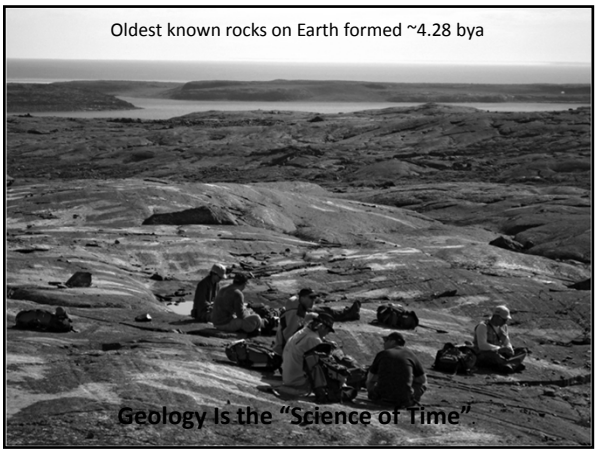
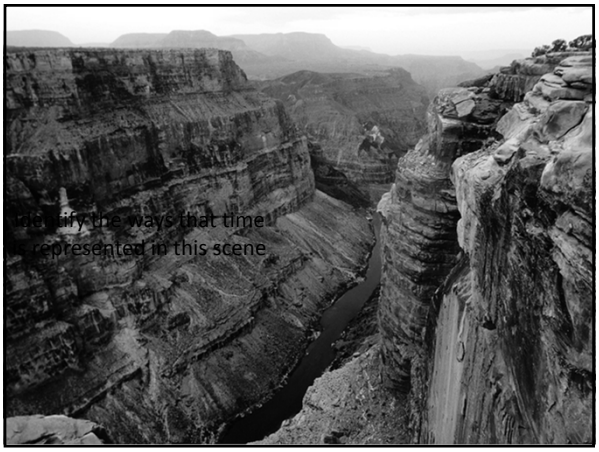
Oldest known rocks on Earth formed ~4.28 bya



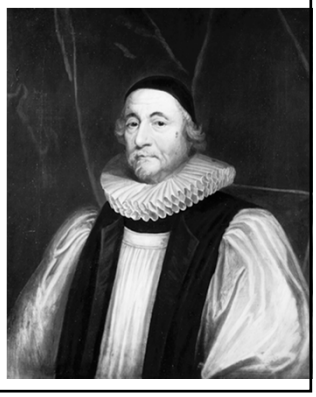
Geology is the "Science of Time"



Early estimates of Earth's age were based on religious dogma.

In the mid 1600s, Archbishop James Ussher determined the exact date of the creation of the Earth ...

"nightfall preceding 23 October 4004 BC"

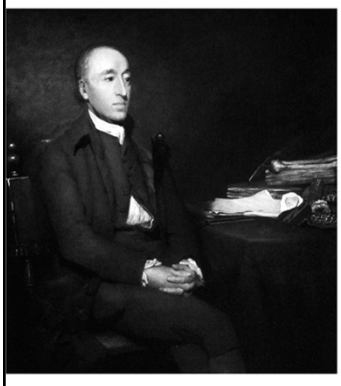


Scientific analysis of Earth's age led to estimates of hundreds of millions of years.

Beginning in the late 1700s, philosophers and naturalists, and geologists using Relative Dating techniques, proposed theories of "Deep Time".

In the 1900s, geologists using Radiometric Dating conclusively determined the age of the Earth ...

~4.55 - ~4.6 by



In 1788, before the Royal Society of Edinburgh, James Hutton theorized that the Earth was so old that ...

"The result ... of this physical enquiry is that we find no vestige of a beginning, no prospect of an end."

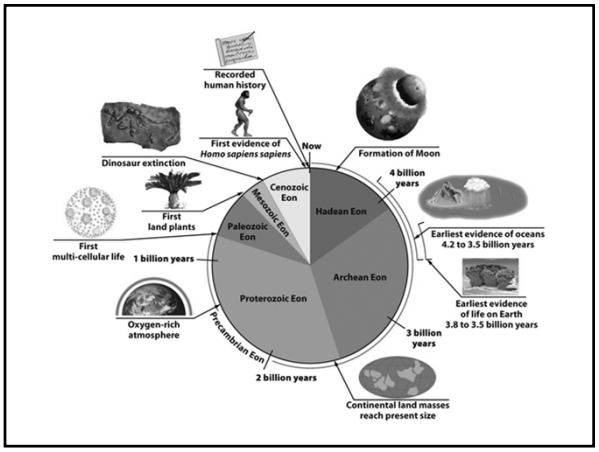
How do Geologists Analyze Time?

Relative Dating

is a system of *reasoning* that is used to determine the chronological sequence or order of a series of geologic events.

Radiometric Dating

uses the natural phenomenon of radioactive decay of radioactive isotopes within minerals to calculate their chronological age.



The Geologic Time Scale Summarizes Earth's History.

Time is divided into progressively shorter intervals defined by specific fossils and strata found in the Rock Record:

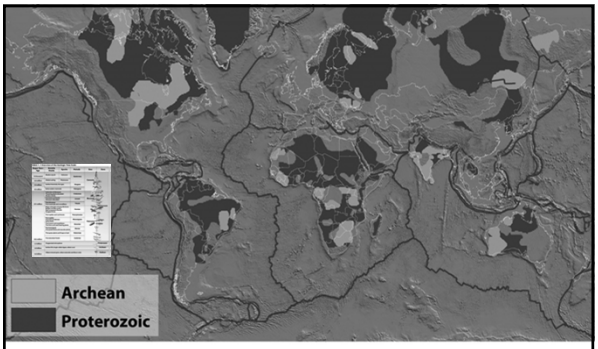
Eons
Eras
Periods
Epochs

TABLE 1.1 Overview of the Geologic Time Scale

Began Years Ago	Notable Events	Epochs	Periods	Eras	Eons
10 thousand	Modern epoch	Holocene	Quaternary	Cenozoic	Phanerozoic
2.6 million	Global cooling	Pleistocene			
23 million	Earliest Hominids, first apes		Neogene		
65 million	Early modern mammals		Paleogene		
	Extinction of dinosaurs Flowering plants abundant Modern sharks		Cretaceous	Mesozoic	
	First birds and lizards Dinosaurs abundant		Jurassic		
251 million	First dinosaurs First mammals and crocodilians		Triassic		
	Major extinction of many life forms Beetles and flies evolve Reef ecosystems flourish Pangaea forms		Permian	Paleozoic	
	First reptiles and coal forests		Pennsylvanian		
	First reptiles First land vertebrates Early sharks		Mississippian		
	First insects and amphibians First ferns and seed-bearing plants		Devonian		
	First land plants First jawed fishes and vascular plants		Silurian		
	First green plants and fungi on land		Ordovician		
542 million	First abundant fossils		Cambrian		
2.5 billion	Oxygenated atmosphere				Proterozoic
3.8 billion	Earliest life (single-celled algae), oldest crust				Archean
4.6 billion	Oldest mineral grain, oldest asteroids and Moon rocks				Hadean

12 people – 4.6 billion years of Earth history

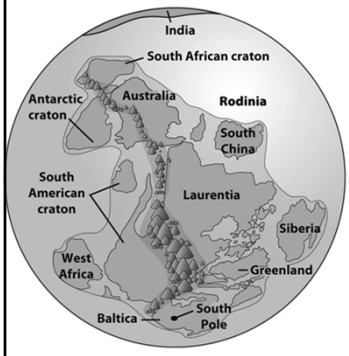
- 4.6-4.2 billion yrs Earth and Moon formed, end of heavy E.T. bombardment, molten Earth, oldest known mineral
- 4.2-3.8 billion yrs Oldest rock, oldest probable microfossils
- 3.8-3.4 billion yrs First known oxygen-producing bacteria, oldest known microfossils, oldest craton (continental cores)
- 3.4-3.0 billion yrs First stromatolites (colonial cyanobacteria) oldest macrofossils
- 3.0-2.6 billion yrs Continental accretion events (orogeny's), first supercontinent
- 2.6-2.2 billion yrs Oxygen catastrophe, banded iron formation
- 2.2-1.8 billion yrs Atmosphere become oxygenic, super continent "Columbia"
- 1.8-1.4 billion yrs Green algae colonies in seas
- 1.4-1.0 billion yrs Second supercontinent, Rodinia
- 1.0-0.8 billion yrs Rodinia breaks up, "Snowball Earth" (glacial deposits at tropical paleolatitude – runaway albedo cooling effect w/ continents clustered on equator)
- 800-400 million yrs First sponges, worm-like creatures in marine mud, trilobites, anomalocaridid, shelled creatures, early extinctions, first fish, early sharks, Gondwana emerges, early corals, starfish, first green plants on land
- 400-present million yrs Pangaea forms and breaks up, first plants on land, reptiles, dinosaurs, crocodiles, birds and lizards, coal forests, mammals
- **HOW MUCH TIME IS REPRESENTED BY HUMANS?**
  - 12 people, each 3 ft wide at shoulders = 36ft = 130 million yrs per ft
  - 1 inch = 11.7 million yrs (the last inch on the last person)
  - Homo sapiens sapiens ~200,000yrs (first anatomically modern human fossil, Africa 195,000 yrs)
  - the last 58th of an inch ON THE LAST PERSONS SHOULDER (about the thickness of a layer of paint)



Cratons

The Archaean and Proterozoic Eons Lasted from 3.8 Billion to 542 Million Years Ago.

Proterozoic Eon

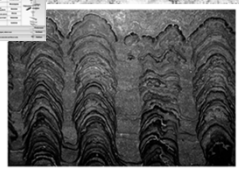


- Continents develop, clustered together (*Rodinia*) in the tropics and southern hemisphere.
- Mountain building.
- Noxious gases displaced by oxygen-rich atmosphere.
- Origin and first diversification of soft-bodied organisms.

Archaean Eon

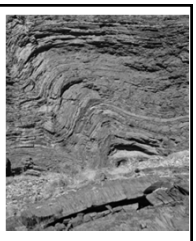
Stromatolites

- **First form of abundant life (3.2bya).**
- **Photosynthesis triggered.**
- **Atmosphere noxious (methane, ammonia, carbon dioxide, and water vapor).**
- **Oxygen catastrophe**



Archaean Eon

- **Oxygen catastrophe**
- **Banded iron formation**

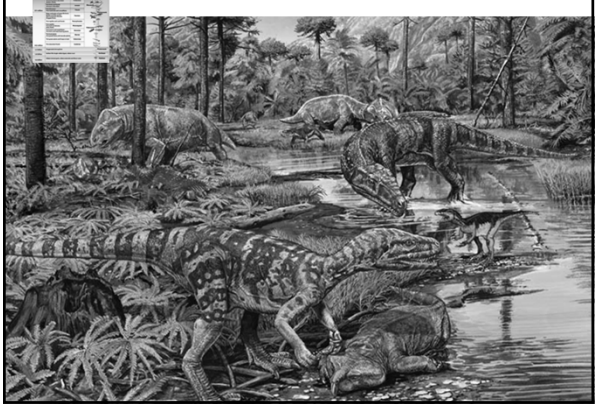


End of the Archaean Eon

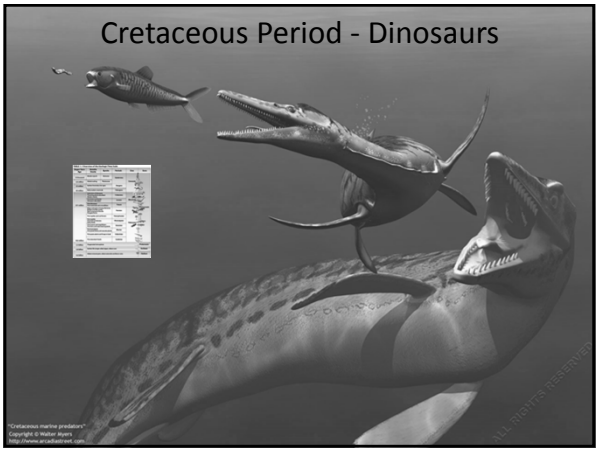
Paleozoic Era

Carboniferous Coal Swamps

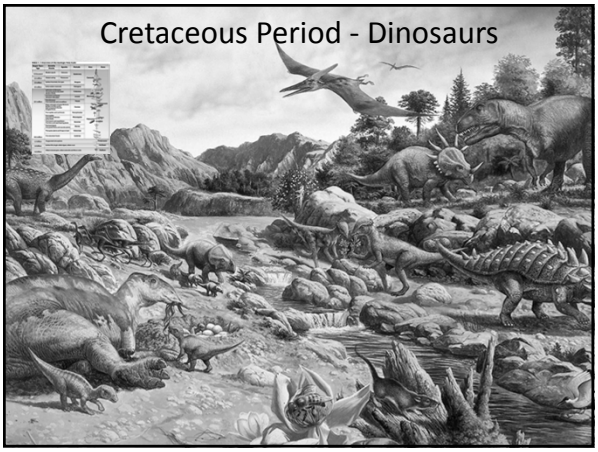
Triassic Period - Dinosaurs



Cretaceous Period - Dinosaurs



Cretaceous Period - Dinosaurs



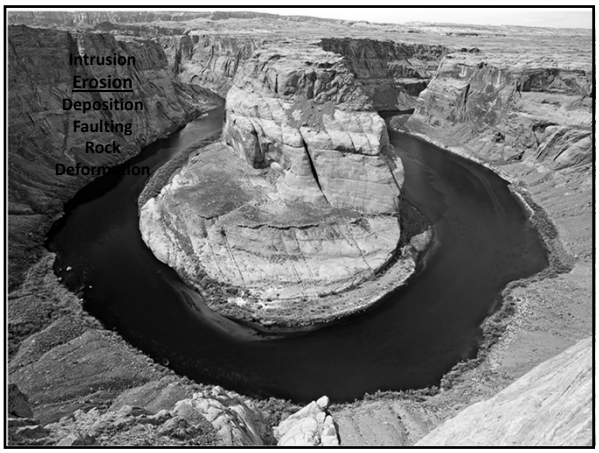
Modern Humans Arose in the Cenozoic Era.

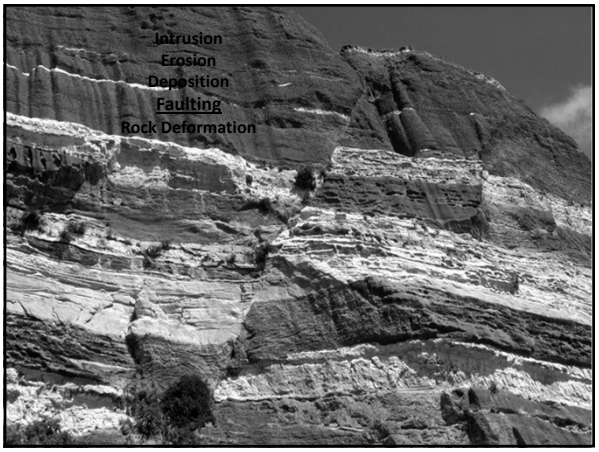
Sahelanthropus tchadensis

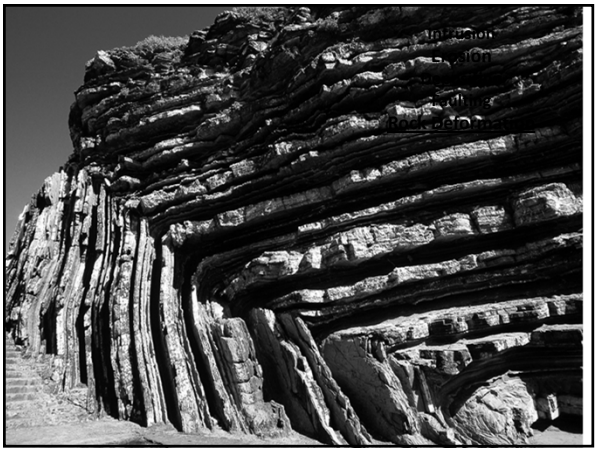
Homo erectus

Five Fundamental <u>Geologic Events</u> are "ordered" by Relative Dating.

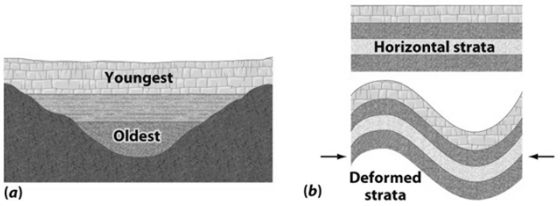
<u>Intrusion</u>
Erosion
Deposition
Faulting
Rock Deformation





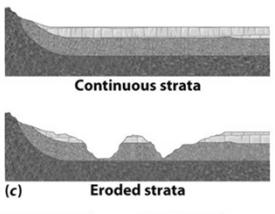


Seven Stratigraphic Principles Are Used in Relative Dating.

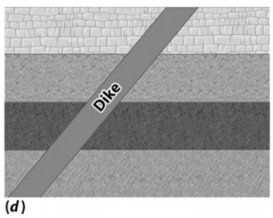


Principle of Superposition

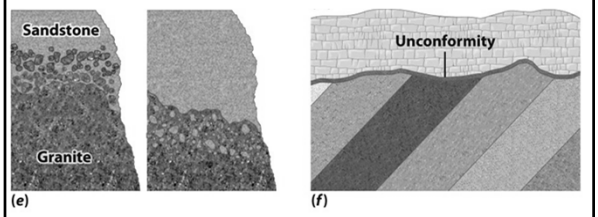
Principle of Original Horizontality



Principle of Original Lateral Continuity

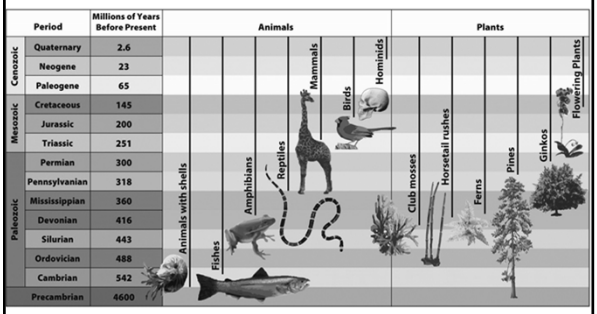


Principle of Cross-Cutting Relationships

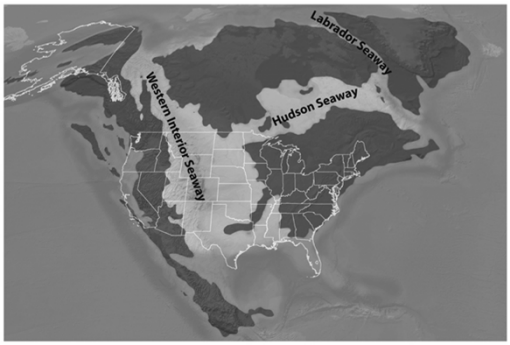


Principle of Inclusions *Principle of Unconformities*

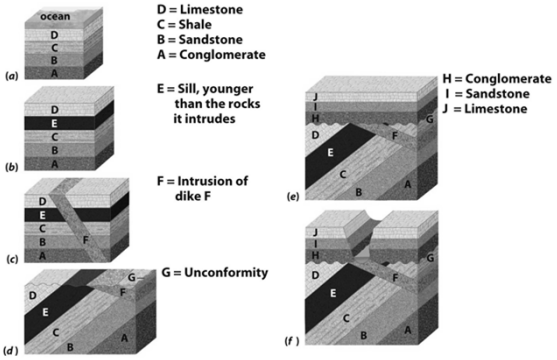
The Principle of Faunal Succession
(Evolution)

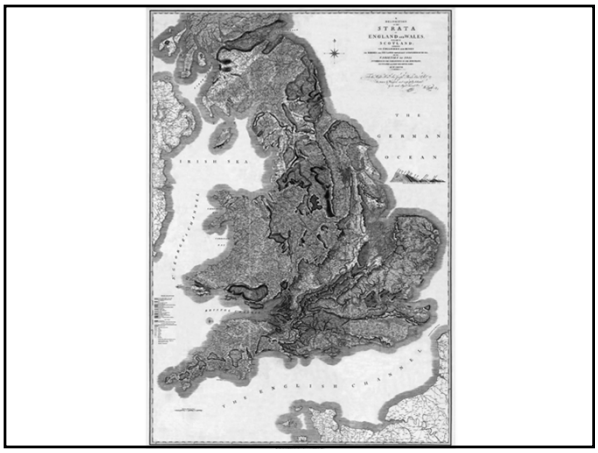


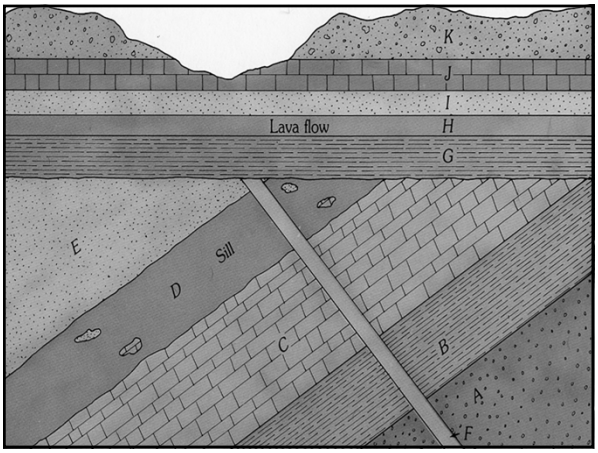
Rise and fall of sea level
produces certain rock sequences

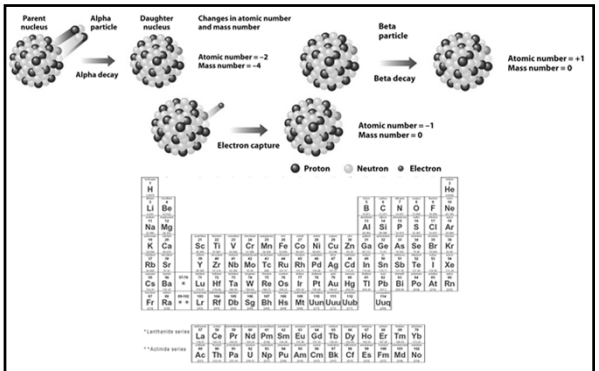


Relative Dating Determines the Order of Geologic Events



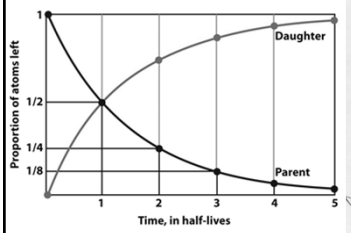


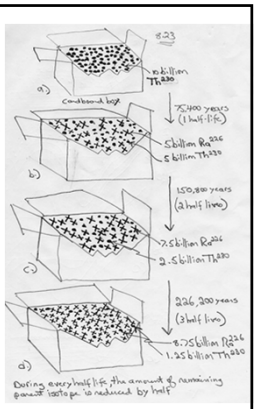




Radiometric Dating Uses Radioactive Decay to Estimate the Age of Geologic Samples.

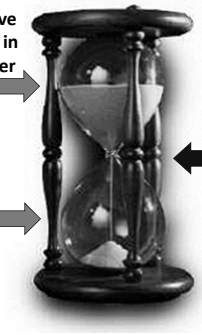
HALF-LIFE





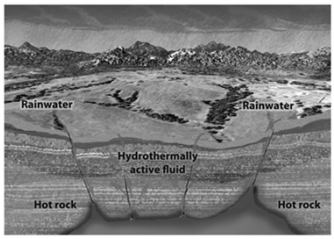
Parent radioactive Isotope trapped in a mineral or other material

Daughter stable isotope trapped in the same mineral or other material



Rate of Decay – which is constant for each isotope

Accurate Dating Requires Understanding Various Sources of Uncertainty.



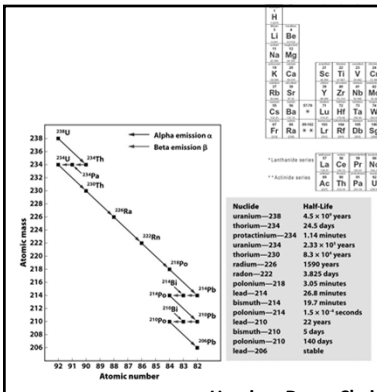
Open-System Behavior

- What is the relationship between the sample and the event it represents?
- What is the approximate age of the sample?
- What radioisotope is most appropriate?
- What are the potential sources of uncertainty?

TABLE 13.1 Common Radioisotopes and Half-Lives Used in Dating Samples

Radioactive (Parent)	Product (Daughter)	Half-Life (Years)	Radioactive (Parent)	Product (Daughter)	Half-Life (Years)
Samarium-147	Neodymium-143	106 billion	Uranium-235	Lead-207	0.7 billion
Rubidium-87	Strontium-87	48.8 billion	Beryllium-10	Boron-10	1.52 million
Thorium-232	Lead-208	14 billion	Chlorine-36	Argon-36	300,000
Uranium-238	Lead-206	4.5 billion	Uranium-234	Thorium-230	248,000
Potassium-40	Argon-40	1.25 billion	Thorium-230	Radium-226	75,400
			Carbon-14	Nitrogen-14	5,730

Geologists Select an Appropriate Radioisotope When Dating a Sample.

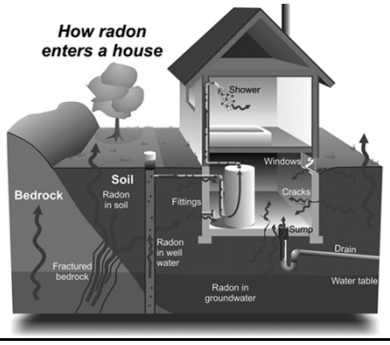


Nuclide	Half-Life
uranium—238	4.5×10^9 years
thorium—234	24.5 days
protactinium—234	1.14 minutes
uranium—234	2.33×10^5 years
thorium—230	8.3×10^4 years
radium—226	1590 years
radon—222	3.825 days
polonium—218	3.05 minutes
lead—214	26.8 minutes
bismuth—214	19.7 minutes
polonium—214	1.5×10^{-4} seconds
lead—210	22 years
bismuth—210	5 days
polonium—210	140 days
lead—206	stable

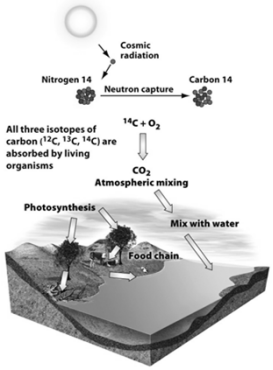
Uranium Decay Chain

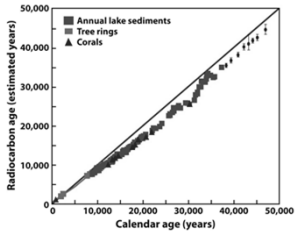
Uranium is the most appropriate radioisotope to date Earth's age.

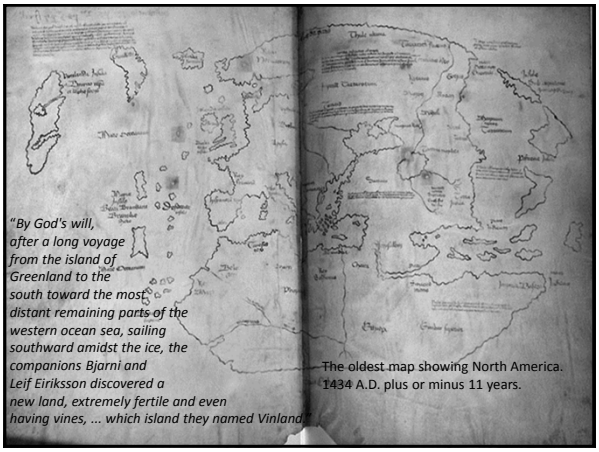
Radon is the second leading cause of lung cancer



CARBON



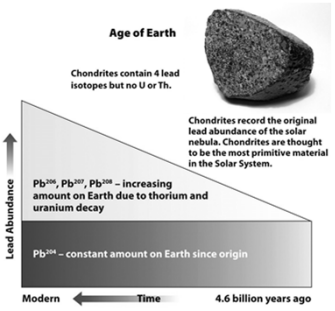




"By God's will, after a long voyage from the island of Greenland to the south toward the most distant remaining parts of the western ocean sea, sailing southward amidst the ice, the companions Bjarni and Leif Eiriksson discovered a new land, extremely fertile and even having vines, ... which island they named Vinland."

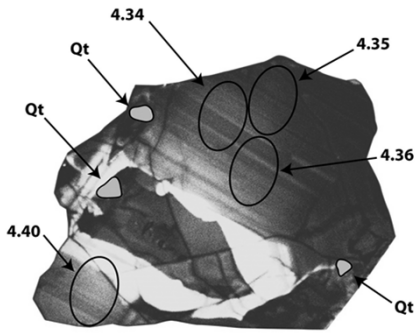
The oldest map showing North America. 1434 A.D. plus or minus 11 years.

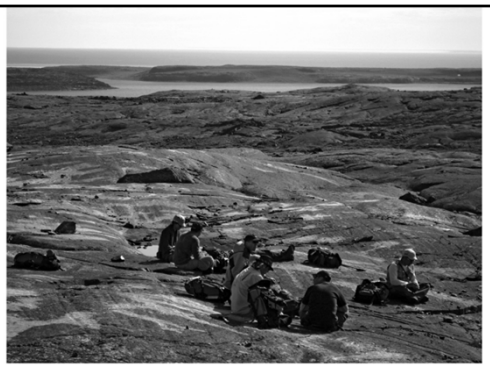
Earth's Age Is Measured Using Several Independent Observations.



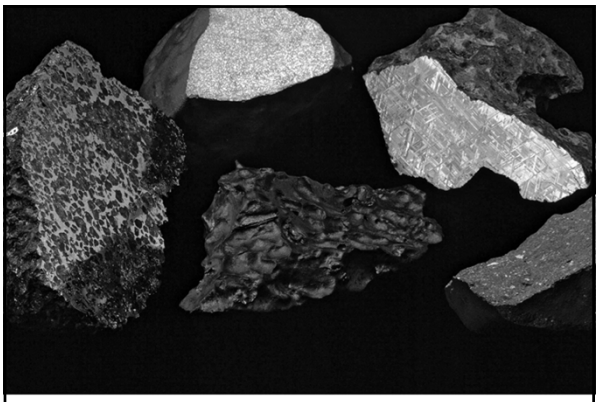
- **"Absolute" ages of primordial crust, Moon, and meteorites.**
- **Abundance of Lead Isotopes.**
- **Consistency between these observations.**

Oldest mineral– ~4.4 bya





Oldest known rocks formed ~4.28 bya



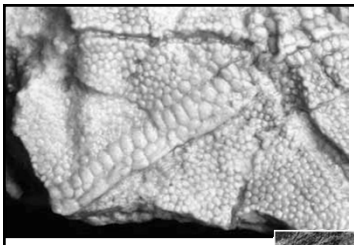
Most meteorites formed ~4.4 - ~4.7 bya.

TABLE 13.4 Oldest Moon Rocks

Mission	Dating Technique	Half-Life	Age (billions of years)
Apollo 17	Rubidium (Rb)-Strontium (Sr)	48.8 billion	4.55 ± 0.1
Apollo 17	Rb-Sr	48.8 billion	4.60 ± 0.1
Apollo 17	Samarium (Sm)-Neodymium (Nd)	106 billion	4.34 ± 0.05
Apollo 16	$^{40}Ar/^{39}Ar$	1.25 billion	4.47 ± 0.1

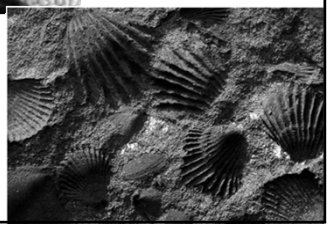
Moon rocks formed
~4.3 - ~4.6 bya.

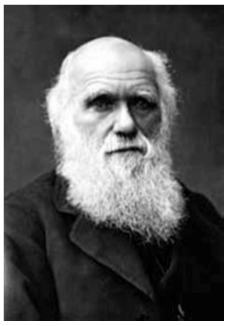
The fossil record provides strong evidence of the evolution of life.



Molds and Casts (brachiopods)

Rare, soft part preservation (dinosaur skin)





Charles Darwin

- **Naturalist aboard HMS Beagle.**
- **Studied *Principles of Geology*.**
- **Wrote *On the Origin of Species by Means of Natural Selection*.**
- **Credited with the Theory of Evolution.**

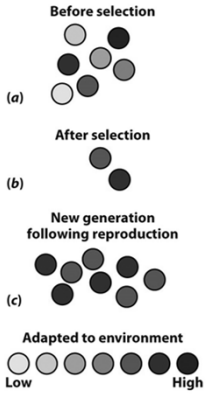
Darwin observed that all living things reproduced at high rates and yet no one group of organisms had been able to overwhelm Earth's surface. In fact, the actual size of any population tends to remain fairly constant over time. This led Darwin to conclude that not all individuals in a generation will survive. But, which survive and which do not?

Nature must select those with favorable variations. **Natural selection** was the mechanism he proposed by which evolution occurred.

Natural Selection

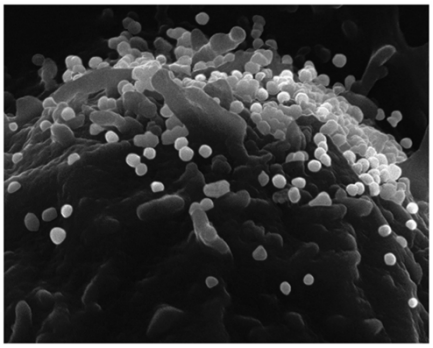
Genetic Mutation (random changes to RNA or DNA)

Genetic Variation (differences in inherited traits)



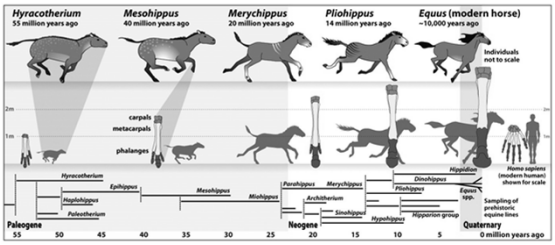
Parasitic Microbes, Viruses, Bacteria ... all Evolve!

A virus can evolve faster than the medical community is able to design medicines to fight it. In scientific parlance, the virus "escapes" drug therapy.

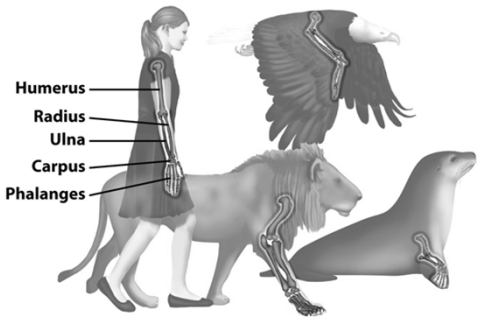


There Are Several Lines of Evidence for Evolution.

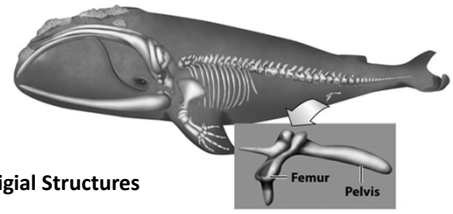
Phylogeny



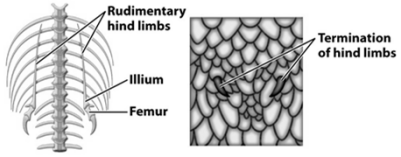
Similar skeletal organization

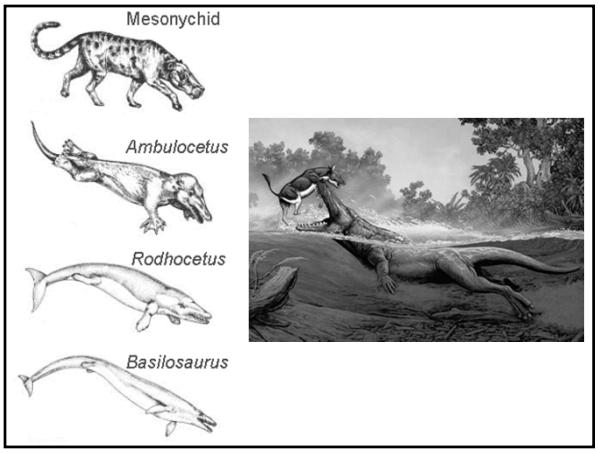


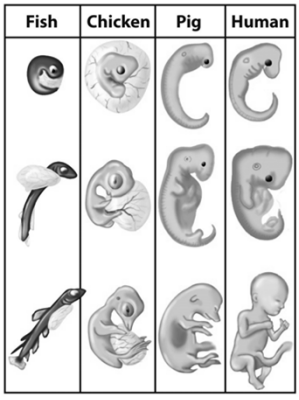
Homologous Structures



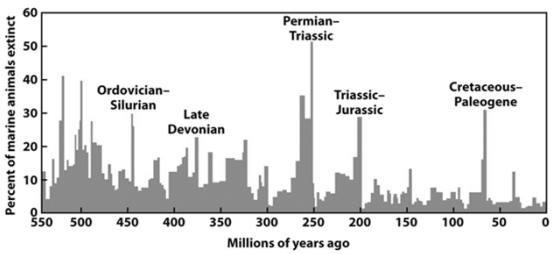
Vestigial Structures





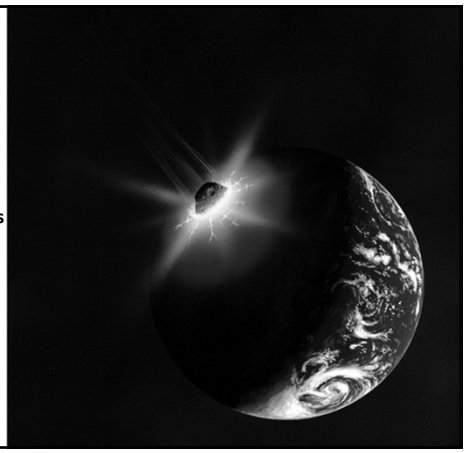


Ontogeny
Embryology



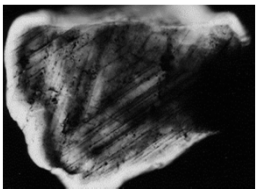
Mass Extinctions Influence the Evolution of Life.

Various hypotheses for each Mass Extinction ...

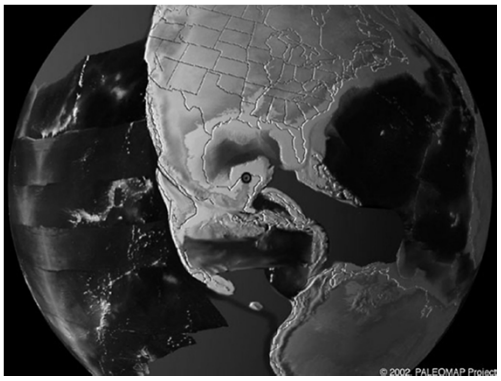


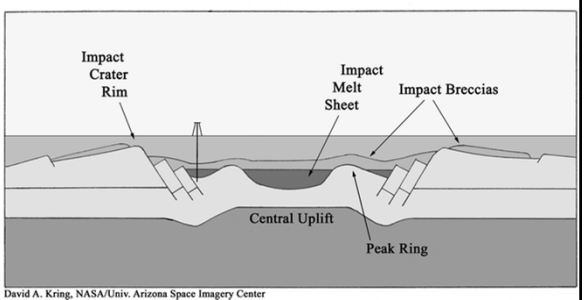
Evidence of cretaceous Event

- Iridium and clay layer
- Shocked quartz
- Glassy tektites
- Impact crater



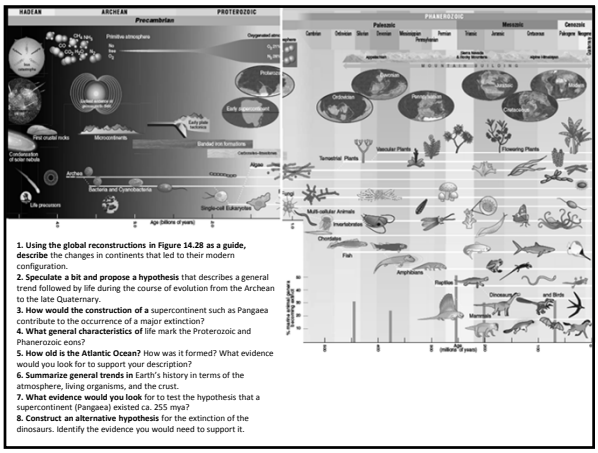
Chicxulub crater





David A. Kring, NASA/Univ. Arizona Space Imagery Center

But there's no need to worry….



1. Using the global reconstructions in Figure 14.28 as a guide, describe the changes in continents that led to their modern configuration.
2. Speculate a bit and propose a hypothesis that describes a general trend followed by life during the course of evolution from the Archean to the late Quaternary.
3. How would the construction of a supercontinent such as Pangaea contribute to the occurrence of a major extinction?
4. What general characteristics of life mark the Proterozoic and Phanerozoic eons?
5. How old is the Atlantic Ocean? How was it formed? What evidence would you look for to support your description?
6. Summarize general trends in Earth's history in terms of the atmosphere, living organisms, and the crust.
7. What evidence would you look for to test the hypothesis that a supercontinent (Pangaea) existed ca. 255 mya?
8. Construct an alternative hypothesis for the extinction of the dinosaurs. Identify the evidence you would need to support it.