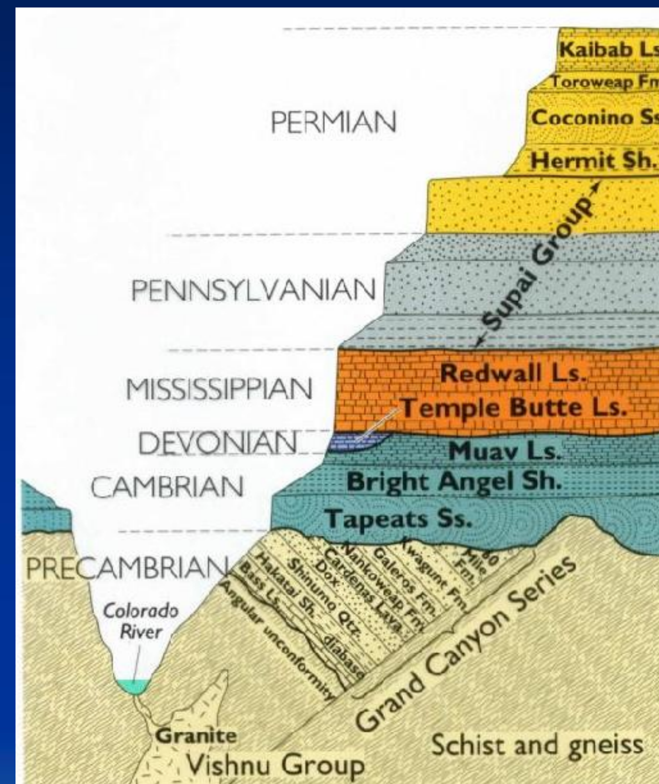
GEOLOGIC DATING
Principles and Applications



Physical Geology - GEOL 100

Ray Rector - Instructor

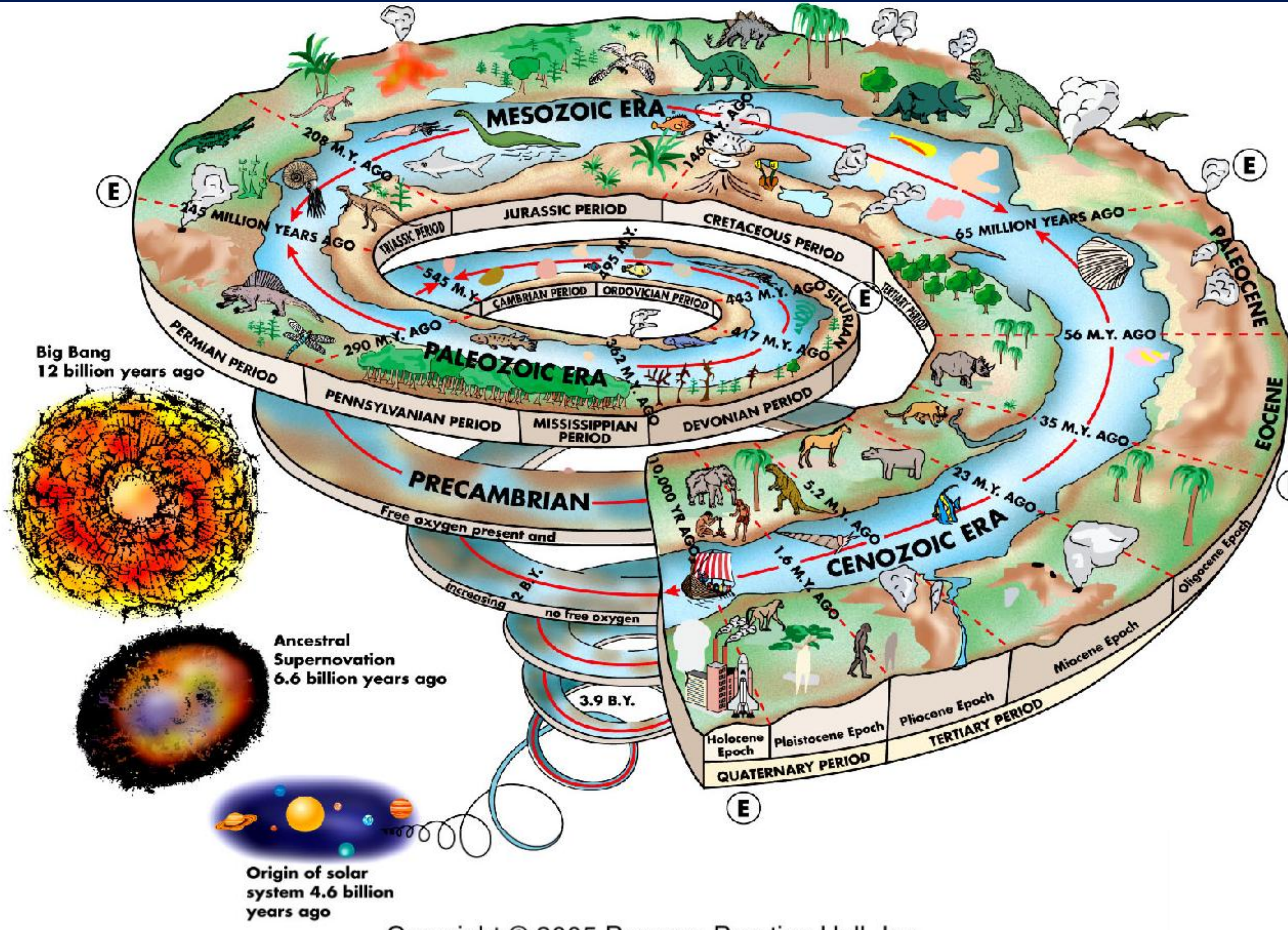
Earth's Age and History

How Old Is the Earth?

How Can We Determine Earth's Geologic History?

How Can We Determine the Age of Geologic Events?

The Twisted Geological Timescale



Two Primary Means of Dating Rocks

1) **Relative Dating**

- ✓ Determines the temporal order of rock forming events
- ✓ Does not give numeric ages
- ✓ Use of stratigraphic principles and fossils
- ✓ Cheap

2) **Absolute Dating**

- ✓ Determines the numeric age of rock forming events
- ✓ Only appropriate for ages of igneous rocks and minerals
- ✓ Primary method is the ***radiometric technique***
- ✓ Used in conjunction with stratigraphic principles and fossils
- ✓ Expensive

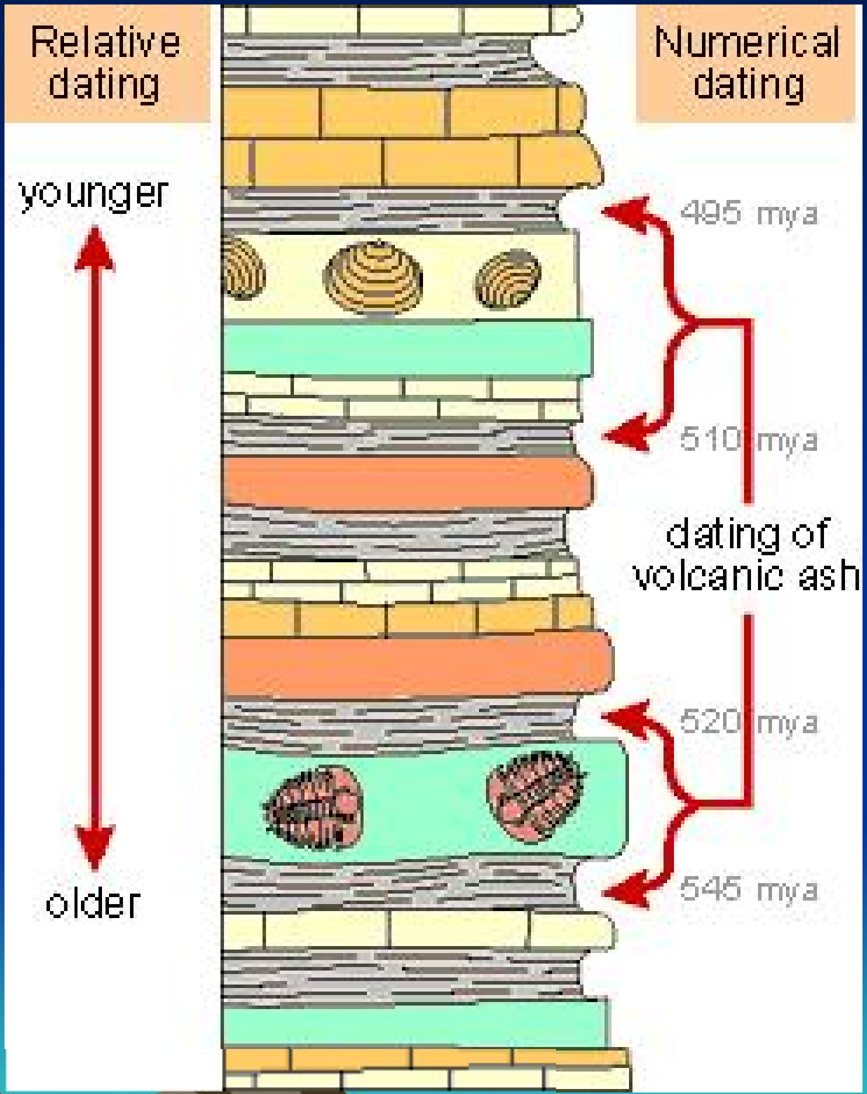
Relative Versus Absolute Dating

Relative Dating

- Stratigraphic principles
- Fossil Succession
- Emphasis on Sed Rocks

Absolute Dating

- Radio-Isotopic techniques
- Emphasis on Igneous Rocks



How Can We Figure Out the Age Sequence of Geologic Events?

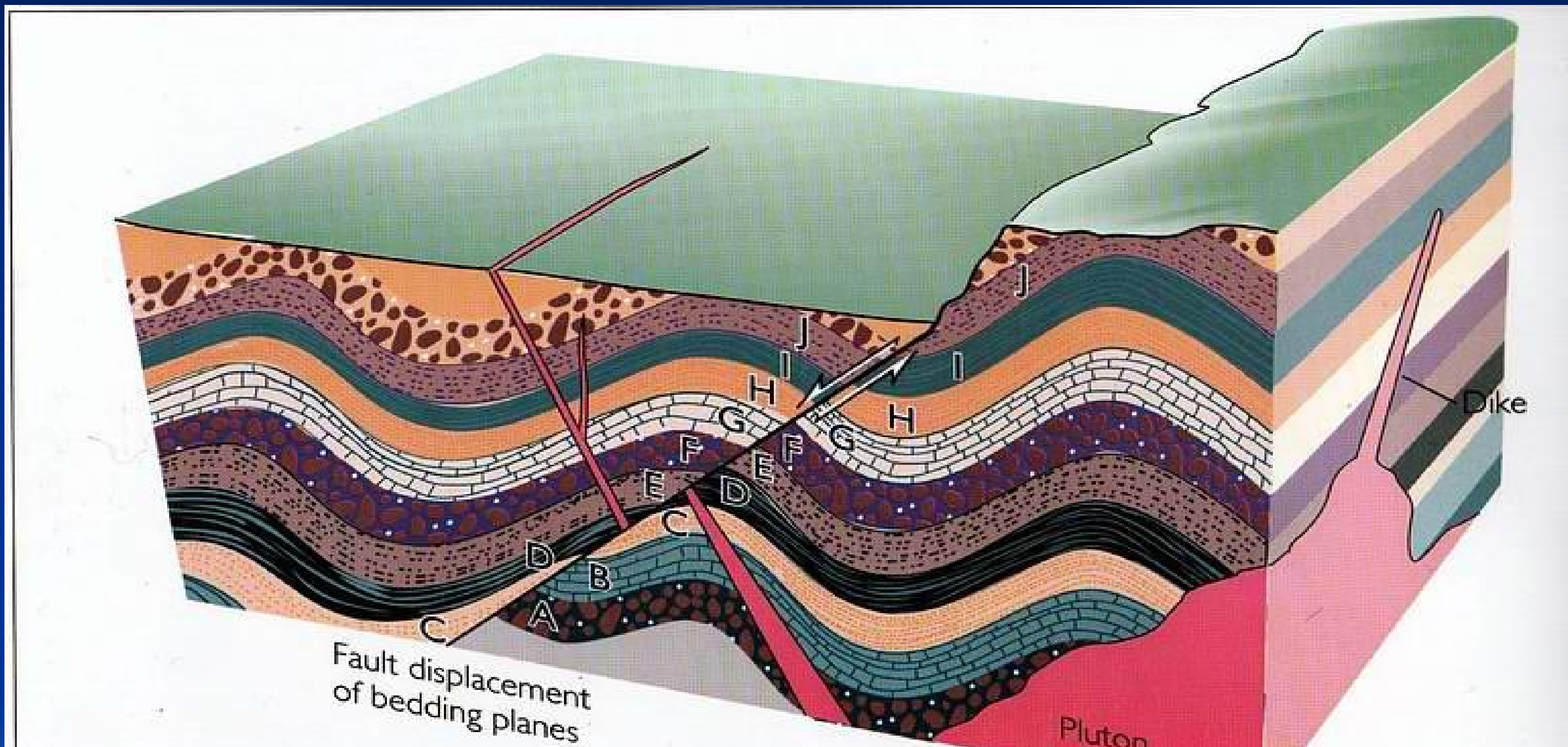


Figure 9.9
Press & Siever: UNDERSTANDING EARTH, Second Edition

Use Stratigraphic Principles and Absolute Dating Methods

The Stratigraphic Principles

1. Superposition - Oldest layer occurs at base of a layered sequence and is overlain by progressively younger rock layers.

2. Cross-Cutting Relations - If a body or discontinuity cuts across a rock structure, it must have formed after that stratum.

3. Law of Inclusions - Rock fragments (in another rock) must be older than the rock containing the fragments.

4. Law of Fossil Succession - Unique fossil groups were succeeded by other fossil groups through time.

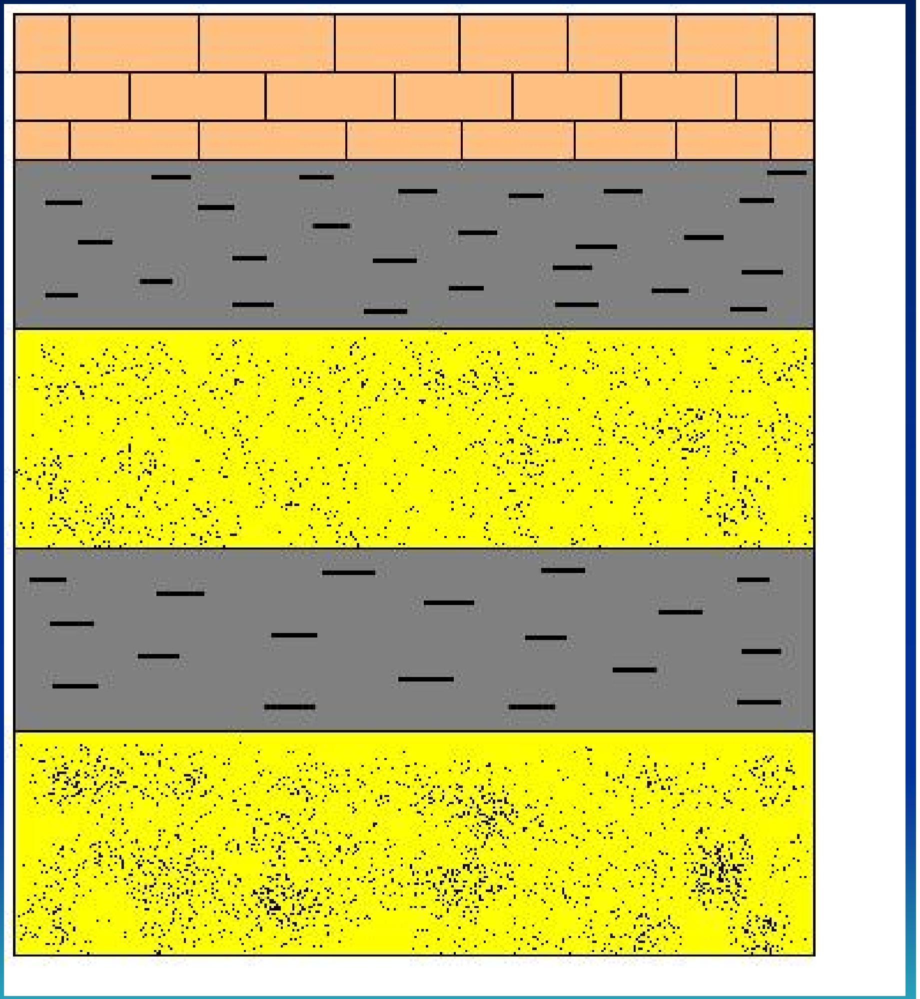
5. Original Horizontality - All sedimentary rocks are originally deposited horizontally. Sedimentary rocks that are no longer horizontal have been tilted from their original position.

6. Lateral Continuity - Sedimentary and volcanic rocks are laterally continuous over large areas.

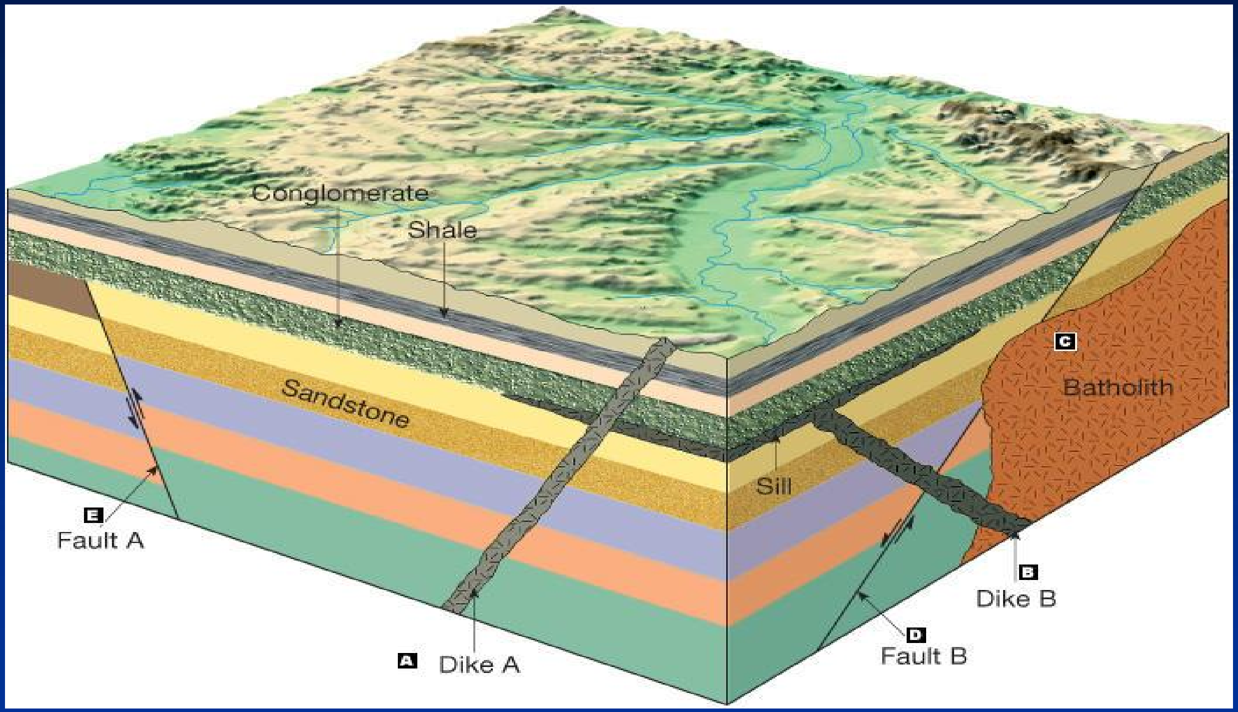
Principle of Superposition

In a vertical stack of layered rock units, the overlying unit is younger than the underlying unit.

The youngest rock layer is on top – the oldest layer is on the bottom.

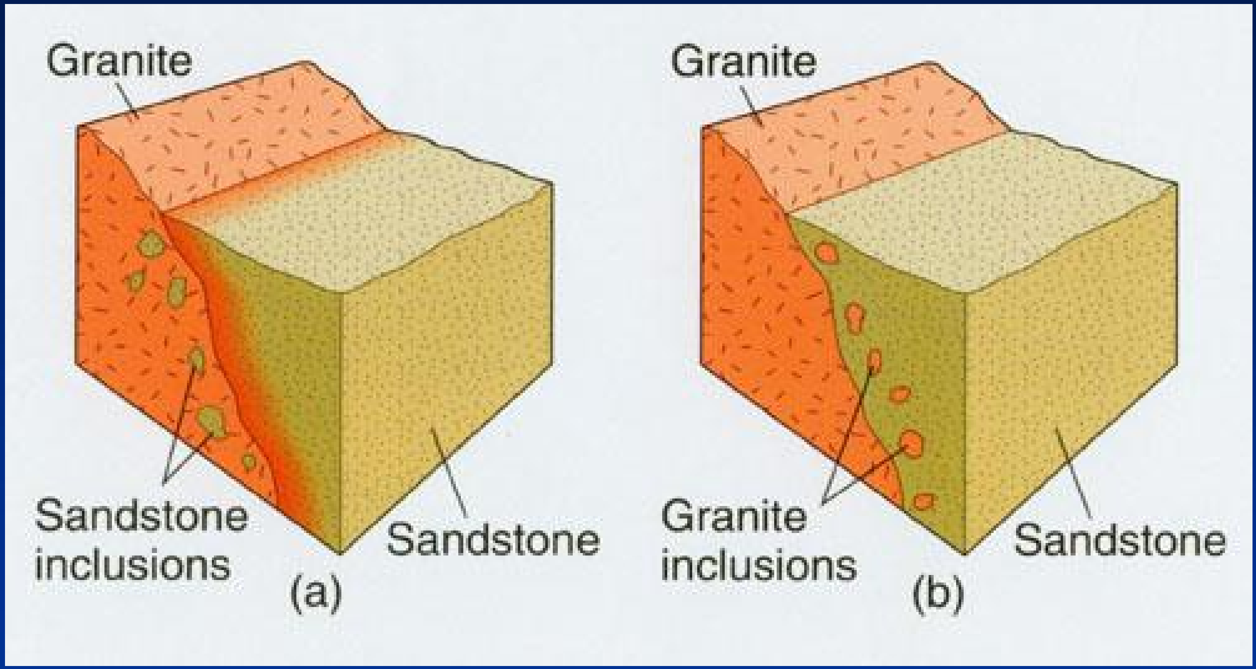


Principle of Cross-Cutting Relations



The rock unit whose layer is being crosscut (disrupted or offset) is older than the rock unit or fault that is doing the crosscutting.

Principle of Inclusions



The rock unit that surrounds the inclusions must be younger than the inclusions.

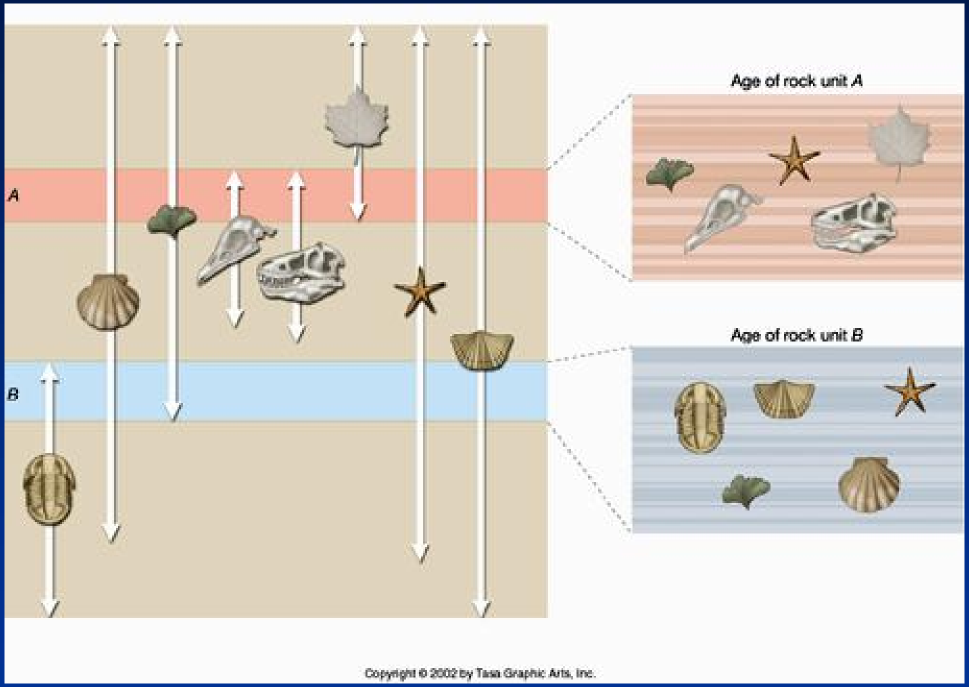
Principle of Fossil Succession

Key Idea:

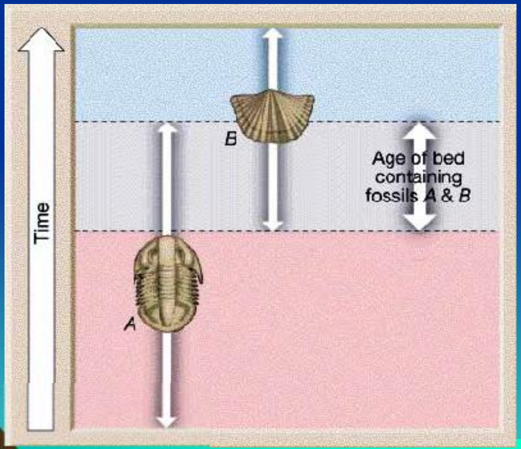
✓ Based on relative dating (law of superposition) and the use of age-specific (index) fossils species.

✓ Unique fossil species of a specific age range are temporally succeeded by other younger fossil species through time.

✓ A rock that contains a specific assemblage of index fossils must be the age of when those organisms (now fossils) were all alive.



Constraining the age (range) of an index fossil assemblage

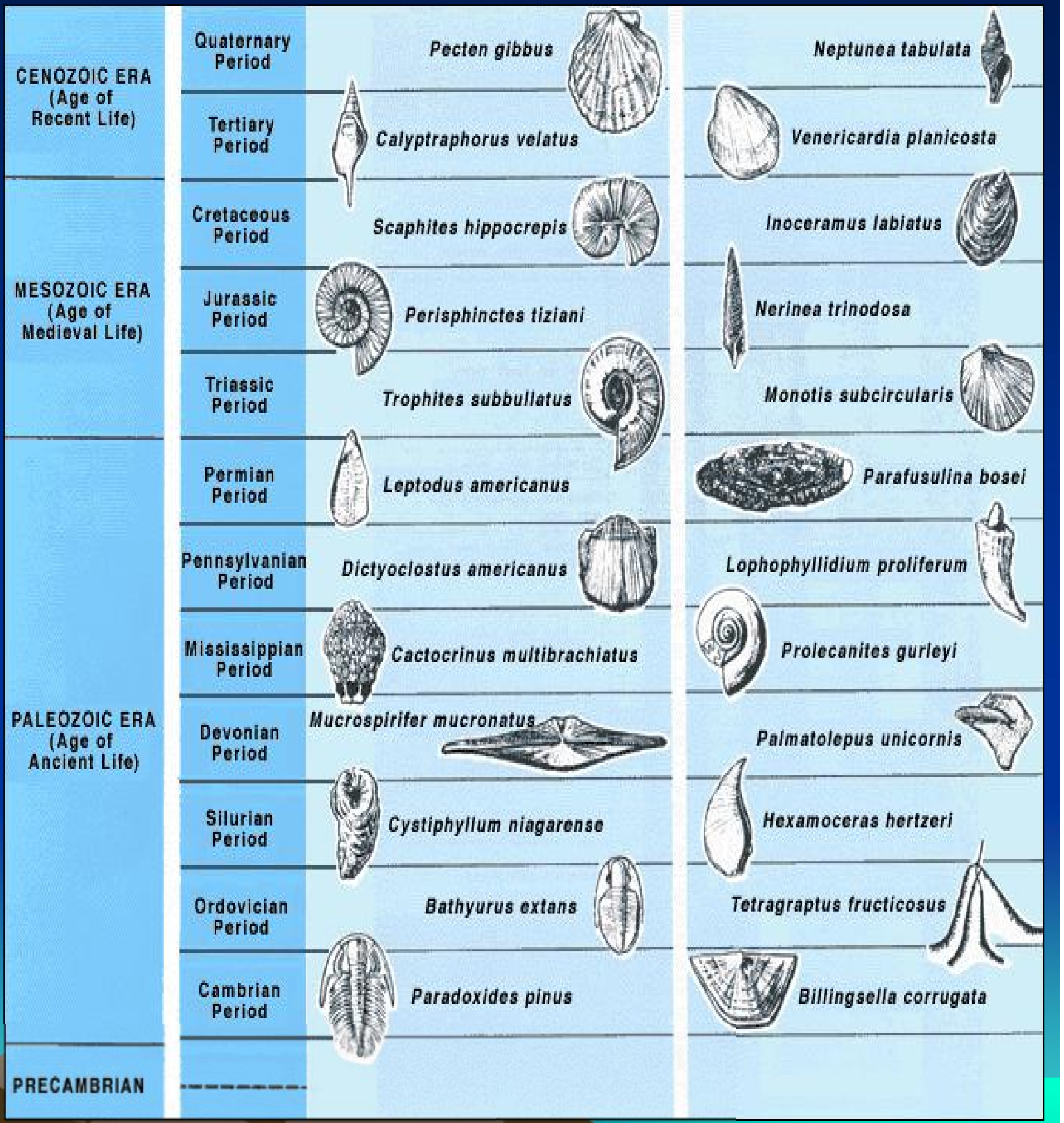


Index Fossils

Criteria to be a Useful Index Fossil:

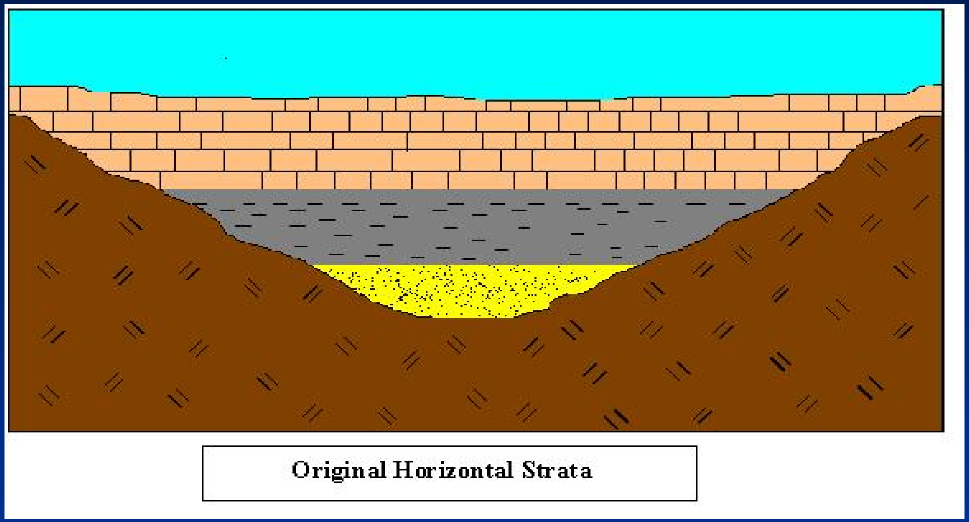
Must have:

1) Narrow time range age
2) Worldwide distribution
3) Preserve in a wide range of depositional settings

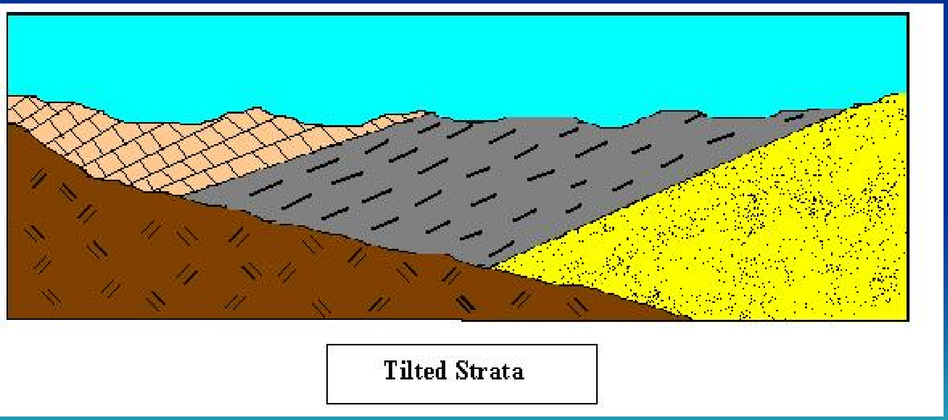


Principle of Original Horizontality

Sedimentary rock units originally deposit in horizontal layers



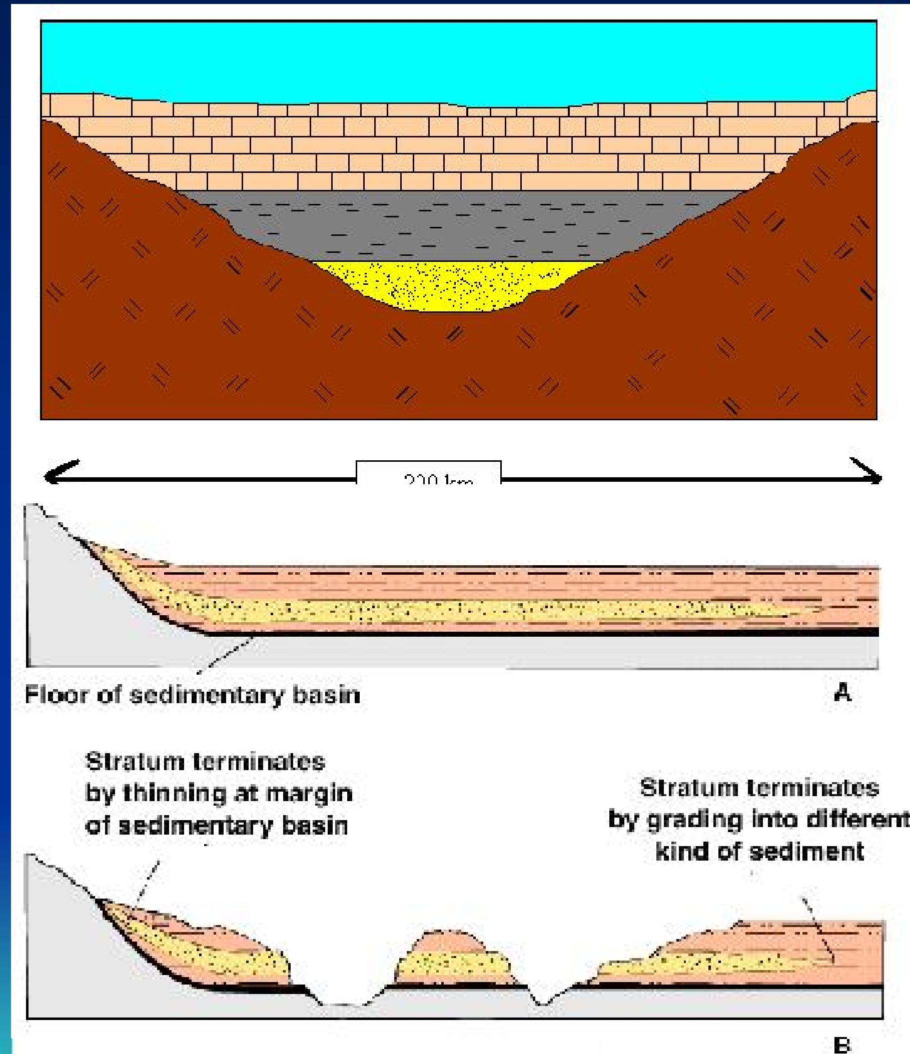
Later events may cause the layers to become tilted or overturned



Principle of Lateral Continuity

Layers of sedimentary material initially extend laterally in all directions.

The layers eventually thin to zero and either terminate at the ends of the sedimentary basin or grade into other units.

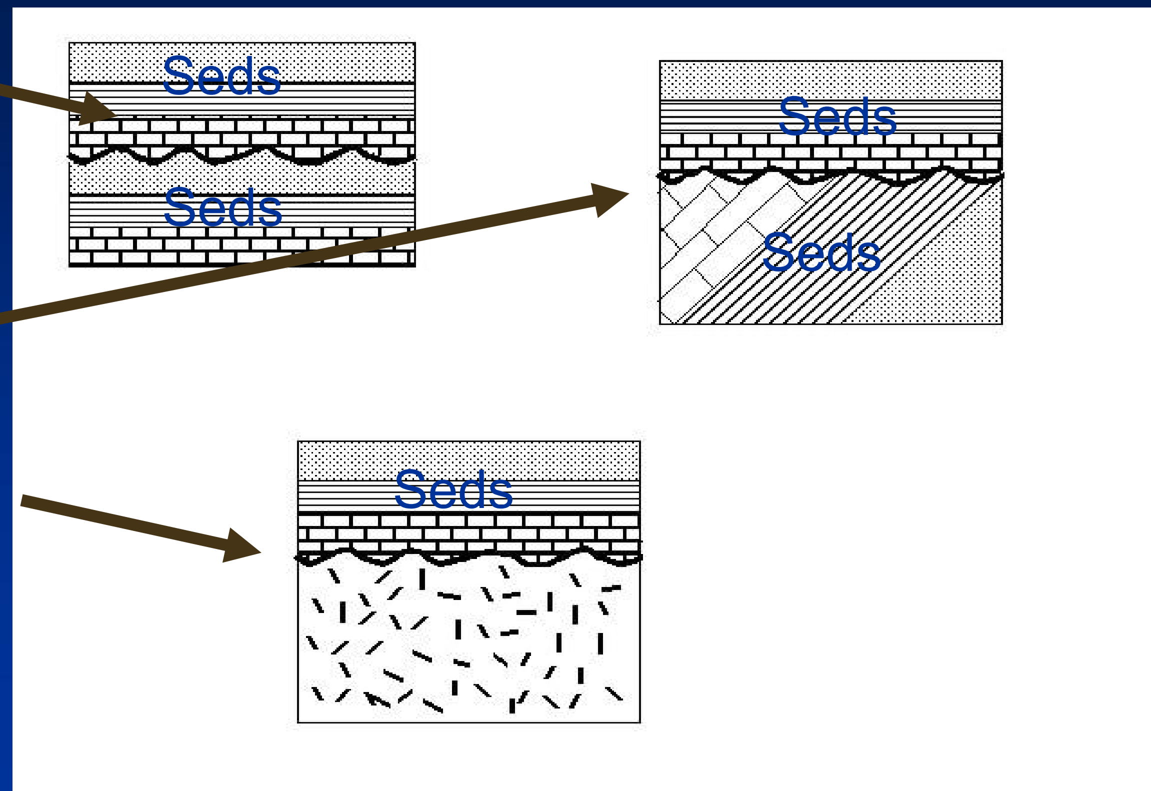


Principle of Unconformities

Unconformity defined:
An unconformity is a buried erosional surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous.

Three Types of Unconformities

1. Disconformity
2. Angular Unconformity
3. Nonconformity

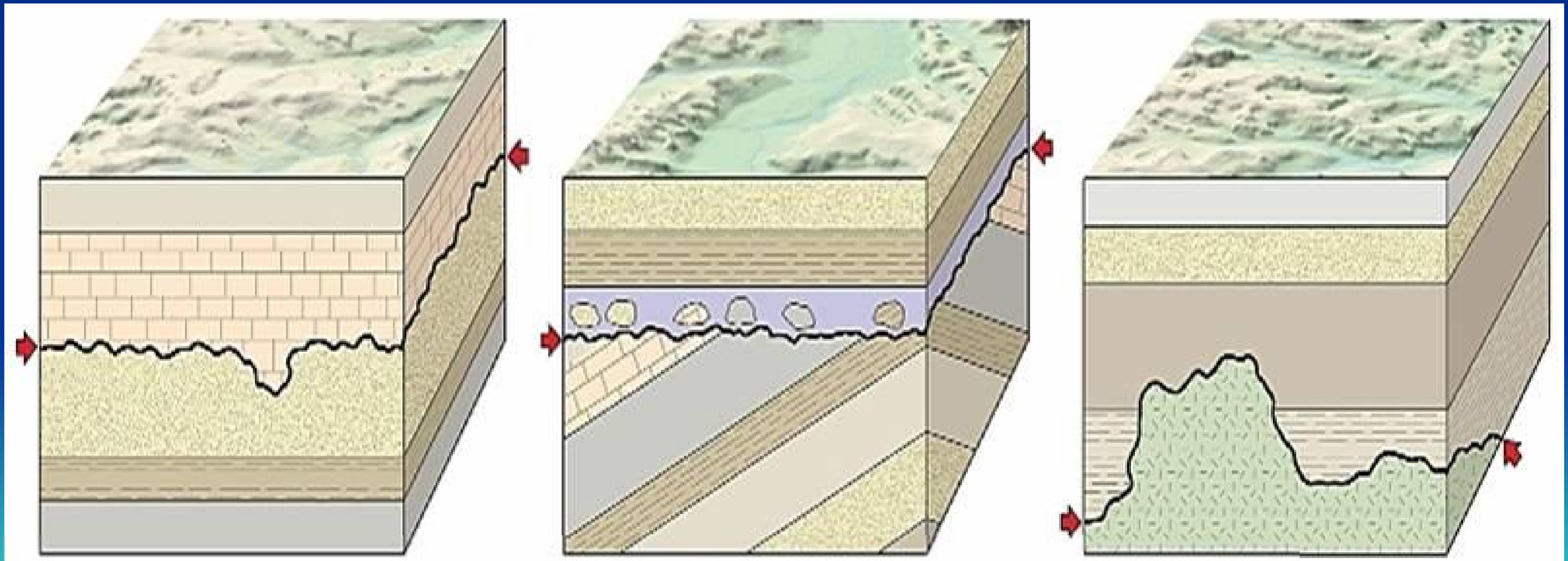


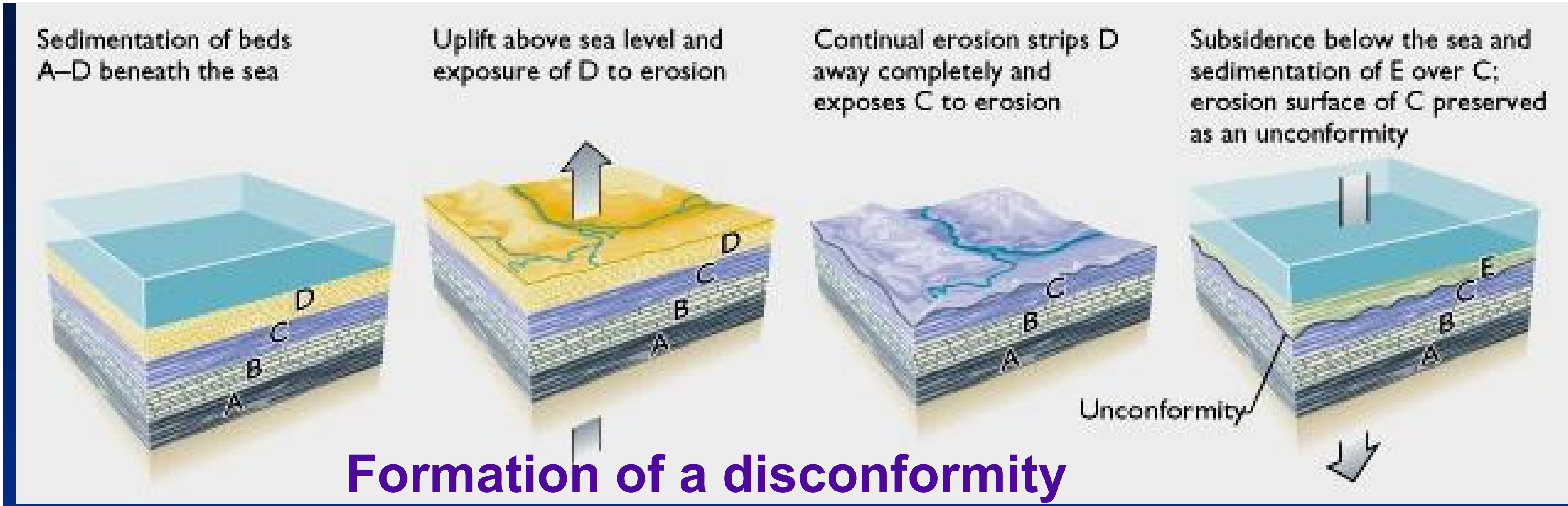
Three Types of Unconformities

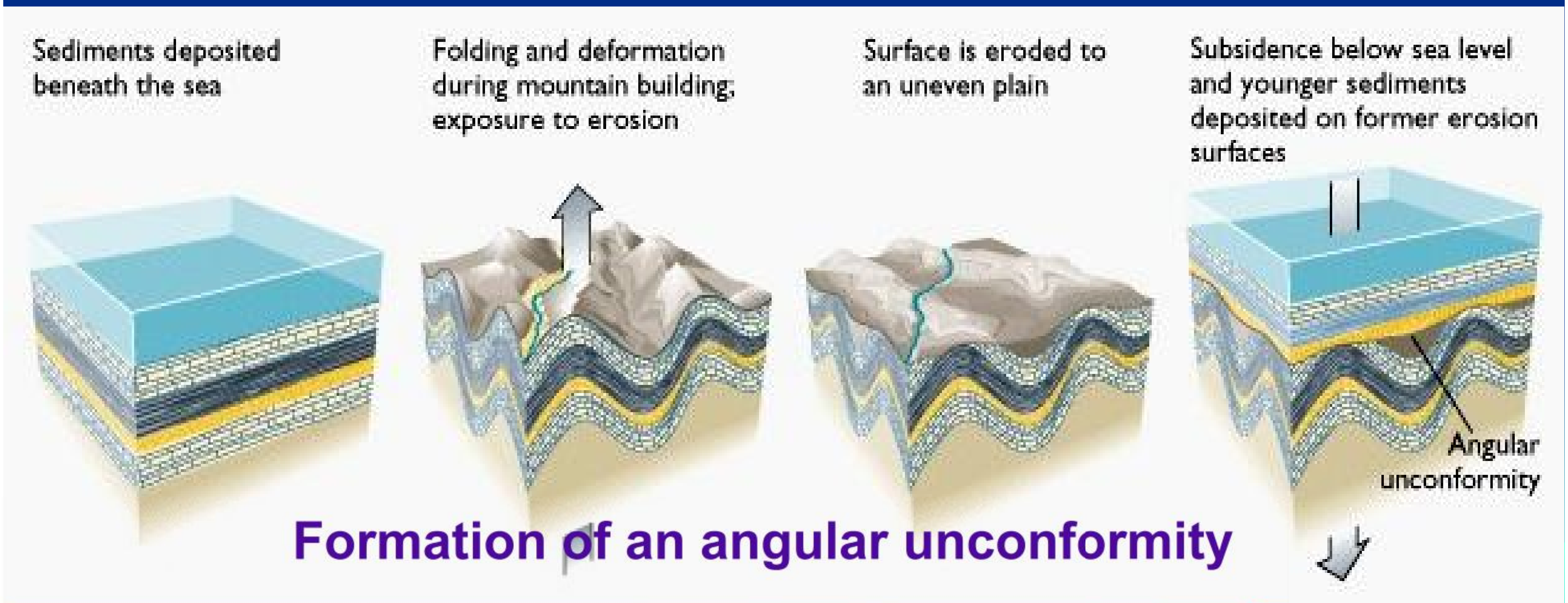
1. Disconformity?

2. Angular Unconformity?

3. Nonconformity?

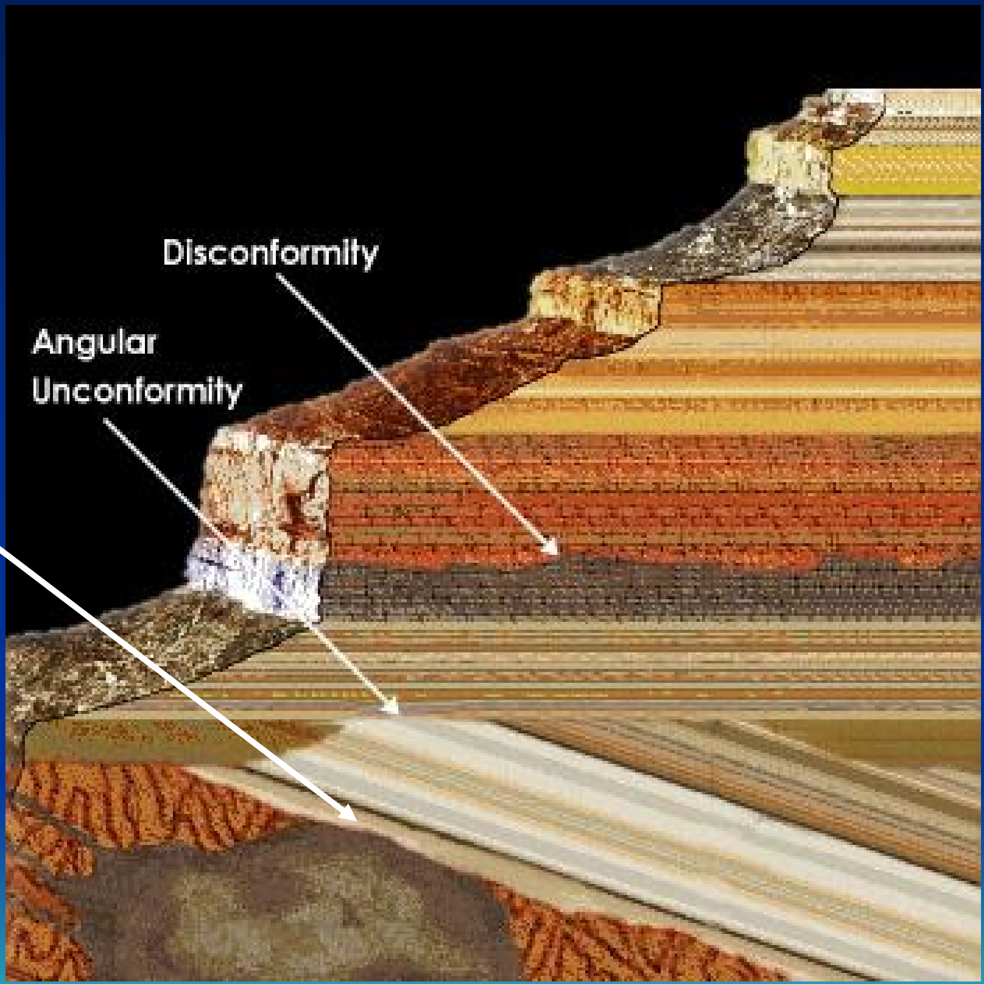



Sedimentation of beds A–D beneath the sea
Uplift above sea level and exposure of D to erosion
Continual erosion strips D away completely and exposes C to erosion
Subsidence below the sea and sedimentation of E over C; erosion surface of C preserved as an unconformity
D
C
B
A
E
Unconformity
Formation of a disconformity


Sediments deposited beneath the sea
Folding and deformation during mountain building; exposure to erosion
Surface is eroded to an uneven plain
Subsidence below sea level and younger sediments deposited on former erosion surfaces
Angular unconformity
Formation of an angular unconformity

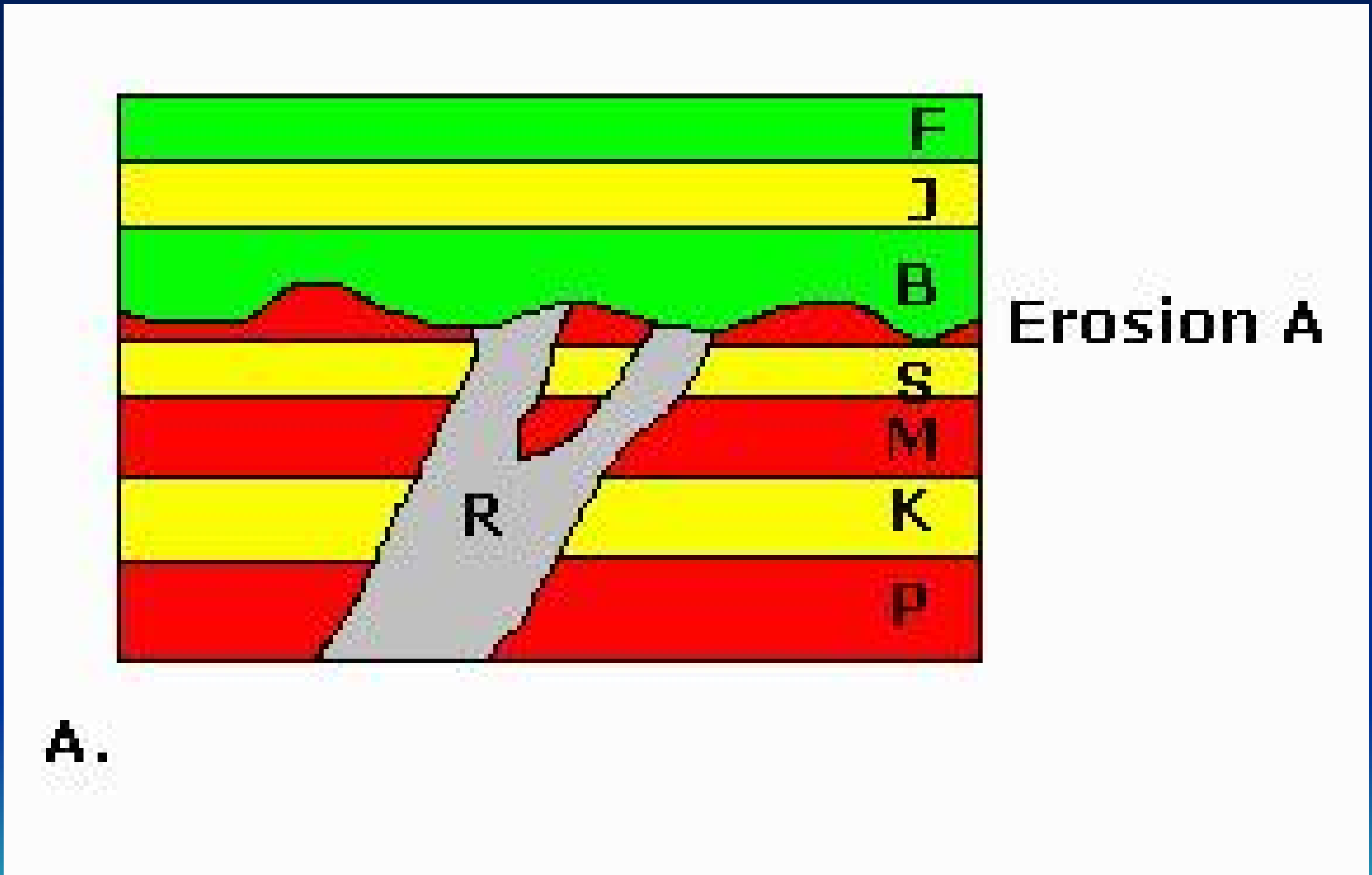
Three Types of Unconformities

1. Disconformity
2. Angular Unconformity
3. Nonconformity

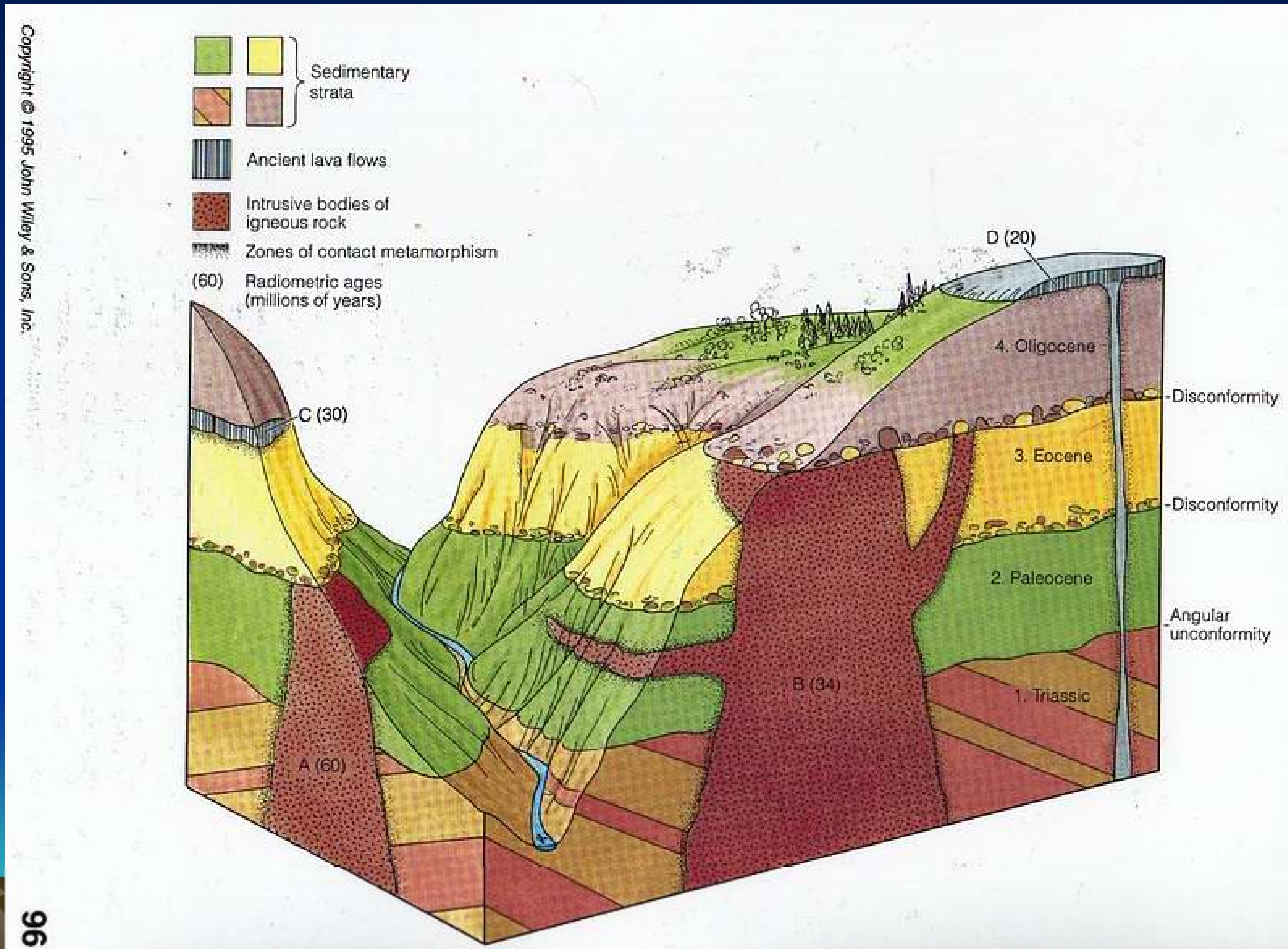


Which Type of Unconformity?

A Very Simple Geologic Cross Section

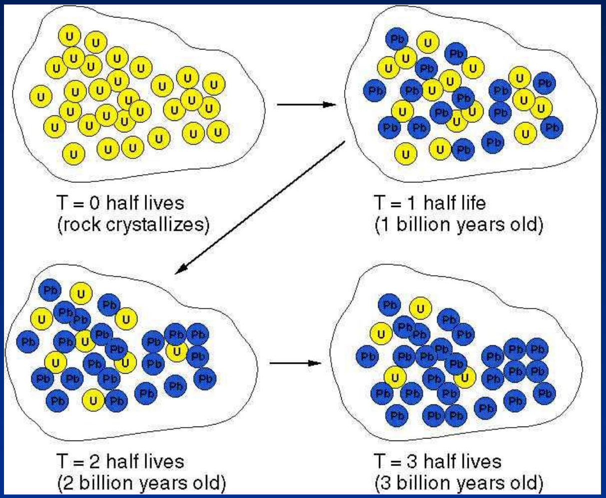


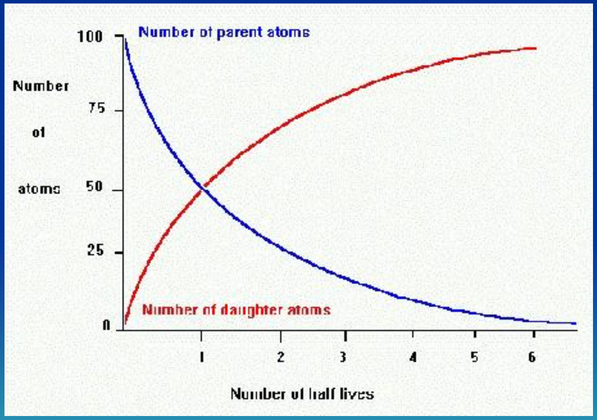
3-D Geologic Cross Section



Absolute Dating of Minerals and Rocks

Zircons Crystals

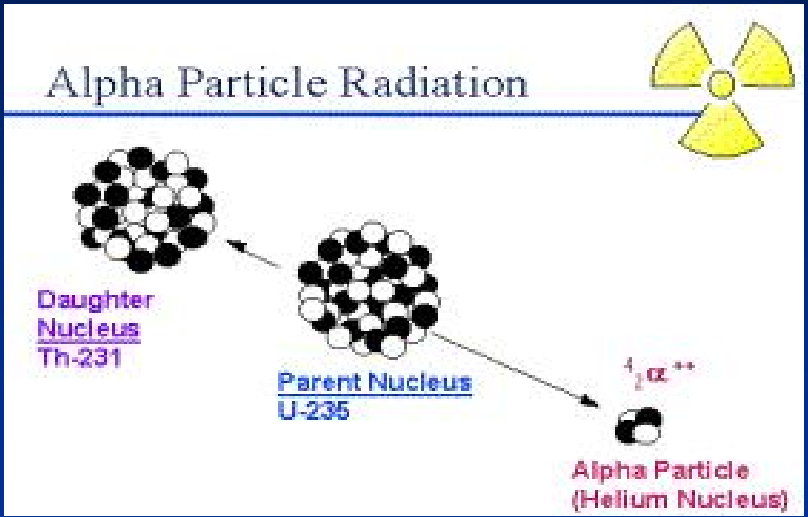


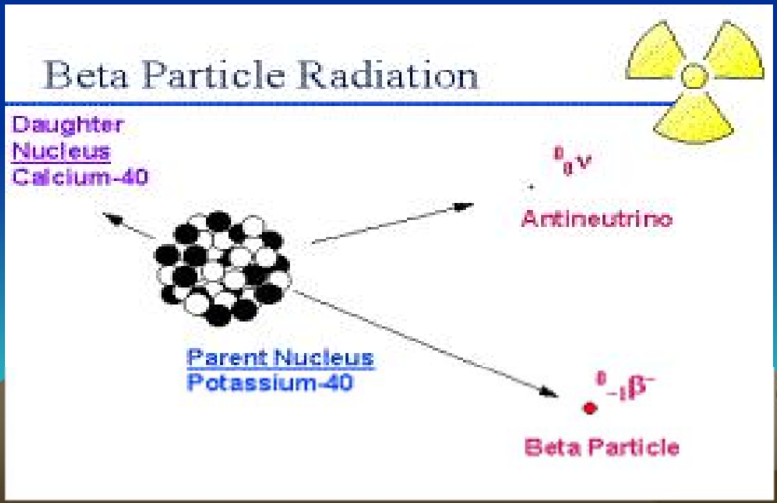


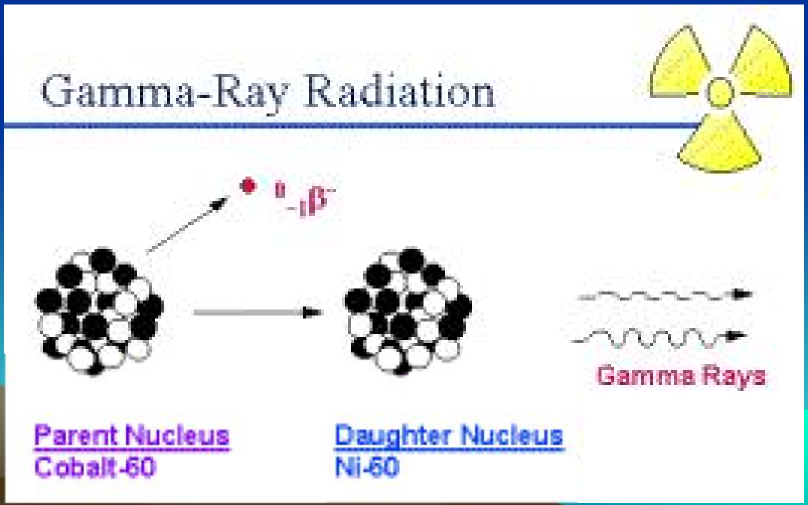
Spontaneous Radioactive Decay

Three Types of Radioactive Decay

1) Alpha Emission
2) Beta Emission
   - Beta minus
   - Beta plus
3) Gamma Emission

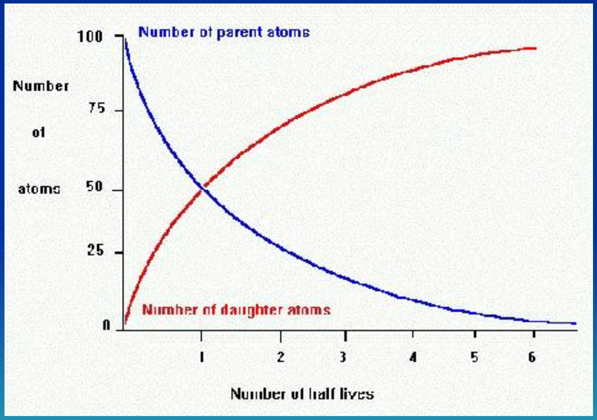


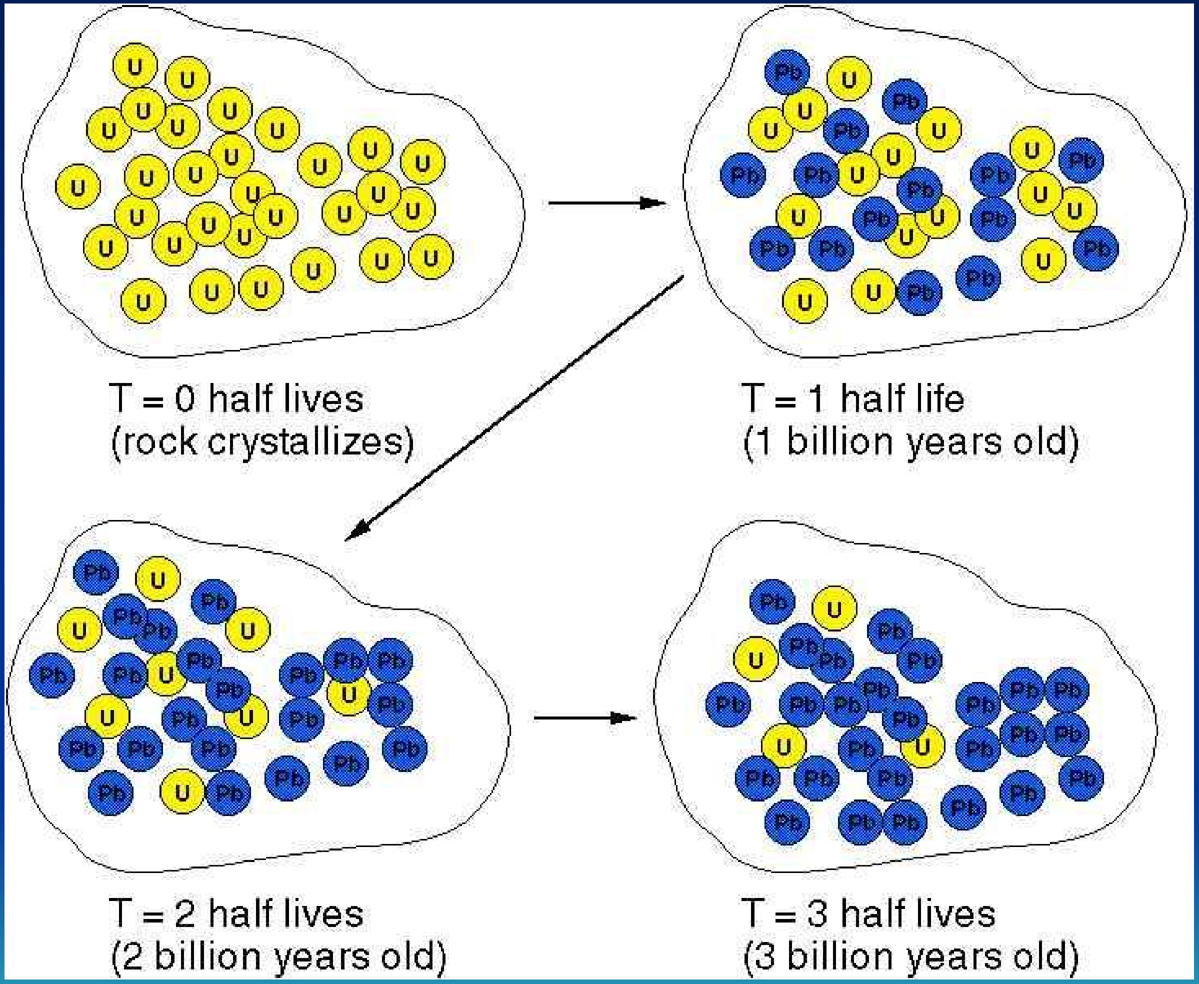




Radioisotopic Dating of Minerals

Zircons Crystals

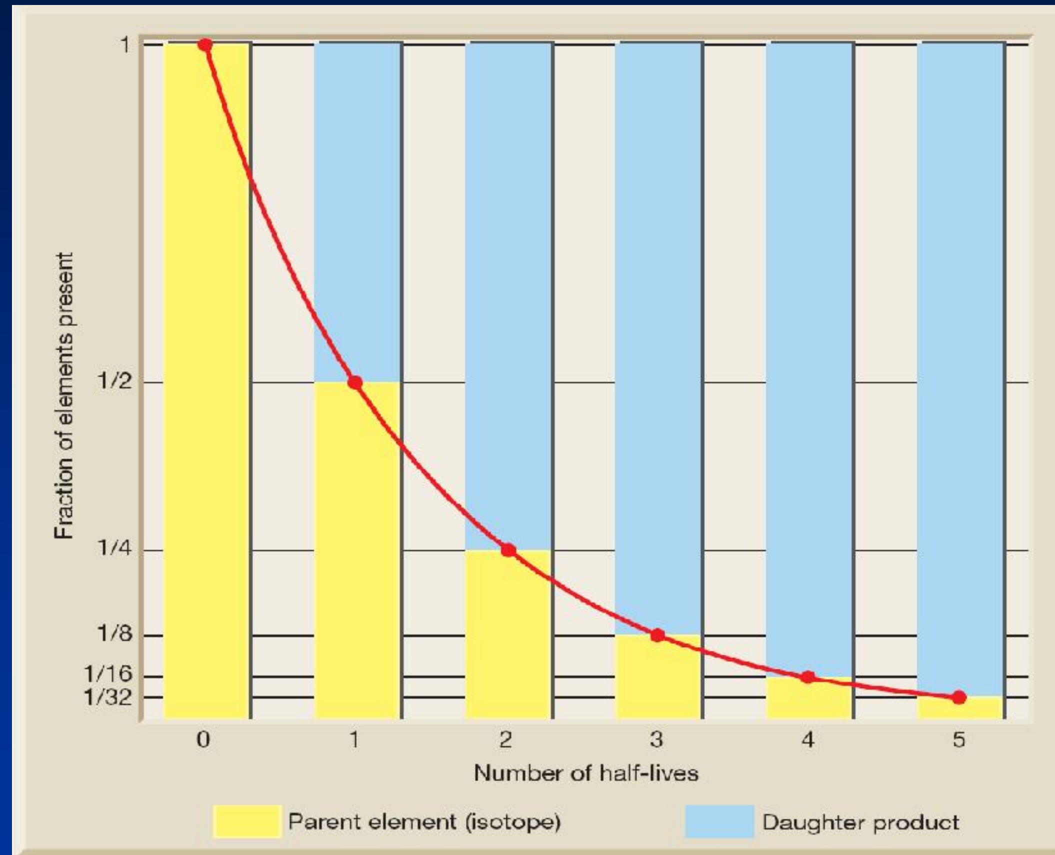


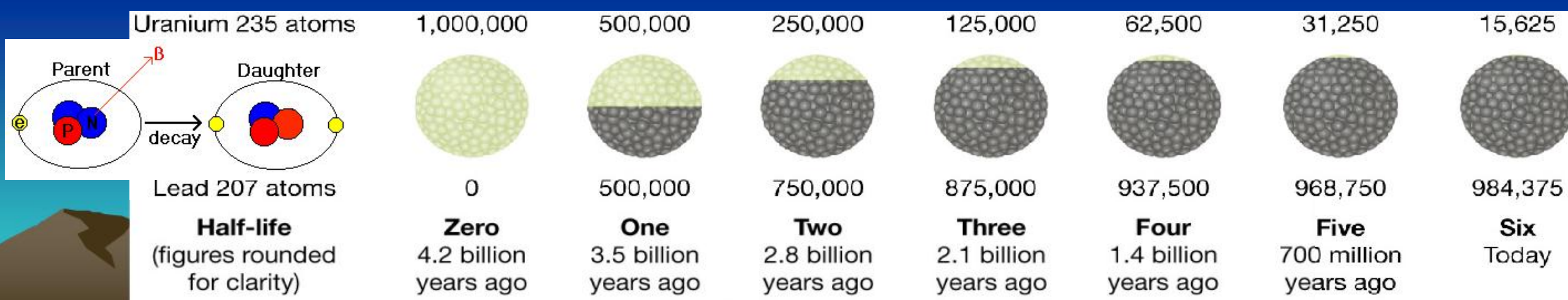


Principles of Radioisotopic Decay

The Principles

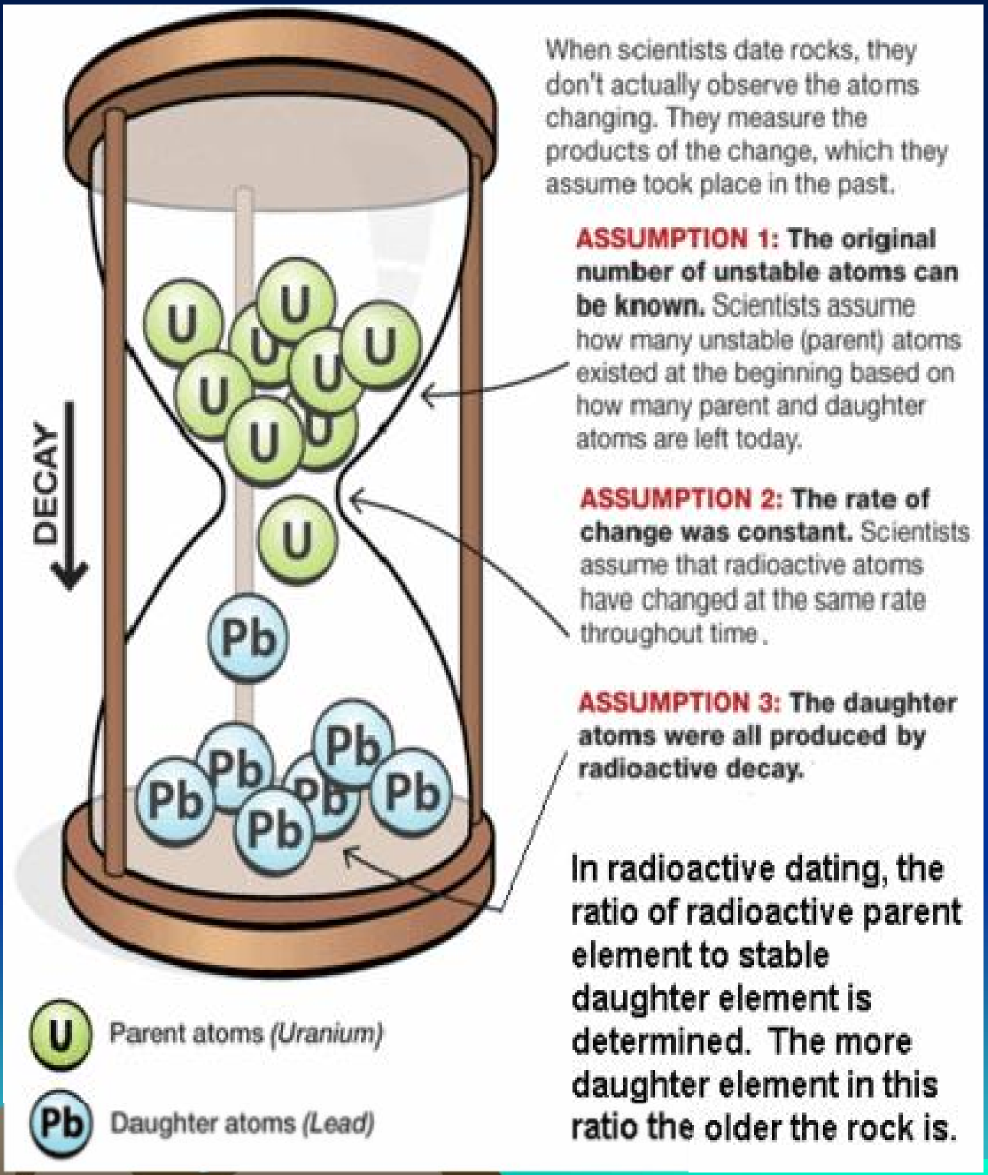
- ✓ Spontaneous decay of unstable parent element into a its unique stable daughter element
- ✓ The half-life of each parent-daughter pair is a constant
- ✓ Age of an igneous rock is determined by measuring the ratio of rock's parent-daughter material



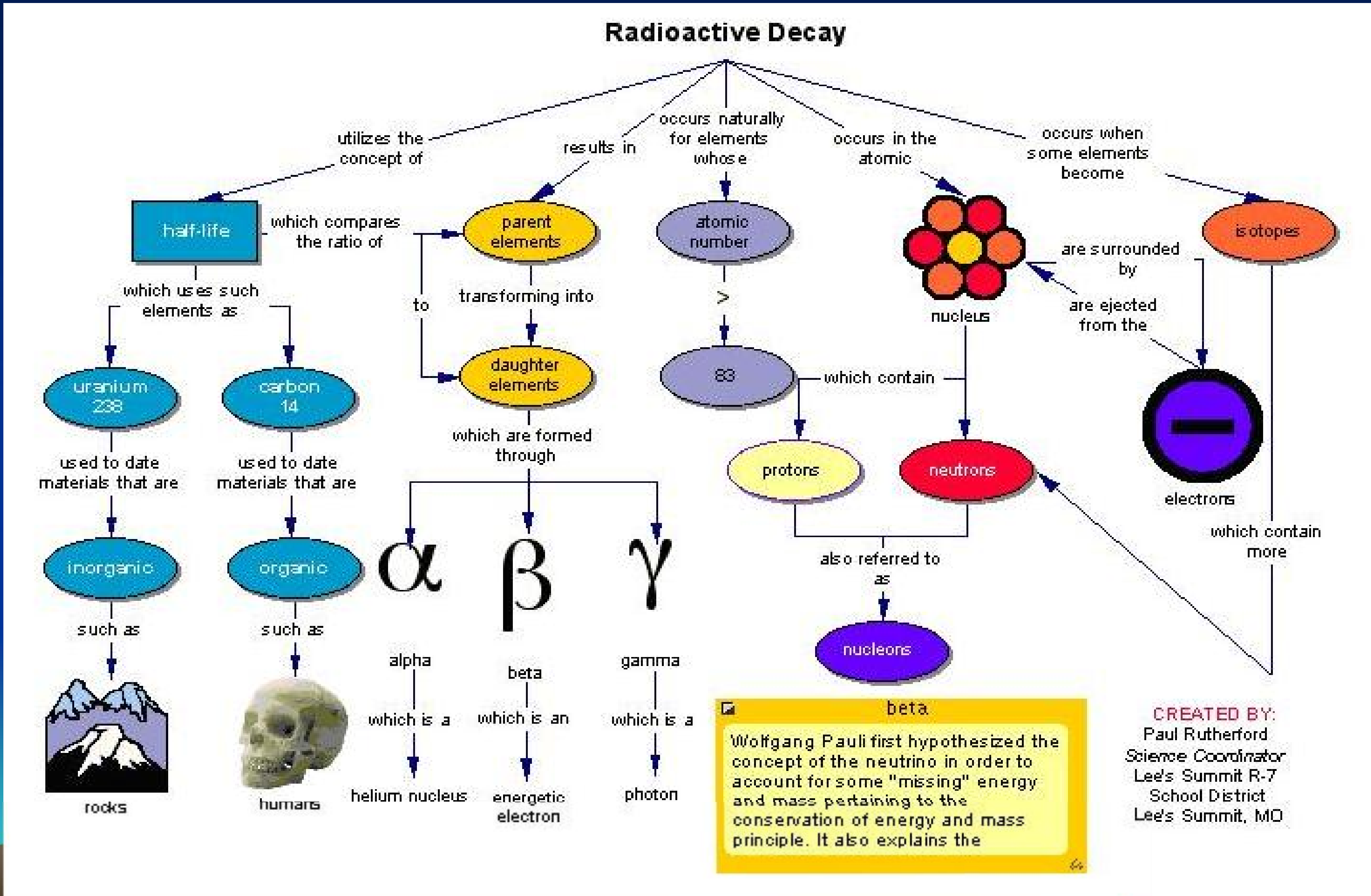


Assumptions Behind Radioisotopic Dating

- ✓ Know the amount of unstable parent elements that were in the mineral/rock from the beginning of time when the mineral/rock first formed
- ✓ The half-life (rate of change) of unstable parent into stable daughter is an unchangeable constant
- ✓ The amount of initial daughter isotopes is known versus the amount of daughter isotopes created from the decay of the parent isotopes in rock.
- ✓ The parent and daughter isotopes did not leave or enter the mineral/rock since time of formation (totally closed system)

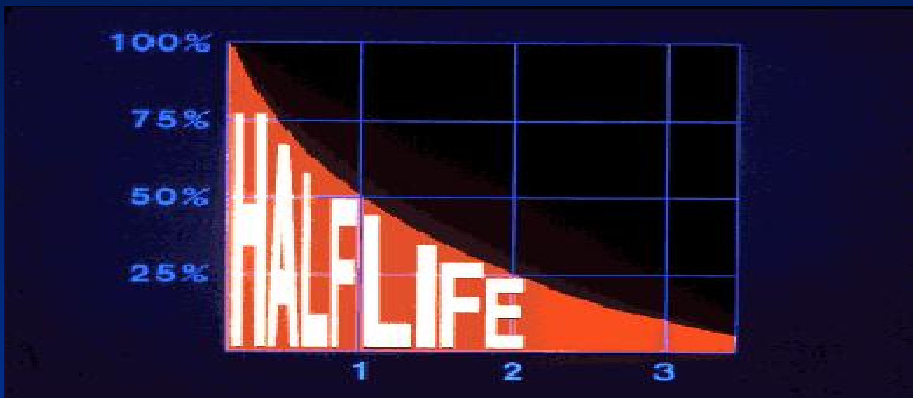


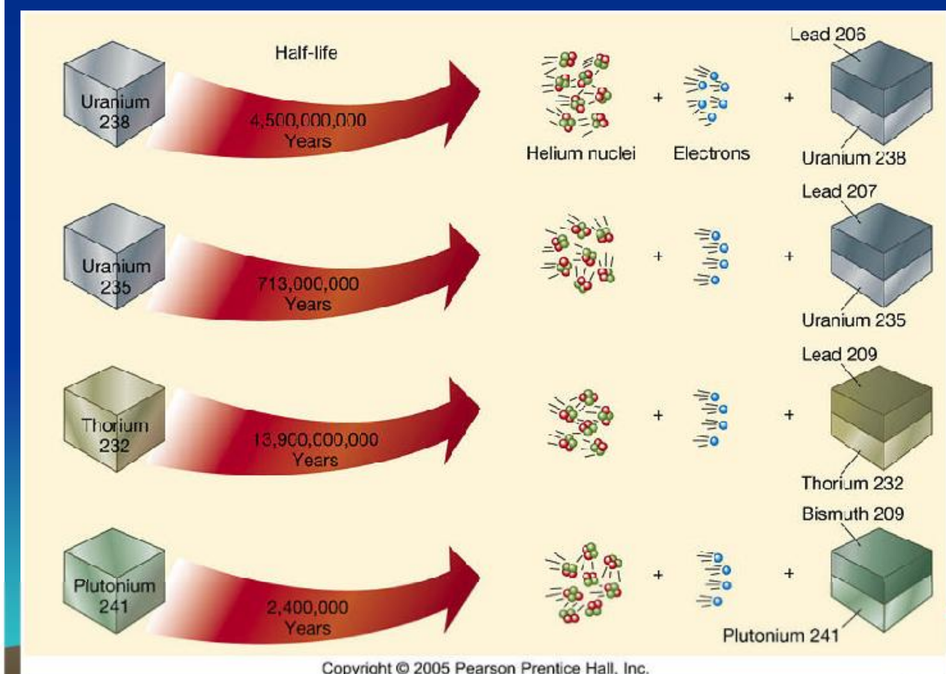
Concept Map of Radiometric Dating



Radioisotopic Half-Lives

Radioactive Parent/Daughter Pairs and Associated Half-Lives





Parent Isotope	Stable Daughter Product	Currently Accepted Half-Life Values
Uranium-238	Lead-206	4.5 billion years
Uranium-235	Lead-207	713 million years
Thorium-232	Lead-208	14.0 billion years
Rubidium-87	Strontium-87	48.8 billion years
Potassium-40	Argon-40	1.25 billion years
Samarium-147	Neodymium-143	106 billion years

Isotopic Decay Sequence

Unstable Parent

Radioactive Decay Sequence of Uranium-238 Parent Isotope into Lead-206 Daughter Isotope

238 U 4.468E+9 yr 238.05078	a --> 4.270 MeV	234 Th 24.10 da 234.04359	B- --> 6.420 MeV	234 Pa 6.70 hr 234.04330	B- --> 2.197 MeV	234 U 2.455E+5 yr 234.04094	a --> 4.859 MeV
230 Th 7.538E+4 yr 230.03312	a --> 4.770 MeV	226 Ra 1600 yr 226.02540	a --> 4.871 MeV	222 Rn 3.8235 da 222.01757	a --> 5.590 MeV	218 Po 3.10 min 218.00896	a --> 6.115 MeV
214 Pb 26.8 min 213.99979	B- --> 1.024 MeV	214 Bi 19.9 min 213.99869	a --> 3.272 MeV	210 Tl 1.30 min 209.99006	B- --> 5.484 MeV	210 Pb 22.3 yr 209.98417	a --> 5.484 MeV
206 Hg 8.15 min 205.97749	B- --> 1.308 MeV	206 Tl 4.199 min 205.97609	B- --> 1.533 MeV	206 Pb 24.1% 205.97444			

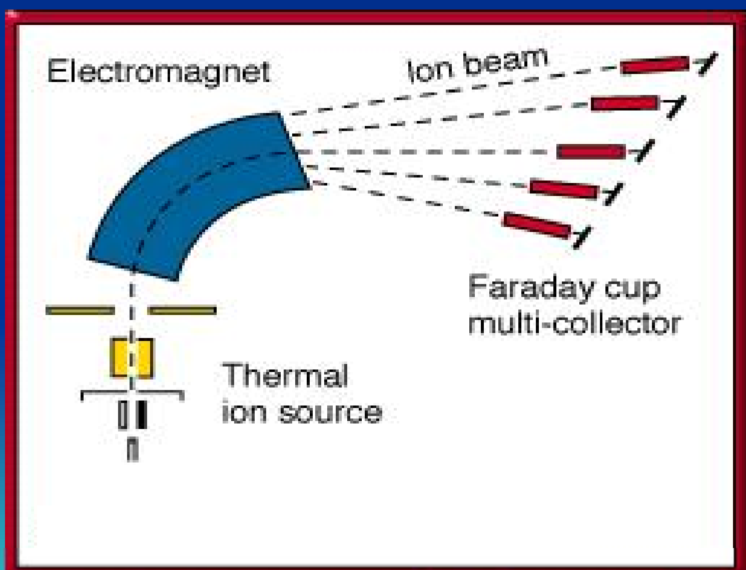
Stable Daughter

- Half-life of U-238/Pb-206 system is 4.5 billion years

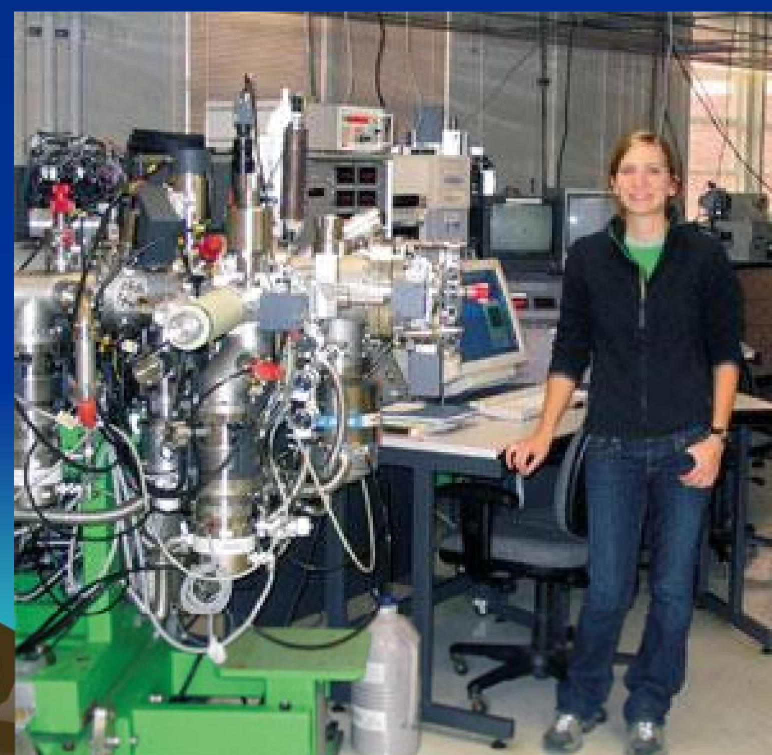
Radioisotopic Dating Method

Analysis of Parent/Daughter Isotopic Compositions in Rocks

- ✓Parent and daughter elements are isolated and refined from host mineral using conventional wet chemistry methods.
- ✓Geochronologists determine the isotopic abundances of each paired parent and daughter element using a mass spectrometer.
- ✓ Isotopic abundance data are then used to determine rock age using the decay formula.



Mass Spectrometer



Radioisotopic Dating Method

Radioactive Decay of Parent Isotope into a Daughter Isotope

The mathematical expression that relates radioactive decay to geologic time is called the ***age equation***:

More simply, all you need to do is multiply the number of elapsed half-lives of the parent-daughter's isotopic system in the mineral (or whole rock) by the system's half-life decay constant:

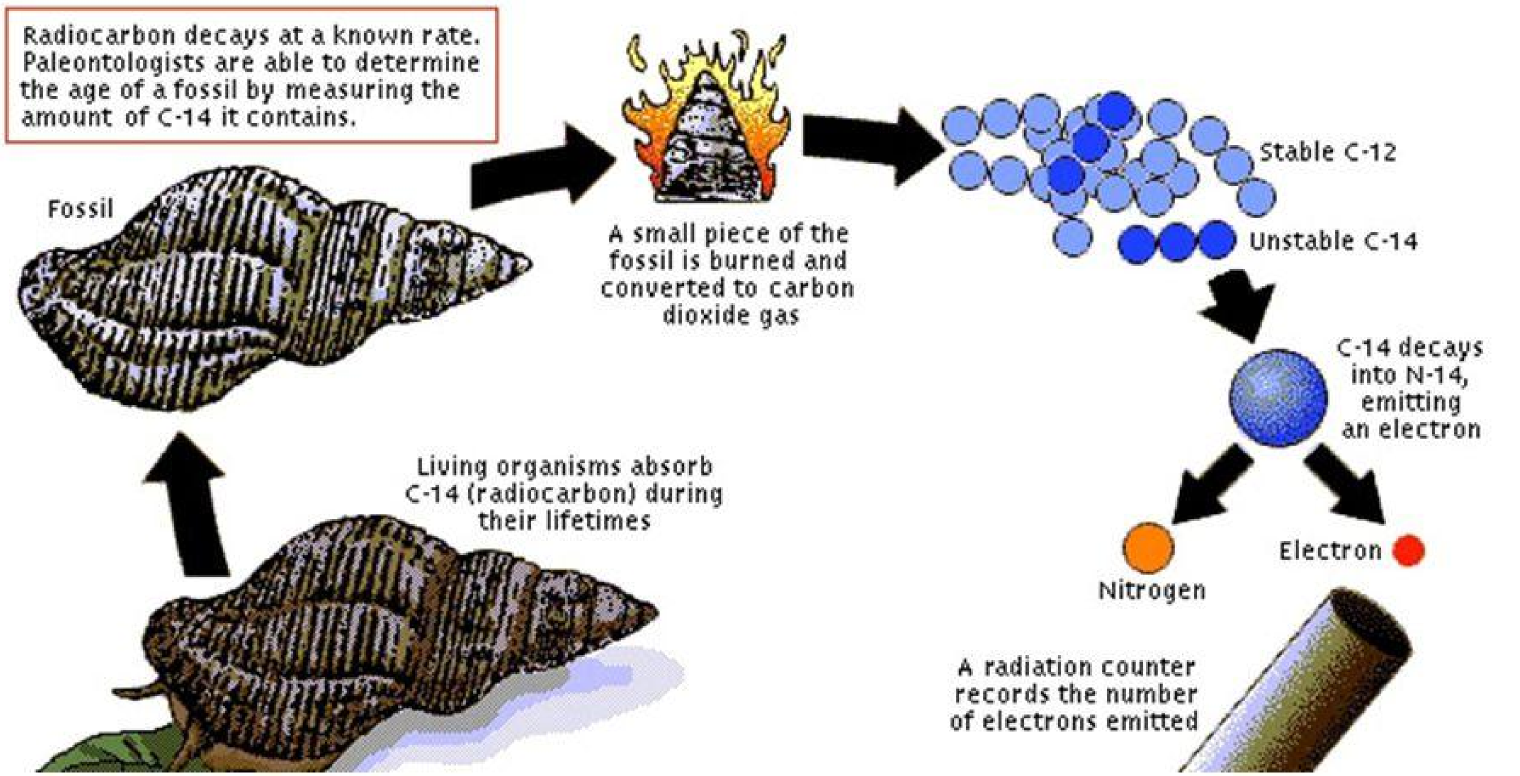
$$t = \frac{1}{\lambda} \ln\left(1 + \frac{D}{P}\right)$$

where t is the age of the rock or mineral specimen,
D is the number of atoms of a daughter product today,
P is the number of atoms of the parent isotope today,
ln is the natural lograithm (logarithm to base e), and
λ is the appropriate decay constant.

(The decay constant for each parent isotope is related to its half-life, $t^{1/2}$ by the following expression: $t^{1/2} = \frac{\ln 2}{\lambda}$

Age Formula: *# of half-lives elapsed x half-life constant*

Carbon-14 Dating



Radioactive Dating

D.3.1 Outline the method for dating rocks and fossils using radioisotopes, with reference to ^{14}C and ^{40}K.

Radioisotopic Dates of Earth Rocks

The Earths Oldest Rocks

Description	Technique	Age (in billions of years)
Amitsoq gneisses (western Greenland)	Rb-Sr isochron	3.70 +- 0.12
Amitsoq gneisses (western Greenland)	207Pb-206Pb isochron	3.80 +- 0.12
Amitsoq gneisses (western Greenland) (zircons)	U-Pb discordia	3.65 +- 0.05
Amitsoq gneisses (western Greenland) (zircons)	Th-Pb discordia	3.65 +- 0.08
Amitsoq gneisses (western Greenland) (zircons)	Lu-Hf isochron	3.55 +- 0.22
Sand River gneisses (South Africa)	Rb-Sr isochron	3.79 +- 0.06

Radioisotopic Dates of Moon Rocks

Oldest Moon Rocks

Mission	Technique	Age (in billions of years)
Apollo 17	Rb-Sr isochron	4.55 +- 0.1
Apollo 17	Rb-Sr isochron	4.60 +- 0.1
Apollo 17	Rb-Sr isochron	4.49
Apollo 17	Rb-Sr isochron	4.43 +- 0.05
Apollo 17	Sm-Nd isochron	4.23 +- 0.05
Apollo 17	Sm-Nd isochron	4.34 +- 0.05
Apollo 16	40Ar/39Ar	4.47
Apollo 16	40Ar/39Ar	4.42

Radioisotopic Dates of Meteorites

Meteorites

Description	Technique	Age (in billions of years)
Juvinas (achondrite)	Mineral isochron	4.60 +- 0.07
Colomera (silicon inclusion, iron met.)	Mineral isochron	4.61 +- 0.04
Carbonaceous chondrites	Whole-rock isochron	4.69 +- 0.14
Bronzite chondrites	Whole-rock isochron	4.69 +- 0.14
Krahenberg (amphoterite)	Mineral isochron	4.70 +- 0.1
Norton County (achondrite)	Mineral isochron	4.7 +- .1

RADIO-ISOTOPIC DATING ACTIVITY

Applied to Stratigraphy in Conjunction with Relative Dating

Procedure:

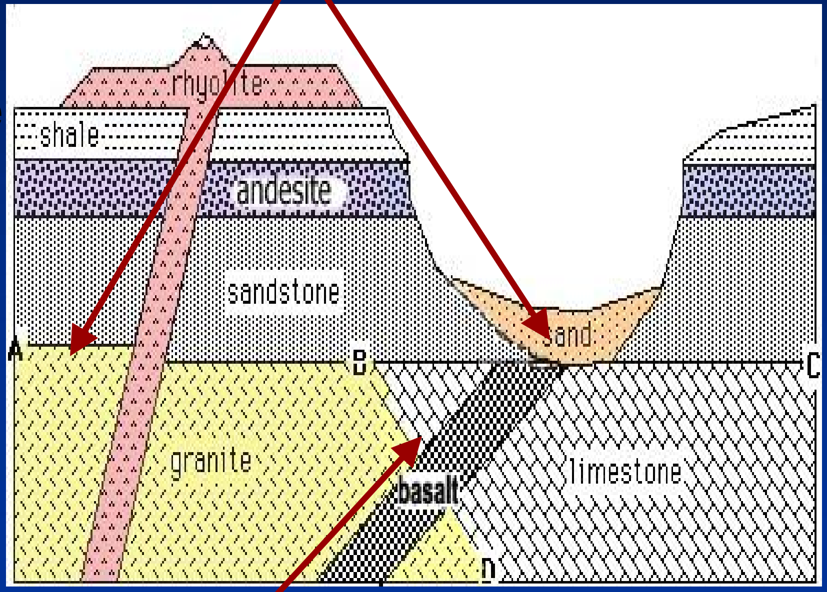
1) Use relative dating laws to determine the relative age sequence for all stratigraphic elements – from oldest to youngest.

2) Identify all igneous units and determine their absolute ages using the radio-isotopic method

3) Write absolute ages on the relative date list

4) Use relative and absolute age data together to establish geologic history of the region.

Unconformity A - C



Unconformity B - D

Youngest

____
____
____
____
____
____
____
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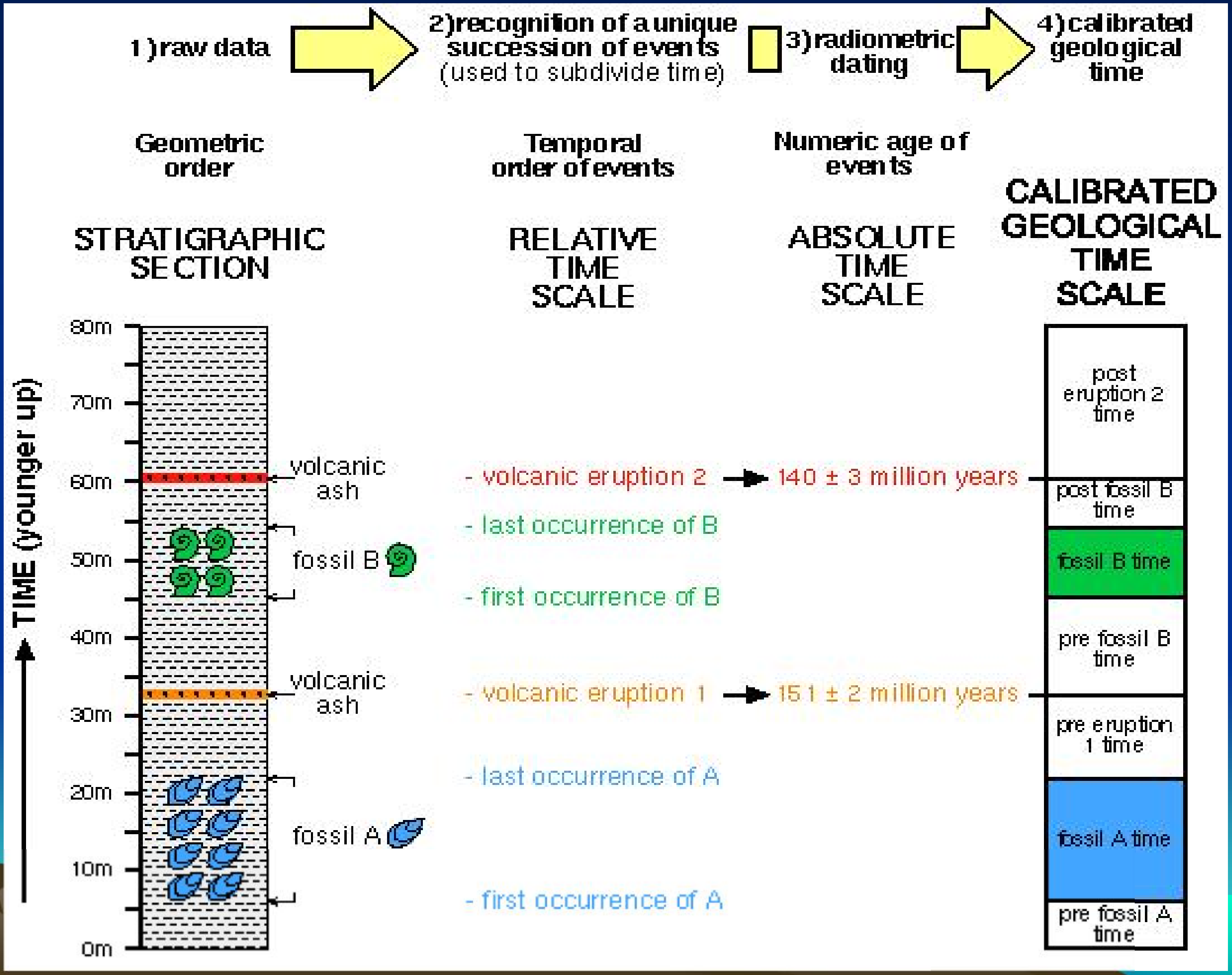
Oldest

Note: There are four igneous rock units

COMBINED USE OF RELATIVE AND ABSOLUTE DATING TO CREATE THE GEOLOGIC TIMESCALE



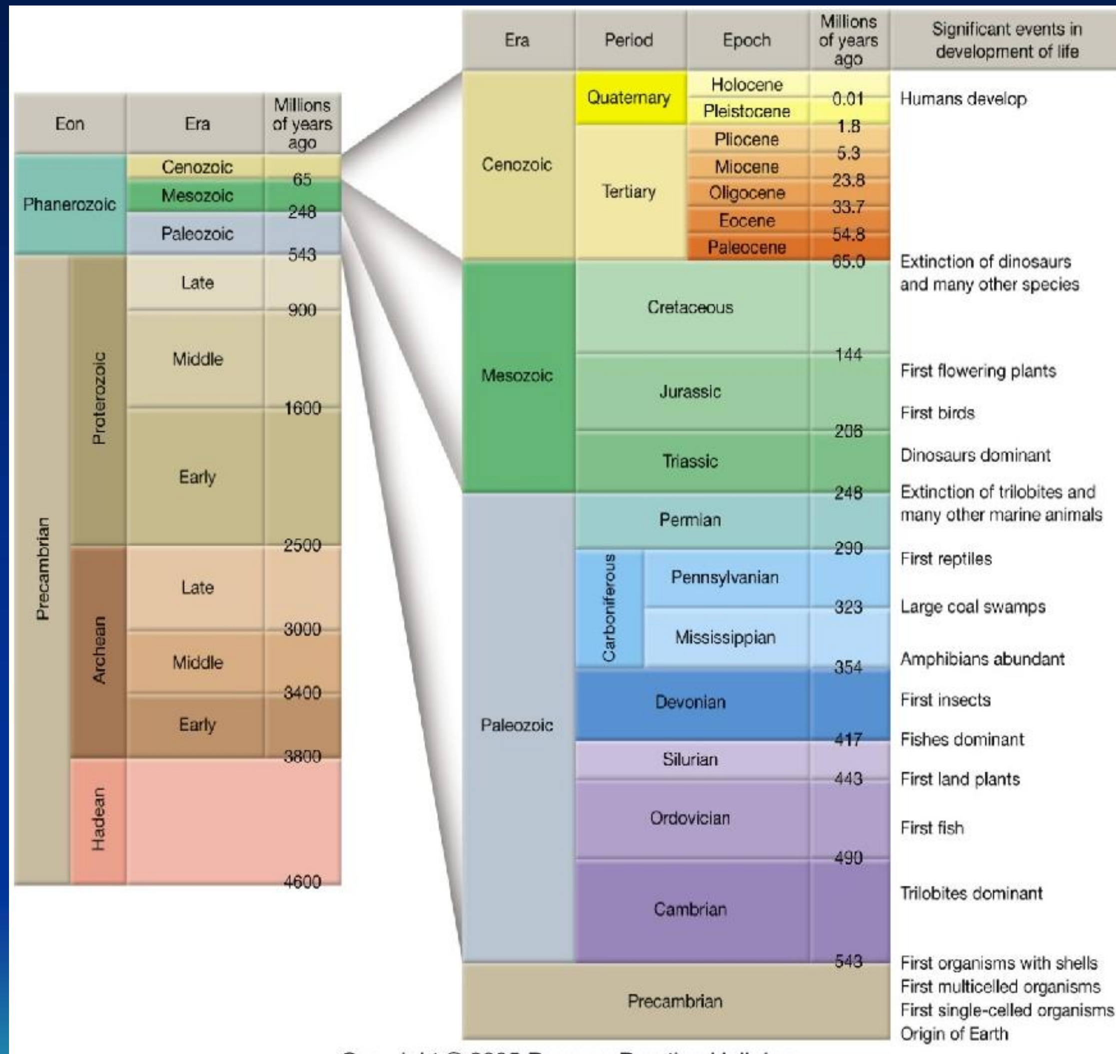
THE GEOLOGICAL TIMESCALE

Key Ideas:

Originally based on relative dating and the use of age-specific (index) fossils

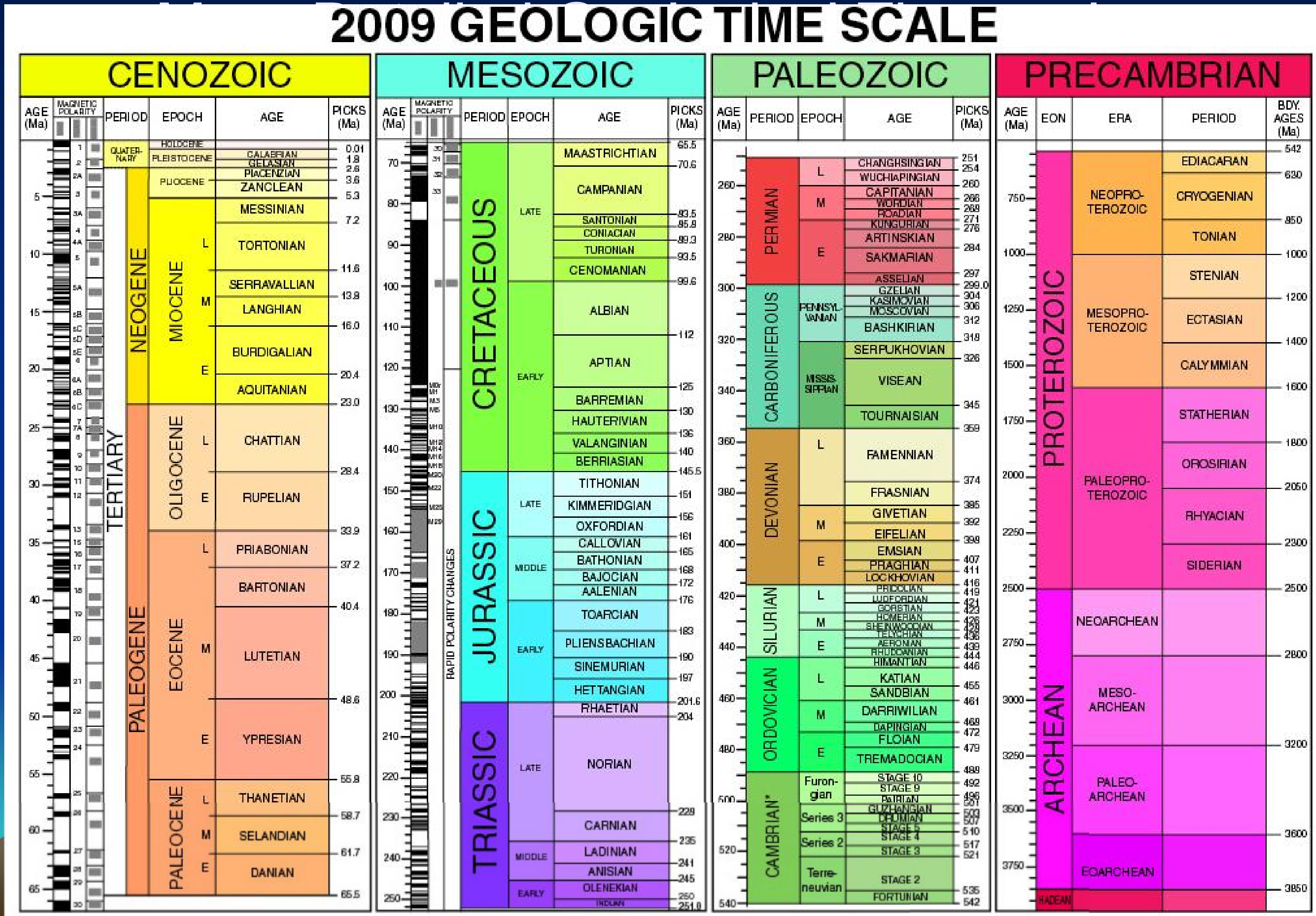
✓ Periods separated by major mass extinction events

✓ Numeric ages derived from radiometric analysis of igneous rocks found within the stratigraphic record



Note: You will need to memorize the basic geo-timescale for the final exam.

THE COMPLETE GEOLOGICAL TIMESCALE



THE GEOLOGICAL TIMESCALE QUIZ

Need to Memorize:

1) The 2 Eons

2) The 5 Eras

3) The 12 Periods

4) The 7 Epochs

5) The Age of Earth

6) Age of Beginning of Paleozoic Period

7) Age of Beginning of Mesozoic Period

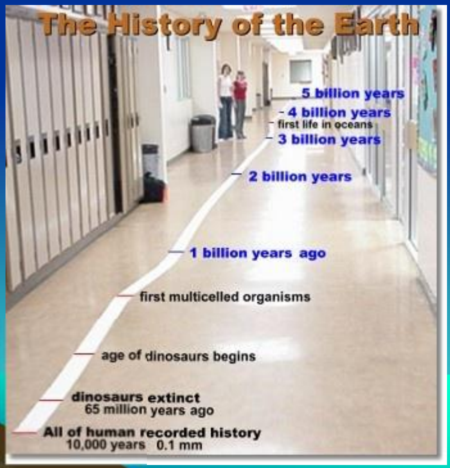
8) Age of Beginning of Cenozoic Period

EON	ERA	PERIOD	EPOCH	MYA	
PHANEROZOIC	CENOZOIC	QUATERNARY	RECENT	0.01	ICE AGE ENDS
			PLEISTOCENE	1.6	ICE AGE BEGINS EARLIEST HUMANS
		TERTIARY – NEOGENE	PLIOCENE	5.3	
			MIOCENE	23.7	
		TERTIARY – PALEOGENE	OLIGOCENE	36.6	
			EOCENE	57.8	FORMATION OF HIMALAYAS
			PALEOCENE	66	DINOSAUR EXTINCTION ROCKY MTS. FORMED
	MESOZOIC	CRETACEOUS		144	
		JURASSIC		208	
		TRIASSIC		245	FIRST MAMMALS PANGEA BREAK UP FIRST DINOSAURS
	PALEOZOIC	PERMIAN		286	
		PENNSYLVANIAN		320	FIRST REPTILES
		MISSISSIPPIAN		360	FIRST ANPHIBIANS
		DEVONIAN		408	
		SILURIAN		438	FIRST LAND PLANTS
		ORDOVICIAN		505	FIRST FISH
		CAMBRIAN		570	
PRECAMBRIAN	PROTEZOIC EON				EARLIEST SHELLED ANIMALS
				2500	
	ARCHEAN EON				EARLIEST FOSSIL RECORDED OF LIFE
				3800	
				4600	

Note: You will need to memorize this basic geo-timescale for the final exam.

Make Your Own Geological Time Line

EON	ERA	PERIOD	EPOCH	Ma	"FOSSIL RECORD"
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01	Human civilizations evolve, great extinctions begin
			Pleistocene		Ice Ages and interglacial periods cause widespread changes in climate
				2.6	Modern humans evolve and migrate around the world
		Tertiary – Neogene	Pliocene		First ice ages begin as Himilayan Mountains rise, Isthmus of Panama closes
				5.3	Most modern families of mammals evolve and migrate across land bridges
			Miocene		Grasses evolve and spread worldwide
					Yellowstone Hotspot migrates eastward, Colorado Plateau and Great Plains rise
				23	Great Basin extension begins as San Andreas Fault System develops
		Tertiary – Paleogene	Oligocene		Deciduous forests (leaves fall in winter) dominate temporate climates
				33.9	
			Eocene		Rocky Mountains rise, shedding sediments throughout western US region
					"Age of Mammals" begins
				56	Western Interior Seaway vanishes
			Paleocene		
				66	Cretaceous/Tertiary boundary extinction wipes out dinosaurs, ammonites, etc.
	Mesozoic	Cretaceous			"Greenhouse Earth" - Dinosaurs at their "peak"
				145	Western Interior Seaway forms in Great Plain region
		Jurassic			Breakup of Supercontinent Pangaea, birds and early mammals appear
				201	
		Triassic			Dinosaurs (warm blooded) replace reptiles (cold blooded) as dominant land animals
				252	End of Permian extinction greatest of all extinction events
	Paleozoic	Permian			"Age of Reptiles" - Pangaea Supercontinent forms
				299	
		Pennsylvanian		323	Carboniferous Period - great coal swamps form as Appalachian Mountains form
		Mississippian		359	"Age of Amphibians"
		Devonian			"Age of Fishes"
				419	First forests (coal beds) appear
		Silurian			
				444	
		Ordovician			"Age of Invertebrates" - brachiopods, trilobites, corals
					First land plants evolve
				485	
		Cambrian			First shelled invertebrates appear
				541	
Precambrian	Proterozoic				Multicellular organisms evolve
					Modern continental shield regions of continents gradually assemble
					Banded Iron Formations are deposited as oxygen atmosphere forms
				2500	Stromatolites appear in "fossil record"
	Archean				single-celled organisms evolve
				4000	Oldest rocks preserved
	Hadean			4500	Solar System forms, Moon and Earth system forms by accretion of extraterrestrial materials



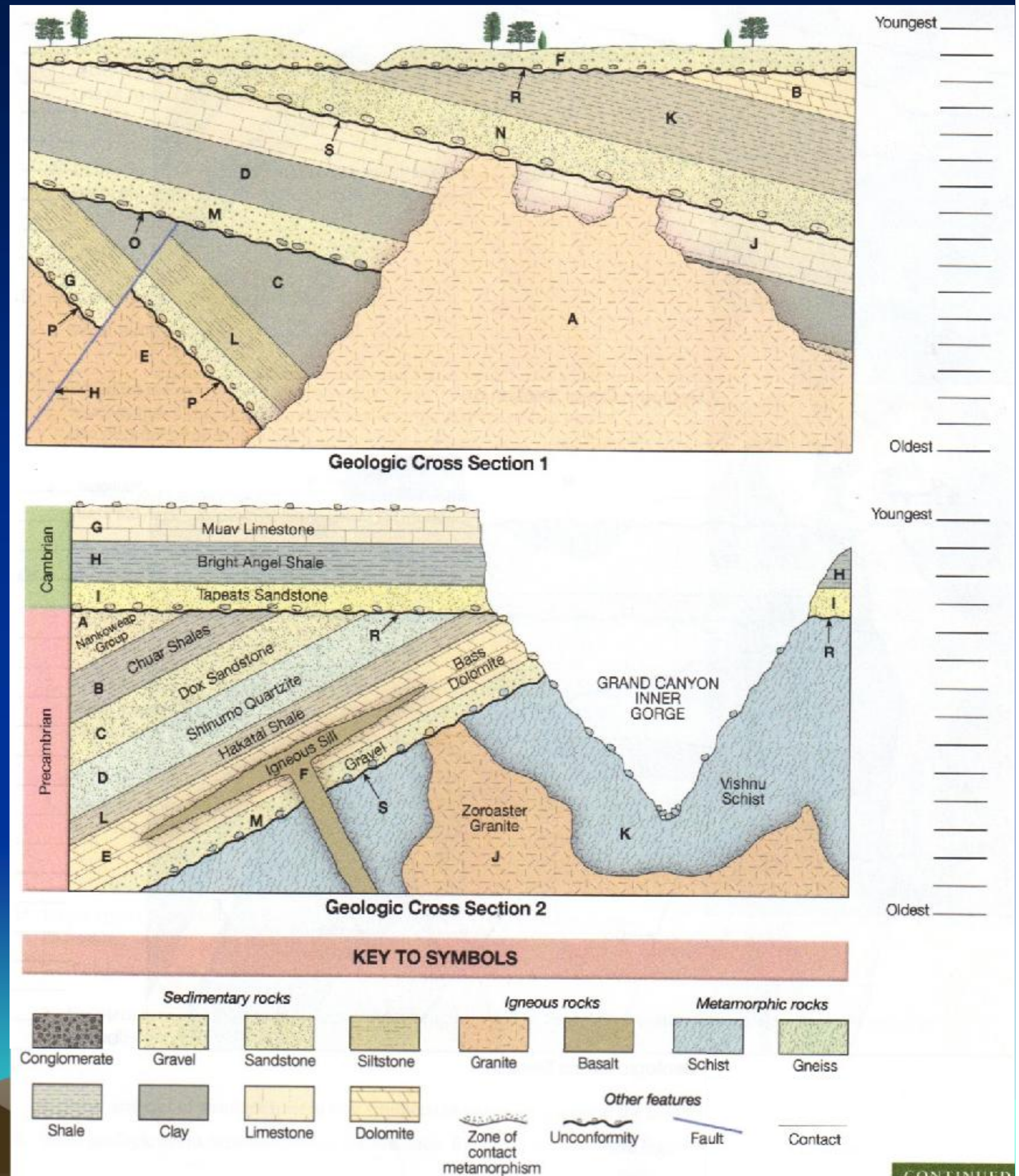
Application of Relative Dating Principles to a Geologic Cross Section

Procedure:

1) Identify all labeled rock formations and structures, including intrusions, faults, and unconformities

2) Use relative dating laws (*mainly the laws of superposition and cross-cutting*) to determine the relative age sequence for all stratigraphic elements – from oldest to youngest.

3) Determine what types of unconformities there are.



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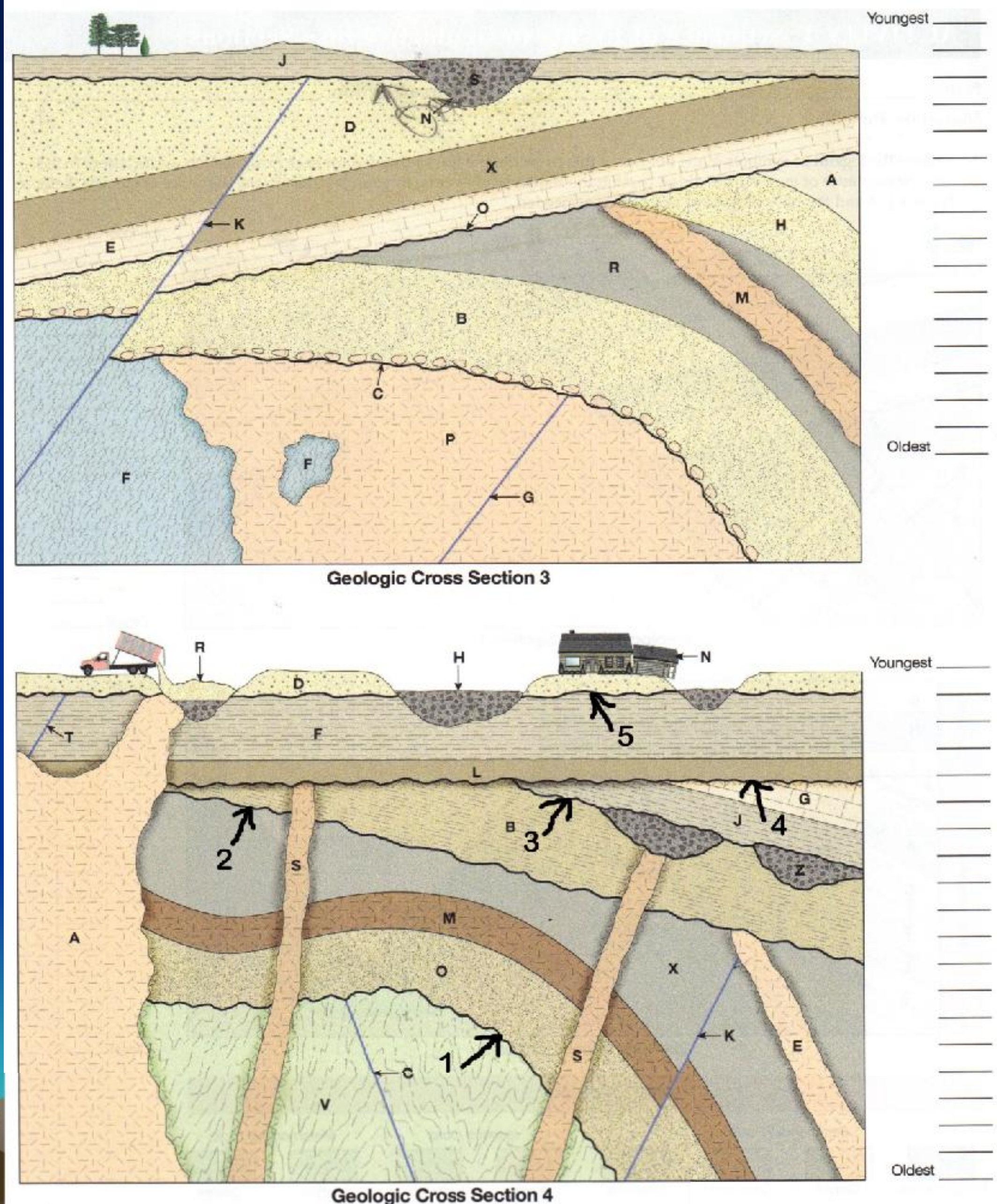
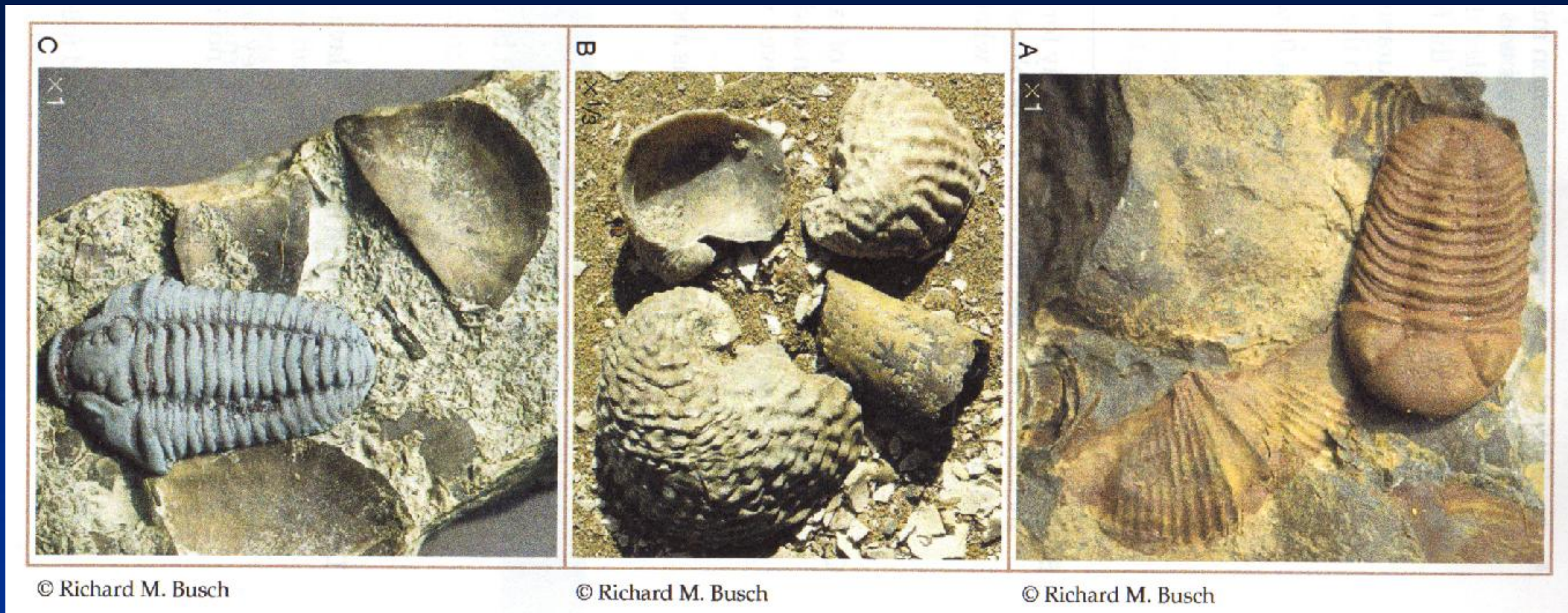


Application of Relative Dating Principles to Fossils



Index Fossils Present Age Range: (in million years

1. ________________________________ __________ mya to _________

2. ________________________________ __________ mya to _________

Resolved **age of sample: __________ mya to _________ mya**

Head's-Up for Next Lecture

Earthquakes

Next Week's Lecture Topics

1) Reid's Elastic Theory of Earthquakes
2) Tectonic Settings, Stresses and Active Faulting
3) Epicenter and Magnitude
4) Ground Motion
5) Fault Displacement

Preparation

Recommended Web Activities (Click on Link)

1) Learn About Earthquakes - USGS Site
2) Virtual Earthqauke!
3) World ocean bottom features and Tectonic plate boundaries

EARTHQUAKE TOPICS

What are Earthquakes?

Where and How do Earthquake Form?

How are Earthquakes Measured?

What are the Effects of Earthquakes?

Can we Predict Earthquakes?

How can we Prepare for an Earthquake?