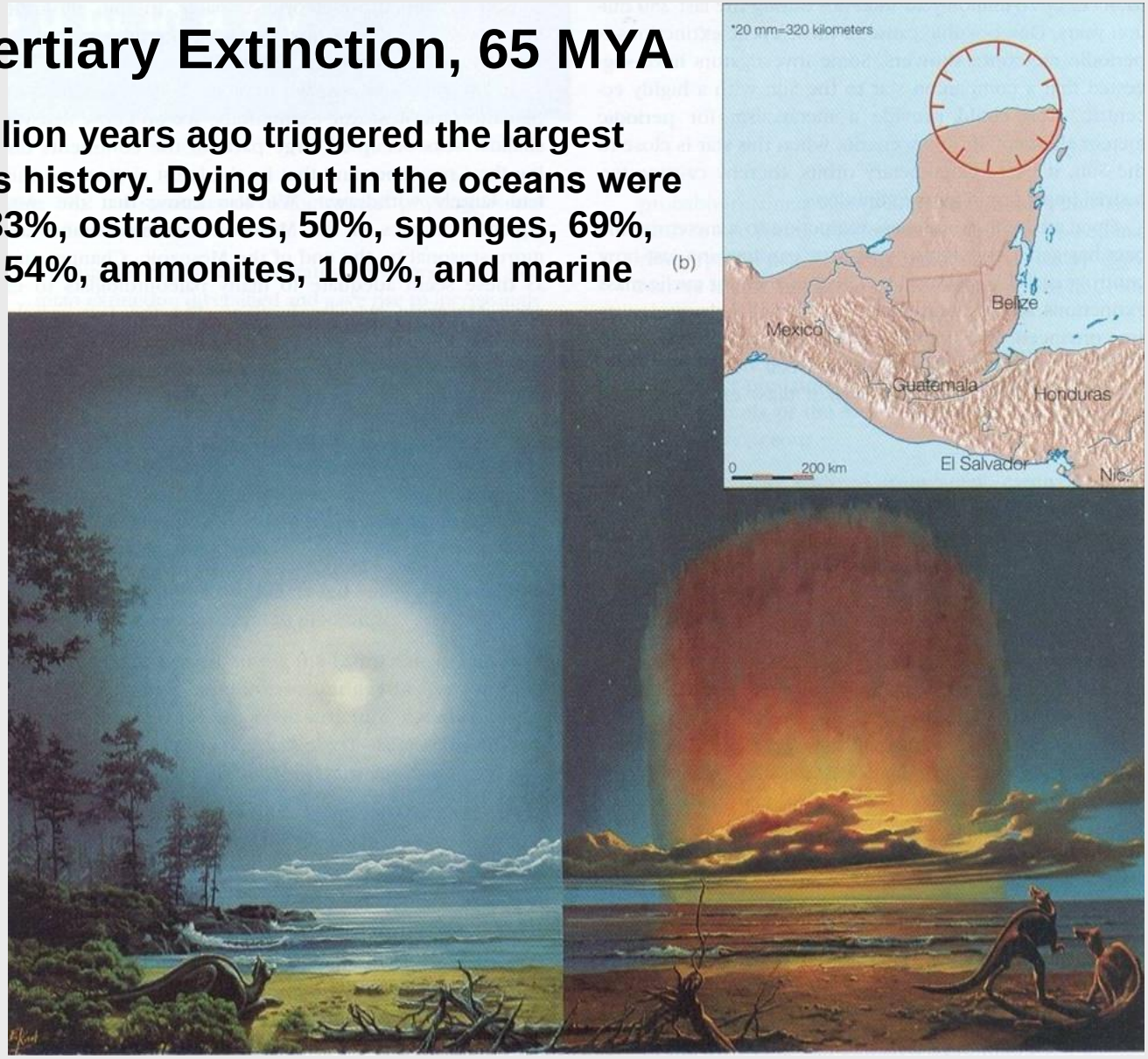
Life in the Cretaceous, 70 Million Years Ago

Diorama of life in the Late Cretaceous. The giant predator *Tyrannosaurus rex* dominates the scene, faced by two horned *Triceratops*. Also visible are the duckbill *Trachodon*, the small ostrich dinosaur Struthiomimus, and armored *Ankylosaurus*. A huge Pteranodon flies overhead, and the vegetation shows a profusion of flowering plants. Although modern dinosaur artists would draw a less blimp-like tyrannosaur leaning forward in a fully balanced posture, in most details this painting is accurate. Such a scene must have been common at the end of the Cretaceous. (Painting by R. Zallinger, courtesy of Yale Peabody Museum.)

Evolution of the Earth. Donald R. Prothero and Robert H. Dott, Jr., McGraw-Hill, 2002.

The Cretaceous-Tertiary Extinction, 65 MYA

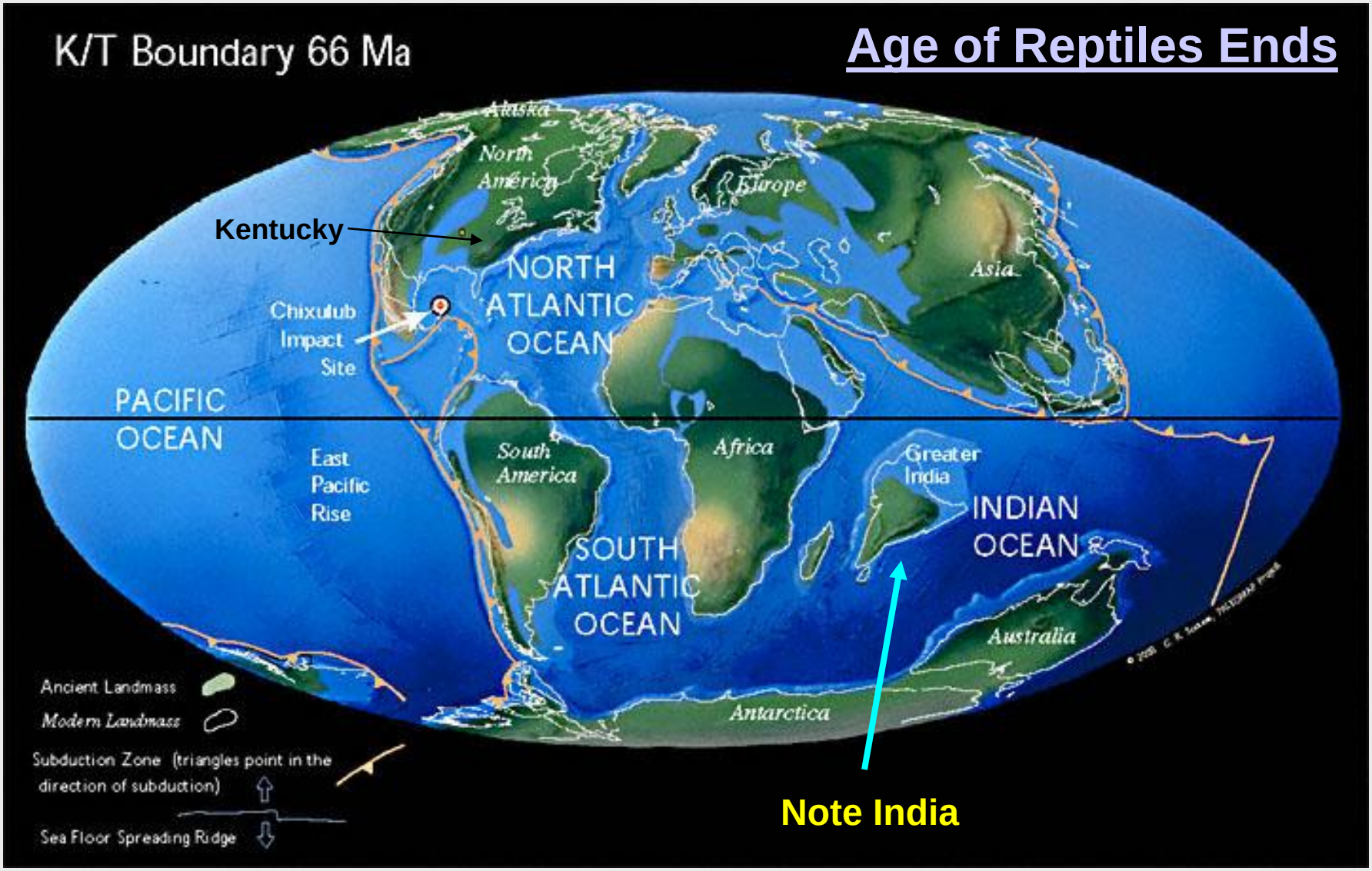
An asteroid impact 65 million years ago triggered the largest extinction event in Earth's history. Dying out in the oceans were planktonic foraminifera, 83%, ostracodes, 50%, sponges, 69%, corals, 65%, sea urchins, 54%, ammonites, 100%, and marine reptiles, 93%. On land, 56% of reptiles in general, but 100% of non-avian dinosaurs and pterosaurs. On land, nothing bigger than 50 pounds survived; all survivors were small—lizards, snakes, crocodiles, turtles, mammals, frogs, and salamanders. The niche for mammals increased.



(a) Proposed meteorite impact at the end of the Cretaceous. (b) A large circular structure centered on Chixculub on the Yucatan Peninsula of Mexico is thought to be a meteorite impact site. It dates from about the end of the Cretaceous.

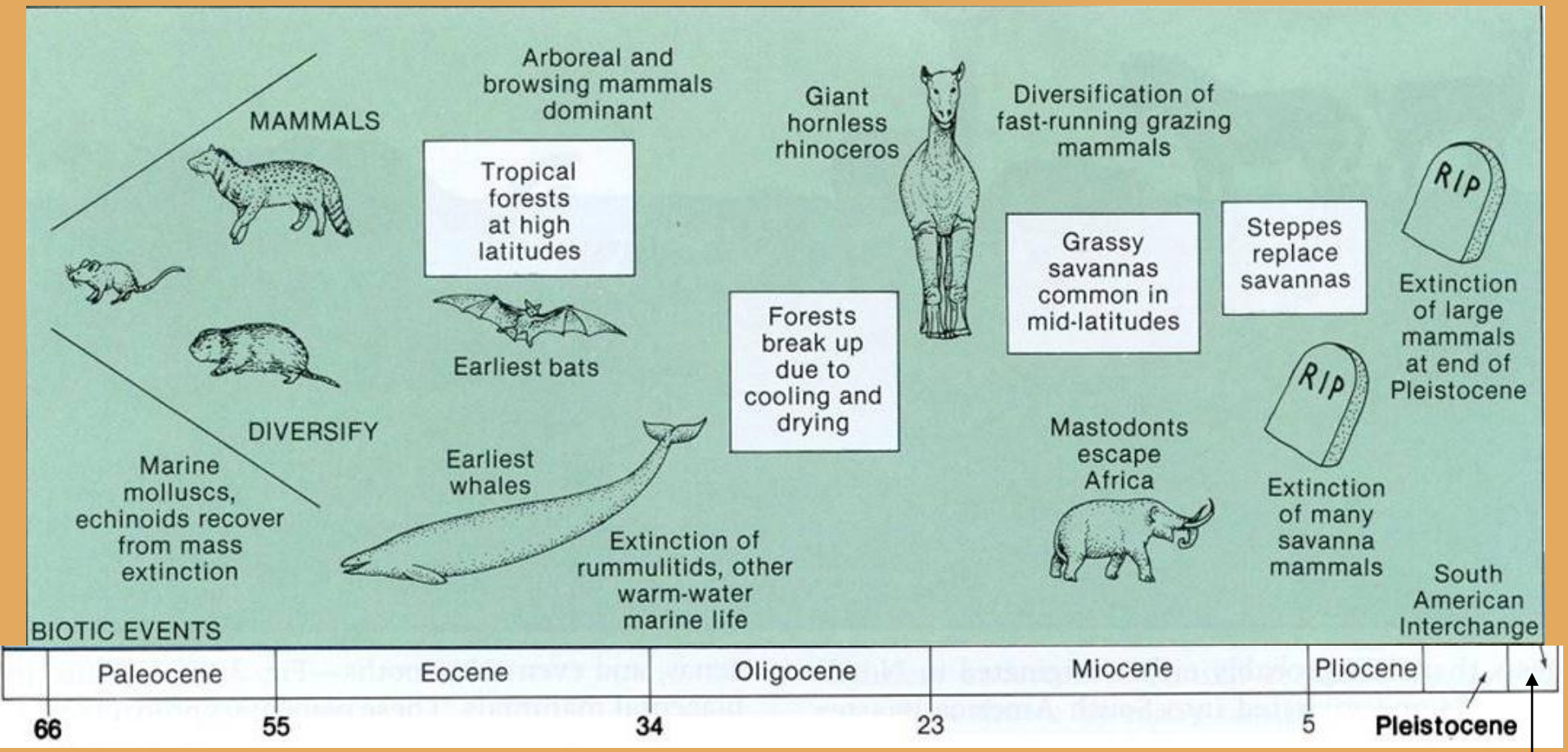
Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

The Cretaceous-Tertiary Boundary, 65 Million Years Ago



From PALEMAP Project, Christopher R. Scotese

The Cenozoic Era, 65 Million Years Ago to Present, The "Age of Mammals"



Following the K-T Extinction, mammals flourished

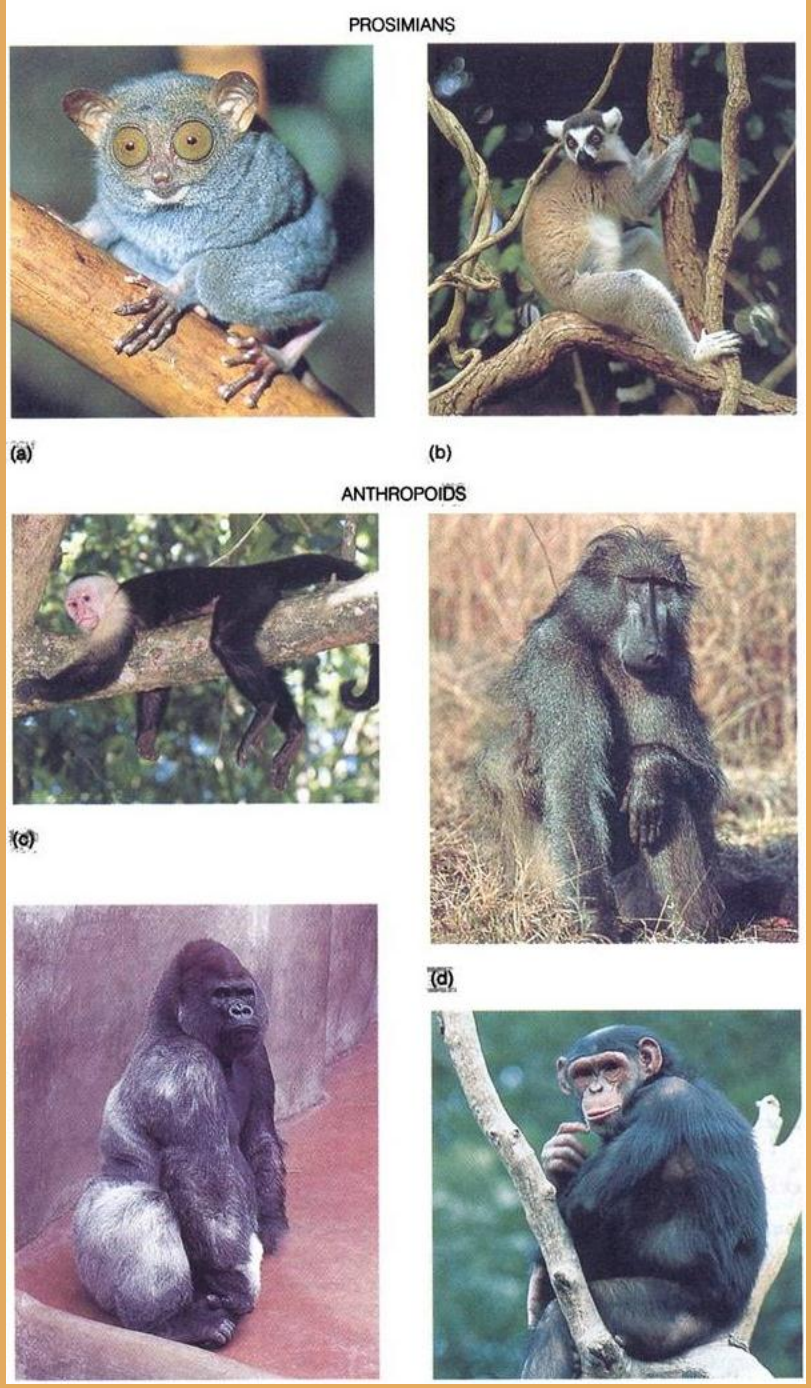
Evolution of the Earth. Donald R. Prothero and Robert H. Dott, Jr., McGraw-Hill, 2002.

The Age of Mammals

The Age of Mammals

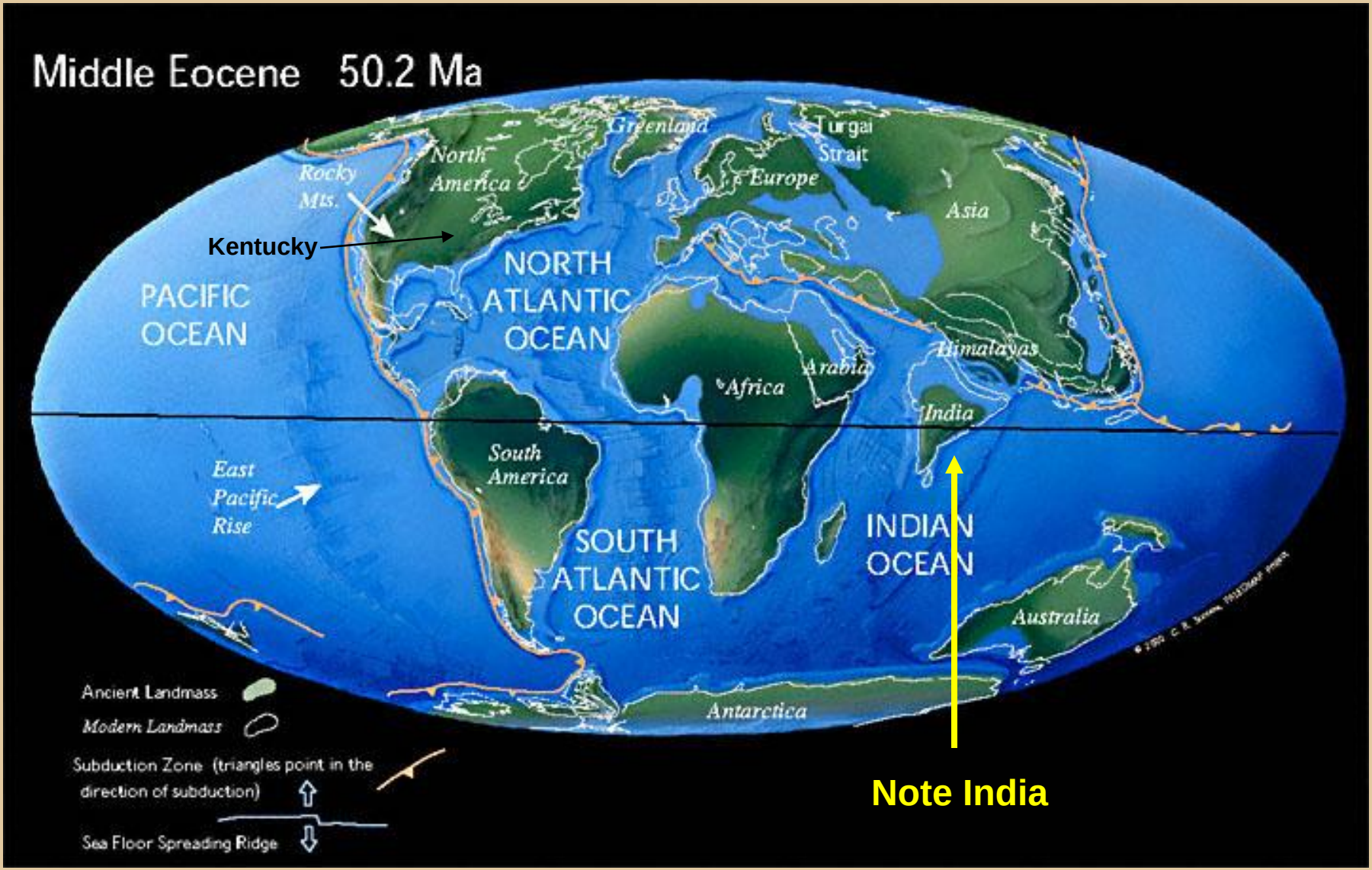
First monkeys, ~ 39 MYA

Primates are divided into two suborders: the prosimians, such as tarsiers (a) and ring-tailed lemurs (b), and (c) through (f) the anthropoids. The anthropoids are further subdivided into three super-families: (c) New World monkeys, (d) Old World monkeys, and the great apes, such as gorillas (e) and chimpanzees (f).



Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

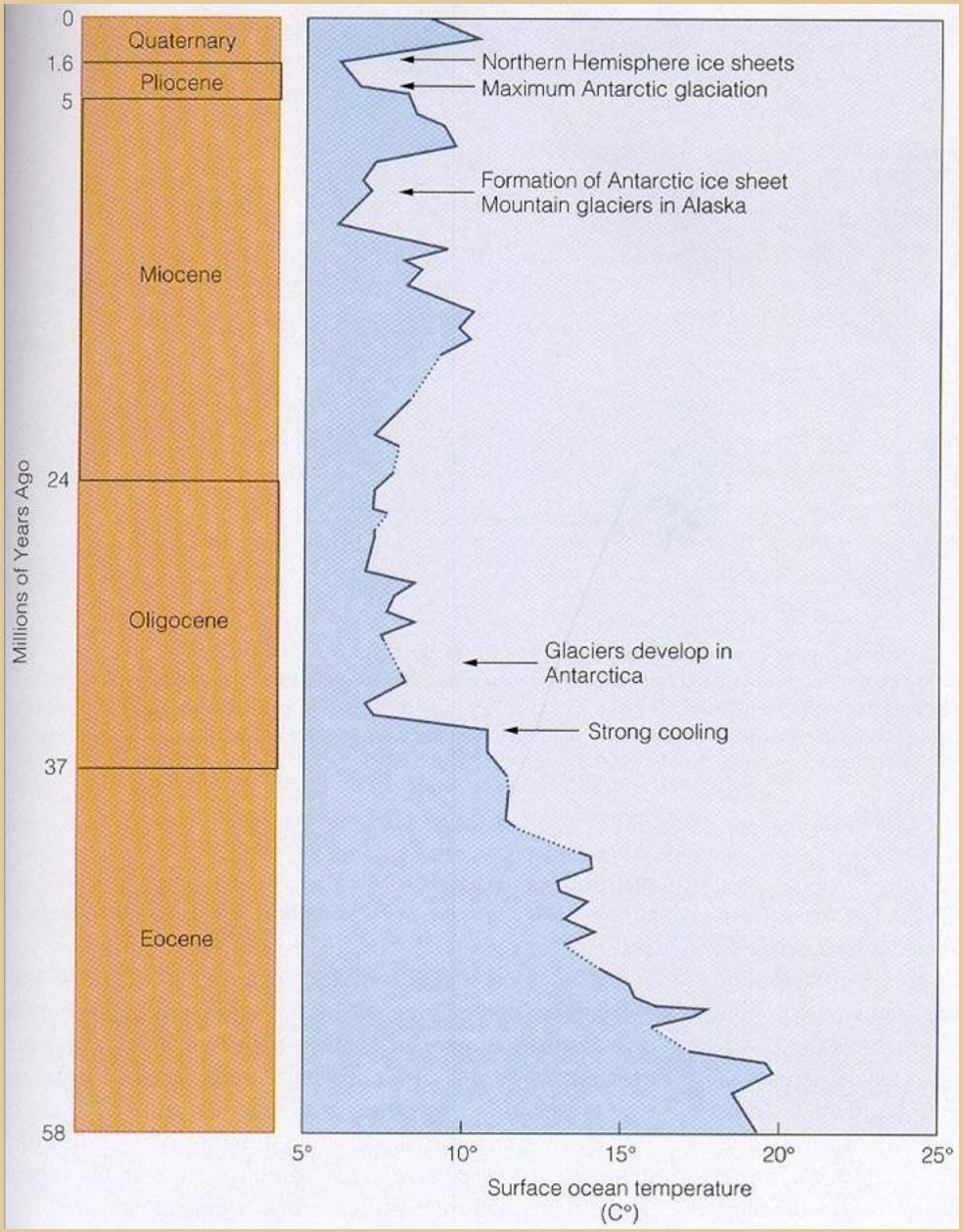
The Eocene Epoch, 55 to 34 Million Years Ago



During the Early Cenozoic, India began to Collide with Asia.

From PALEMAP Project, Christopher R. Scotese

Cooling Earth, ~35 Million Years Ago

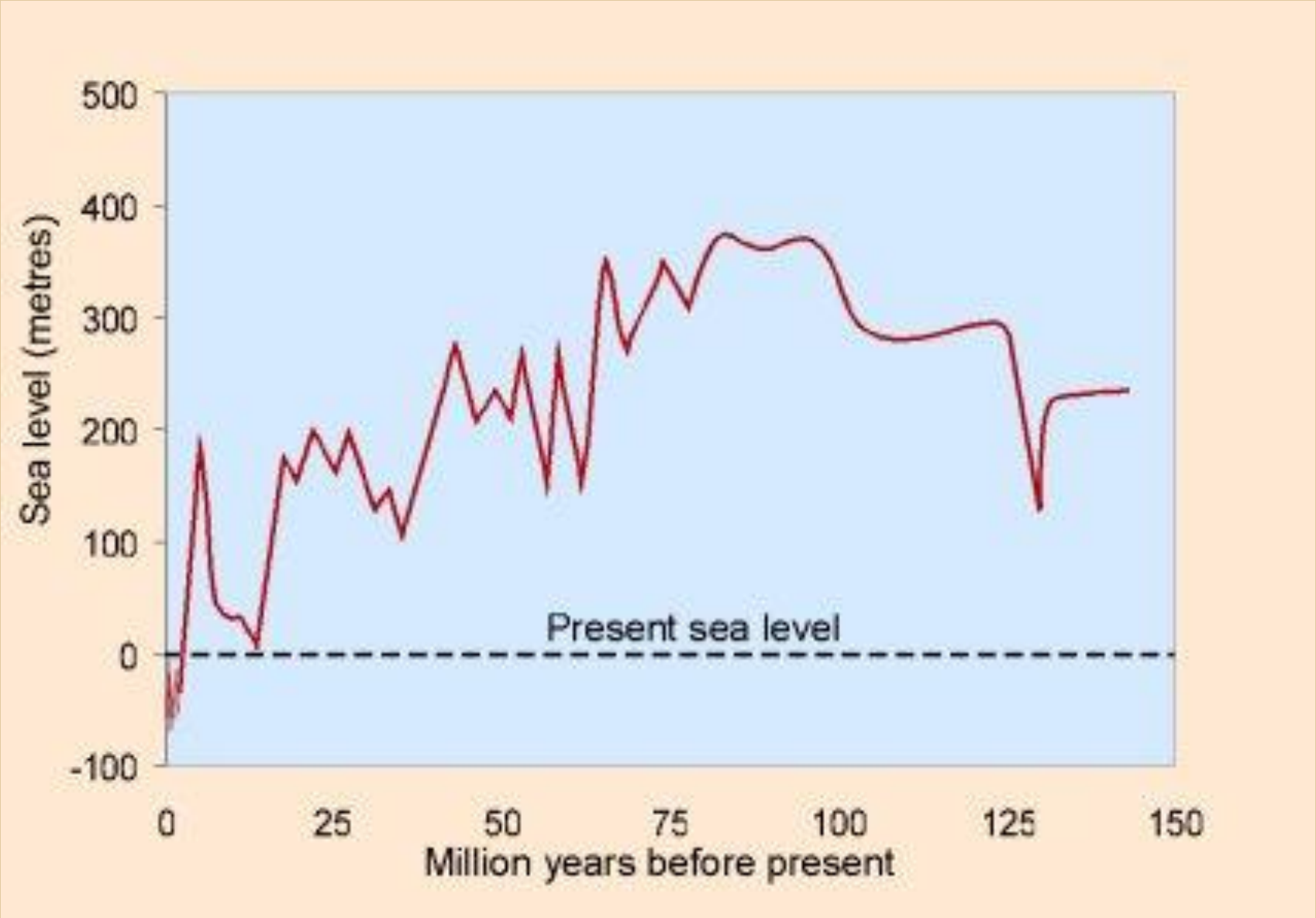


Fluctuations in the ration of O^{18} to O^{16} isotopes from a sediment core in the western Pacific Ocean reveal changes in surface ocean temperatures during the past 58 million years. A change from warm surface water to colder conditions occurred around 35 million years ago.

Why did the Earth cool?

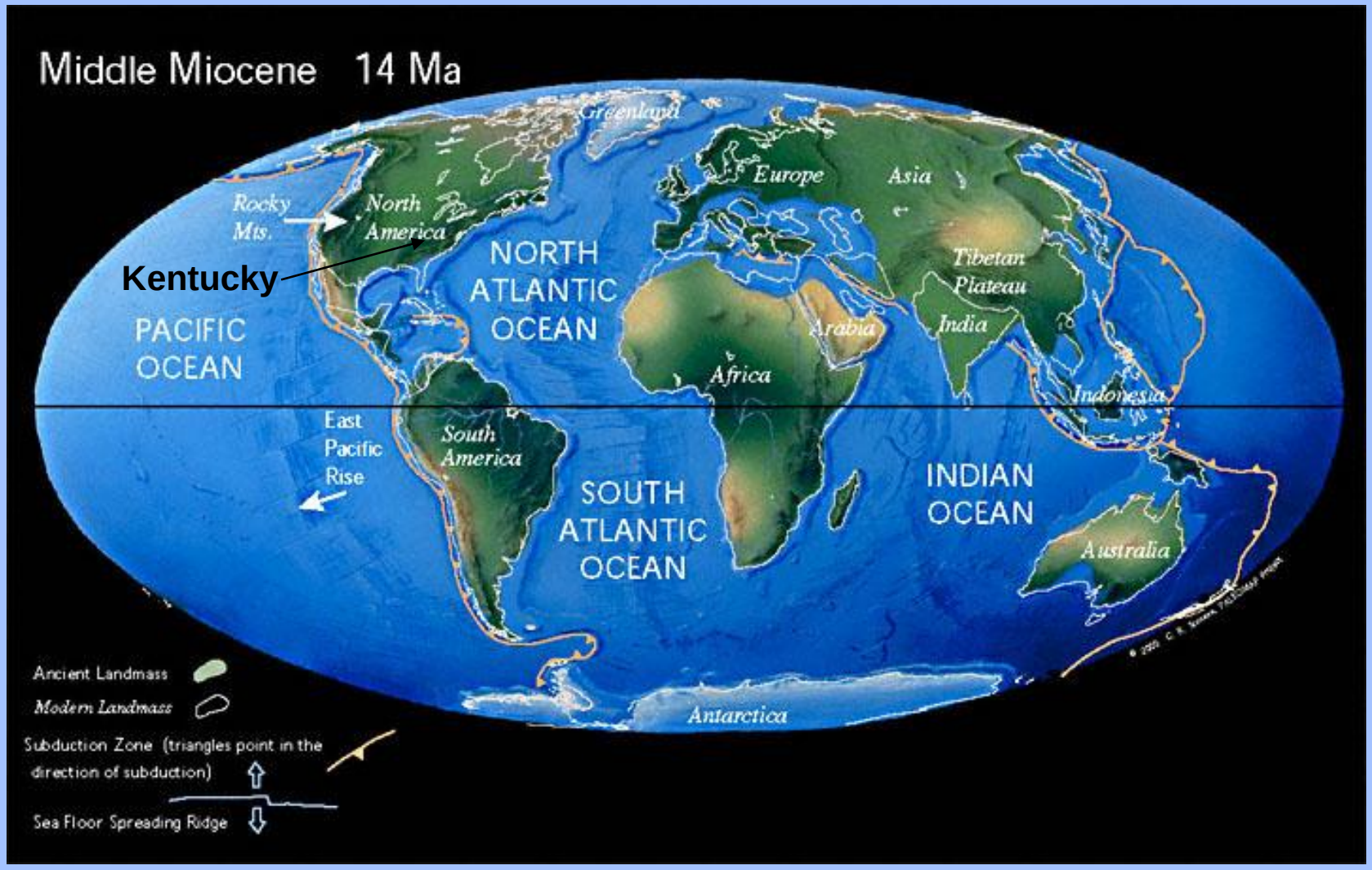
Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

Glaciation and sea level changes



As the earth cooled, glaciers increased and sea levels dropped.

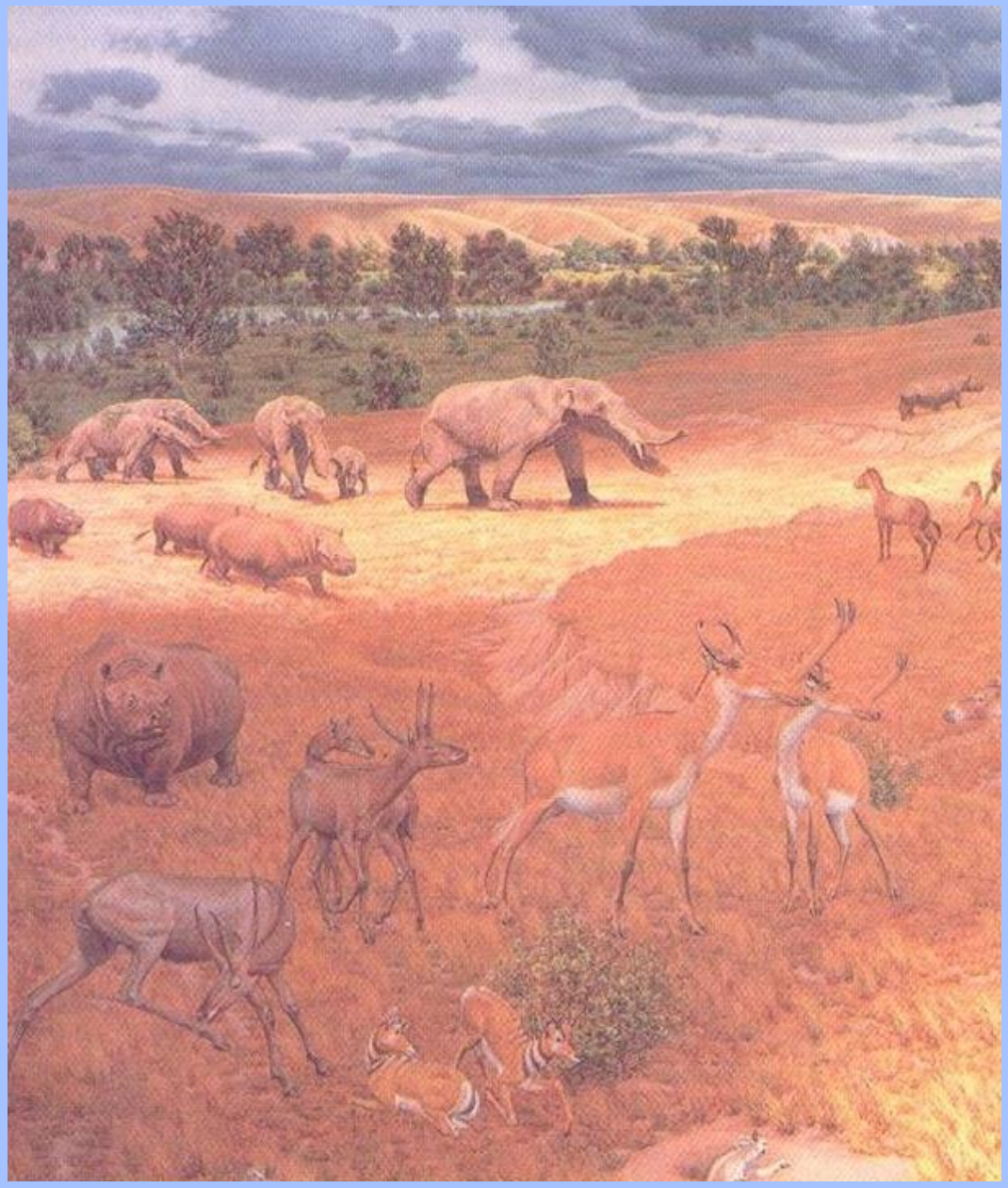
The Miocene Epoch, 23 to 5 Million Years Ago



The World Assumed a Modern Configuration 14 Million Years Ago in the Middle Miocene

From PALEMAP Project, Christopher R. Scotese

Western U.S., 5 million years ago



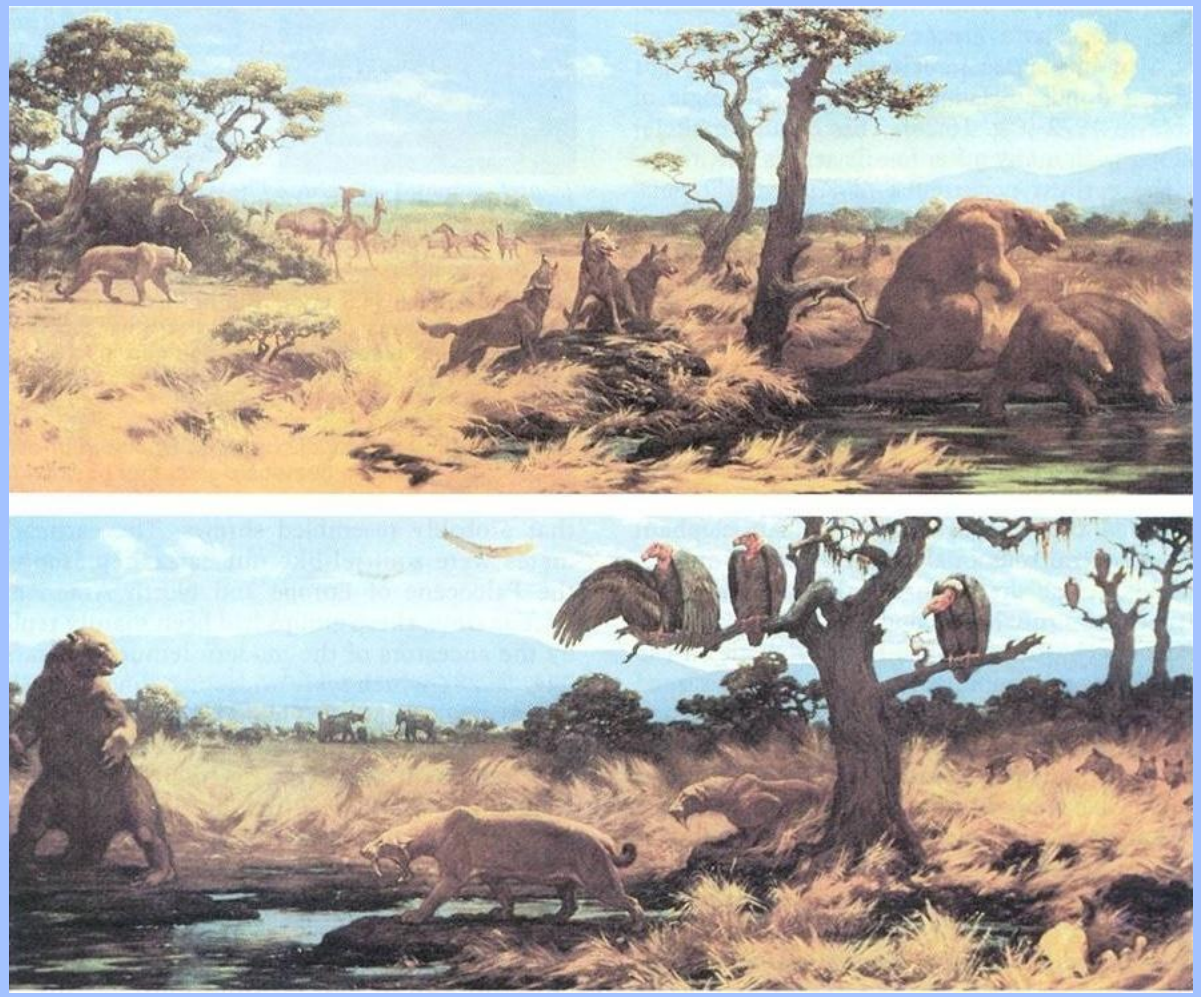
The Pliocene Epoch, 5.3 to 1.8 Million Years Ago

By Pliocene time, most mammals resembled those of today. This mural shows Pliocene mammals of the grasslands of western North America and include *Amebeledon*, a shovel-tusked mastodon (background); *Teleoceras*, a short-legged rhinoceros (left center); *Cranioceros*, a horned, hoofed mammal (left foreground); *Synthetoceros*, a hoofed mammal with a horn on its snout (right foreground); *Merycodus*, and extinct pronghorn (middle foreground); and three small mammals in the foreground.

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

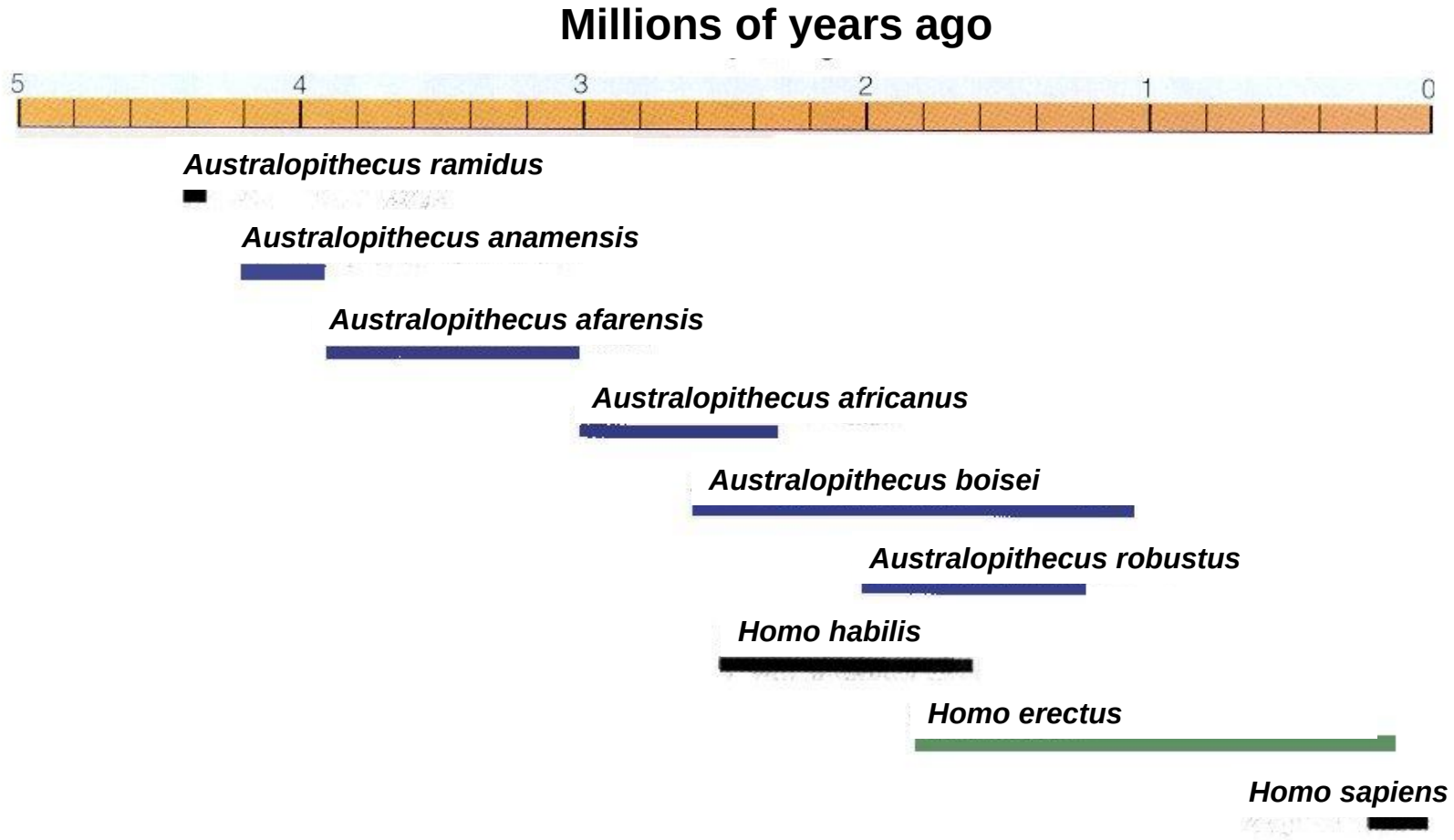
Los Angeles, 40,000 years ago

Reproduction of life in Los Angeles about 40,000 years ago, as preserved in the famous tar pits of Rancho La Brea. The tar came from oil seeping up from the Miocene rocks in the Los Angeles Basin and forms natural ponds which are typically covered by rainwater. Thirsty animals waded into the water and became trapped by the sticky tar. Typically, the panicked cries of a single trapped animal would attract many predators and scavengers, so the tar pits have many more fossils of saber-toothed cats, dire wolves, lions, bears, and vultures than they have bison, camels, horses, ground sloths, or mammoths and mastodonts. However, in nature there is much more biomass of prey species than predators, so the tar pits were a selective death trap that preserves a biased sample of life. In this famous reconstruction by Charles R. Knight, prey species (such as the ground sloth, camels, horses, and mammoths) are in the background relative to the predators and scavengers (saber-toothed cats, lions, dire wolves, and giant vultures). (Courtesy Los Angeles County Museum.)



Evolution of the Earth. Donald R. Prothero and Robert H. Dott, Jr., McGraw-Hill, 2002.

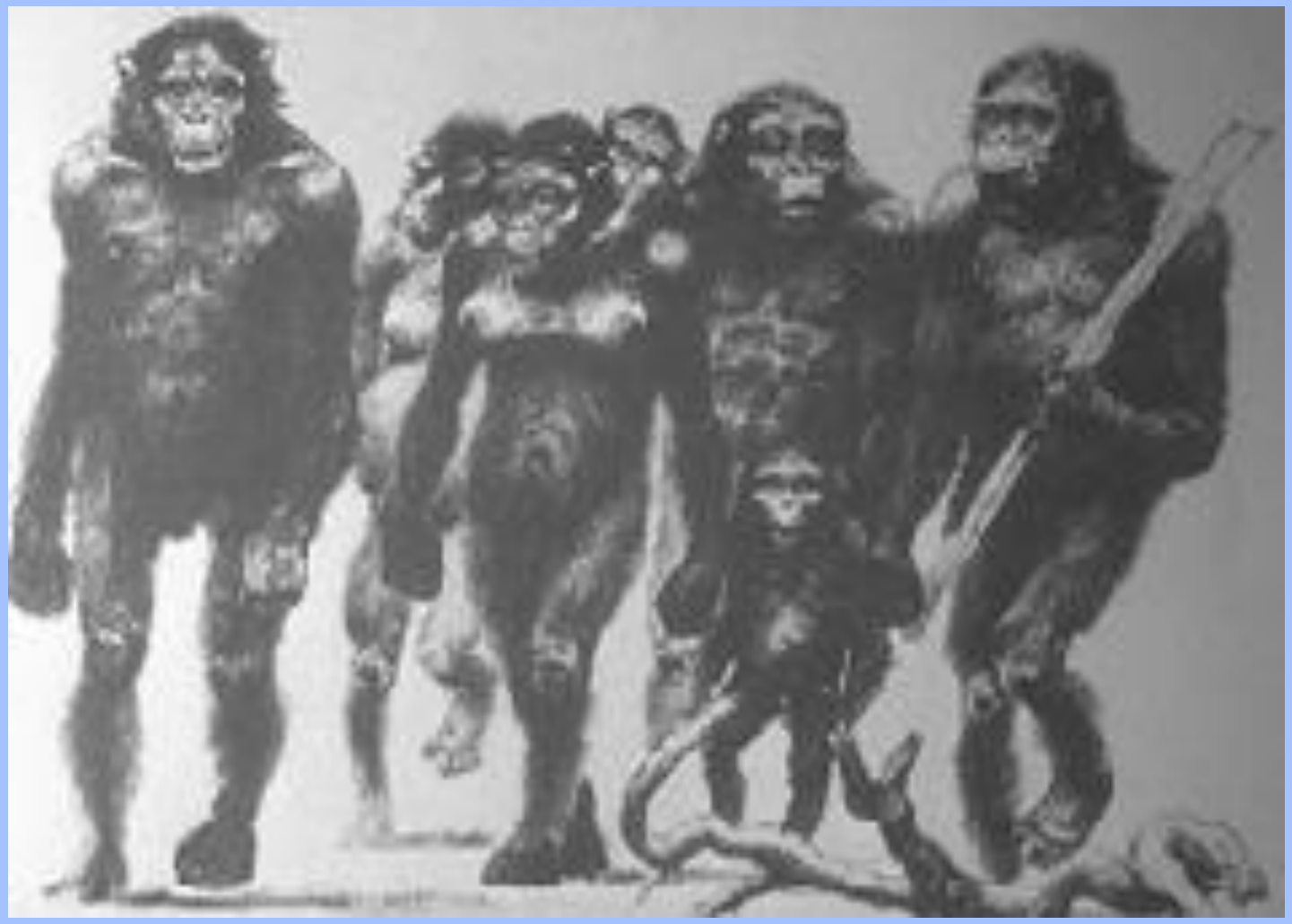
Hominids, ~ 4.5 million years ago to present



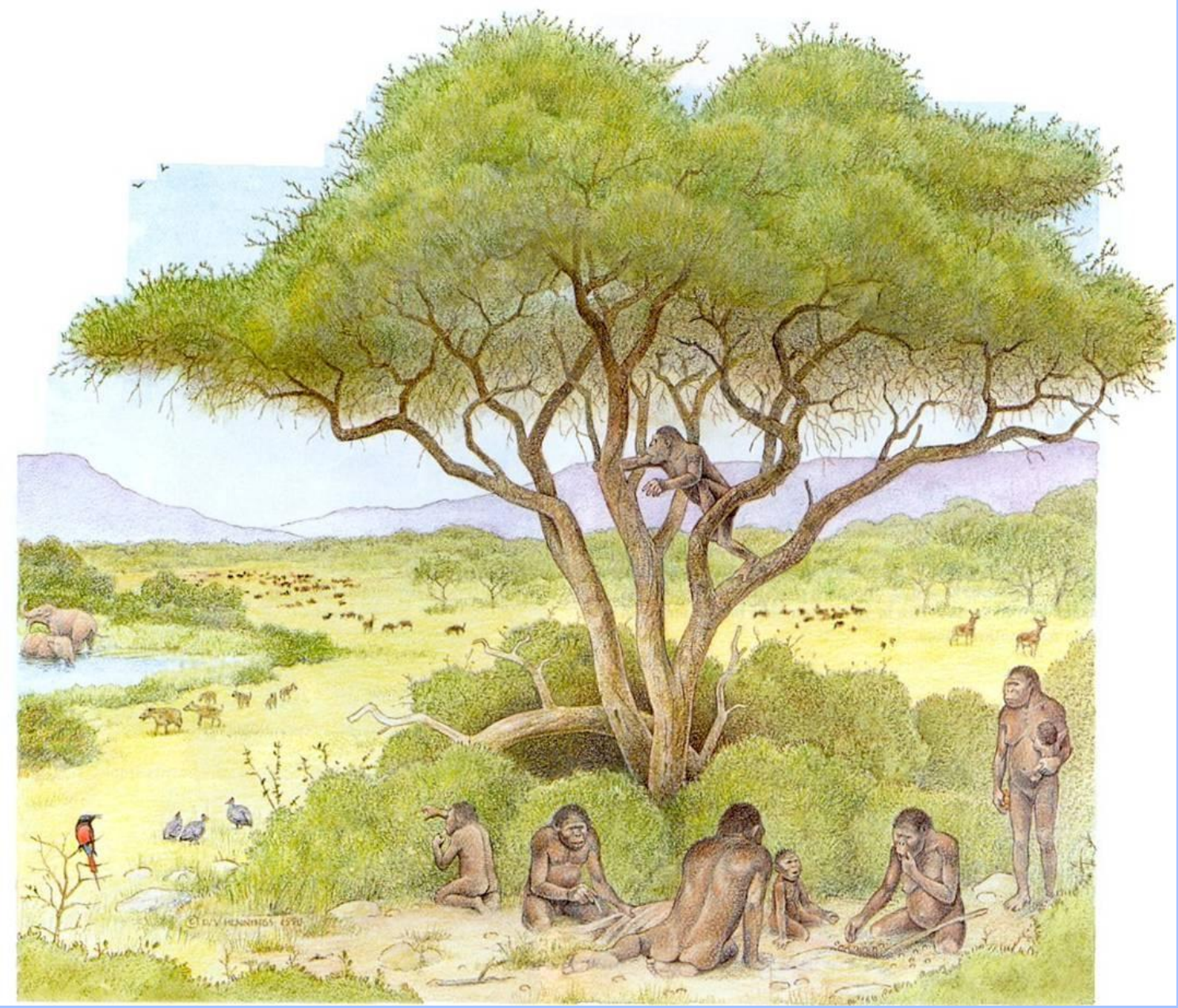
The geologic age ranges for commonly accepted species of hominids

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

Hominids, ~4 million years ago



Australopithicus afarensis, ~3.5 million years ago



Re-creation of a Pliocene landscape showing members of *Australopithecus afarensis* gathering and eating various fruits and seeds.

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

Homo Erectus, ~ 500,000 years ago

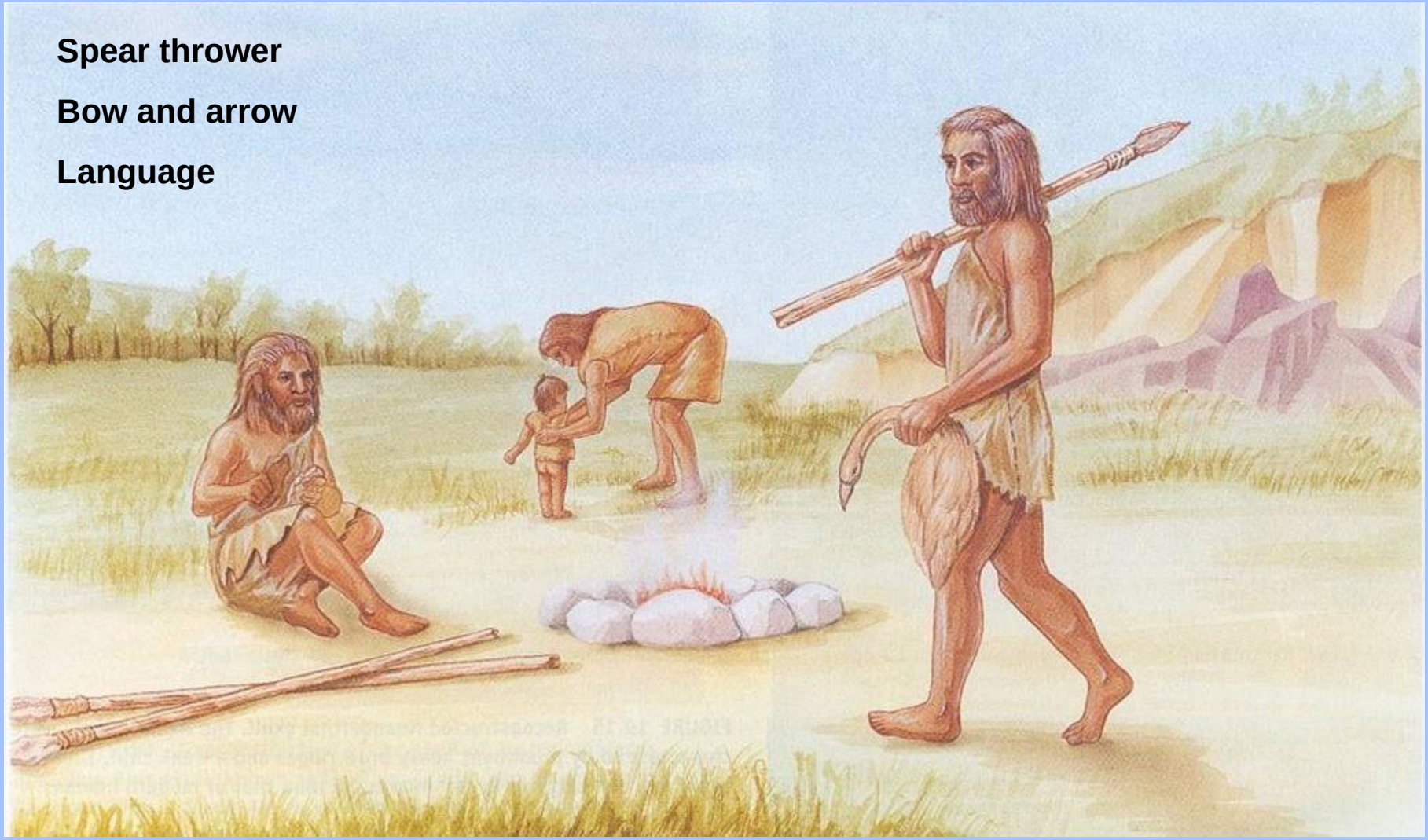
Re-creation of a Pleistocene setting in Europe in which members of *Homo Erectus* are using fire and stone tools.

Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

Homo Neanderthalensis

Life was hard for Neanderthal Man, and then it got worse.

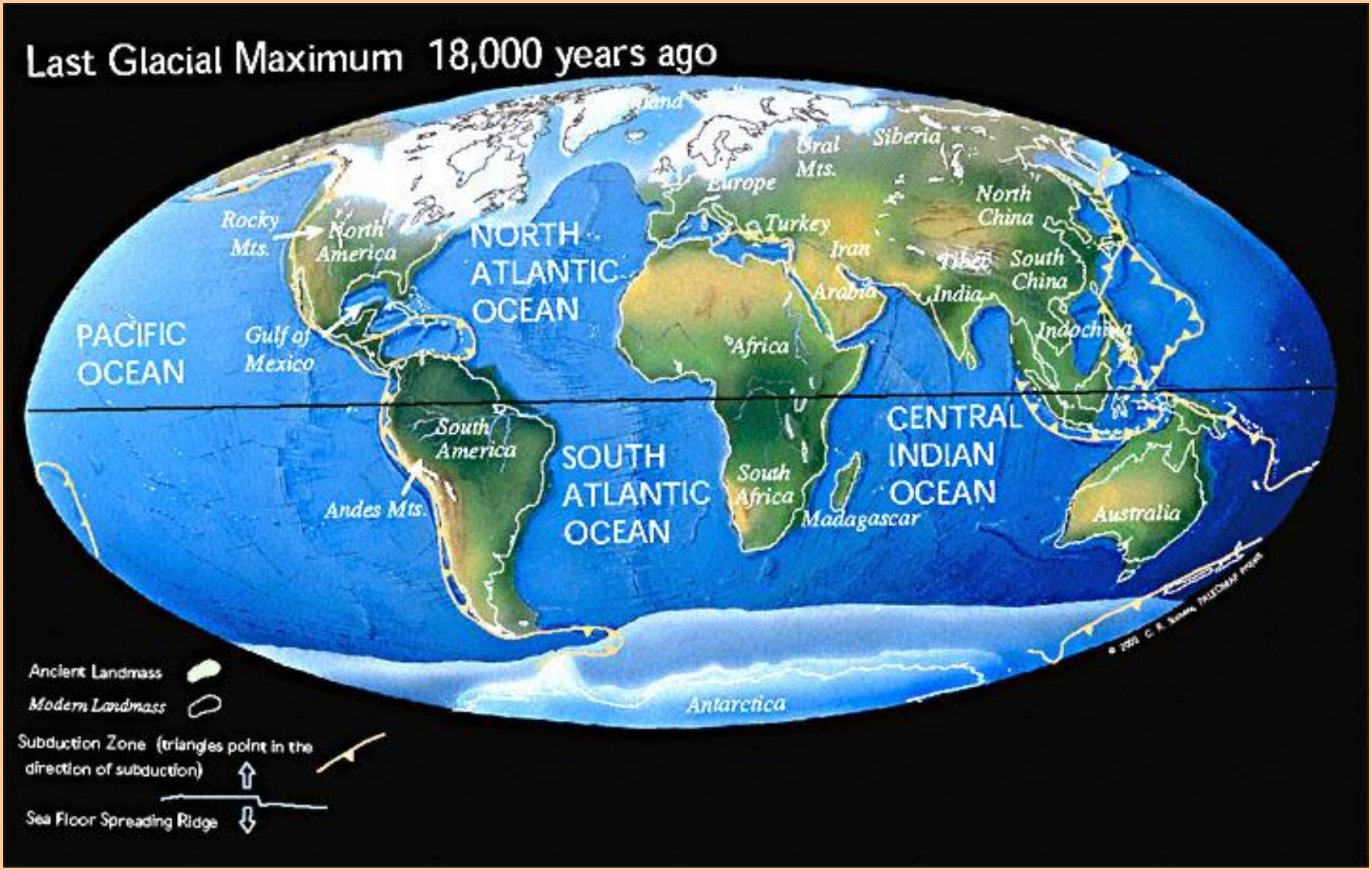
Homo Sapiens (Wise Man)



Re-creation of a Cro-Magnon camp in Europe. Cro-Magnons were highly skilled hunters who formed living groups of various sizes.

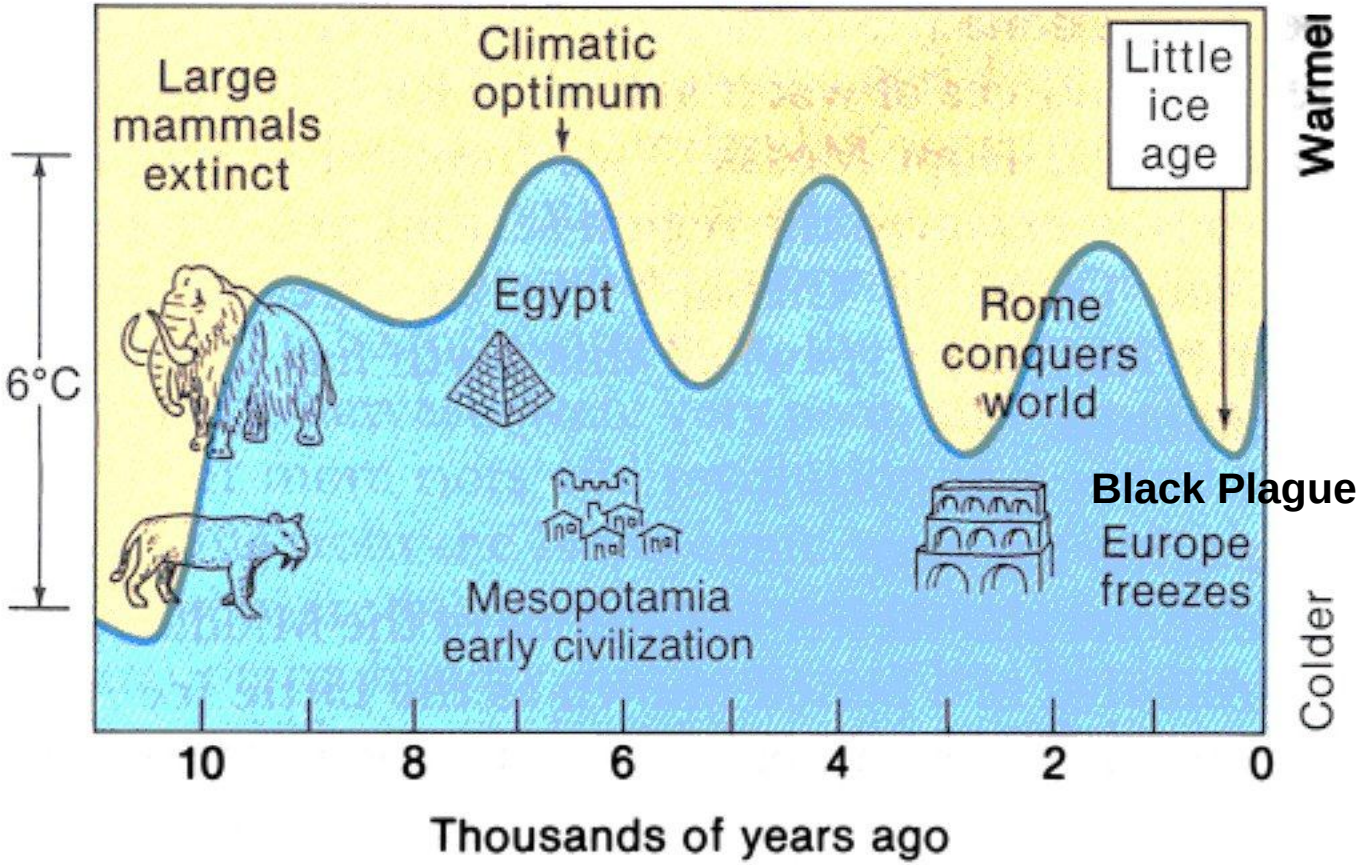
Historical Geology: Evolution of Earth and Life Through Time. Reed Wicander and James S. Monroe, Brooks/Cole, 2000.

Earth grew warmer about 12,000 year ago after the last period of glaciations



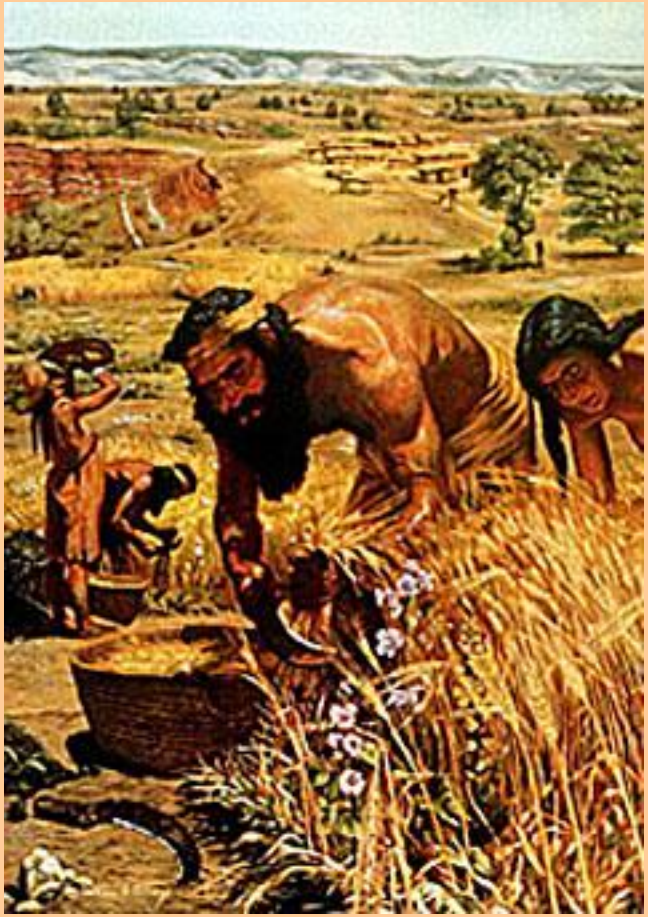
From PALEMAP Project, Christopher R. Scotese

The Holocene Epoch, 10,000 Years Ago to Present



Many large mammals became extinct about 10,000 years ago, either from climate change or human activities. The warming climate and the establishment of agriculture changed human life.

Agriculture



Settle down

More kids

More stuff

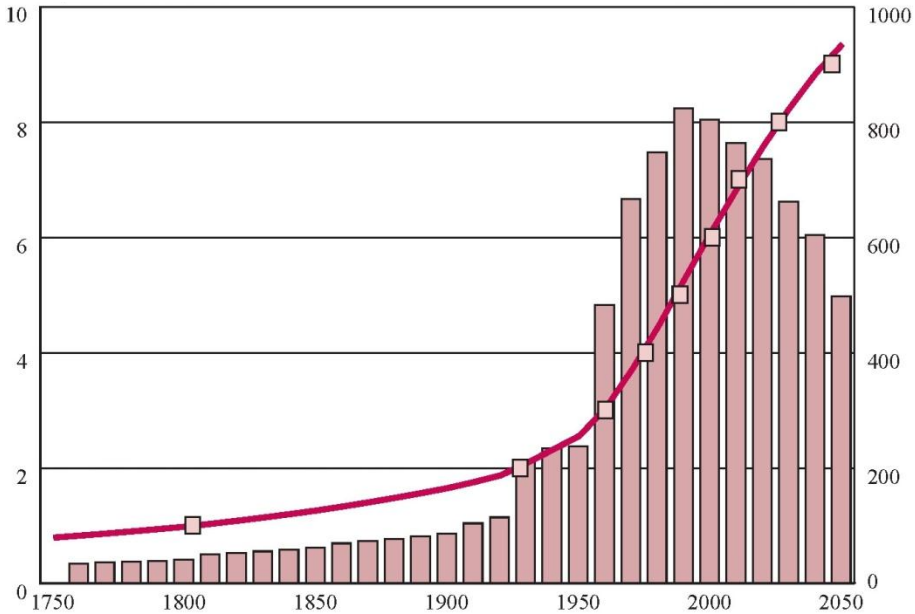
Specialization--social cells

War for fun and profit

The introduction of agriculture changed human culture. The settled society could have larger families, accumulate more stuff, work activities became more specialized, and wars became larger and more frequent.

HUMAN POPULATION GROWTH

The earth has become very crowded in the last 100 years.



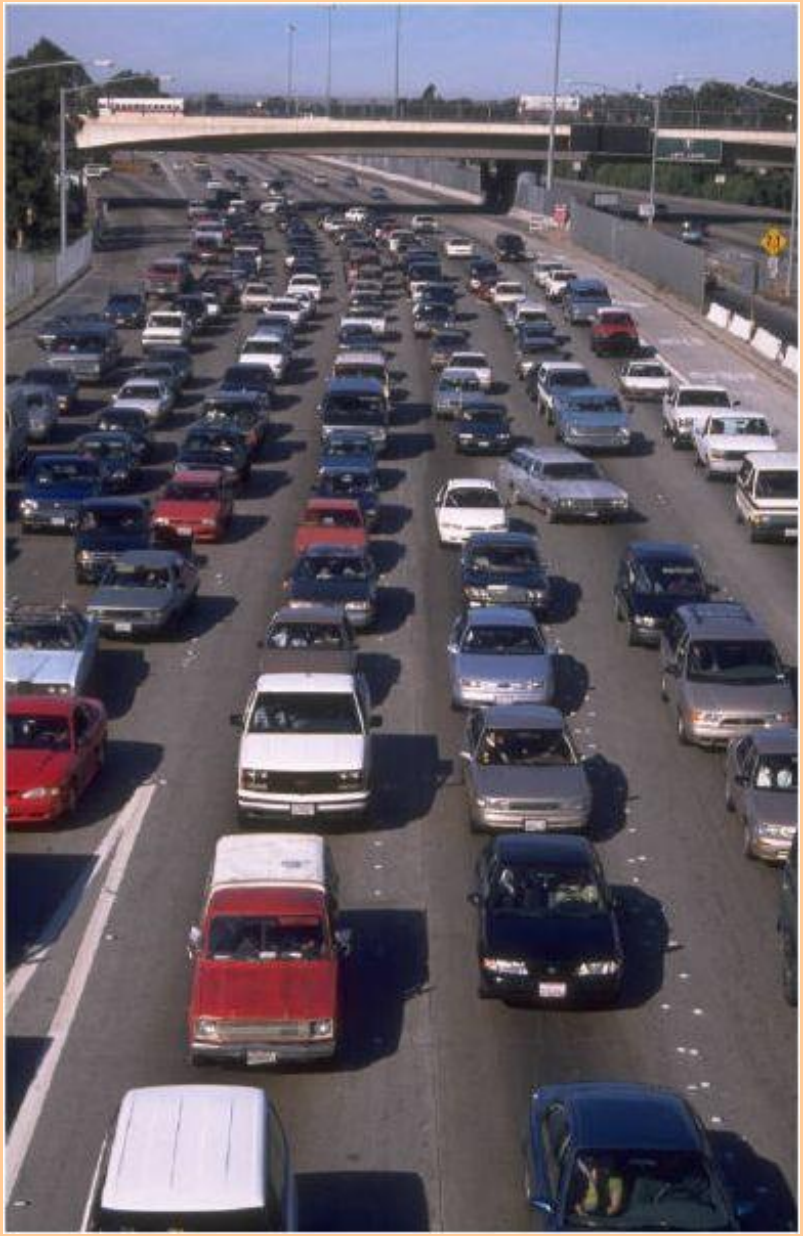
Source: United Nations 1995b:97 and U.S. Bureau of the Census, International Data Base

World human population

35,000YA	3,000,000
8,000 b.c.	8,000,000
4,000 b.c.	86,000,000
500 a.d.	200,000,000
1800	1,000,000,000
1930	2,000,000,000
2008	6,700,000,000
2042	9,000,000,000 ??

"Be fruitful and multiply, and take Dominion over the earth."

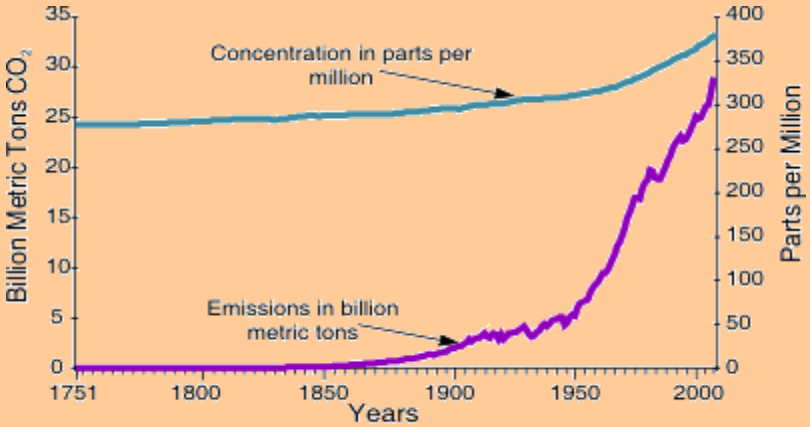
HOMO AUTOMOBILUS



Humans rely on fossil fuels for energy, using the equivalent of over 600 billion barrels of oil each year, or about 93 barrels of oil for every person on earth. Africans use about 1/5 the average, and Americans use about 5 times the average.

30 billion metric tons of carbon dioxide are emitted into the atmosphere each year as a result of burning fossil fuels, about 4.3 tons for every person on earth. CO_2 emissions caused by Americans are 5 times greater than average.

With 5 percent of the world's population, the U.S. consumes nearly 25 percent of the resources and creates 25 percent of the waste.



Source: Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center.

Table 12.1 The Measure of the Twentieth Century

Item	Increase Factor 1890's to 1990's
World population	4
Urban proportion of world population	3
Total world urban population	13
World economy	14
Industrial output	40
Energy use	13
Coal production	7
Air pollution	~5
Carbon dioxide emissions	17
Sulfur dioxide emissions	13
Lead emissions to the atmosphere	-8
Water use	9
Marine fish catch	35
Blue whale population	-99.5%
Fin whale population	-97%
Bird and mammal population	-1%
Irrigation area	5
Forest area	-20%
Cropland	2

Something New Under the Sun: An Environmental History of the 20th Century World, J.R. McNeill

The Anthropocene Epoch

Some scientists have proposed that we are at the beginning of a new geologic epoch—the Anthropocene.

Humans are changing the face of Earth.

Strip mining for lignite in Germany

The Sixth Extinction

Present	Anthropocene Extinction Human activity ??% lost
65 million years ago	Cretaceous Extinction Impact and volcanos 17% lost
208 million years ago	Triassic Extinction ?? 23 % lost
245 million years ago	Permian Extinction Climate change? Plate movements? Impact? 54% lost
354 million years ago	Devonian Extinction Climate change? 19% lost
438 million years ago	Ordovician Extinction Climate change 25% lost

"In pushing other species to extinction, humanity is busy sawing off the limb on which it is perched." – Paul Ehrlich

As the human population grows and our demand for natural resources increases, more and more habitats are devastated. Today, we may be losing 30,000 species a year—a rate much faster than at any time since the last great extinction 65 million years ago that wiped out most of the dinosaurs.

Can we stop the devastation of our planet and save our own species? We are in a biodiversity crisis — the fastest mass extinction in Earth's history, largely due to:

- **human destruction of ecosystems**
- **overexploitation of species and natural resources**
- **human overpopulation**
- **the spread of agriculture**
- **pollution**

Issues in Environment