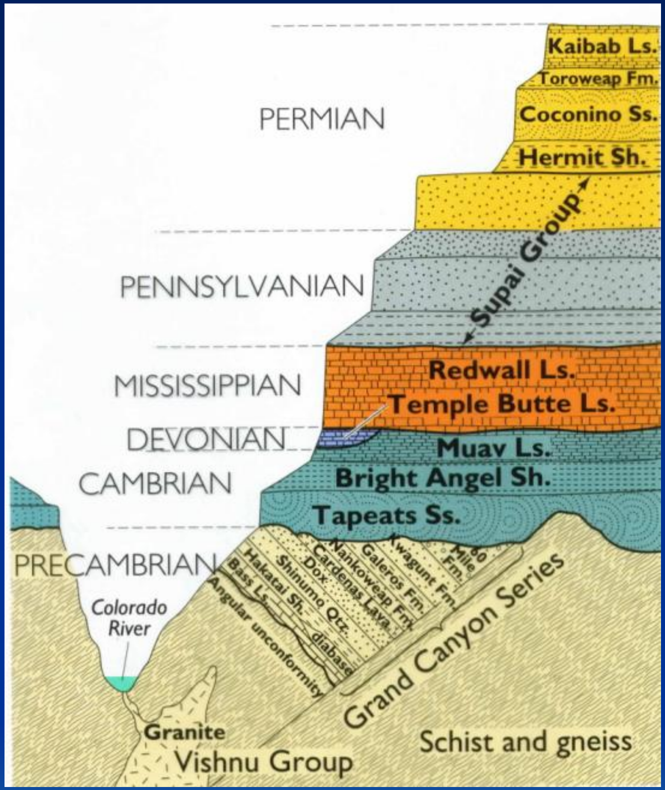
Geologic Dating Lab

Principles and Applications



Geology Laboratory - GEOL 101

Ray Rector - Instructor

Earth's Age and History

How Old Is the Earth?

How Can We Determine Earth's Geologic History?

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

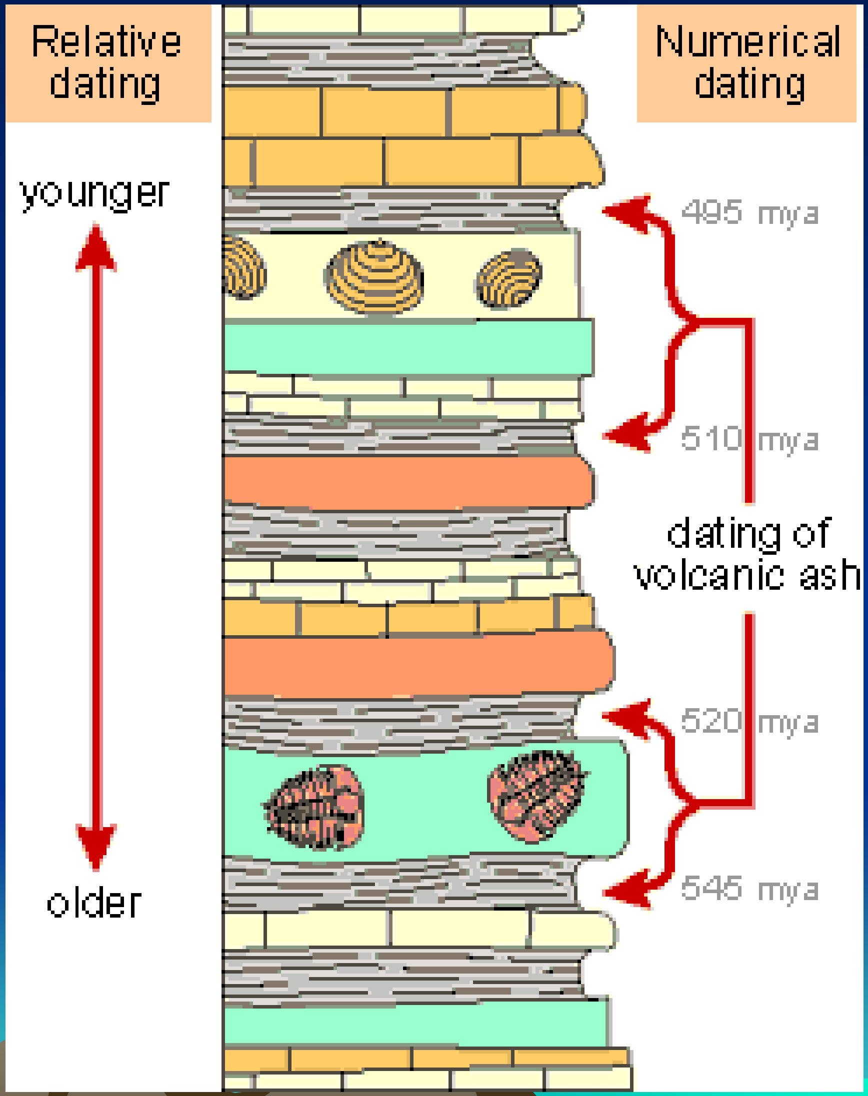
Fossil Succession

Emphasis on Sed Rocks

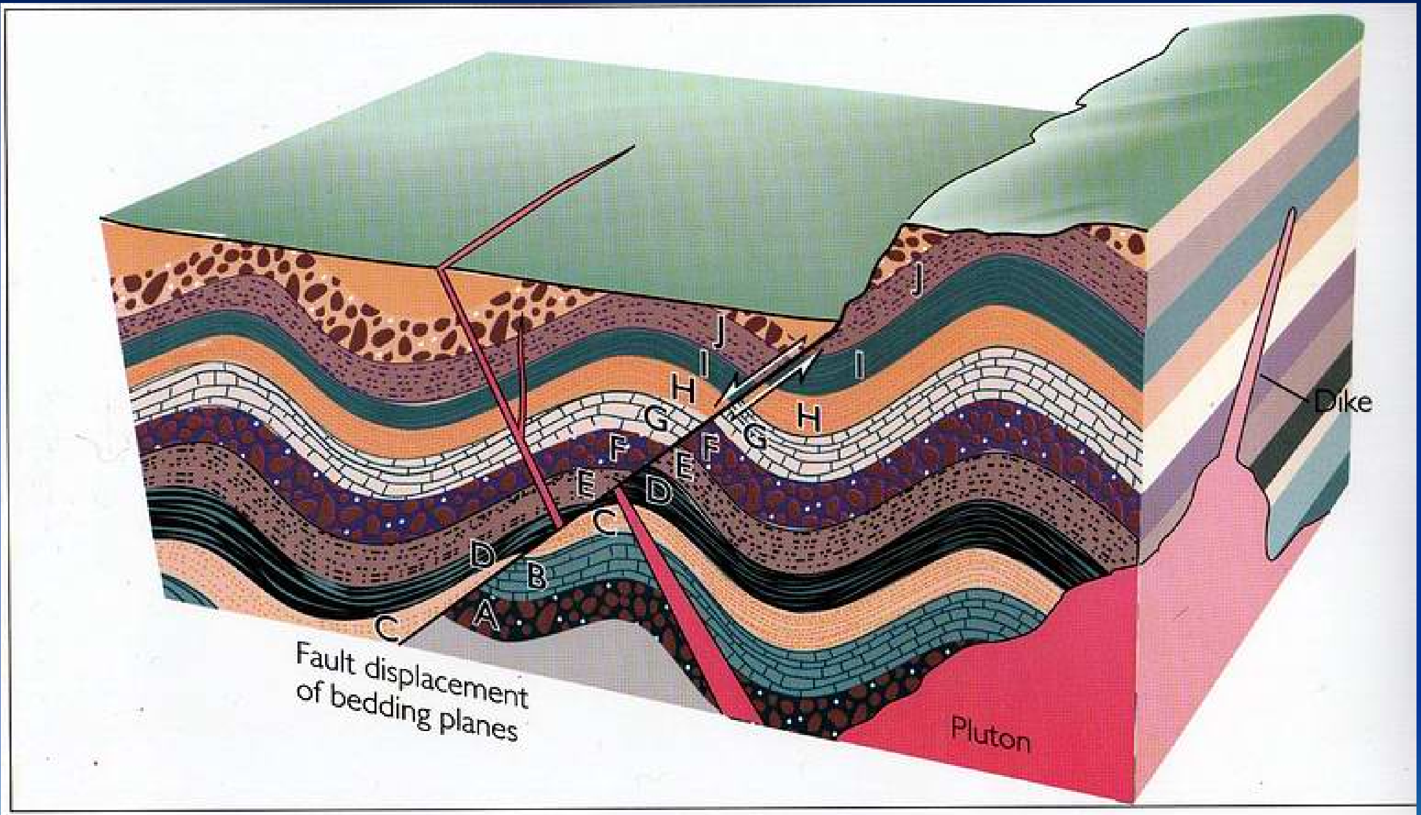
Absolute Dating

Radiometric techniques

Emphasis on Igneous Bodies



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



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.

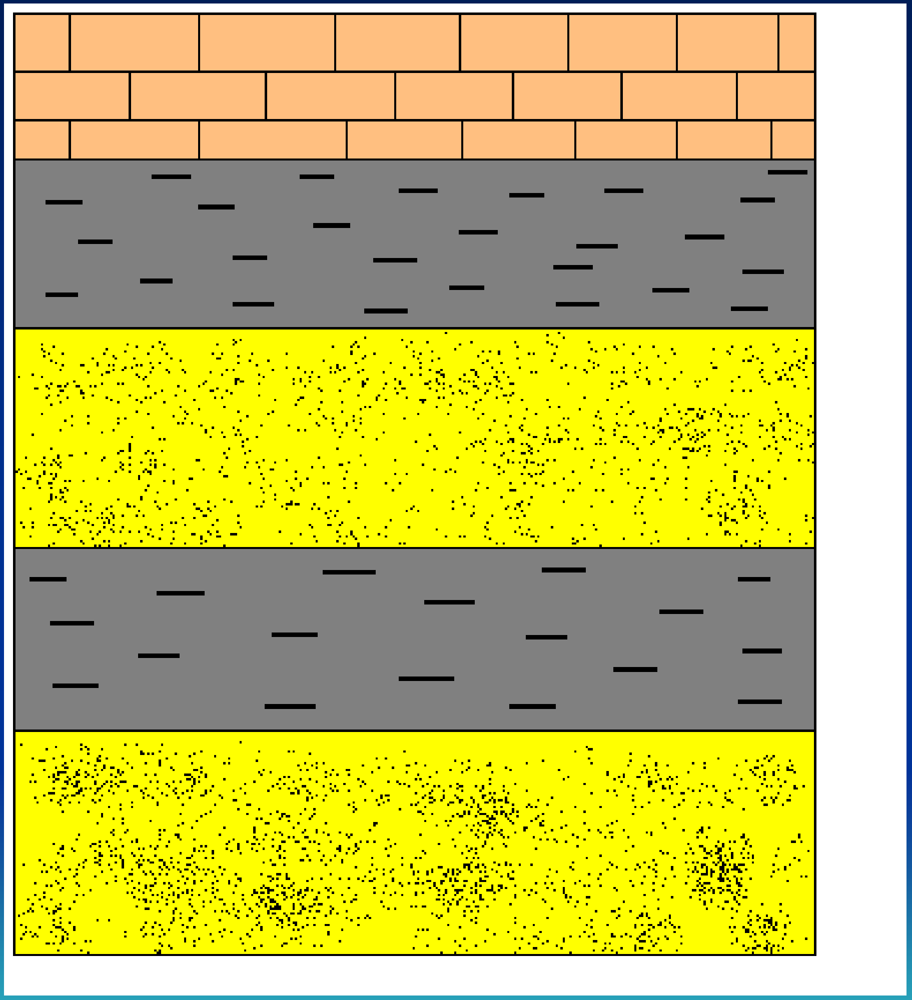
5. **Original Horizontality** - All sedimentary rocks are originally deposited horizontally. Sedimentary rocks that are no longer horizontal have been tilted from their original position.

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

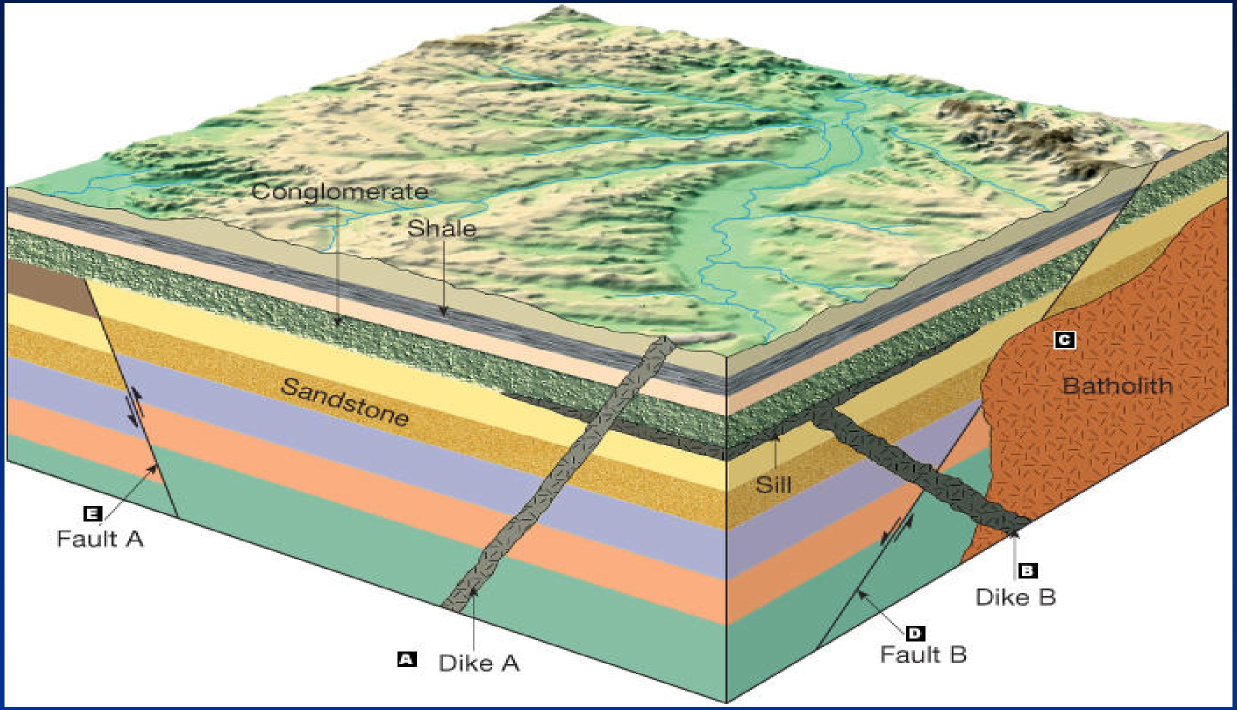
Principle of Superposition

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.

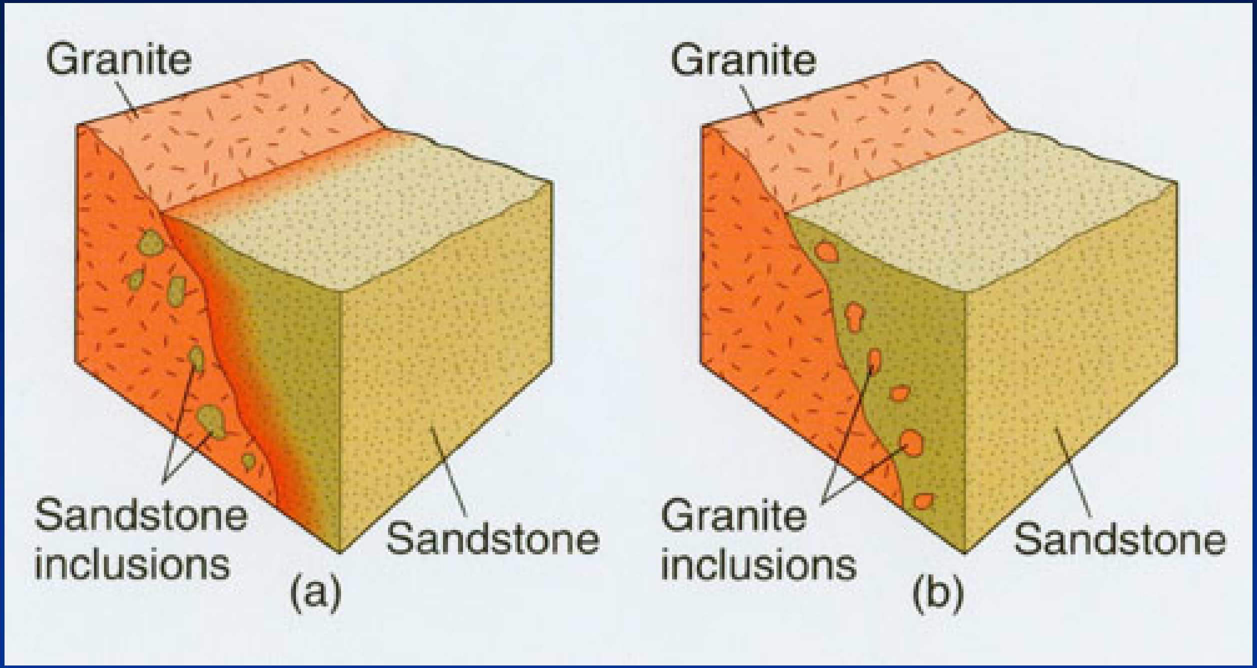


Principle of Cross-Cutting Relations



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.

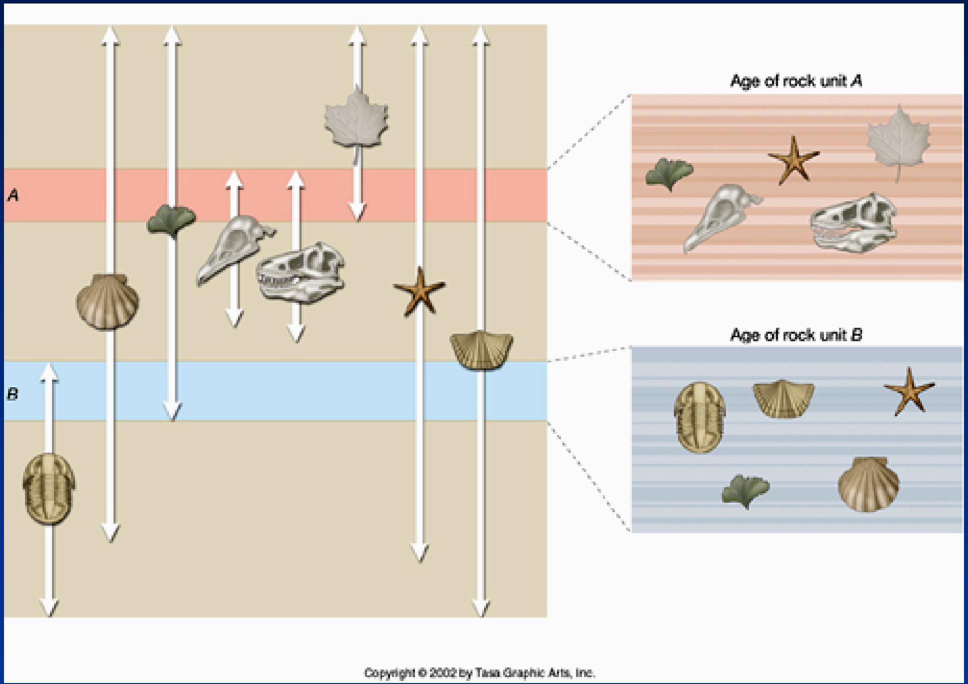
Principle of Fossil Succession

Key Idea:

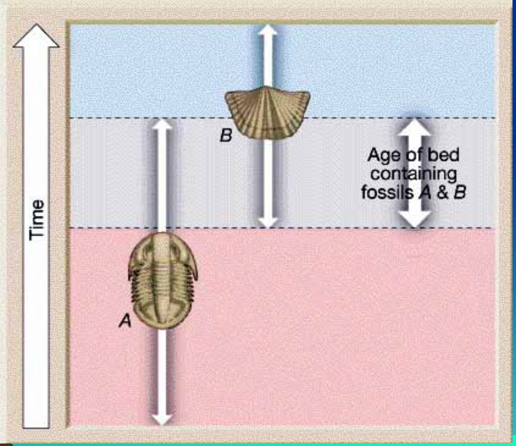
✓ Based on relative dating (law of superposition) and the use of age-specific (index) fossils species.

✓ 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

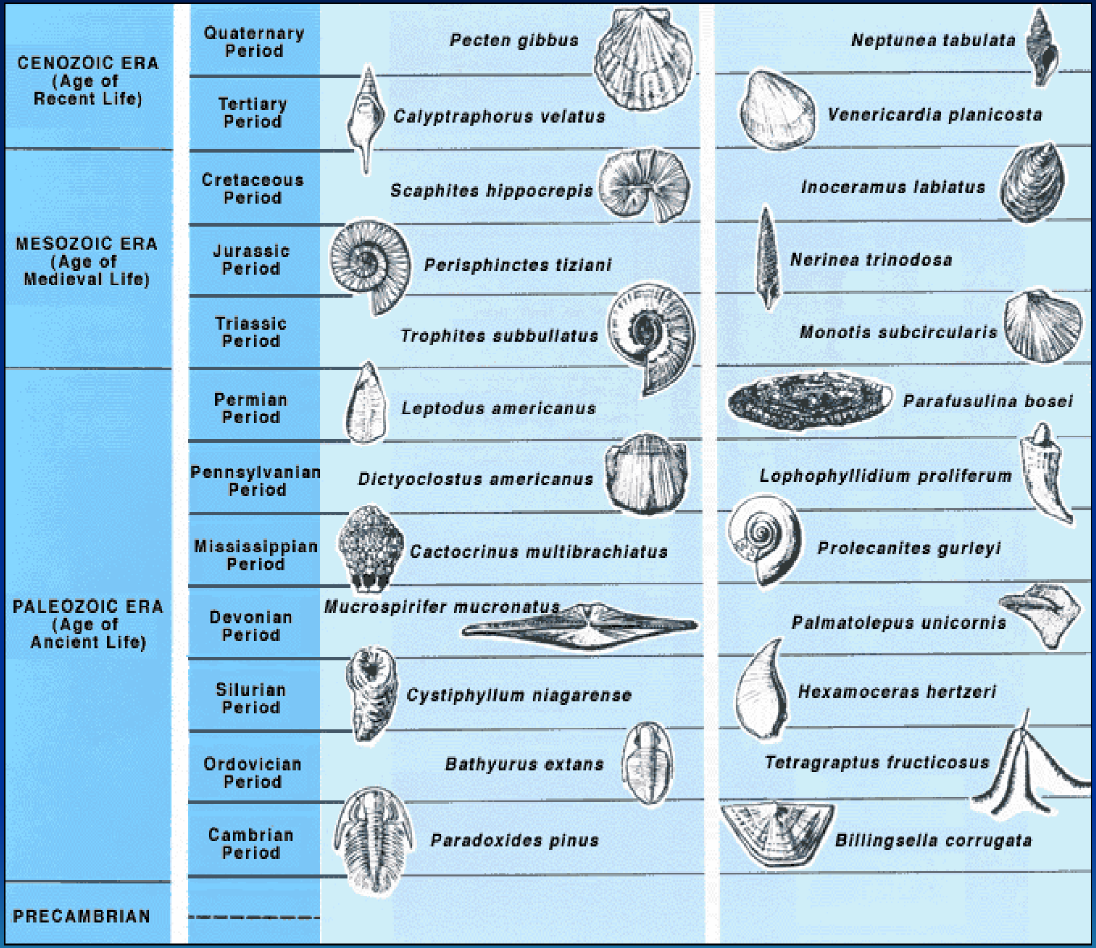


Index Fossils

Criteria to be a Useful Index Fossil:

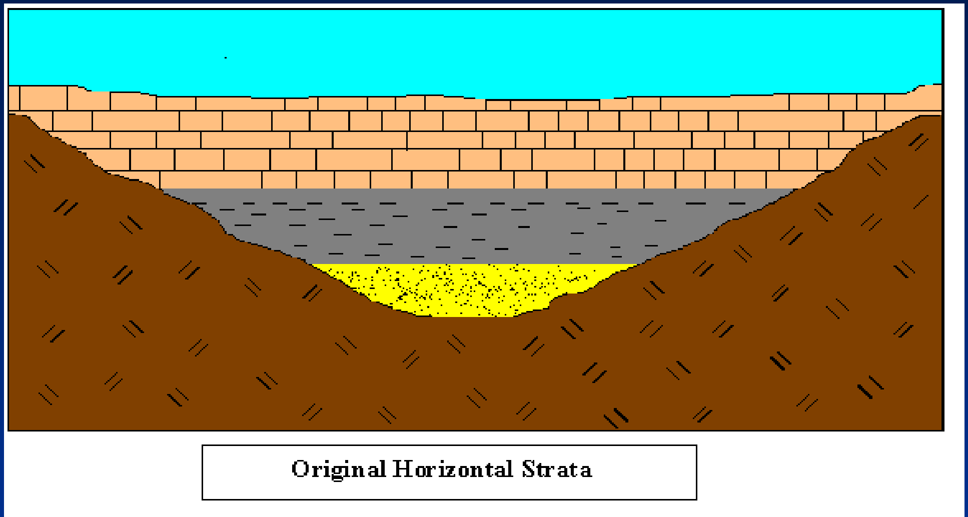
Must have:

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

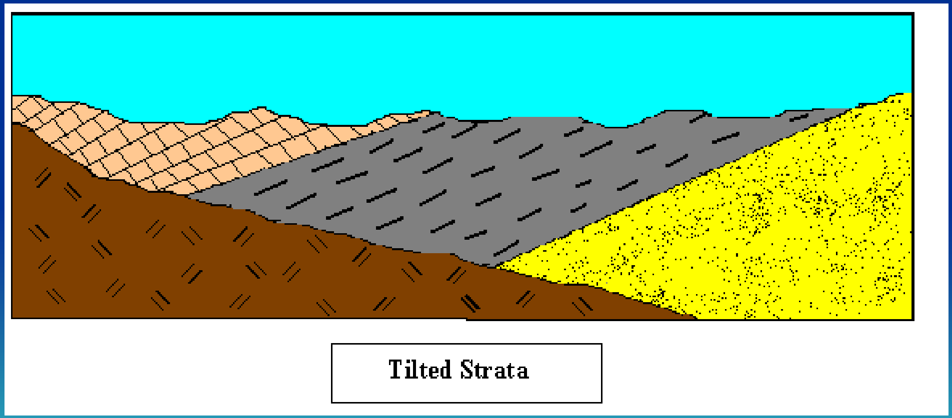


Principle of Original Horizontality

Sedimentary rock units originally deposit in horizontal layers



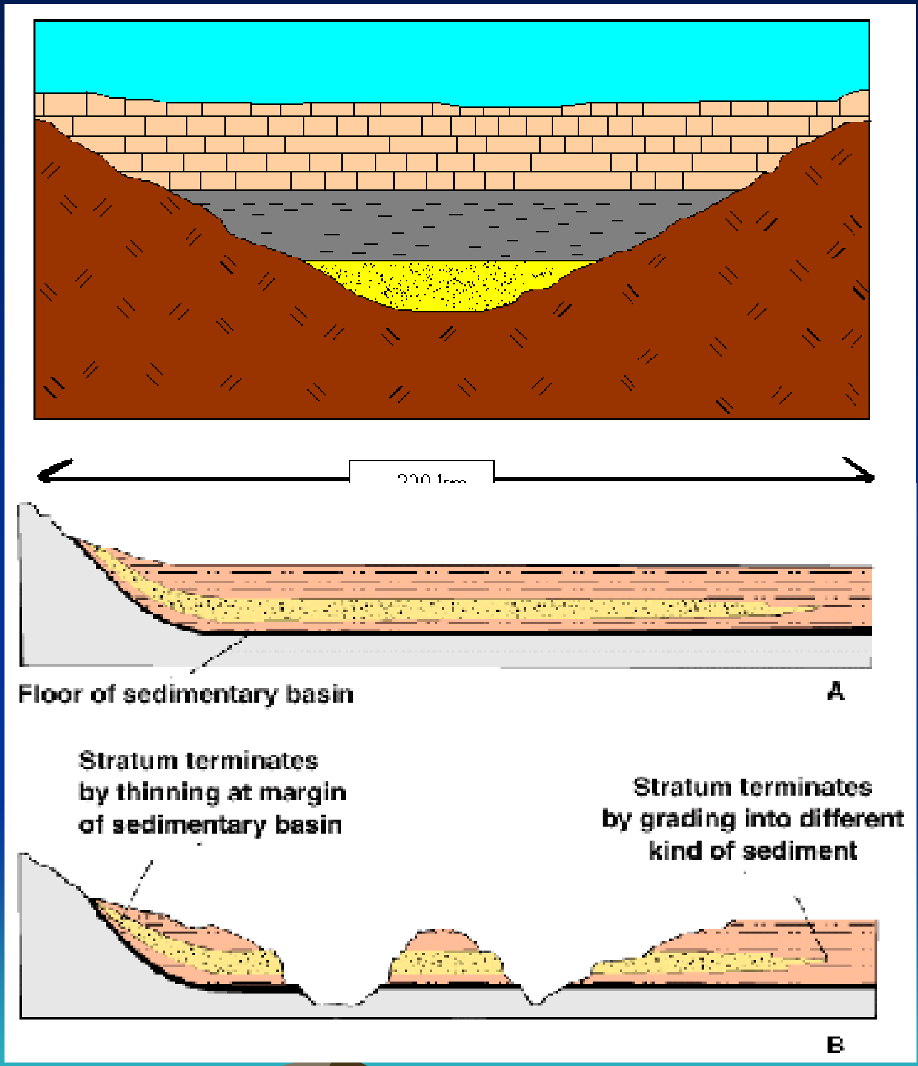
Later events may cause the layers to become tilted or overturned



Principle of Lateral Continuity

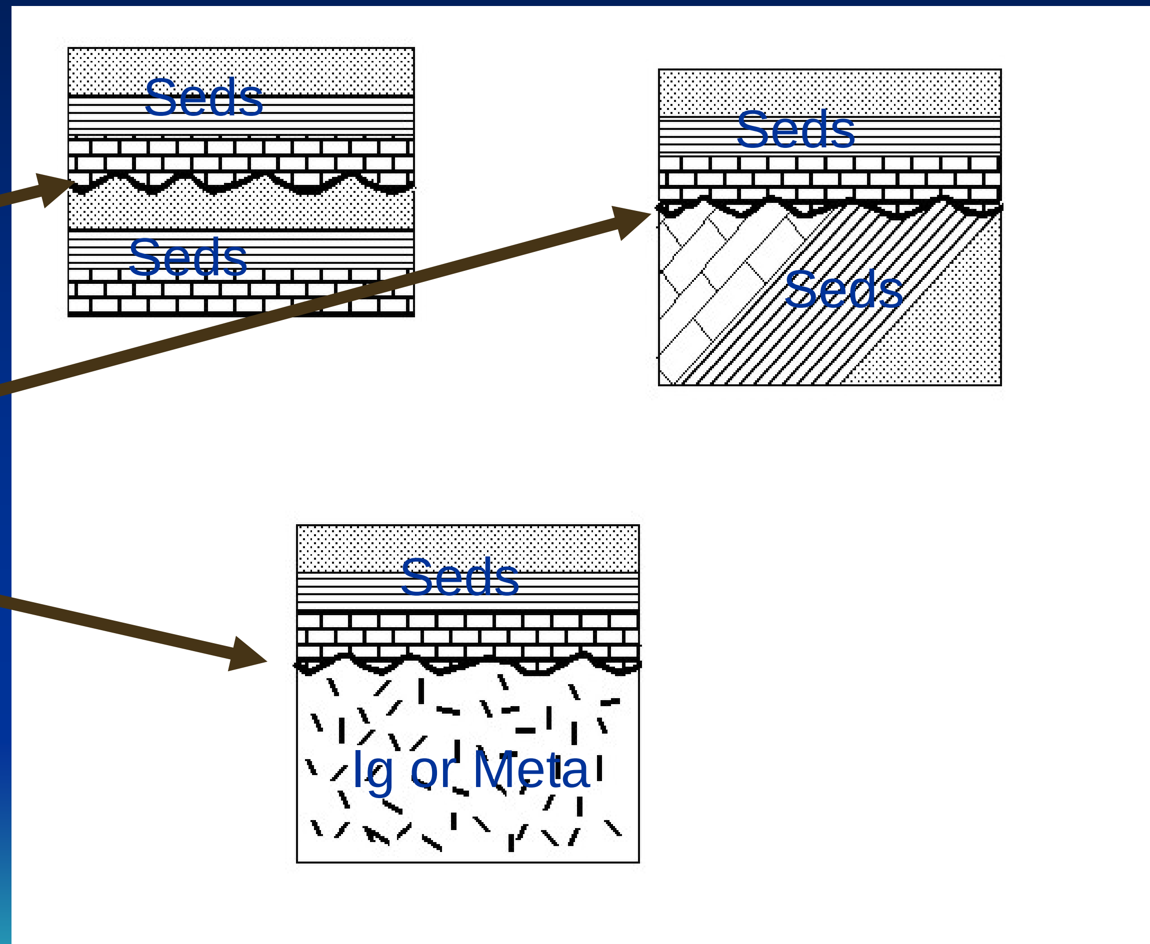
Layers of sedimentary material initially extend laterally in all directions.

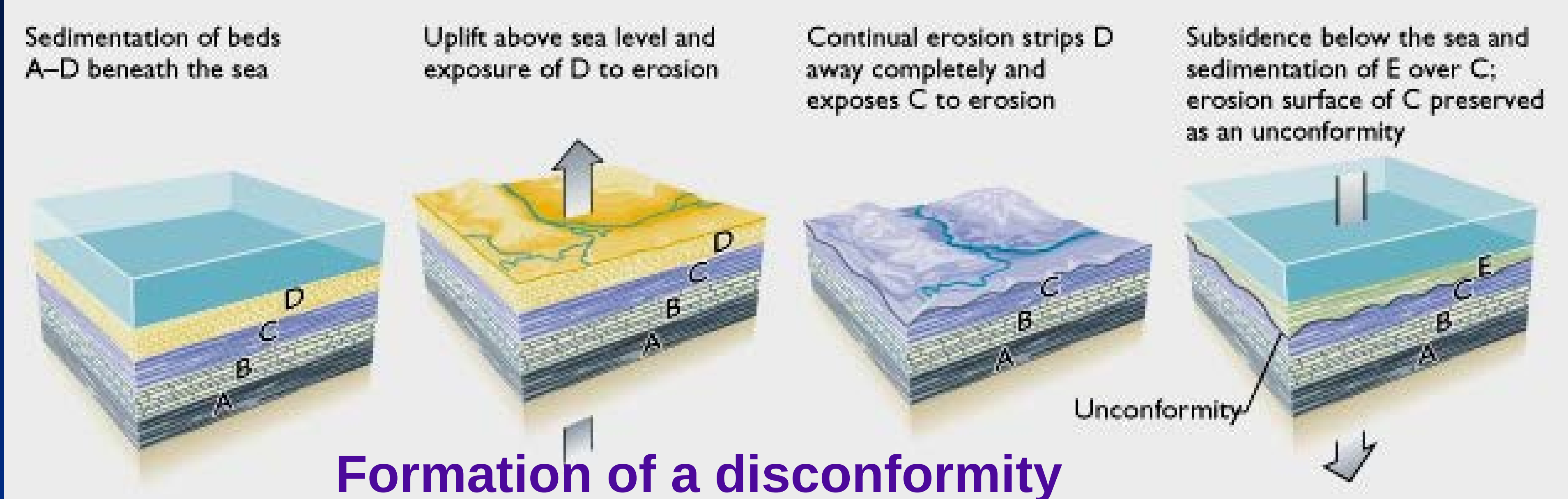
The layers eventually thin to zero and either terminate at the ends of the sedimentary basin or grade into other units.



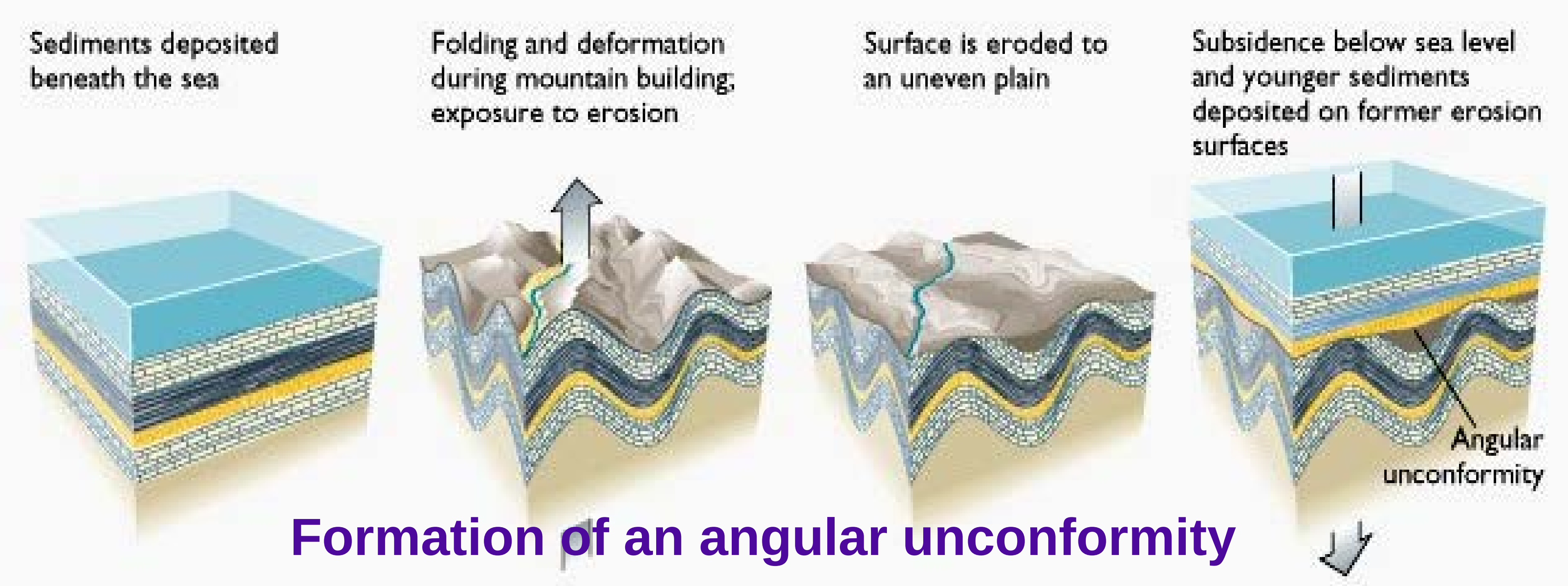
Three Types of Unconformities

1. Disconformity
2. Angular Unconformity
3. Nonconformity





Formation of a disconformity



Formation of an angular unconformity

Three Types of Unconformities

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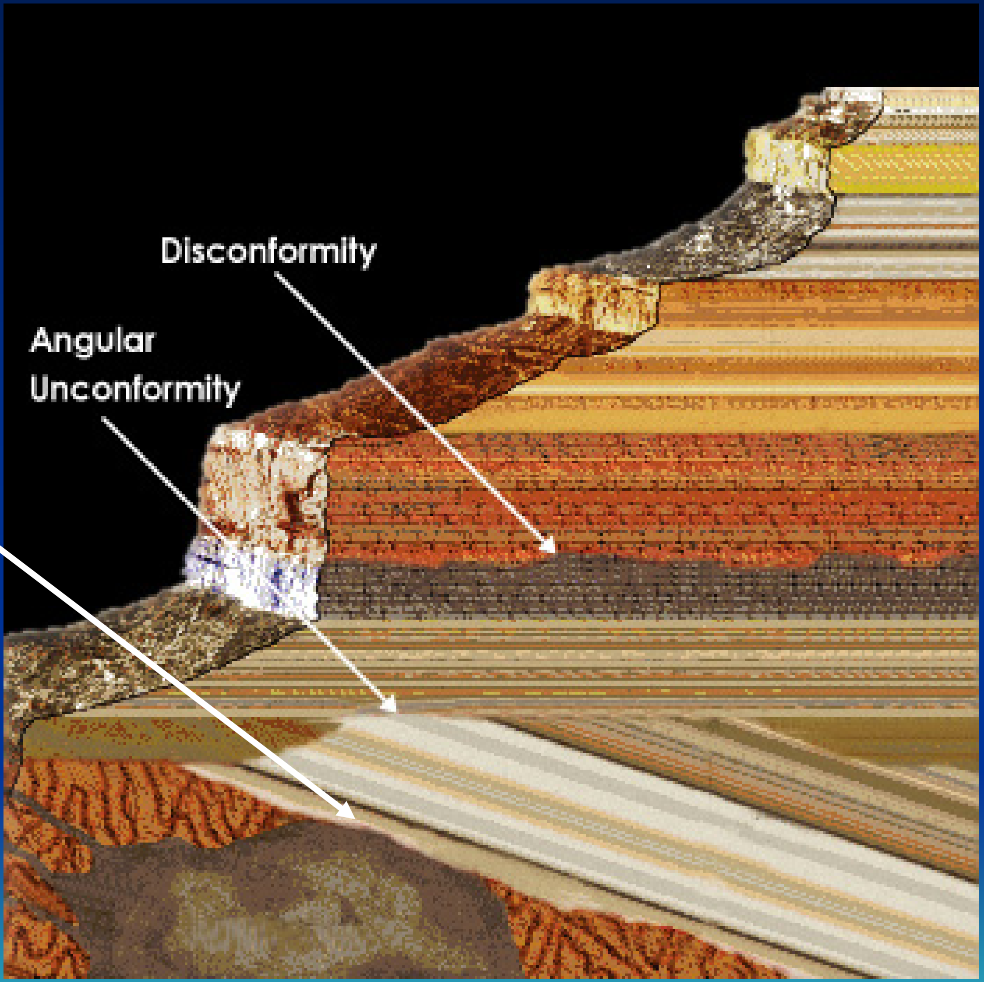
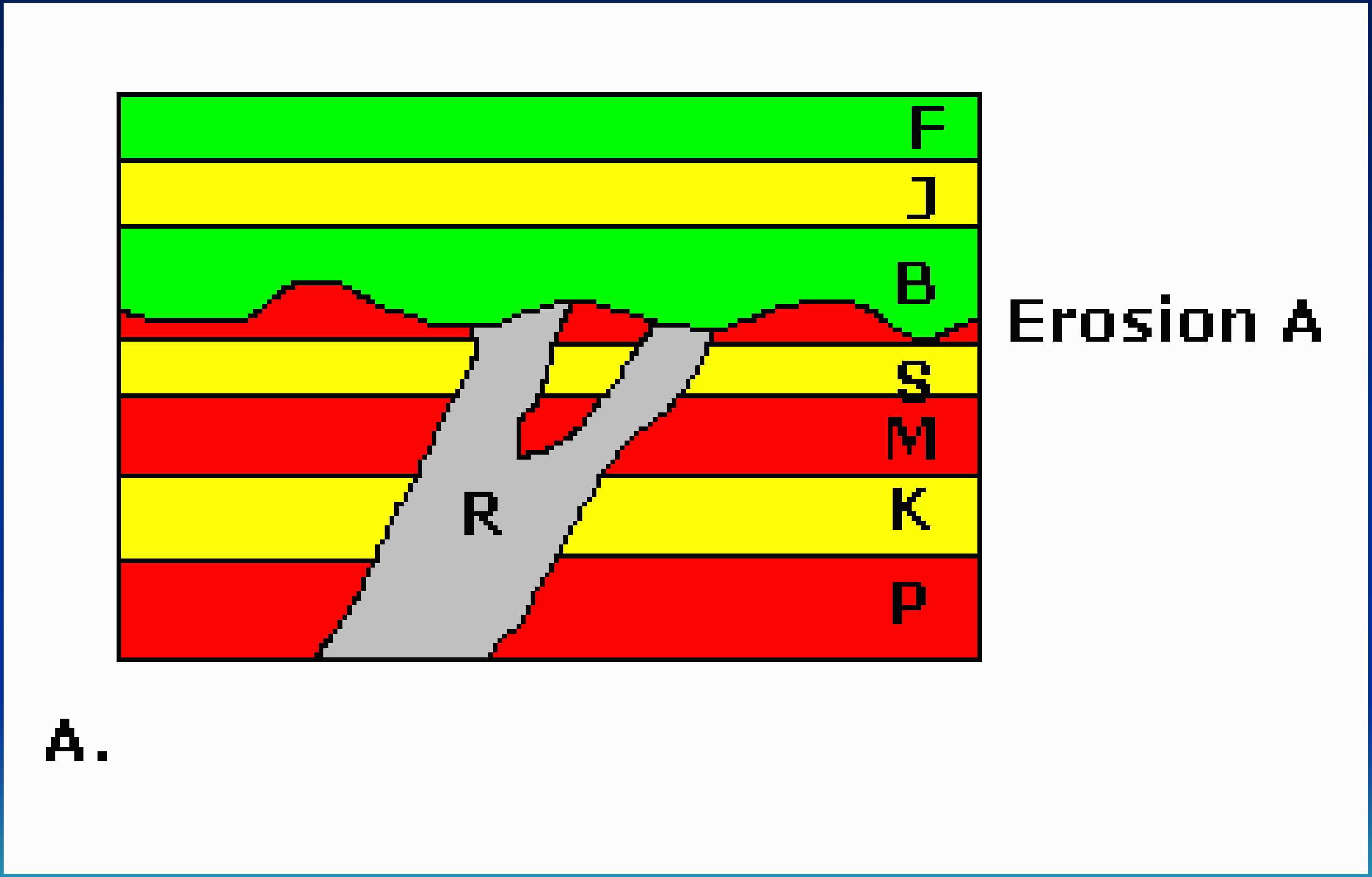
2. Angular Unconformity
3. Nonconformity

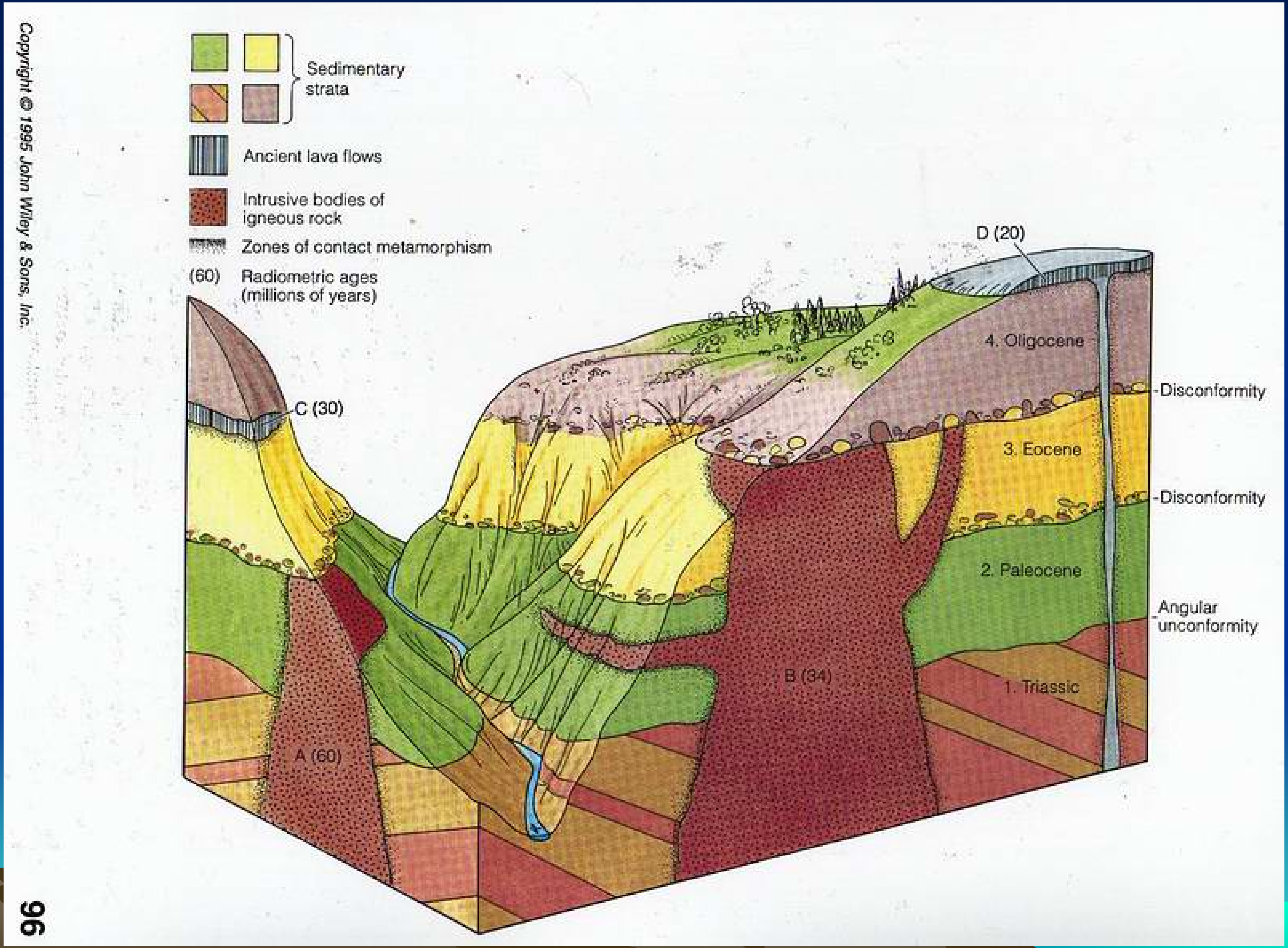


Which Type of Unconformity?

A Very Simple Geologic Cross Section



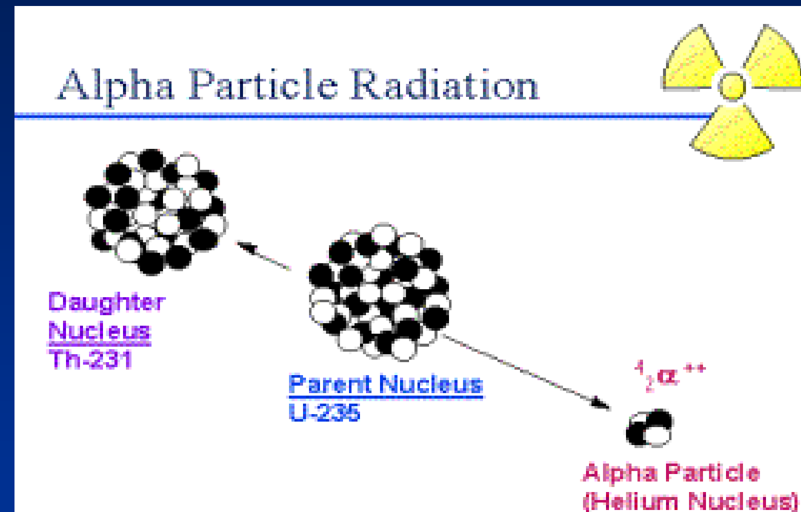
3-D Geologic Cross Section

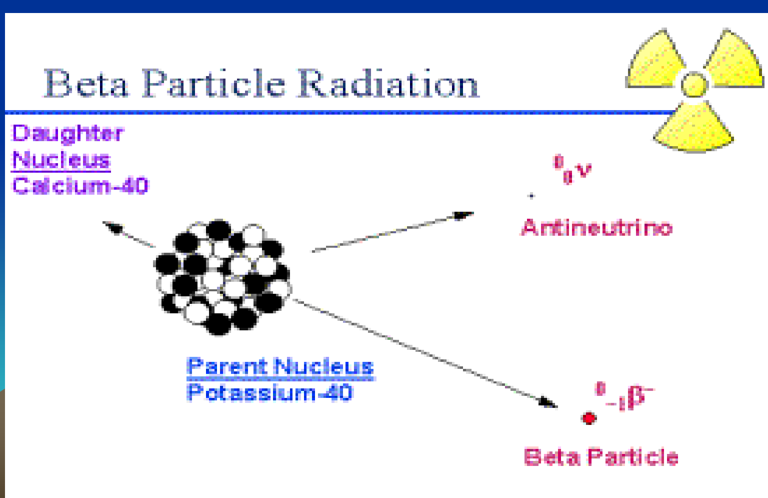


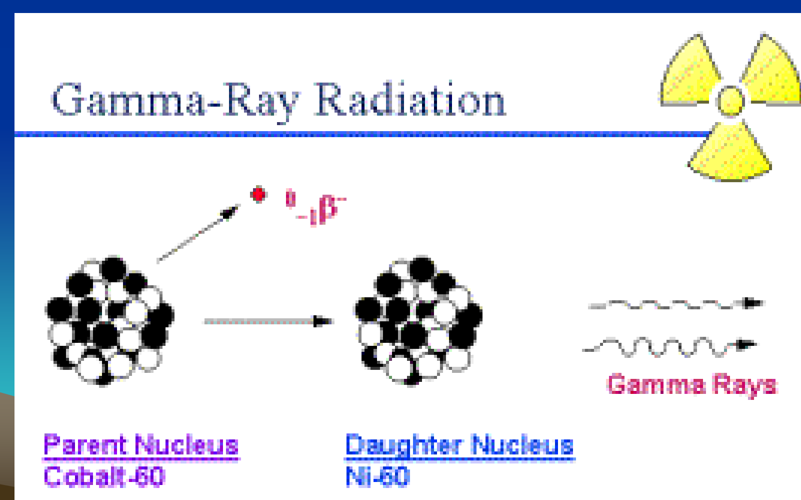
Spontaneous Radioactive Decay

Three Types of Radioactive Decay

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

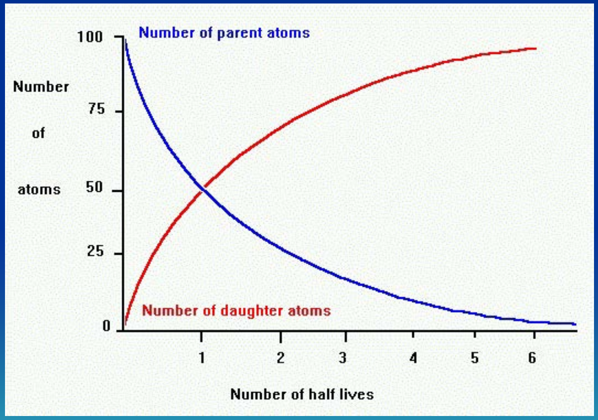


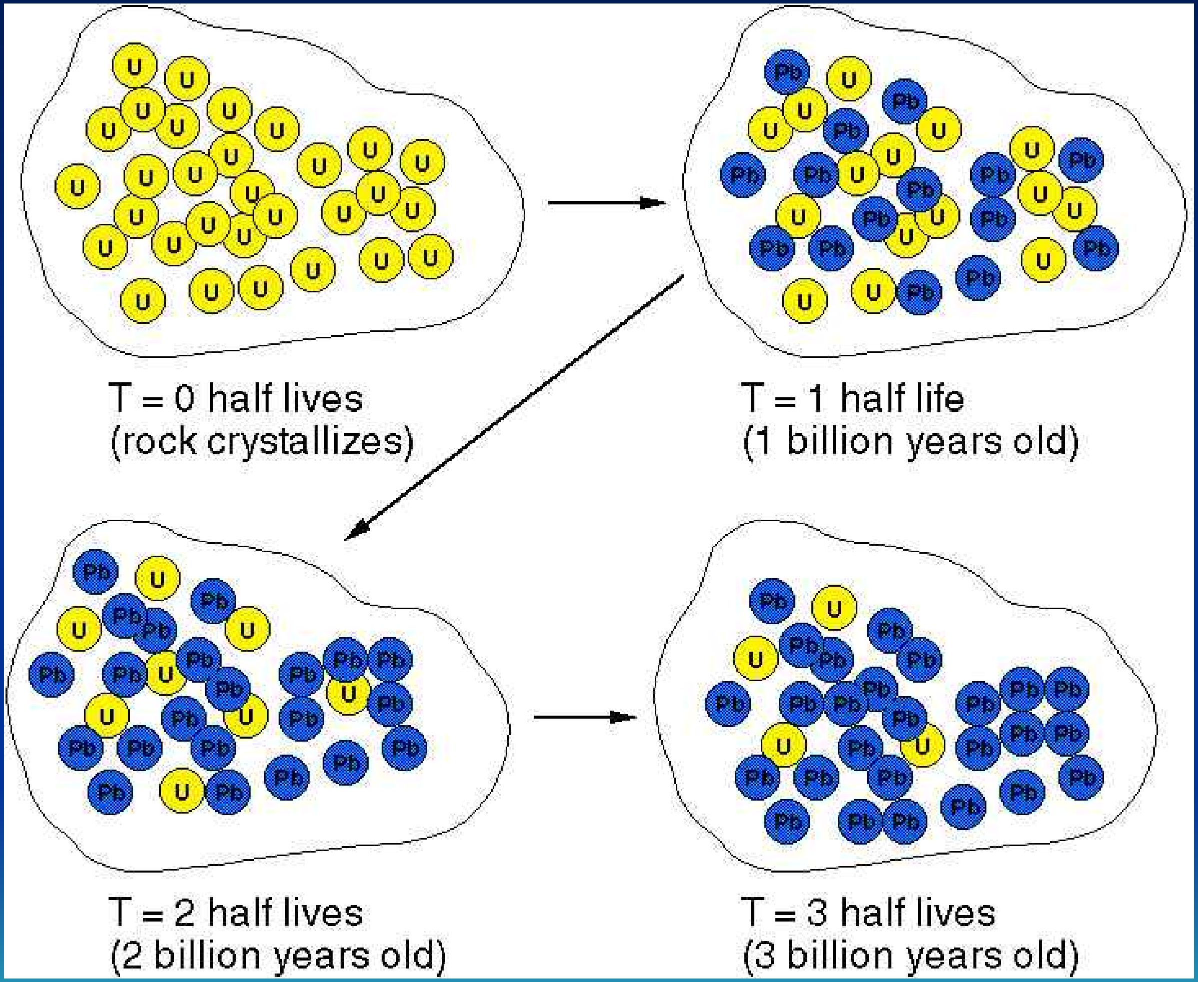




Radioisotopic Dating of Minerals

Zircons Crystals

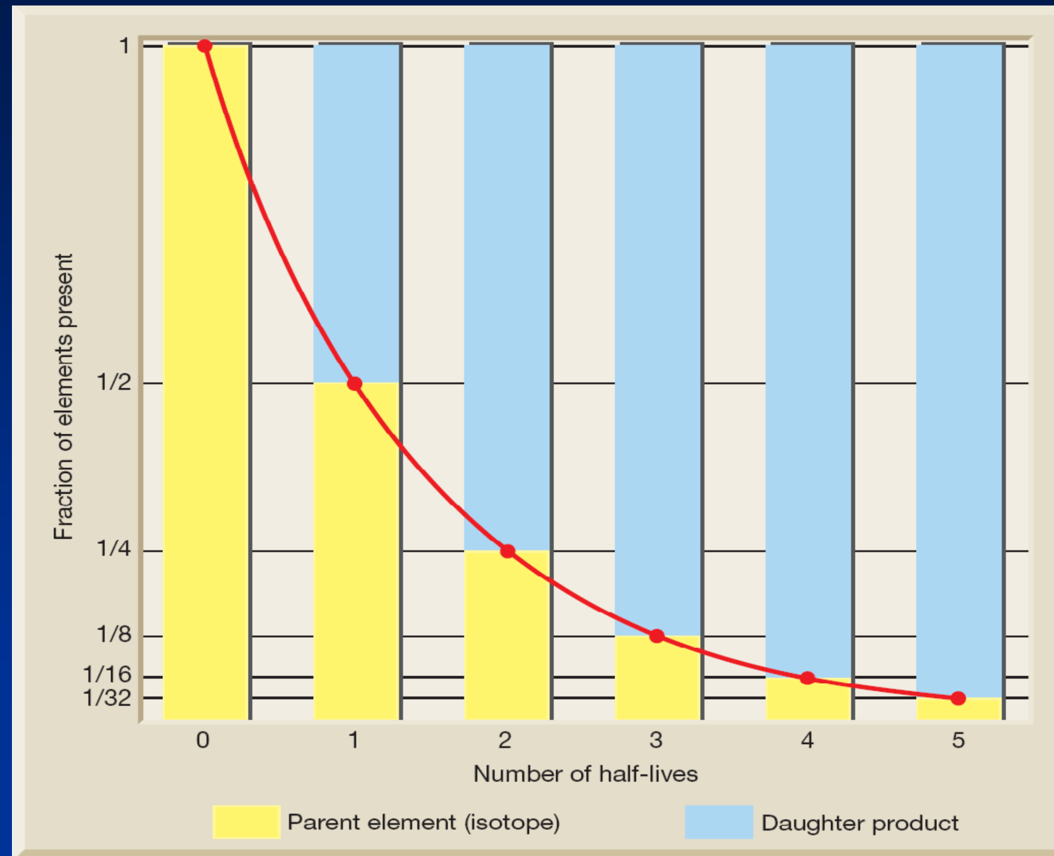


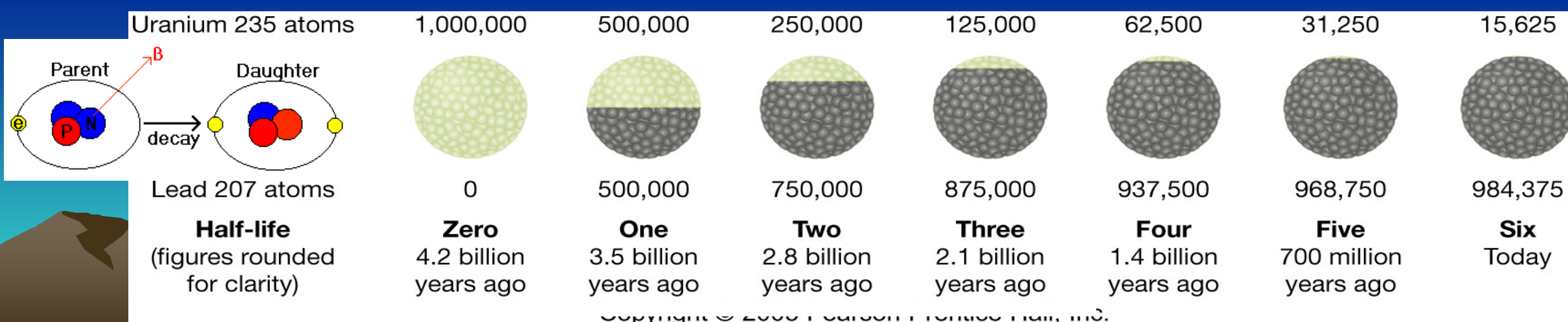


Principles of Radioisotopic Decay

The Principles

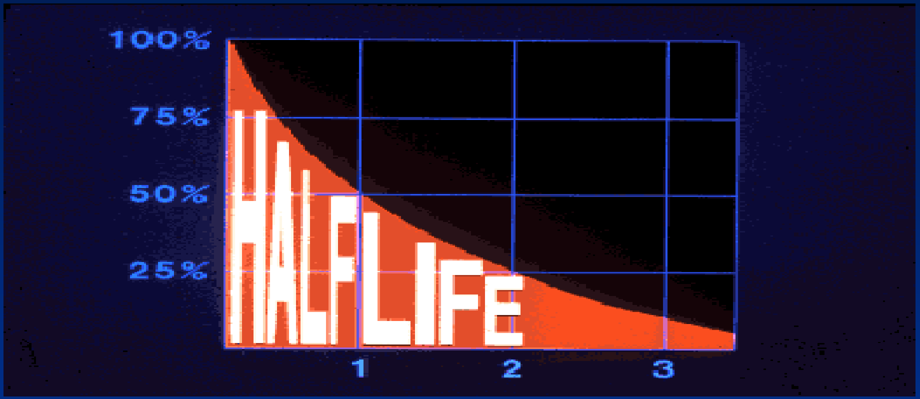
- ✓ Spontaneous decay of unstable parent element into a its unique stable daughter element
- ✓ The half-life of each parent-daughter pair is a constant
- ✓ Age of an igneous rock is determined by measuring the ratio of rock's parent-daughter material

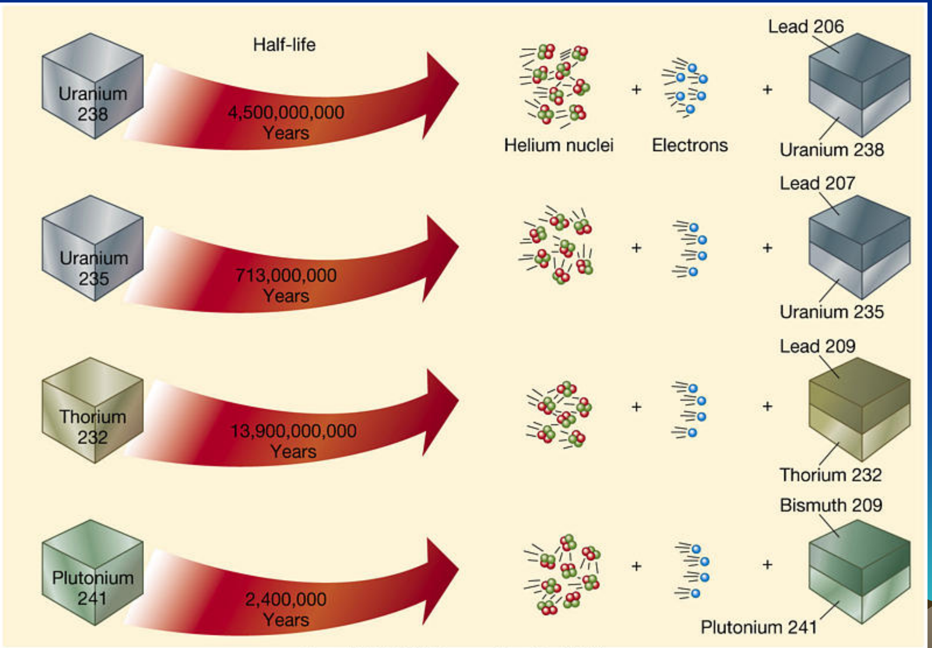




Radioisotopic Half-Lives

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

Stable **Daughter**

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

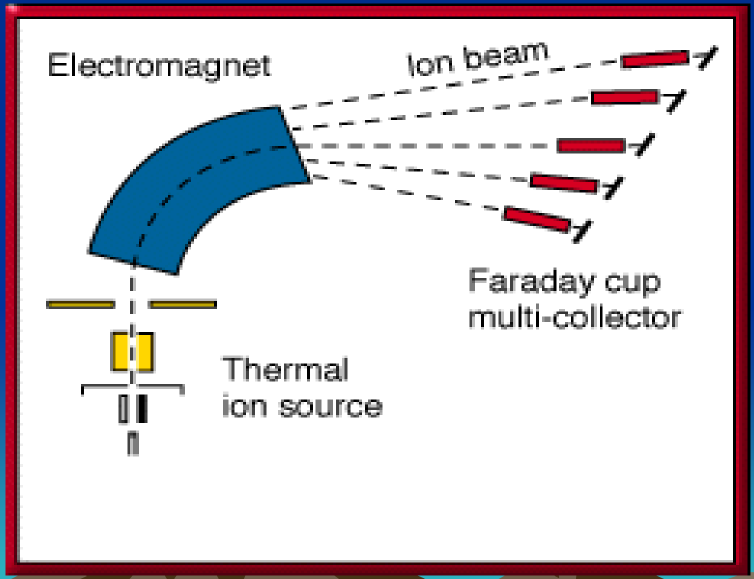
Radioisotopic Dating Method

Analysis of Parent/Daughter Isotopic Compositions in Rocks

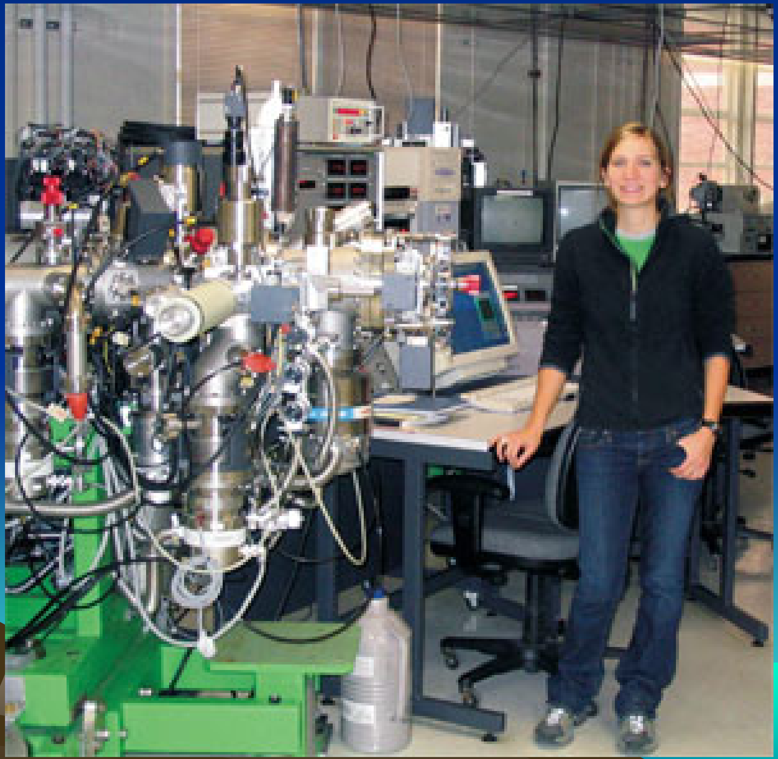
✓ Parent and daughter elements are isolated and refined from host mineral using conventional wet chemistry methods.

✓ 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***

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

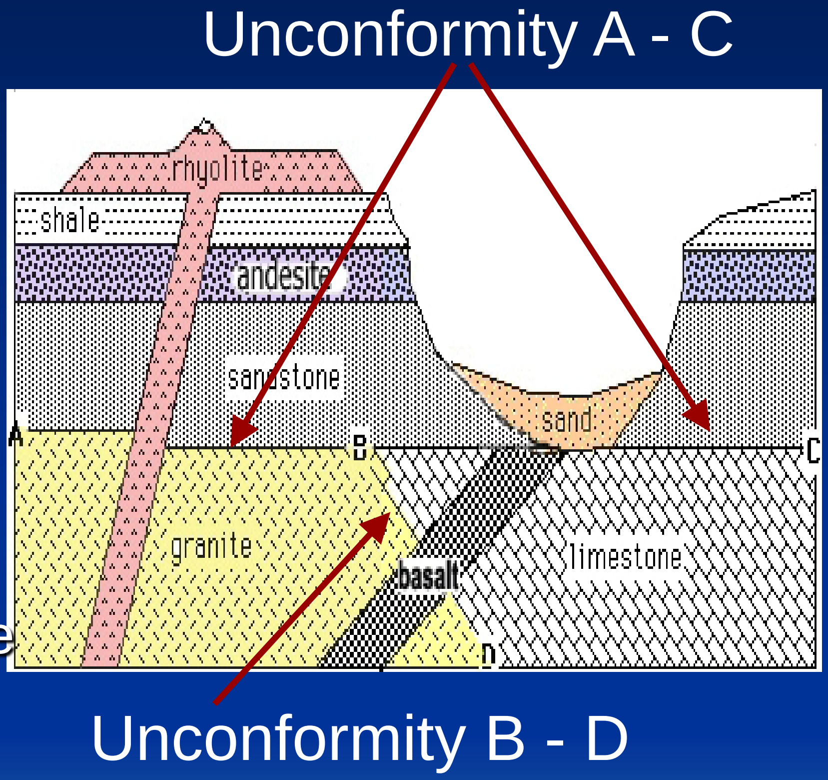
Procedure:

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



Youngest ________

____

____

____

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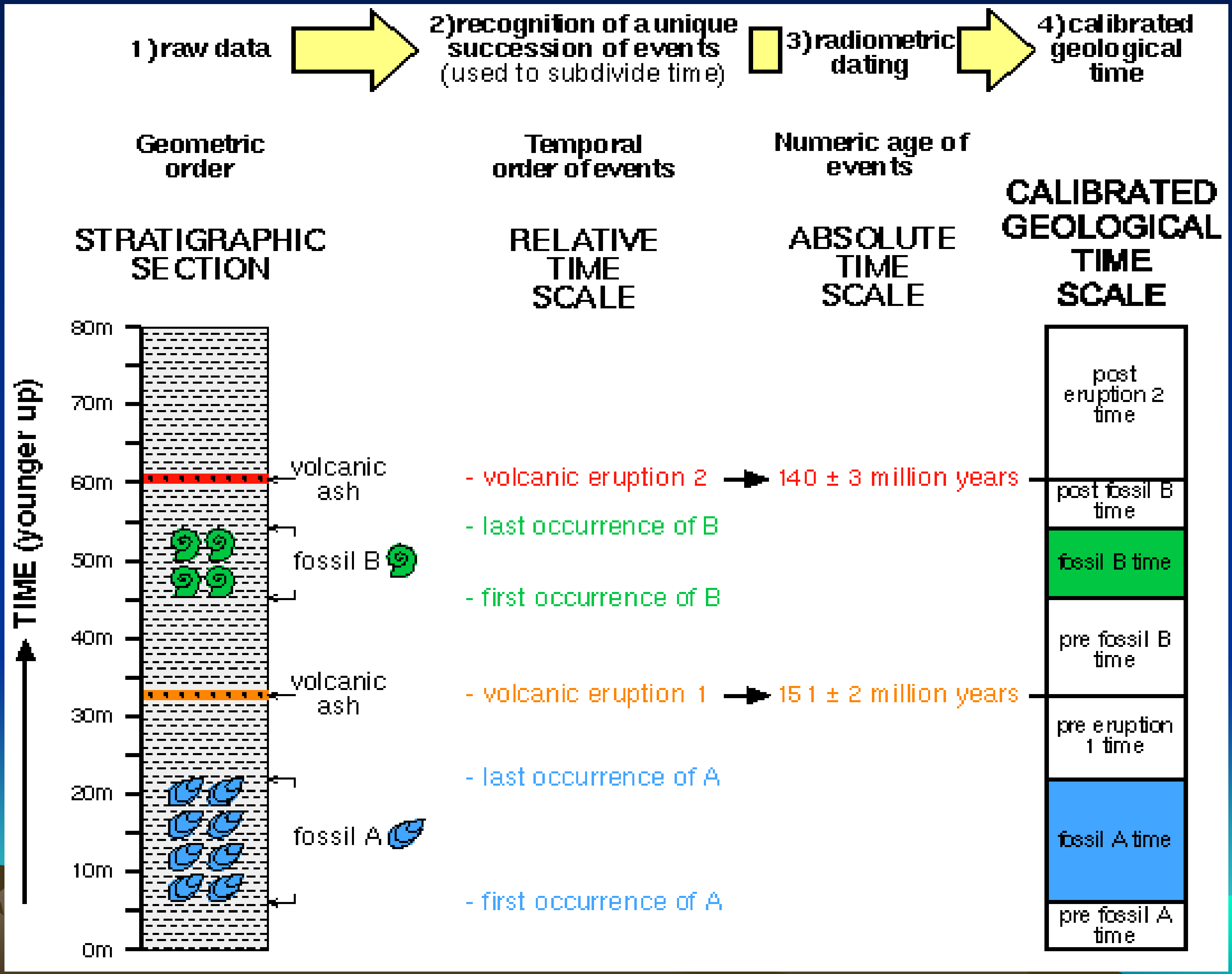
Oldest ________

Note: There are four igneous rock units

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



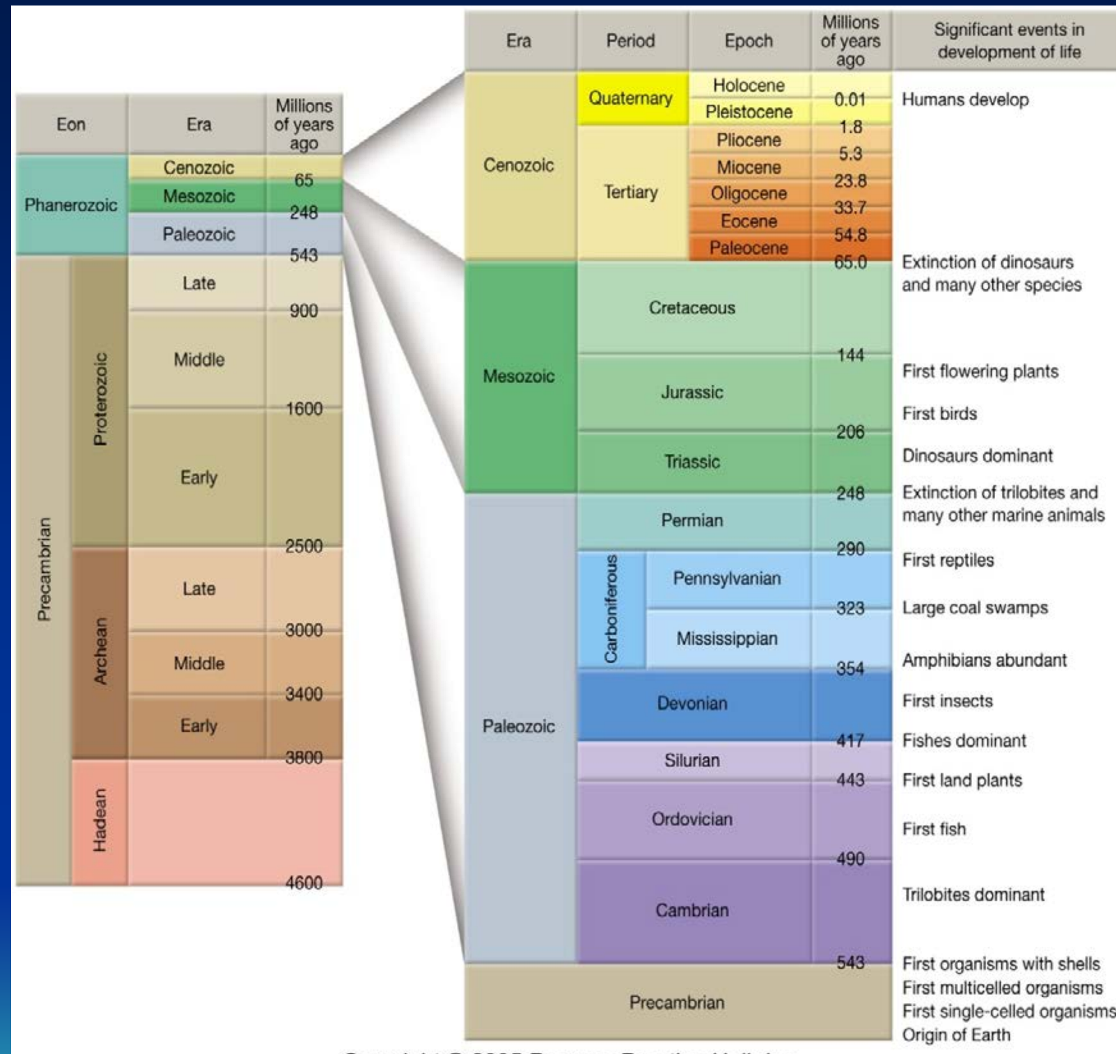
THE GEOLOGICAL TIMESCALE

Key Ideas:

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

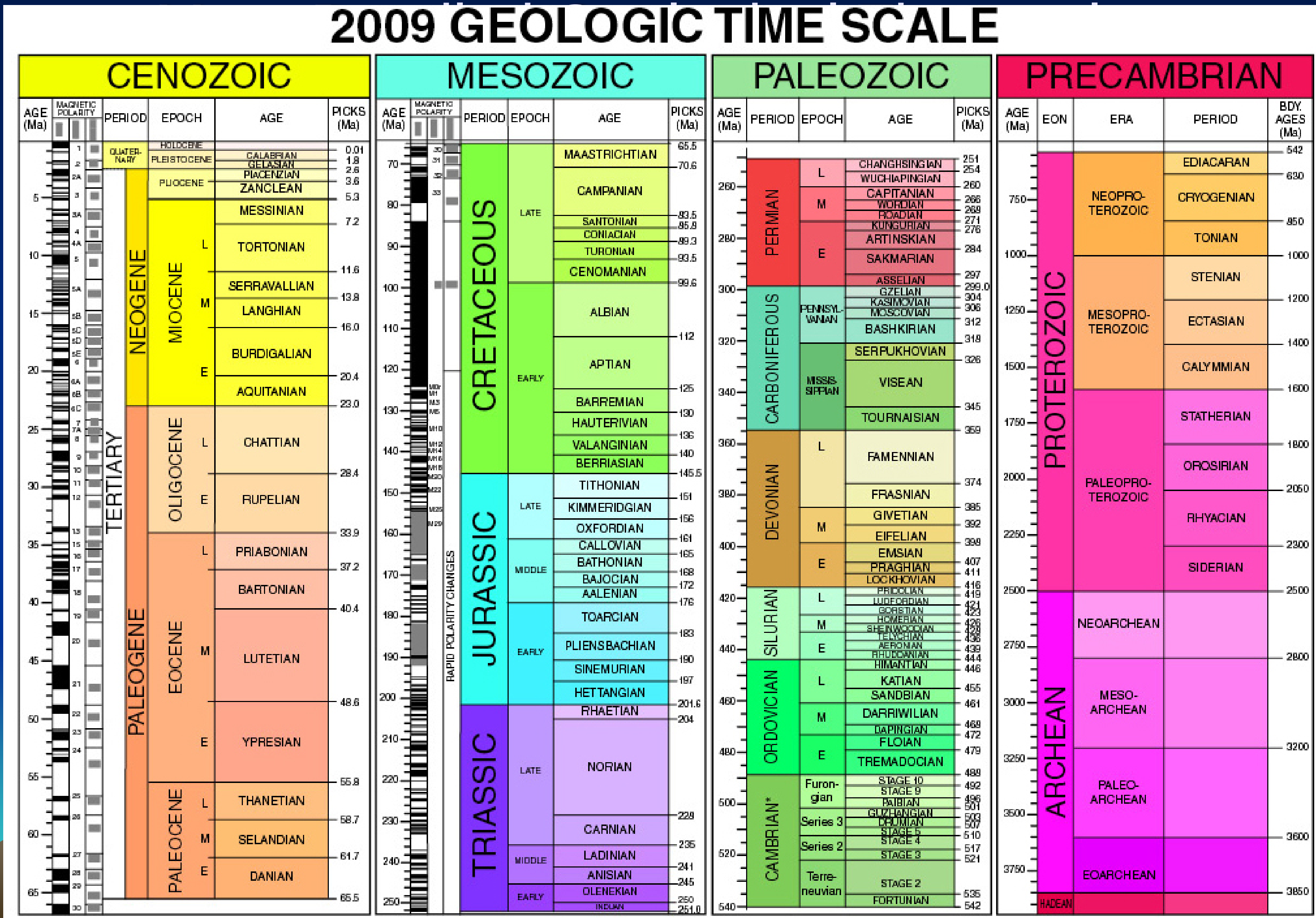
✓ Periods separated by major mass extinction events

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

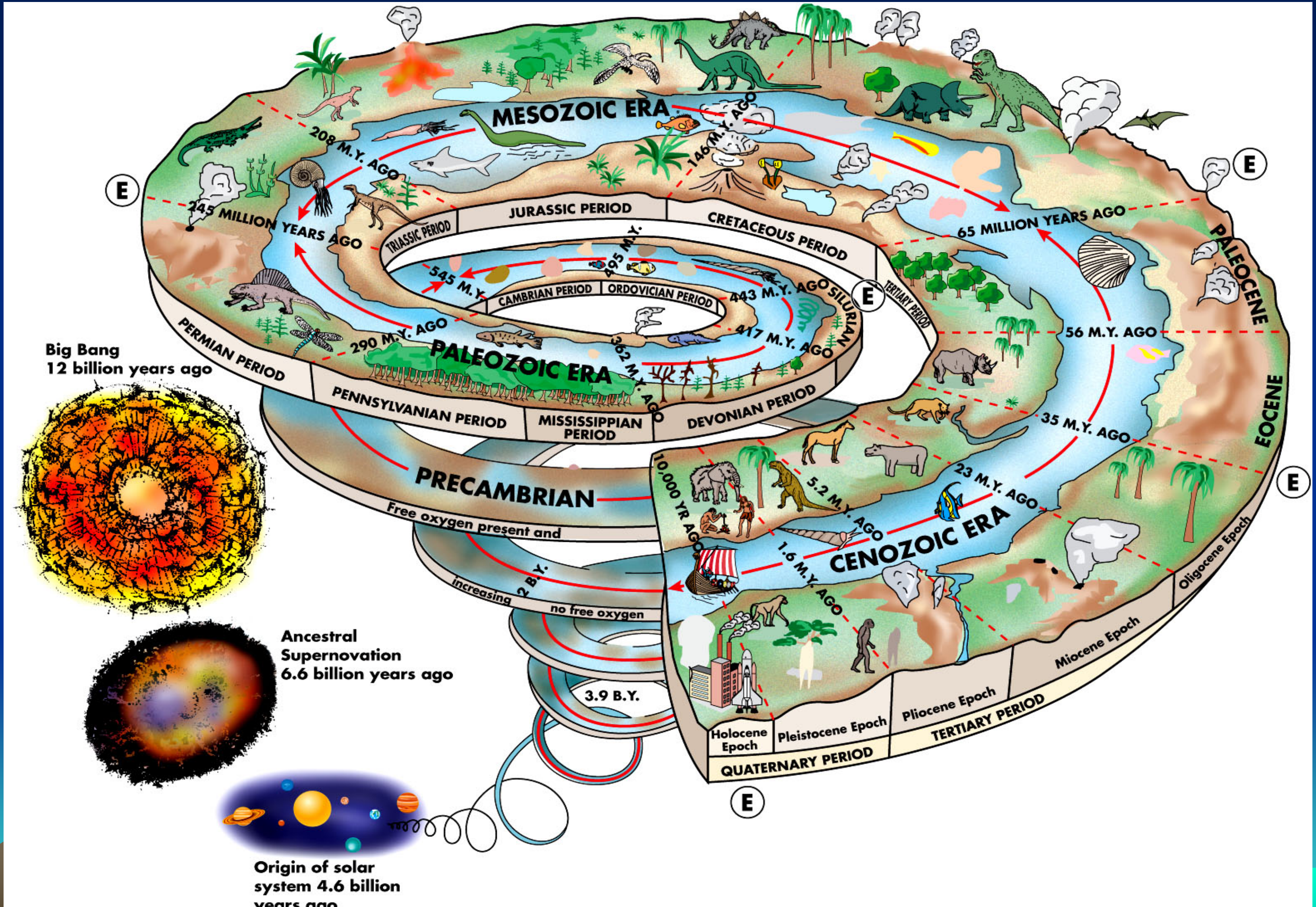


Note: You will need to memorize the basic geo-timescale for the final exam.

THE COMPLETE GEOLOGICAL TIMESCALE



THE TWISTED GEOLOGICAL TIMESCALE



THE GEOLOGICAL TIMESCALE QUIZ

Need to Memorize:

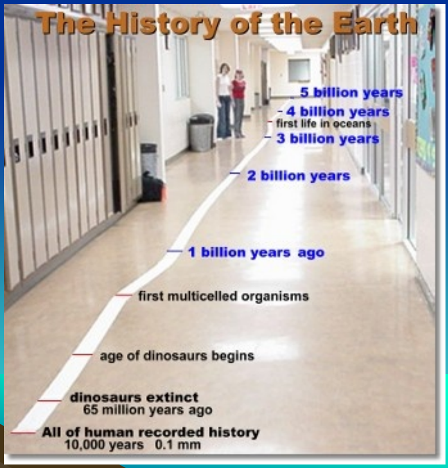
1) The 2 Eons
2) The 5 Eras
3) The 12 Periods
4) The 7 Epochs
5) The Age of Earth
6) Age of Beginning of Paleozoic Period
7) Age of Beginning of Mesozoic Period
8) Age of Beginning of Cenozoic Period

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	
			PALEOGENE	OLIGOCENE	36.6	
				EOCENE	57.8	FORMATION OF HIMALAYAS
				PALEOCENE	66	DINOSAUR EXTINCTION
	MESOZOIC	CRETACEOUS			144	ROCKY MTS. FORMED
		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				2500	EARLIEST SHELLED ANIMALS
	ARCHEAN EON				3800	EARLIEST FOSSIL RECORDED OF LIFE
					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
Phanerozoic	Cenozoic	Quaternary	Pleistocene	2.6	Ice Ages and interglacial periods cause widepread changes in climate Modern humans evolve and migrate around the world
Phanerozoic	Cenozoic	Tertiary – Neogene	Pliocene	5.3	First ice ages begin as Himilayan Mountains rise, Isthmus of Panama closes
Phanerozoic	Cenozoic	Tertiary – Neogene	Miocene	23	Most modern families of mammals evolve and migrate across land bridges Grasses evolve and spread worldwide Yellowstone Hotspot migrates eastward, Colorado Plateau and Great Plains rise
Phanerozoic	Cenozoic	Tertiary – Paleogene	Oligocene	33.9	Great Basin extension begins as San Andreas Fault System develops Deciduous forests (leaves fall in winter) dominate temporate climates
Phanerozoic	Cenozoic	Tertiary – Paleogene	Eocene	56	Rocky Mountains rise, shedding sediments throughout western US region "Age of Mammals" begins
Phanerozoic	Cenozoic	Tertiary – Paleogene	Paleocene	66	Western Interior Seaway vanishes Cretaceous/Tertiary boundary extinction wipes out dinosaurs, ammonites, etc.
Phanerozoic	Mesozoic	Cretaceous		145	"Greenhouse Earth" - Dinosaurs at their "peak" Western Interior Seaway forms in Great Plain region
Phanerozoic	Mesozoic	Jurassic		201	Breakup of Supercontinent Pangaea, birds and early mammals appear
Phanerozoic	Mesozoic	Triassic		252	Dinosaurs (warm blooded) replace reptiles (cold blooded) as dominant land animals
Phanerozoic	Paleozoic	Permian		299	End of Permian extinction greatest of all extinction events "Age of Reptiles" - Pangaea Supercontinent forms
Phanerozoic	Paleozoic	Pennsylvanian		323	Carboniferous Period - great coal swamps form as Appalachian Mountains form
Phanerozoic	Paleozoic	Mississippian		359	"Age of Amphibians"
Phanerozoic	Paleozoic	Devonian		419	"Age of Fishes" First forests (coal beds) appear
Phanerozoic	Paleozoic	Silurian		444	
Phanerozoic	Paleozoic	Ordovician		485	"Age of Invertebrates" - brachiopods, trilobites, corals First land plants evolve
Phanerozoic	Paleozoic	Cambrian		541	First shelled invertebrates appear
Precambrian	Proterozoic			2500	Multicellular organisms evolve Modern continental shield regions of continents gradually assemble Banded Iron Formations are deposited as oxygen atmosphere forms
Precambrian	Archean			4000	Stromatolites appear in "fossil record" single-celled organisms evolve
Precambrian	Hadean			4500	Oldest rocks preserved Solar System forms, Moon and Earth system forms by accretion of extraterrestial materials



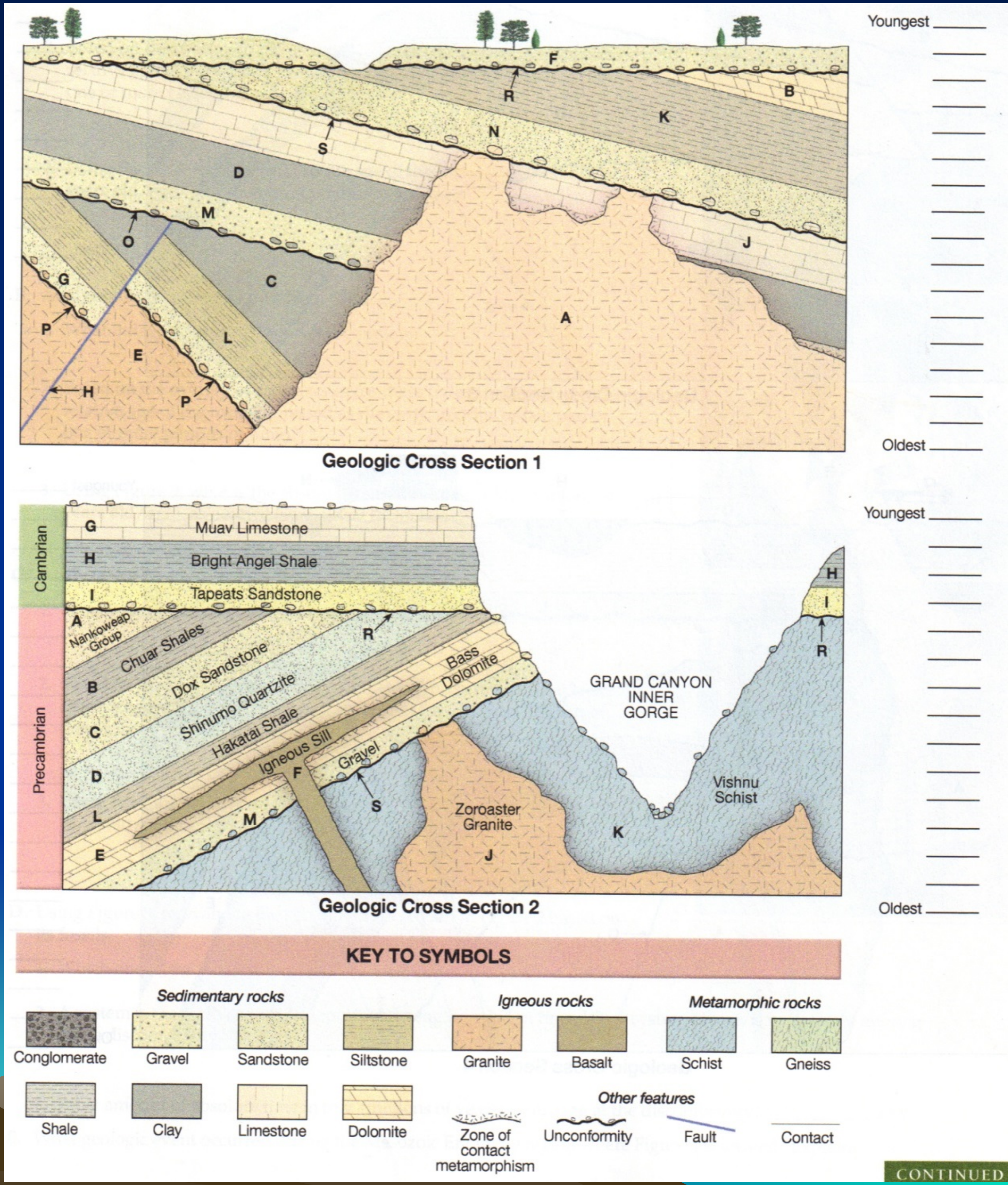
Application of Relative Dating Principles to a Geologic Cross Section

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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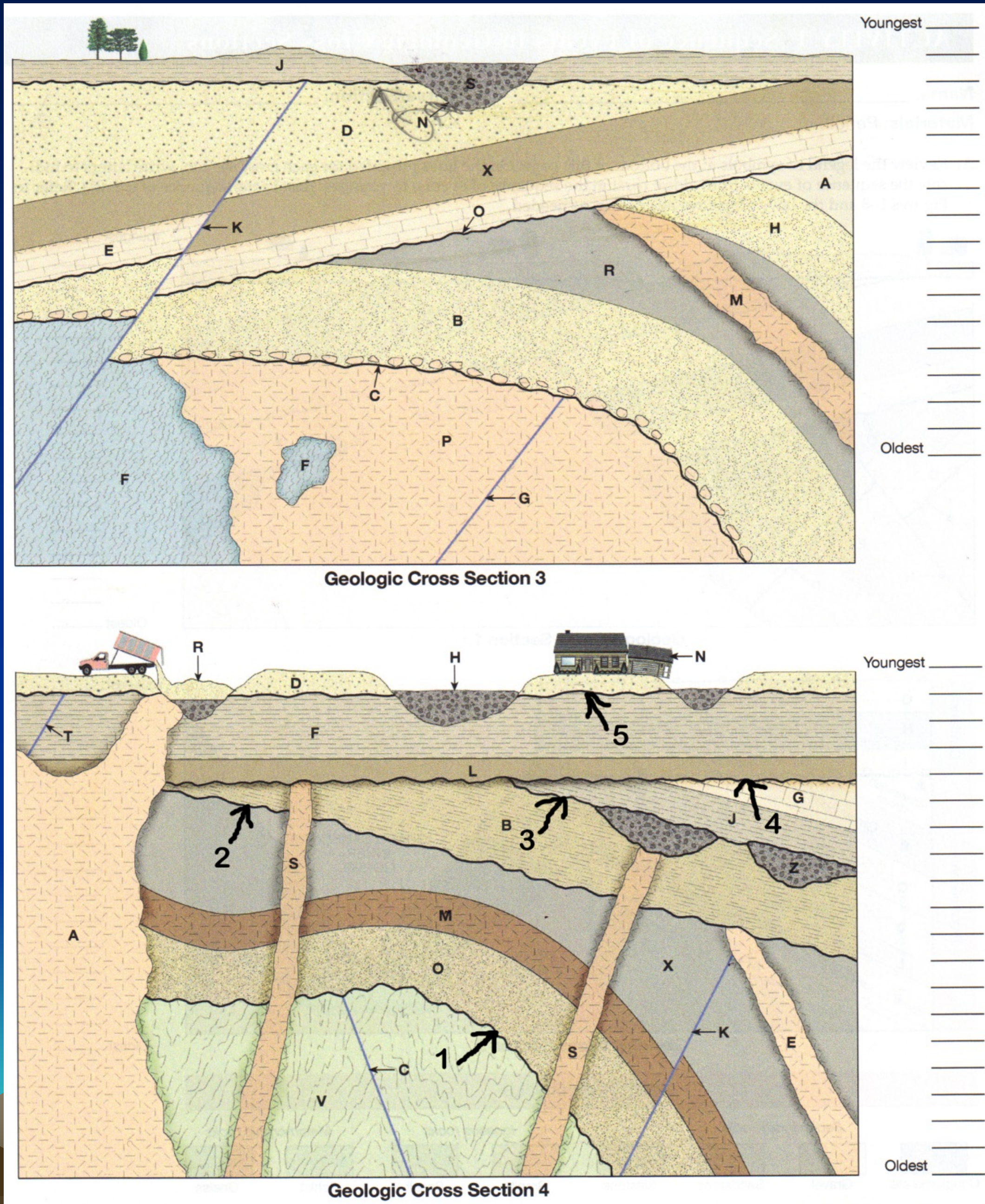
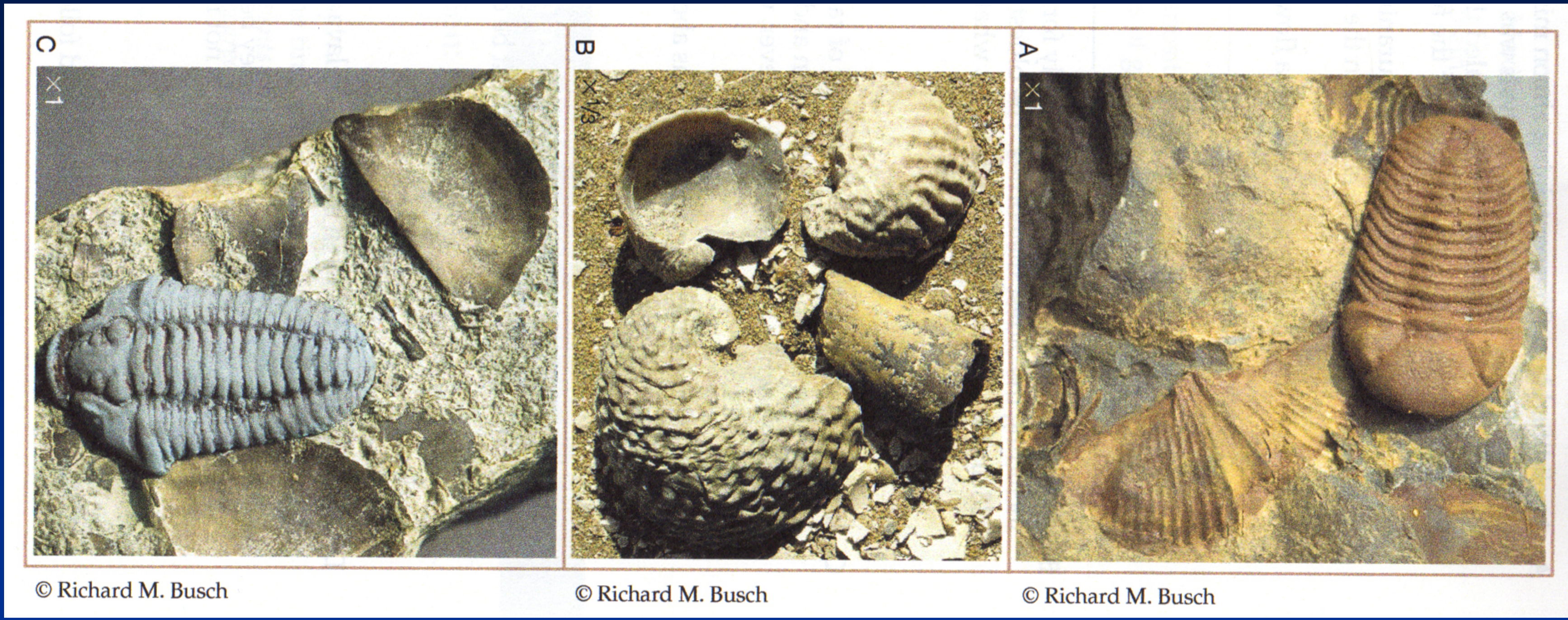
3) Determine what types of unconformities there are.



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 Week's Lab

Earthquakes

Next Week's Lab Activities

1) Measure Epicenter and Magnitude
2) Ground Motion Experiment
3) Measure Fault Displacement

Preparation

Recommended Pre-Lab 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?