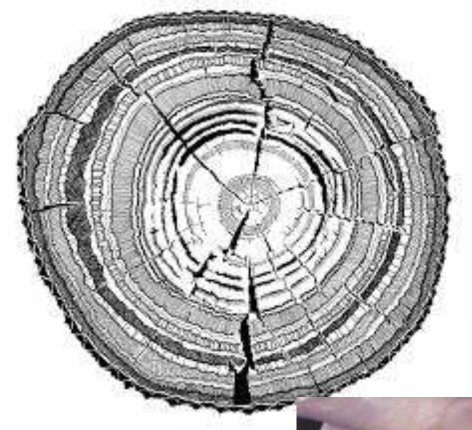
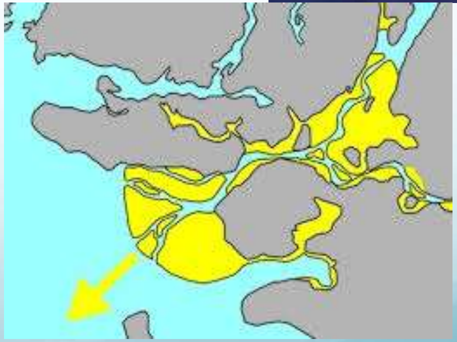
Geologic Time

- Dates on coins and newspapers are **direct** evidence of age of items or events.

- However, rocks don't come with dates on them!
- Indirect evidence is used to determine the **age** of geological events.

- Indirect clues require **observation** of changes that have occurred:
  - growth in trees,
  - wearing of teeth,
  - growth of a river delta.





Geologists use two different frames of reference when discussing geologic time.

- **Absolute age dating** gives rocks an actual **age** range, in number of years
- **relative age dating** only puts geological events and rocks in order from **oldest** to **youngest**.

Relative Age

- It is very difficult to talk about geologic events that happened many millions of years ago without referring to approximate **age** of rocks, features, and events.
- However, there are no written **records** from which we can infer their ages.

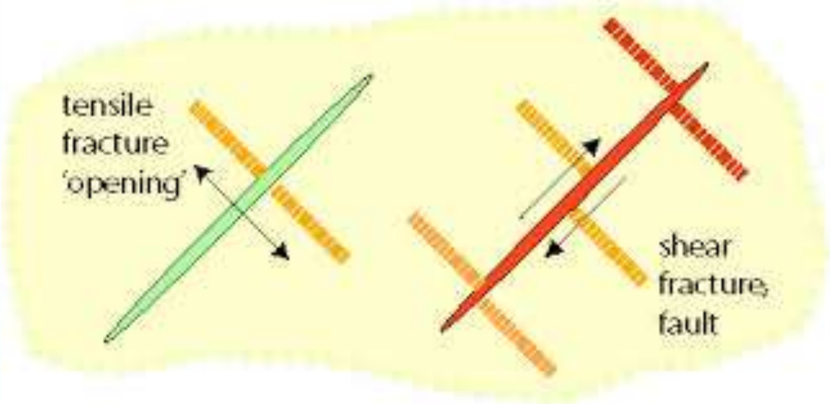
- When you look at members of a typical family, it is fairly easy to rank them in terms of their **relative** **ages**.
- You can easily distinguish between the children, the parents, and the grandparents.
- You can determine their relative **order**, but unless you specifically ask their ages, you would not know the actual, or **absolute age**, of each individual.

- The concept of relative age was one of the first most important **dating** principles to be proposed in geology.
- A layer of sedimentary rock that is visually separable from other layers is called a **stratum** (plural: strata).
- Because of the way they form, strata generally follow or obey certain laws called the **Laws of Stratigraphy.**

Review: Geological Structures

- **Strata –** layers (sedimentary rock).
  Formed from the settling and depositing of different kinds of sediment.

- **Fractures** – cracks in a body of rock



- **Faults** – fractures along which there was movement.

- **Dykes** – igneous rocks that are formed in rock fractures when magma is squeezed upwards.

- **Folds –** sedimentary layers which have been squeezed and buckled.

- **Erosion surfaces –** exposure of rock to weathering, and is later buried. Layers appear rough and uneven.

Unconformities

- In the late 18th century, James Hutton proposed that the processes that we see today are the same processes that have always influenced the formation of the Earth's surface.
- This is known as the **Law of Uniformitarianism**.
- He noticed that there was 'missing', or **discontinuous strata** at many locations.
- This suggested that there may be large **gaps** in the rock record, and that these gaps may be due to the same **erosional** processes we see at work today.

- For example, At Siccar Point in Scotland, almost vertical grey shales have been eroded and lie beneath almost horizontal sandstones.

- **Unconformities** are produced when rock on the surface of the Earth is eroded and then more dirt and rock are piled on top.
- They are identified by a rough/wavy surface that represents “**missing**” time separating young rock from old rock.

LAWS OF STRATIGRAPHY

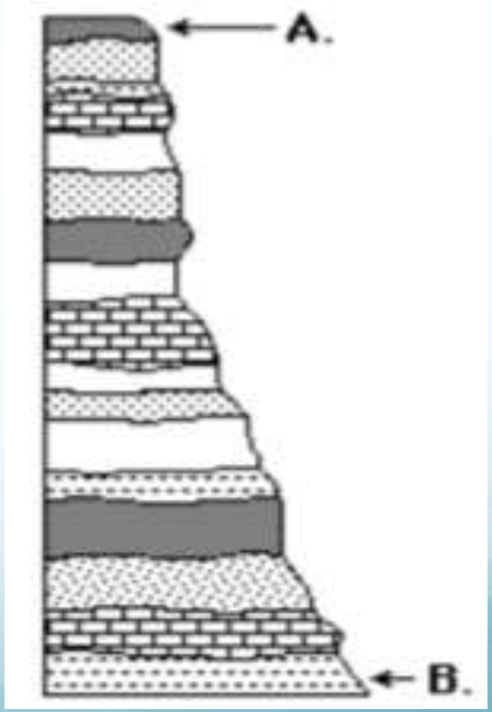
Layers of **strata** generally follow or obey certain laws called the **Laws of Stratigraphy**

These 'laws' allow us to determine the **relative** ages of different geological strata and structures within rock.

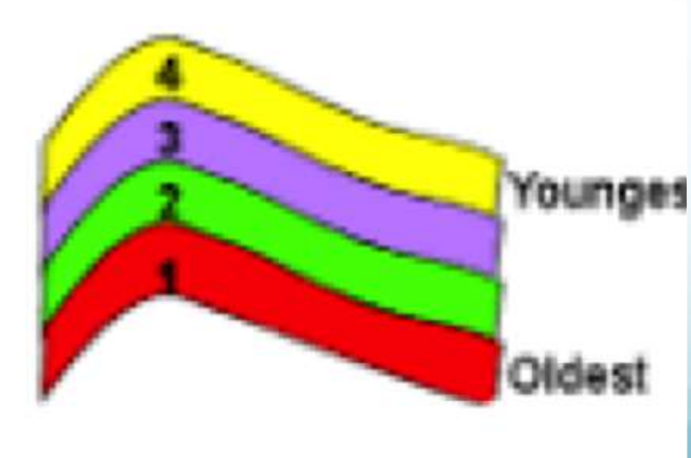
- Where a layer of undisturbed sedimentary rock is exposed at a cliff face, canyon, or mountainside, the rocks on the **bottom** were usually deposited first and are therefore **older** than the rocks at the top.

- This is known as the **Law of Superposition.**

- In the adjacent diagram, Layer B would be **older** than Layer A.



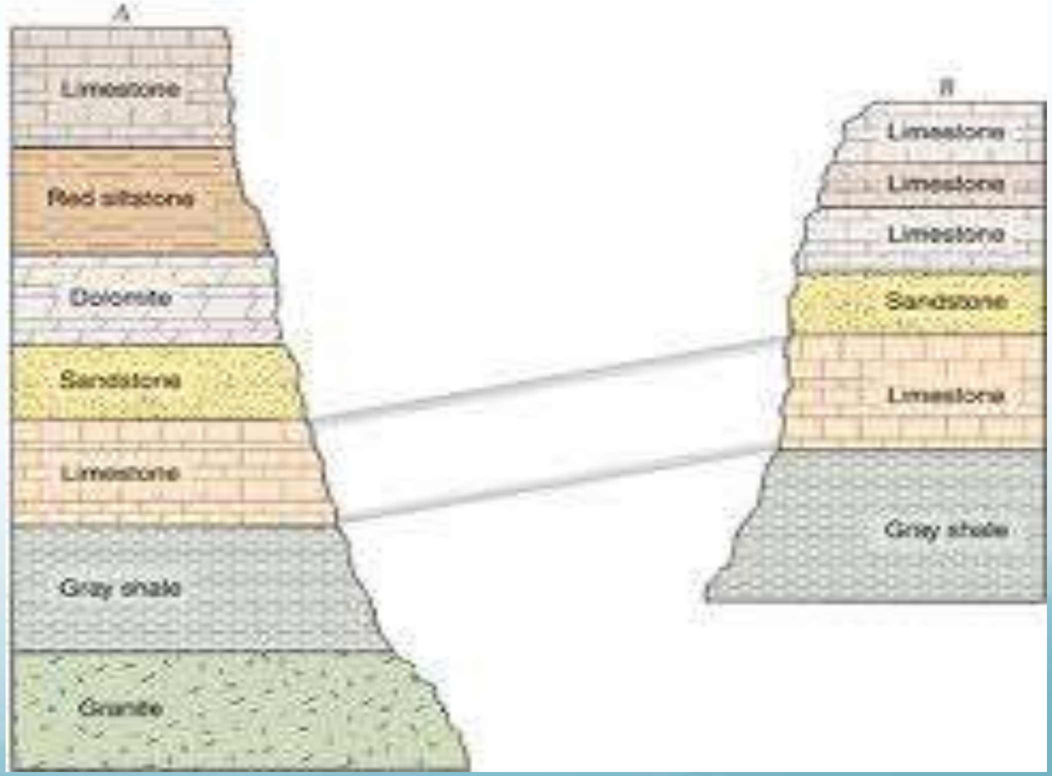
- **Law of Original Horizontality** states sedimentary rocks, regardless of their current orientation, were laid down as **horizontal** sedimentary layers.
- If the layers are **tilted** then we must consider their relative positions as if they were still horizontal.



- In regions where the rocks have been compressed, folded, and pushed on top of one another, it is not uncommon to find **older** rocks on top of **younger**.

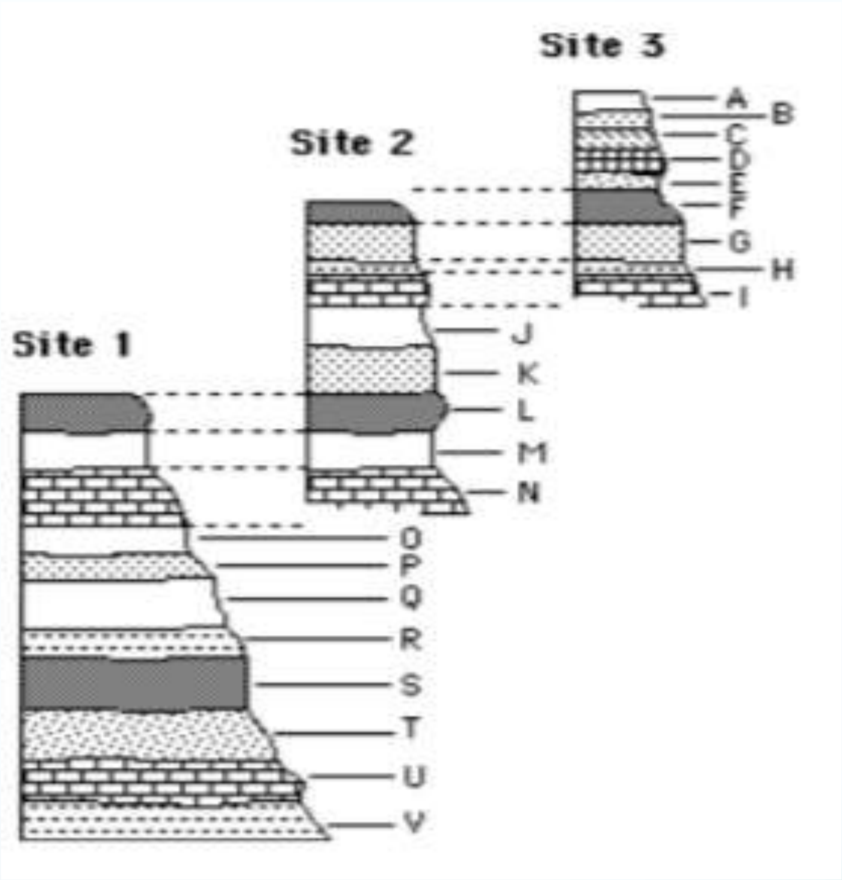
- The geologist must therefore look for other **clues** to determine the relative ages.

- Different layers in adjacent areas can often be **matched** up as shown in the adjacent.
- This is the **Principle of Correlation**.



When Sites '2' and '3' are compared, Layers F, G, H and I are common to both.

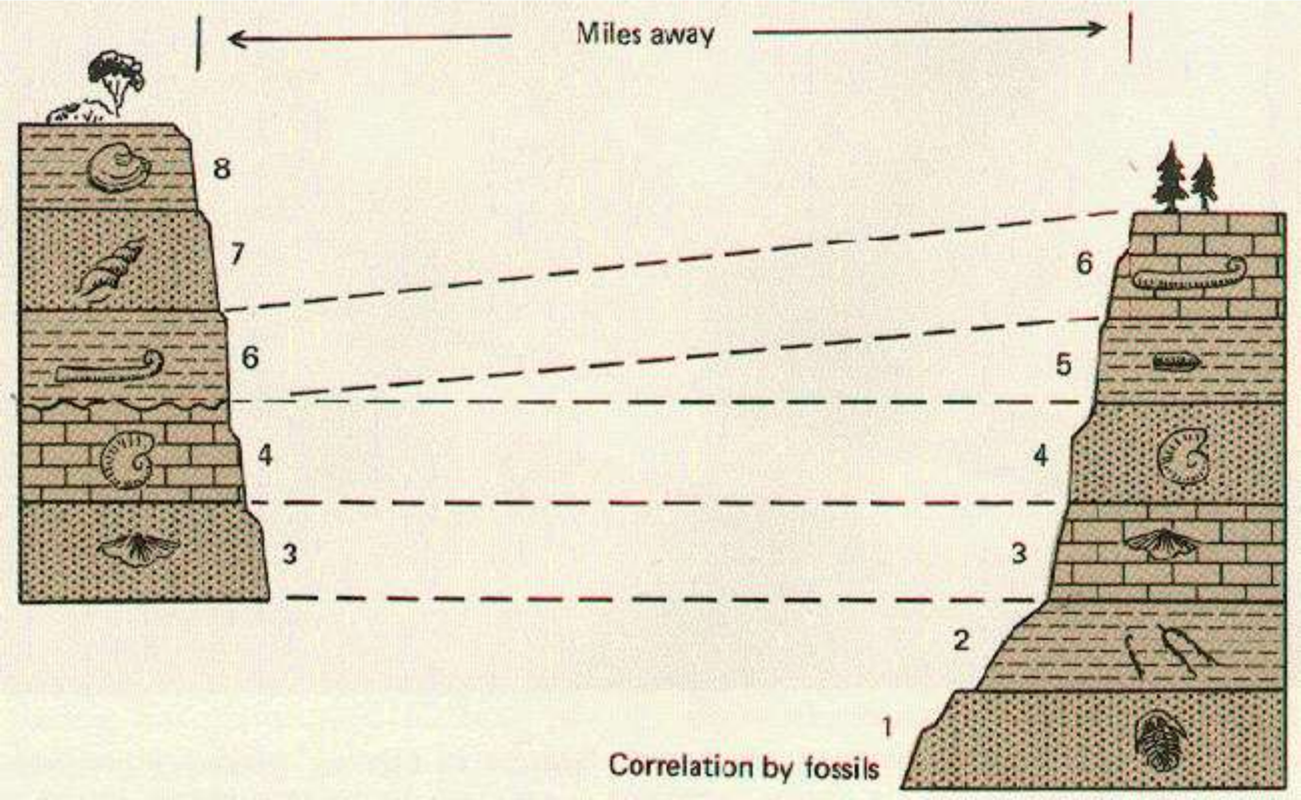
Layers L, M, and N are common to Sites '1' and '2'.



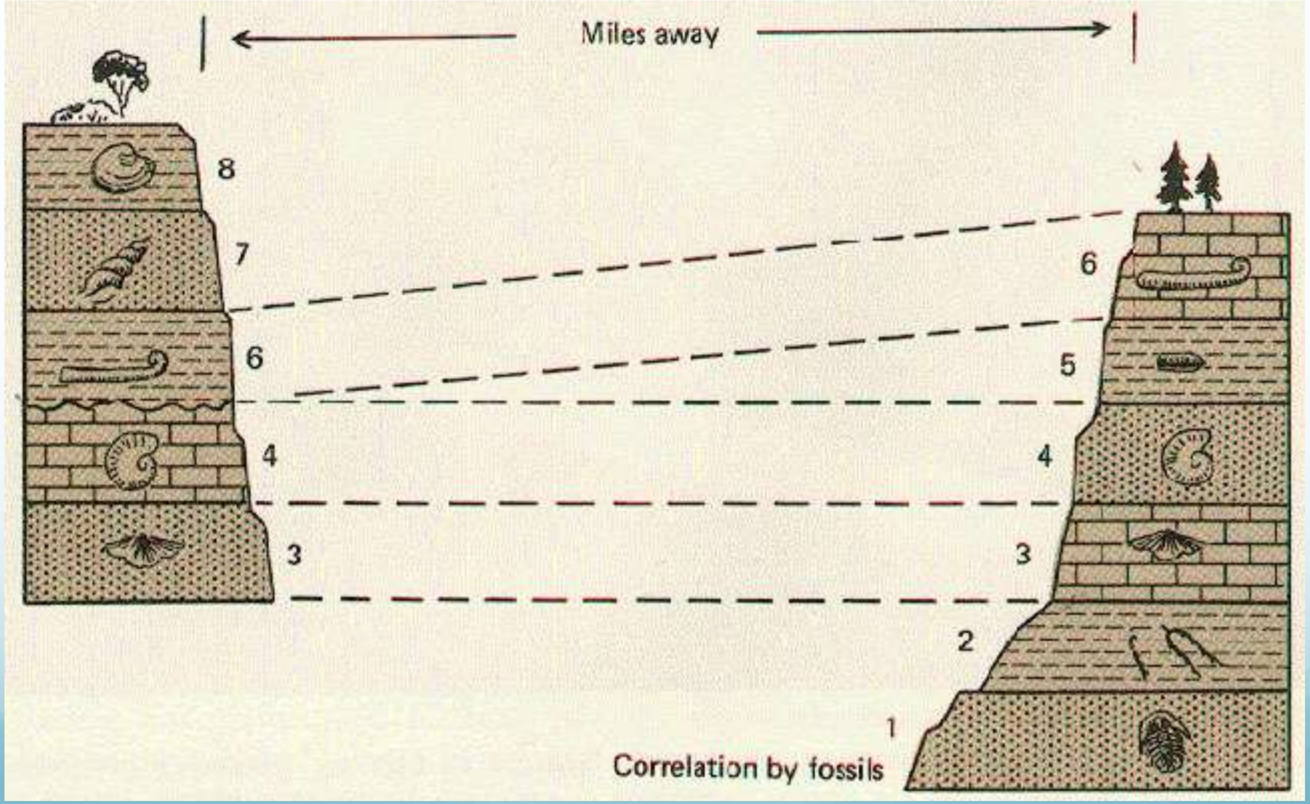
- Some fossils are also very characteristic of certain time periods and could therefore be used to **correlate** the relative ages of the sediments they were found within.
- These fossils are called **index fossils.**

- A species can be used as an index fossil if it was:
  - **Widely** distributed on the earth
  - Occurred in large **numbers**
  - Existed for a relatively **short** time
  - Is often **fossilized**
  - Easy to **recognize**

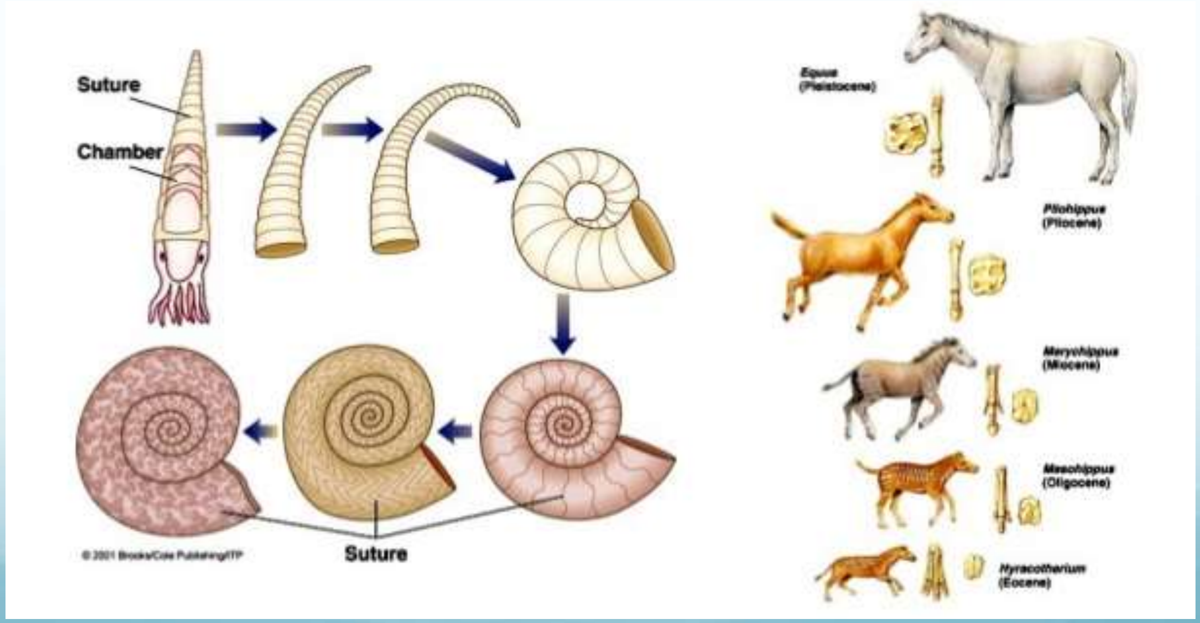
- Consider that a specific type of fossil was found in Layer 6 of the rock cliff below.
- If similar fossils are found at a different site, then the layers must be the same **age**.



- Looking at the complete sequence shows that Layer 8 is the most **recent** and Layer 1 is the **oldest**.
- This comparison would be **true** even if the sites are hundreds of kilometres apart and contain different types of rocks.



- It was also observed that fossils changed if you go **deeper** into a mine.
- The **Law of Fossil Succession** states that organisms **change** over time, and each form is **different** than those that came before and after in their history.

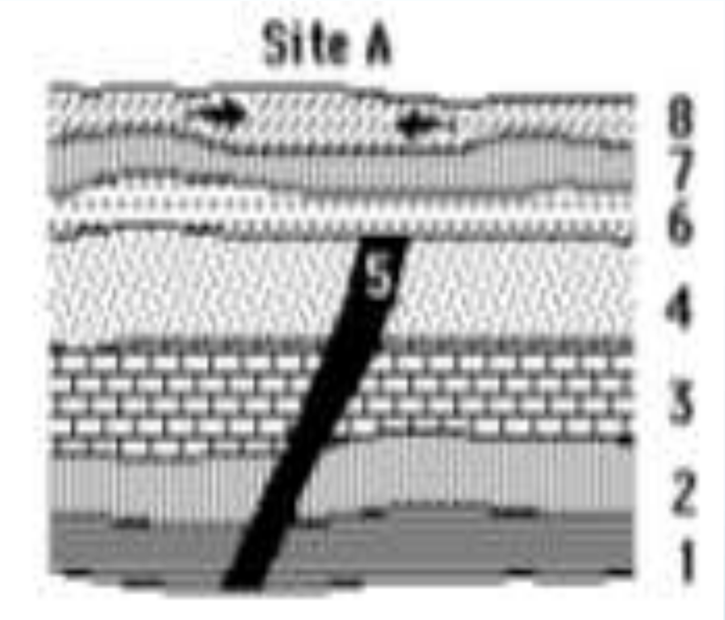


- In some rock faces, one feature may **cut** across another feature.
- For example, a fault or a volcanic intrusion such as a **dike** or sill can cut **across** sedimentary layers.

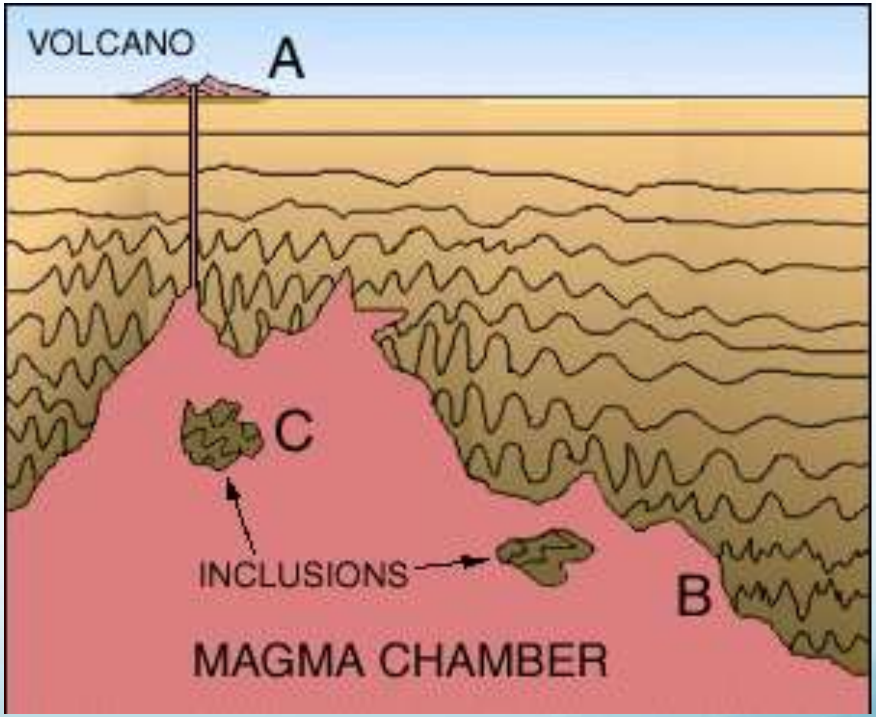
- The **Principle of Cross-Cutting Relationships** states that a feature that cuts across another is **younger**.

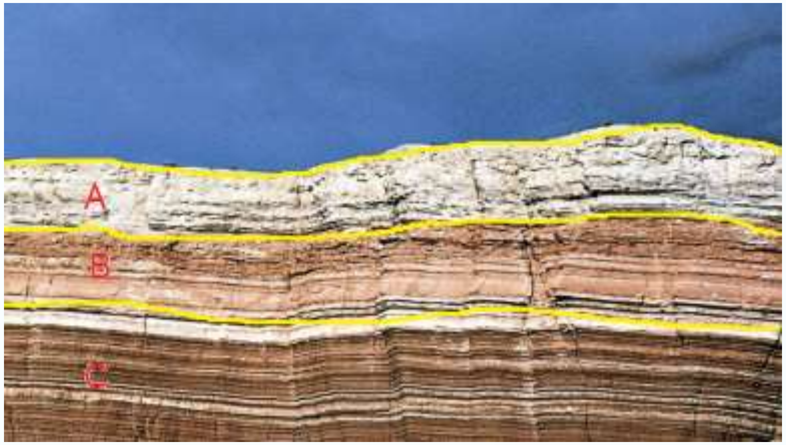
- Dike ('5') cuts across layers '1' through '4', so it must be **younger** than them;

- Layers '6' through '8' are above the top of the dike, suggesting through the law of **superposition** that they are younger than the dike.



- The **Principle of Inclusion** establishes that an inclusion (i.e., a rock fragment) within a rock is always **older** than its matrix.

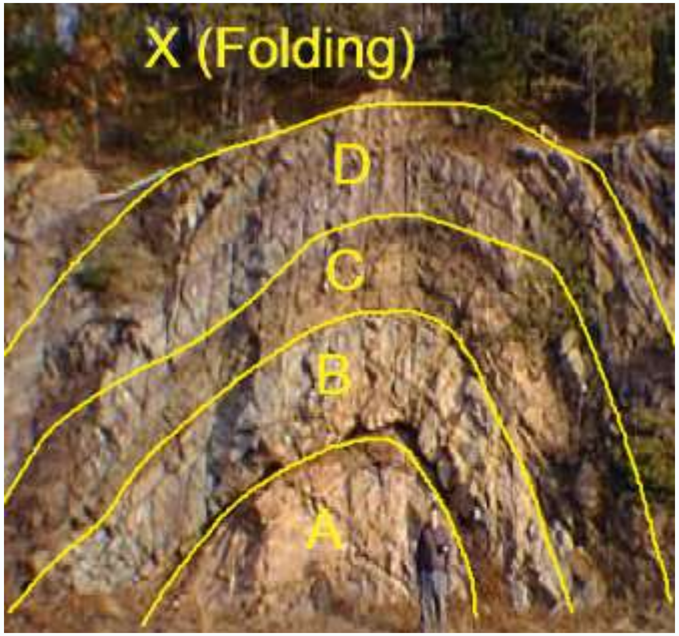




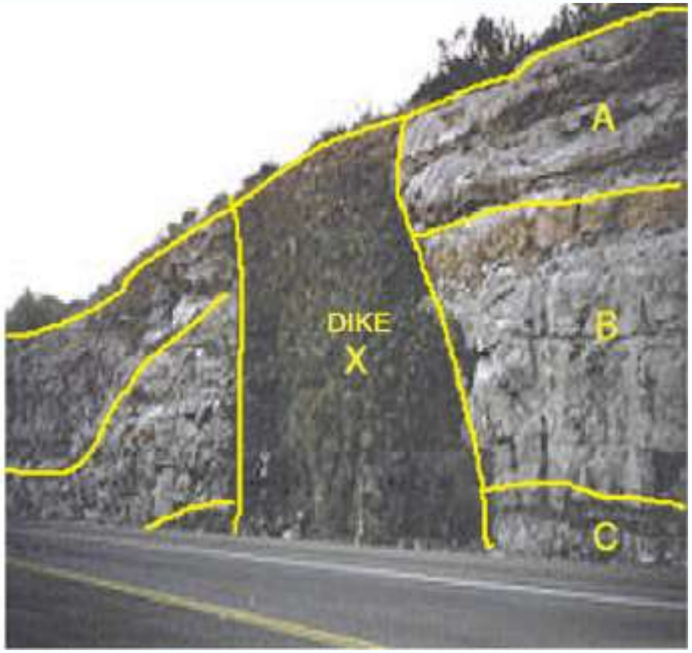
YOUNGEST: A

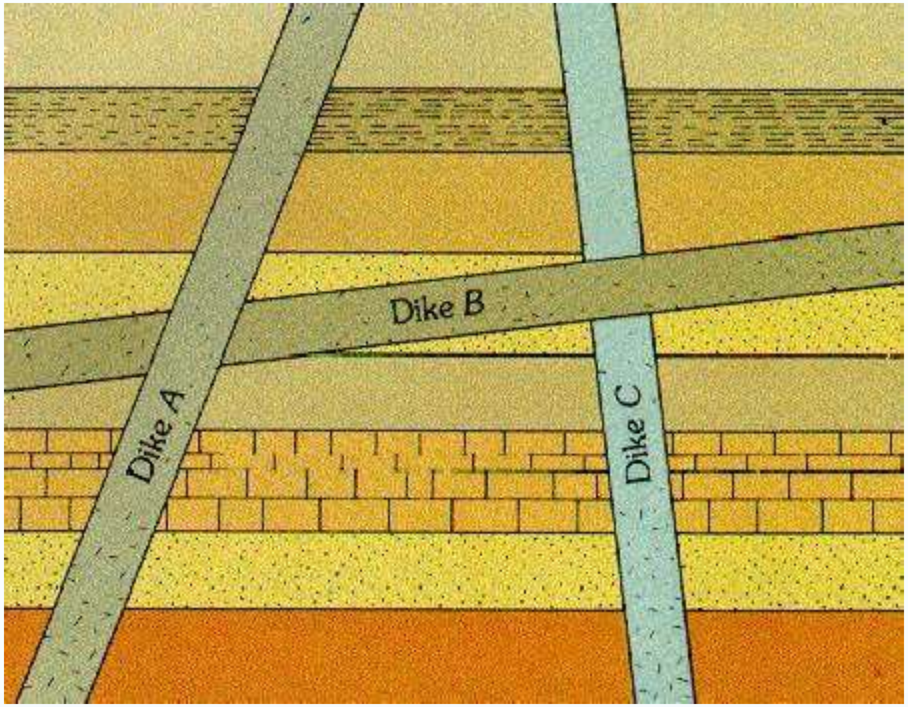
B

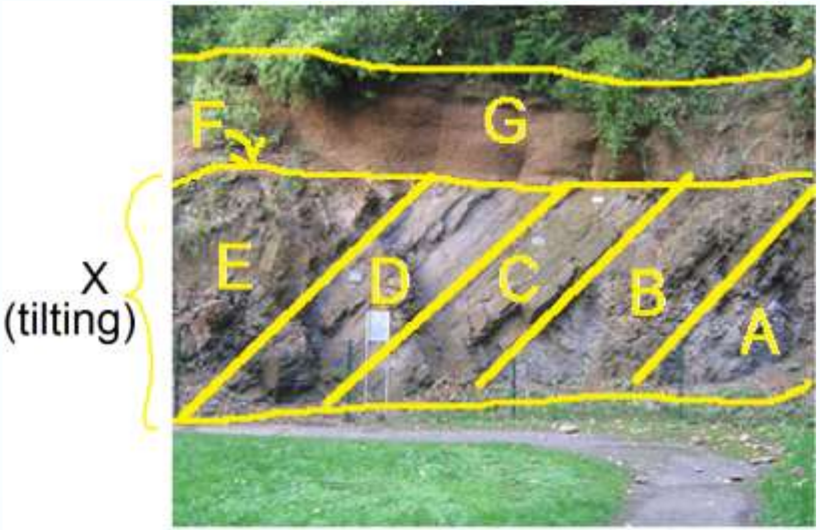
OLDEST: C



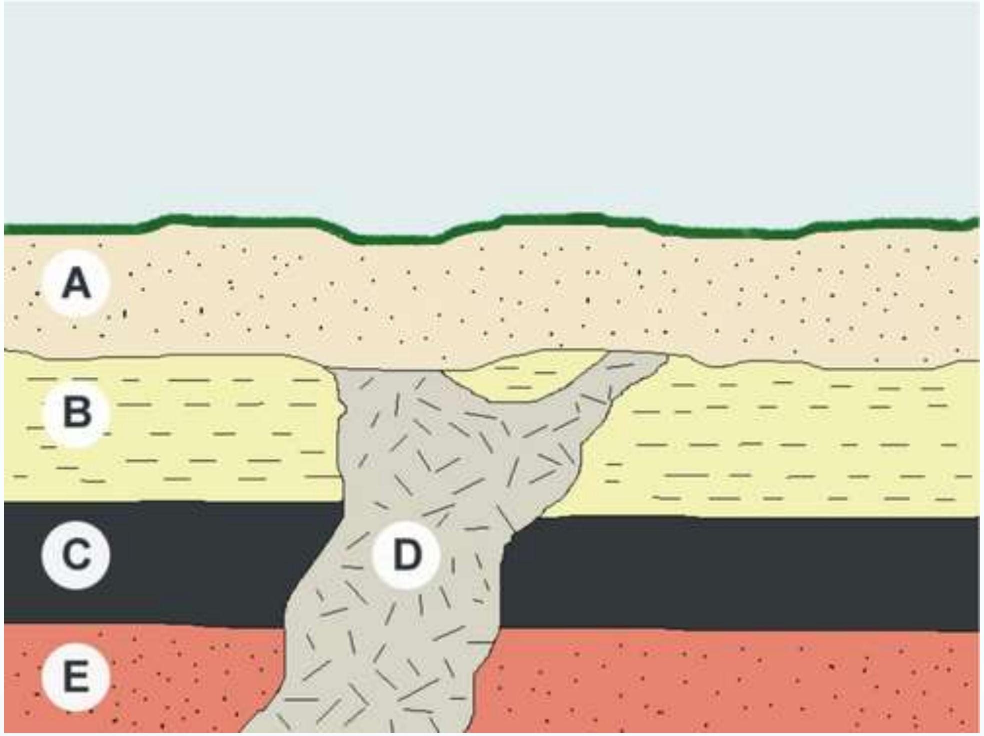
X (Folding)
D
C
B
A


A
DIKE
X
B
C

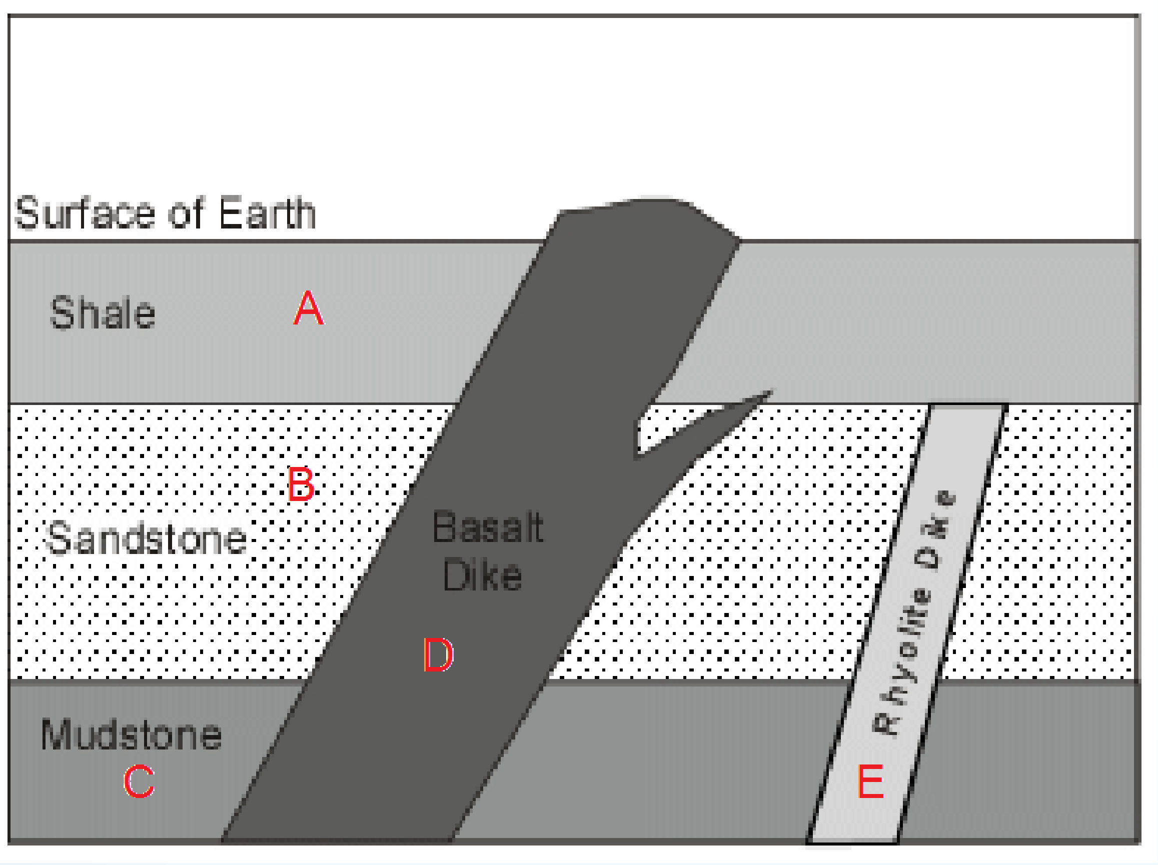

Dike B
Dike A
Dike C

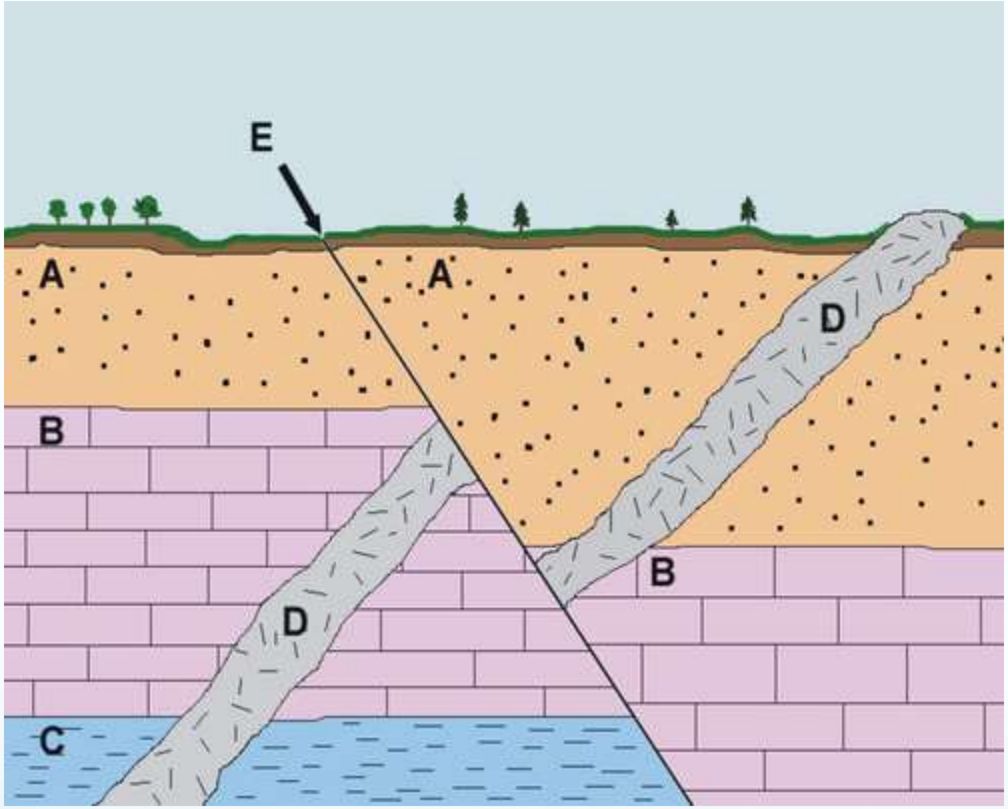


G
F
X
(tilting)
E
D
C
B
A



A
B
C
D
E


Surface of Earth
Shale
A
B
Sandstone
Basalt Dike
D
Rhyolite Dike
Mudstone
C
E


E
A
A
D
B
B
D
C

The Fossil Record

- One of the major clues that show that the Earth is very old, and that life has existed for a long time is the presence of **fossils** of organisms that do not exist at the present.
- A **fossil** is considered to be any evidence of **ancient** life - that is, life before written human history.

- The first organisms that appeared on earth were **simple** in structure.
- Over time, organisms increased in **size** and complexity.
- Some organisms disappeared, and some were **replaced** by new, but similar organisms.

Uses of Fossils

- **Fossils have three major uses:**
  - To **date** geologic structures and events (both relative and absolute ages).
  - To allow scientists to make **inferences** about ancient climates and landforms
  - To show the **variety** of life forms that have existed in the past and may or may not be extinct. This gives us a better knowledge and understanding of the **evolution** and development of present life forms.

Classification of Fossils

- The common system used today to classify **lifeforms** has a hierarchical structure.
- Starting from the individual organism, it works up through larger and larger **categories** until we are left with a few very large groupings.
- It is a seven step sequence, with the major groups from largest down to individual organism being - **Kingdom**, Phyla, Class, Order, Family, Genera and **Species**.

Classification of the common dog:

Kingdom animalia

Phyla chordata

Class mammalia

Order carnivora

Family canidae

Genera canis

Species familiaris

- Paleontologists use a simplified form of this classification that focuses mainly on **phylum** and **class**
- This is partly because we cannot go back and examine the **internal** structures of fossils, but also because most **soft** organisms have not been preserved in the fossil record.

Table 16-1 ABBREVIATED CLASSIFICATION SYSTEM (Paleontologists)

Kingdom	Phylum	Class	Common name and/or description
Protista	Cyanophyta		Blue green algae
	Protozoa		Foraminifera, Radiolaria - single celled microorganisms
Animalia	Porifera		Sponges
	Cnidaria		Jellyfish, Corals, Sea Anemones
	Bryozoa		Moss animals - small colonial animals
	Brachiopoda		Brachiopods/Lamp Shells - unequal shelled bivalves
	Echinodermata		Starfish, Sand dollars, Sea Cucumbers, Sea Urchins, Crinoids,
			Blastoids (ext), Cystoids (ext) - animals with five-fold symmetry
	Mollusca	Pelecypods	Clams, Oysters - animals with approximately equal shells
		Gastropods	Snails
		Cephalopods	Squid, Octopus, Nautiloid,
			Ammonoid (ext)
	Annelida		Segmented Worms
	Arthropoda	Trilobita	Trilobites (ext),
			Eurypterids (ext)
		Crustacea	Lobsters, Crabs - animals with an exoskeleton & jointed legs
		Insecta	Insects, Spiders
	Hemichordata		Graptolites (ext)
	Chordata	Pisces	Fish
		Amphibia	Frogs & Amphibians
		Reptilia	Dinosaurs (ext), Icthyosaurs (ext), Plesiosaurs (ext), Reptiles
		Aves	Birds
		Mammalia	Mammals
Monera			Bacteria
Fungi			Fungi, Lichens
Plantae	Bryophyta		Mosses, Liverworts
	Pterophyta		Ferns, Horse Tails, Club Mosses
	Spermaphyta	Gymnosperms	Seed Ferns, Cycads, Ginkos, Conifers
		Angiosperms	Trees, Shrubs, Palms, Grasses - flowering plants

Note: - ext. = extinct

Coral


Brachiopod


Crinoid


Ammonite


Trilobite


Graptolite

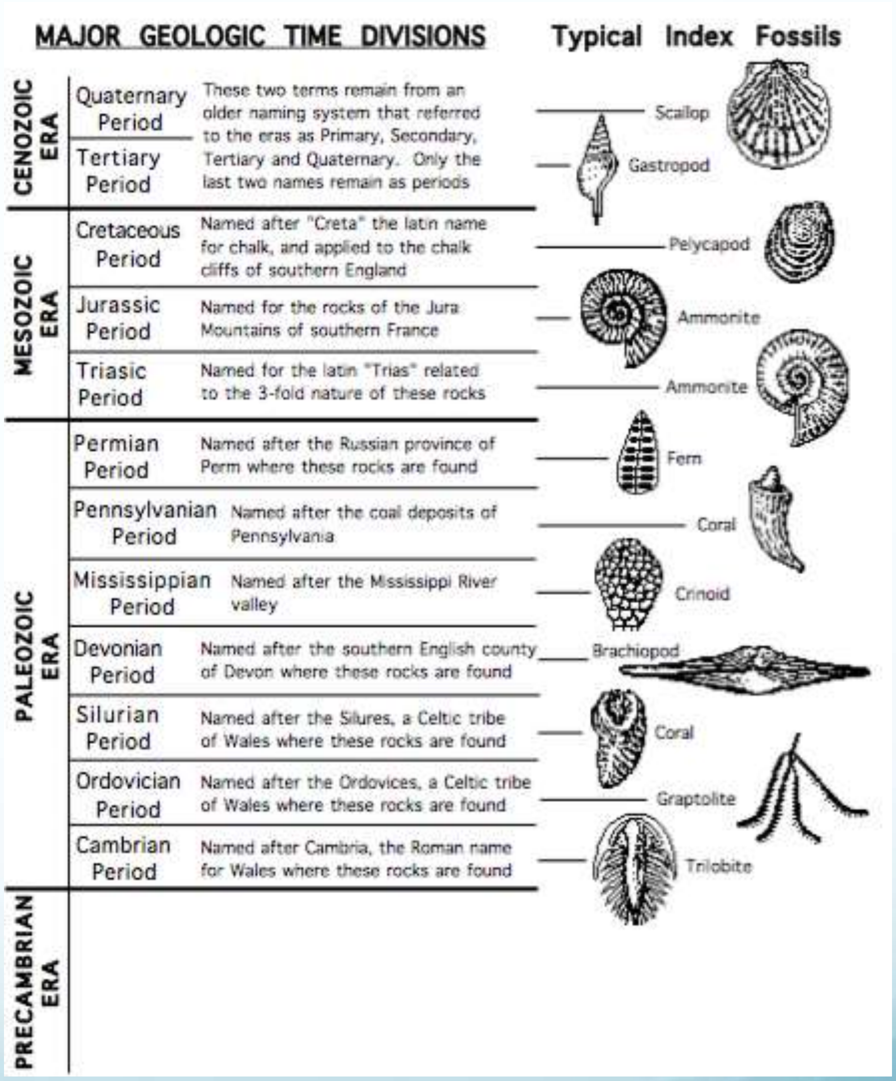

Fossils and the Relative Time Scale

- For the longest time, determining relative ages was the **best** that geologists could do in their attempts to date rocks and determine an age for the Earth.
- Index fossils were reliable dating **tools**, as certain key fossils only appear in rocks of specific **relative** ages.

Divisions of Time

- Geologic time was originally divided into four **eras**, which were further divided into **Periods**.
- The Eras were named according to their common **life forms**:
  - The Cenozoic is **recent** Life
  - The Mesozoic is **Middle** Life
  - The Paleozoic is **Early** Life.
  - The Precambrian (the greatest part of Earth's history, was originally thought to be **devoid** of life)

- The traditional Geologic Time Divisions of Eras and Periods, defined during the **1930s**, are listed in the figure along with the derivations of their names and sample **index** fossils.



Modern Divisions of Geologic Time

Eras

- **largest** division on the time scale
- ranges from millions of years to **billions** of years

Archean Era (4.6 billion y.a. – 2.5 billion y.a.)

- **earliest** rocks
- no evidence of **life**

Proterozoic Era (2.5 billion y.a. – 570 million y.a.)

- simple plants and animals in **oceans** ONLY (no land animals)
- few fossils, as organisms lacked hard **shells** or skeletons
- time of great **volcanic** activity and metamorphism

Paleozoic Era (570 million y.a. – 250 million y.a)

- more abundant fossil record
- both **land** and **ocean** plants and animals

Mesozoic Era (250 million y.a. – 65 million y.a.)

- Age of **reptiles** (dinosaurs ruled the earth!)

Cenozoic Era (65 million years ago – present)

- age of **mammals**

Periods

- **subdivision** of eras
- periods differ in plant and animal life, but **less** so than between eras

e.g., Quaternary, Jurassic

Epochs

- subdivisions of **periods**
- changes in life not as **large** as in periods

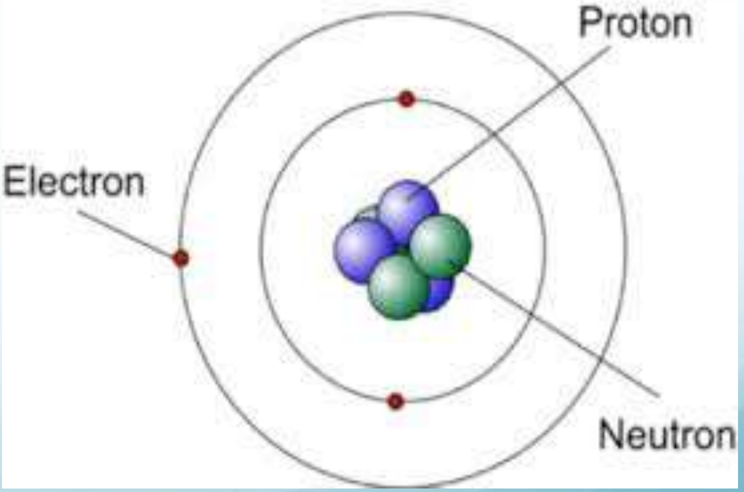
  e.g., Holocene, Pleistocene

Absolute Age

- Although relative ages can be useful, absolute age methods that try to place a **narrow** specific age range on a rock formation can be much more **informative**.
- The most common method of dating rocks is using **isotopes**.

<u>Structure of the Atom (Review)</u>

- According to the Bohr model of the atom, the atom has a central **nucleus** surrounded by **electrons** that orbit in very discrete zones or **<u>shells</u>**.
- The nucleus contains:
  - the **<u>positively</u>** charged protons
  - The neutrons with no **<u>charge</u>**
- In a neutral atom, number of positively charged protons **<u>equals</u>** number of negatively charged electrons.



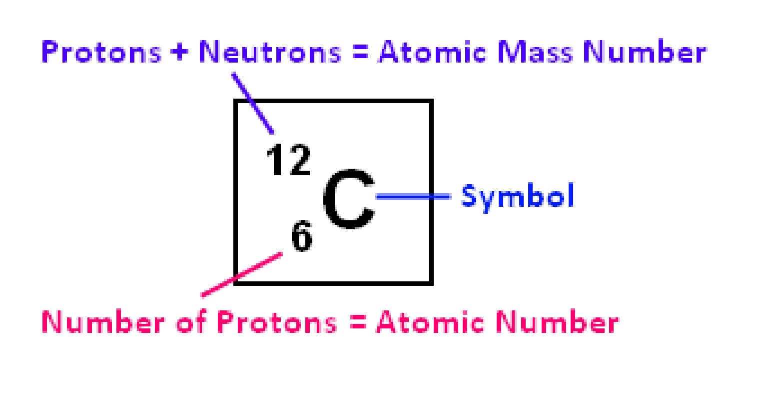
The Atomic Number (Z):

- Represents the number of **protons** and electrons in a neutral atom

Atomic Mass (A):

- total **mass** of protons and neutrons (each has a mass of 1u).

- It takes about 2000 electrons to equal the mass of a proton or neutron, and therefore their mass is **ignored**.



Neutral Lithium atom:

- Atomic Number (Z) = ____
- Number of Protons = ____
- Number of Electrons = _____
- Number of neutrons = ______
- Atomic Mass (A) = ___________

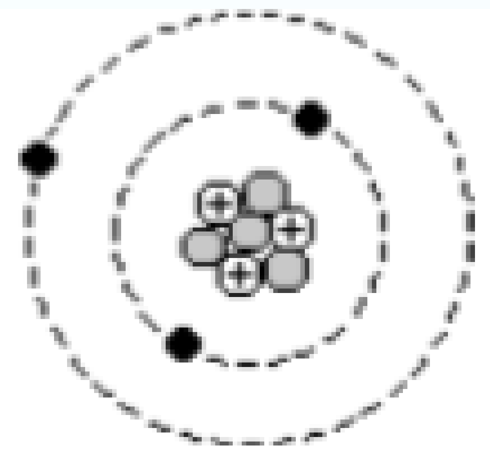


Fig. 17-2 Bohr model of a neutral Li atom.

Isotopes

- Changing the number of protons, neutrons or electrons in an atom can change the **nature** of the atom.
- If **protons** are removed or added to an atom, it changes to a **new element**.
- If **neutrons** are added or removed, the only thing that changes is **mass** of the atom.
- These heavier or lighter forms of the same atom are known as **isotopes.**

- All of the isotopes of an element have the same number of **protons**.
- However, there are different numbers of **neutrons** in atoms of different isotopes, so the masses are also different.
- Some isotopes occur naturally and are generally **stable**. Other isotopes are made **artificially**.

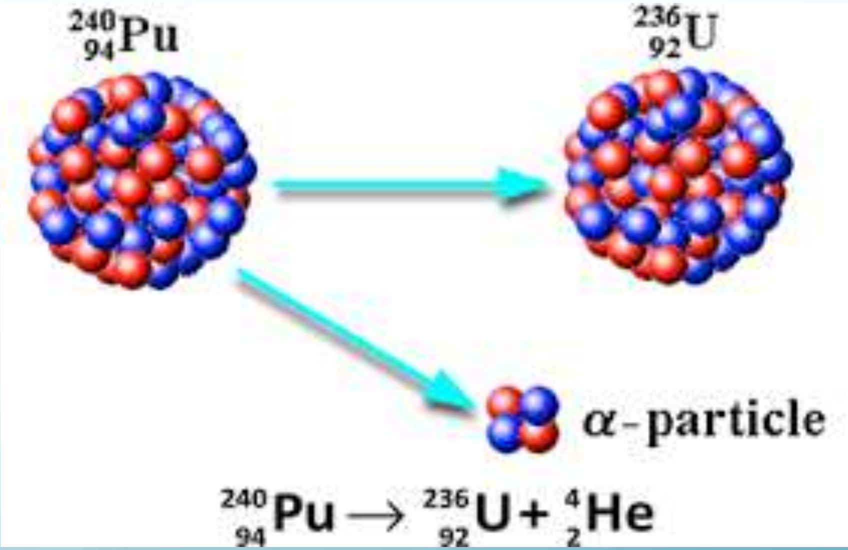
Radioactive Decay

- Most **natural** isotopes are stable, while many isotopes that are made in the laboratory are **unstable**.
- Unstable isotopes have a nucleus that does not have the correct "**energy** balance" between the protons and neutrons.
- Neutrons provide **stability** to the nucleus.

Radioactive Decay

- If an isotope has too few or too many neutrons, it may break apart in a process called **radioactive decay,** to form new elements.

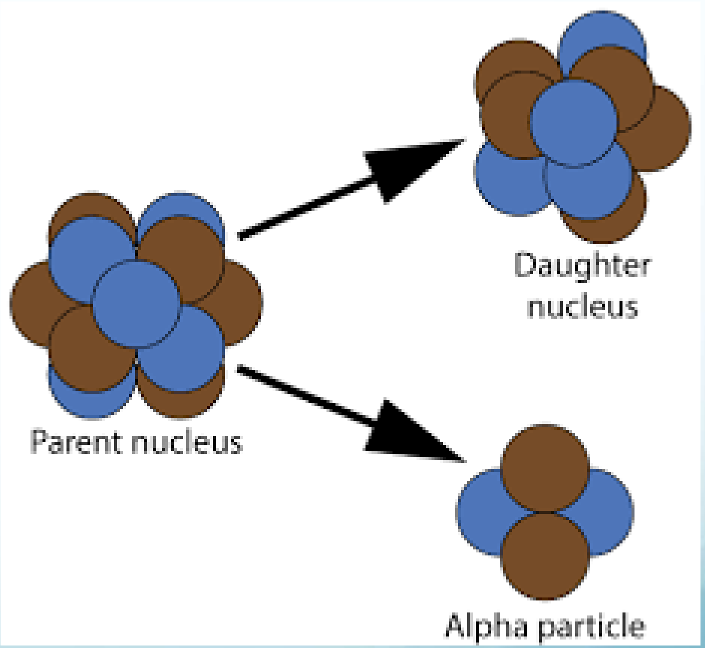
- This decay occurs either by losing extra **neutrons**, or by changing them in some way.



- Isotopes that tend to undergo radioactive decay are called **radioisotopes**.

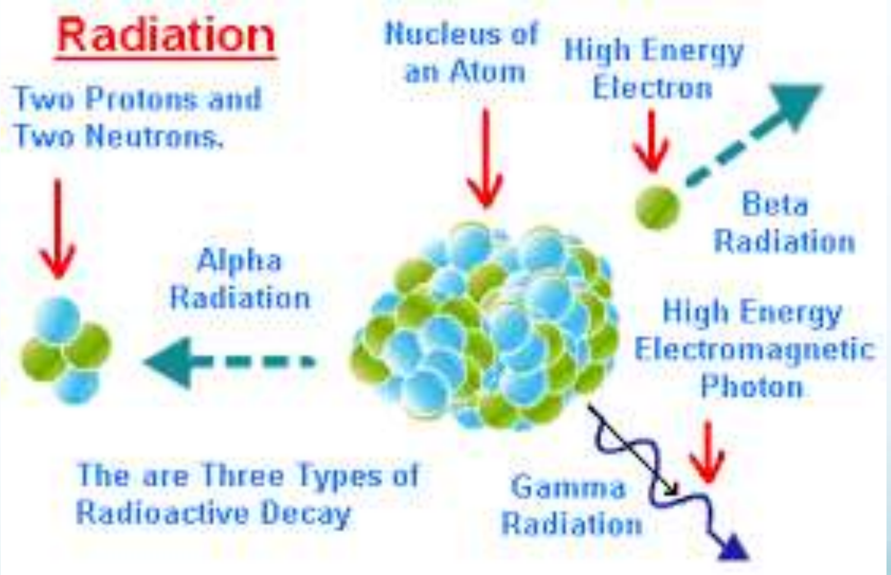
- The decaying nucleus is often called the '**Parent** nucleus'

- The product is called the '**Daughter** nucleus'



Radioactive Decay Products

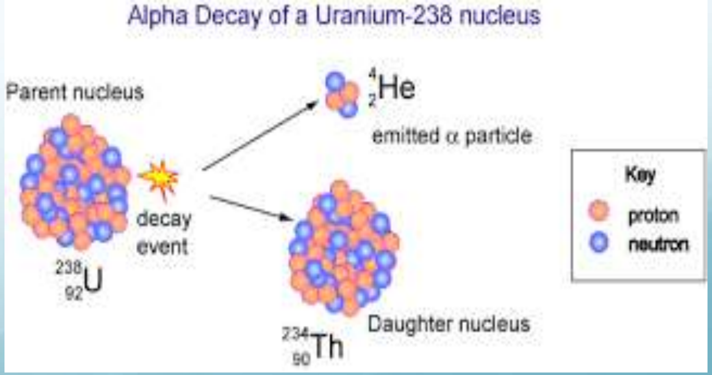
- Although many particles can be given off by these decay products, the main ones are:
  - **Alpha** particles
  - **Beta** particles
  - **Neutrons**
  - **Gamma** rays



Alpha Decay

- An **alpha (α) particle** consists of two **protons** and two **neutrons** (the same as the nucleus of a helium atom).
- When an α particle is emitted, the mass of the atom drops by **4** u and the atomic number drops by **2**.
- This is illustrated by the decay of Uranium-238 to Thorium-234:

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$$



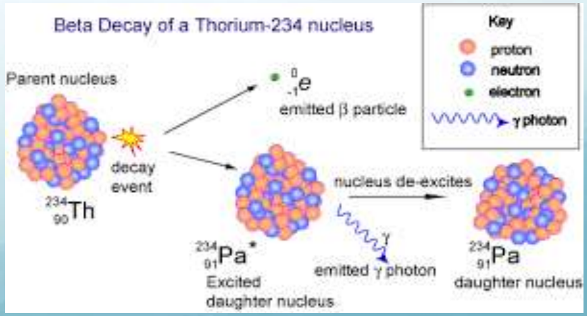
$$^{191}_{76}\text{Os} \rightarrow {}^{?}_{?}? + {}^{4}_{2}\text{He}$$

$$^{209}_{84}\text{Po} \rightarrow {}^{?}_{?}? + {}^{4}_{2}\text{He}$$

Beta Decay

- A **beta particle (β)** is a high-speed **electron** produced from the nucleus of an unstable atom.
- β particles come from the decay of a neutron into a **proton**, so the mass stays the same. T
- However, the number of protons (and therefore the atomic number) increases by **one** while the number of neutrons **decreases** by one.
- β particle decay occurs when Thorium-234 decays to Protactinium-344:

$$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}\mathrm{e}$$



$$^{14}_{6}\text{C} \rightarrow {}^{?}_{?}? + {}^{0}_{-1}e$$

$$^{87}_{37}\text{Rb} \rightarrow {}^{?}_{?}? + {}^{0}_{-1}e$$

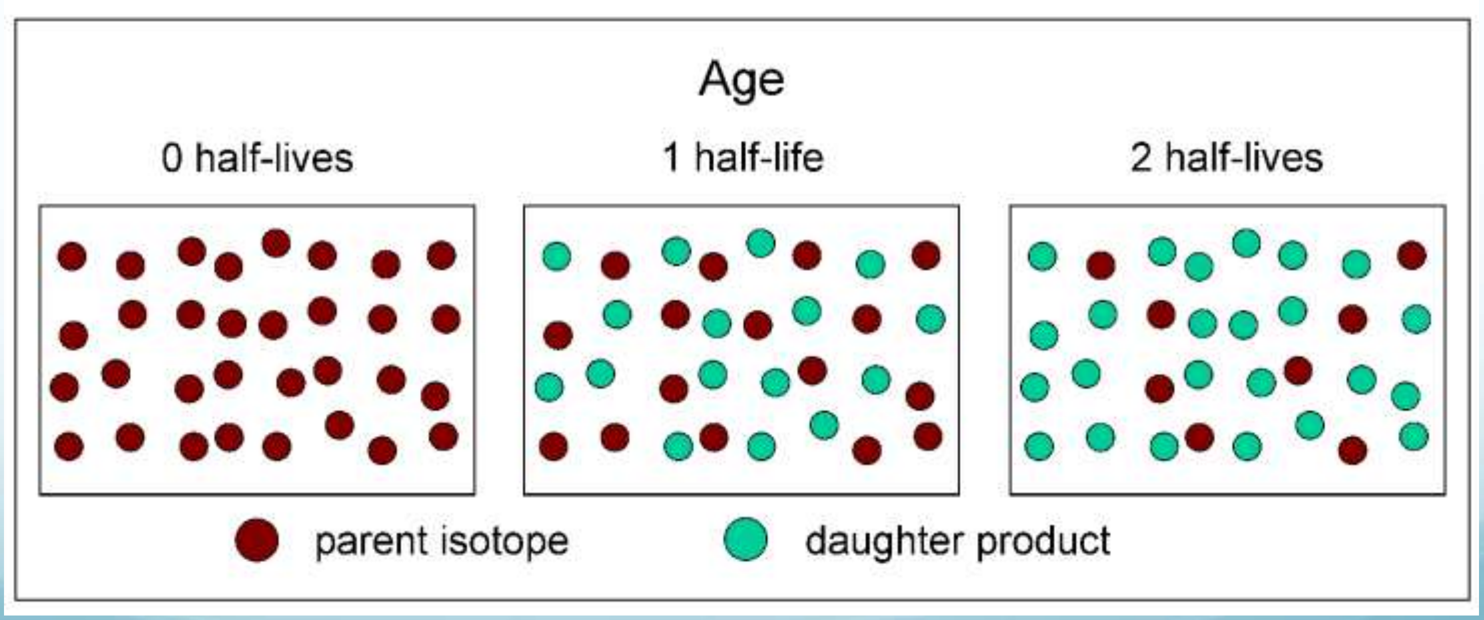
Neutrons

- **Neutrons** are a heavy neutral particle found in the nucleus of almost all atoms.
- Loss of a neutron reduces the **mass** of the isotope by 1 u.

Half-Lives and Decay Curves

- In any sample of a radioisotope no one can predict when any one **specific** atom will decay.
- It could decay in the next second, tomorrow, next month, next year or even not for **hundreds** of years.
- Although the actual time that this particular atom will decay cannot be predicted, scientists can measure the average **rate** at which many particles disintegrate.

- . The decay rate of a material is called the **half-life** of that material.
- The half-life is the time it takes for half the sample to **decay** to its new product.



Decay Curve

- A typical decay curve of element ‘A’ to Element ‘B’:

- Element ‘A’ starts with mass of **16** g.
- After 1st half-life, mass of ‘A’ has dropped to **8** g, while the rest has changed into **8** g of Element ‘B’.
- After 2nd half-life, there is only **4** g of ‘A’ and now **12** g of ’B’.
- After 3rd half-life, **2** g of ‘A’ and **14** g of ‘B’
- This process continues to the last **atom** of ‘A’.

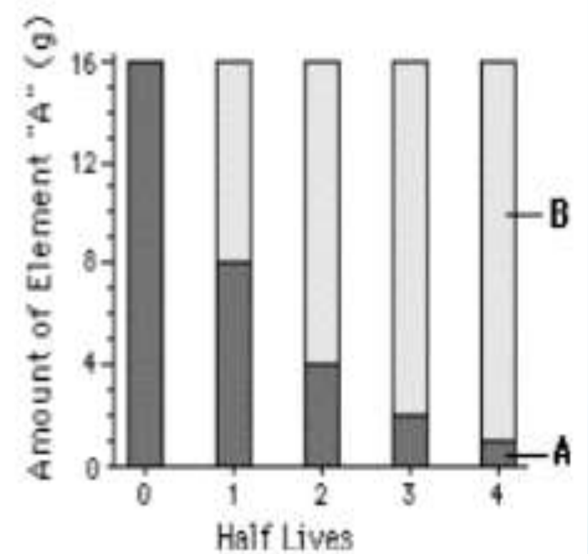
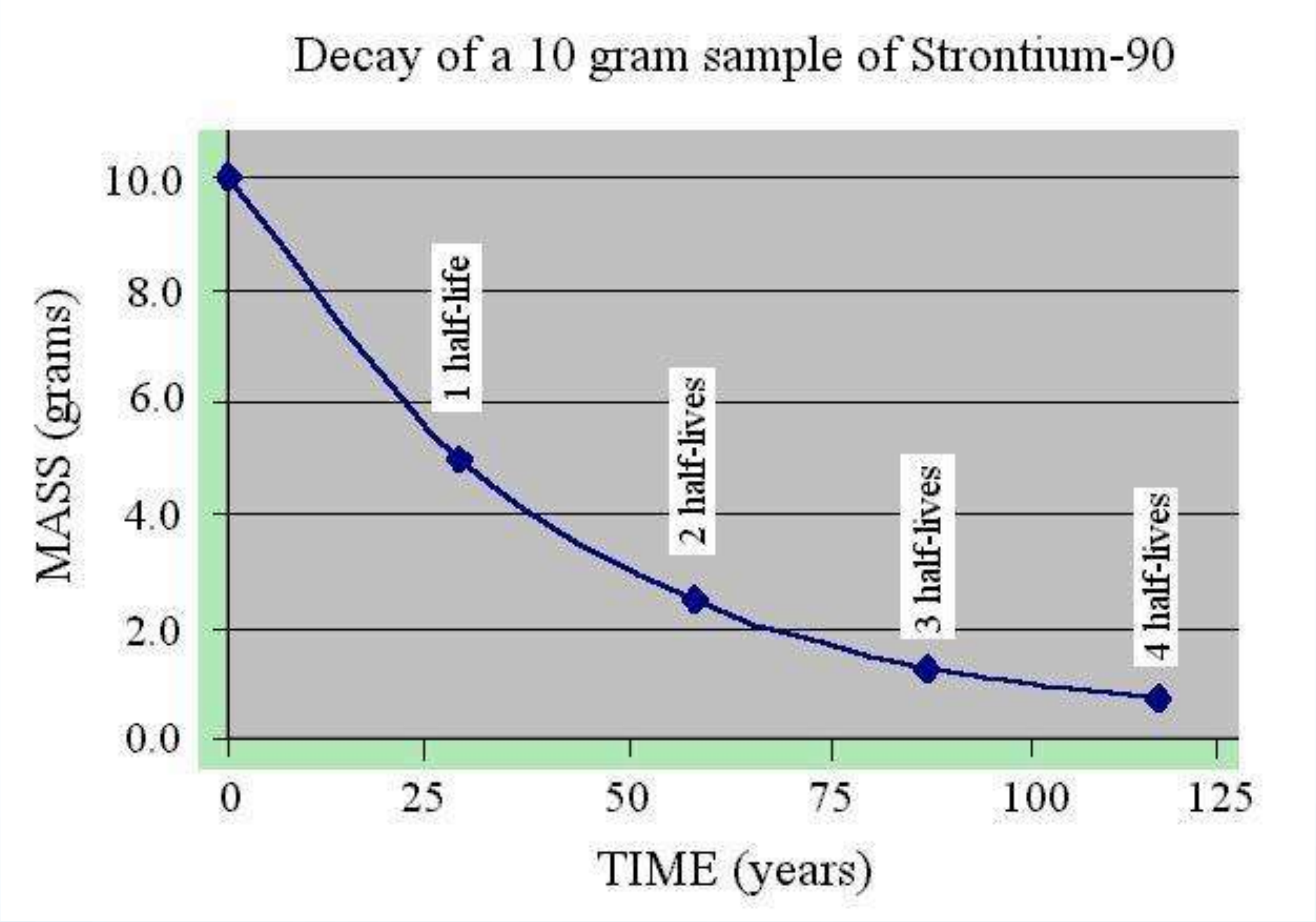
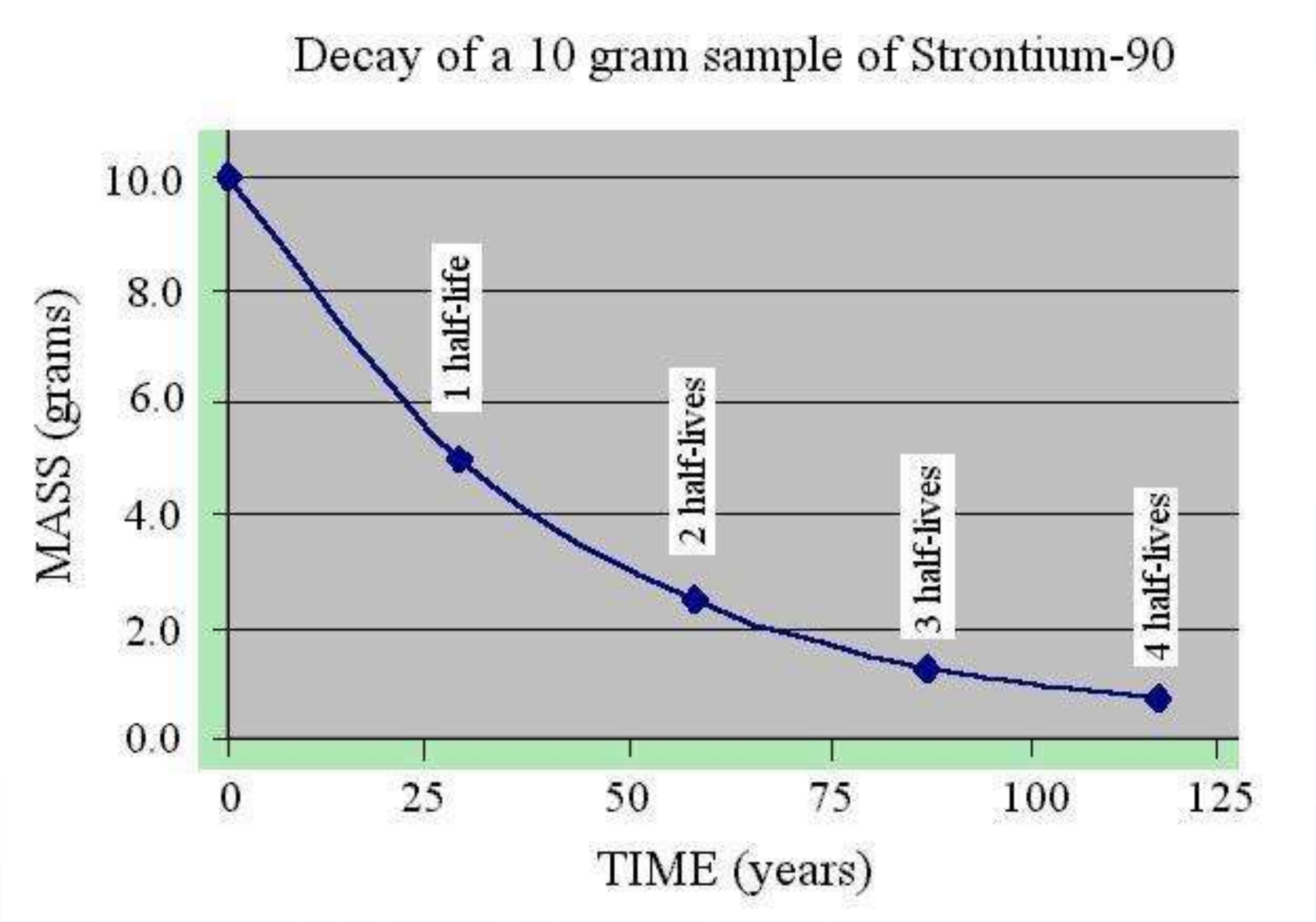


Fig. Typical decay bar graph of element A to element B.



What mass of strontium-90 would remain after 2 half-lives?



If 0.625 g of strontium-90 remain, how many half-lives have passed?

Practice:

1. Element Z-50 has a half-life of 25 days. If 3 g remains of from the original 81 g sample…
   a) How many half-lives have passed?
   b) How many days have passed?

Practice:

1. Element Q-205 has a half-life of 40 years.
   a) How many years have passed after 3 half-lives?
   b) How many grams would remain from a 100 g sample of Q-205?

Common Geological Isotopes

- The common decay processes used in **age** measurements are listed in the table below together with their accepted half-life values (the symbol "a" after the number represents years) and **dating** range

Isotope Pairs Used for Radiometric Dating

Isotope		Half-life of Parent (years)	Effective Dating Range (years)
Parent	*Daughter*		
Uranium-238	Lead-206	4.5 billion	1 million to 4.5 billion
Rubidium-87	Strontium-87	48.8 billion	10 million to 4.5 billion
Potassium-40	Argon-40	1.3 billion	10 000 to 3 billion
Uranium-235	Lead-207	715 million	10 million to 4.6 billion
Carbon-14	Nitrogen-14	5 730	< 100 000

- Although these isotopes are found in many rocks, the process is really only useful for finding the age of unaltered **igneous** rocks.
- These methods cannot be used to find the ages of clastic sedimentary or metamorphic rocks because they have always been **changed** from their original state.

- For example strata (rock layers) are often comprised of "undateable" rock.
- In clastic sedimentary rocks, any dates would be for the '**parent**' material, not the sediments.
- However, the ages can be estimated based on the dateable ages of igneous rocks above or below the strata, or of **dikes** within the strata (which must be **younger** than the sediments they intrude).

Choice of Isotopic System

When choosing an isotope, you must have:

- Enough **parent** isotope left to measure
- The **daughter** isotope should not be found in the rock to begin with.
- The half-life must be **appropriate** for the age of the rock.

- If the half-life is 5000 years, you cannot use it to date a rock that is 500,000 years old (there won't be enough **parent** material left)
- If the half-life is 1 million years old, you cannot use it to date a rock that is 5000 years old (there won't have been enough **daughter** material produced yet).

Long-Lived Radioactive Dating Pairs

- **Long-lived** parent-daughter isotope pairs have half-lives that are millions or billions of years.
- All were present when the earth **formed**, and can still be found in measurable amounts.

Uranium-Lead Pair

- One dating pair is uranium-lead, where U-238 undergoes a series of decay processes to produce Pb-206 (the stable **daughter** product).
- Since the half-life of U-238 is 4.5 billion years, this method can be used to date the **oldest** rocks on Earth, but tends to be unreliable in rocks less than about **10 million** years old.

- In addition, this method can only be used on rocks that contain the right kind of **uranium** isotope.
- Uranium is **rare** and is only found in some igneous rocks.

Rubidium-Strontium Pair

- The rubidium-strontium pair is often more useful because it **naturally** occurs in feldspars and micas.
- Like uranium-238, however, it has an extremely long **half-life** (about 49 billion years!), so it can also only be used to date **ancient** rocks.

Potassium-Argon Pair

- Potassium-40 can be incorporated into igneous rock during the crystallization of many common minerals, including potassium **feldspar**.
- Its daughter product (Ar-40) is a **noble** gas, so doesn't usually get incorporated it rocks when they crystallize.
- Therefore, any Argon-40 found within a rock must be daughter material produced from the **decay** of K-40.

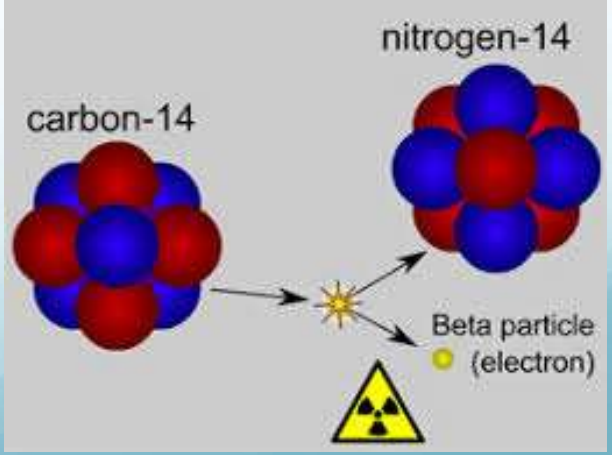
- By looking at the ratio of K-40 to Ar-40, it’s possible to estimate how **long** ago the rock crystallized.
- Because potassium is a **common** element and has a shorter half-life, the K-Ar method can be used to date many igneous rocks that cannot be dated by uranium or rubidium.

Carbon-14 Dating

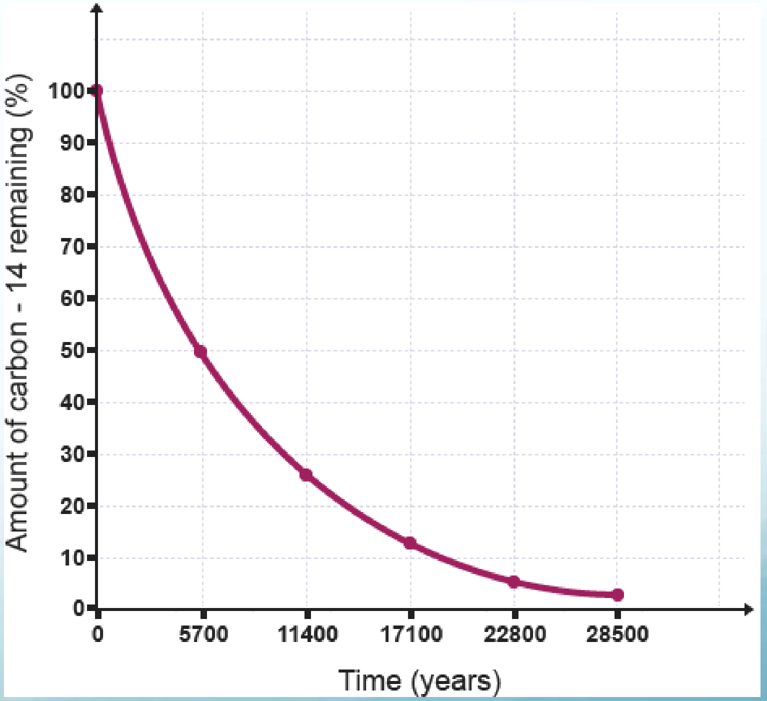
- Since the early 1940's, carbon-14 has been used for dating purposes.
- This method, however, can only be used on **carbon-**containing material such as bones and wood that have not been petrified.
- These dates can then be used to predict an age for the **sediments** in which they are found.
- This age can be compared and checked with the accepted **relative** age.

Carbon-14 Dating

- Radioactive carbon-14 continuously forms in the upper atmosphere when Nitrogen-14 is bombarded with **cosmic** rays.
- Living organisms **absorb** carbon-14 during their life (along with regular, non-radioactive carbon-12).
- After death, the carbon-14 starts to **decay** back to nitrogen-14.



- The decay graph shows the **change** from carbon-14 to nitrogen-14.
- Since nitrogen is a **gas**, it escapes into the atmosphere and cannot be accurately measured.
- Instead of looking at the Carbon-14/Nitrogen-14 ratio, scientists use the ratio of Carbon-14 to **Carbon-12**.



- As time passes and carbon-14 decays, the ratio will get smaller and **smaller**, and an age of the sample can be estimated.
- One problem with carbon-14 dating, however, is it can become very difficult to count very **small** numbers of carbon-14 particles, so the useful range is less than **50 000 a**.