CE/SC 10110-20110

Geologic Time

Earth

Portrait of a Planet

Fifth Edition

Chapter 12
Interlude E

Deep Time: How Old is Old?

Geologic Time

Geologic time provides a frame of reference for understanding:

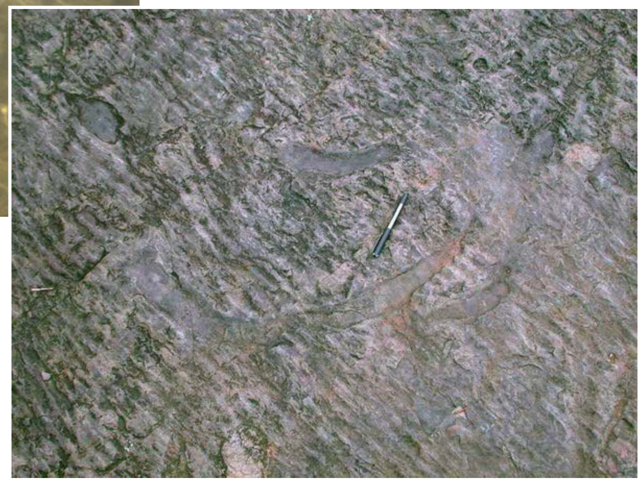
- Rocks
- Fossils
- Geologic structures
- Landscapes
- Tectonic events
- Change

Geologic Time

James Hutton (1726–97), a Scottish physician and farmer, was the first to articulate the Principle of Uniformitarianism. He realized that vast amounts of time were necessary for Earth processes to create rocks. For this discovery, he is called the "Father of Modern Geology."

Geologic Time

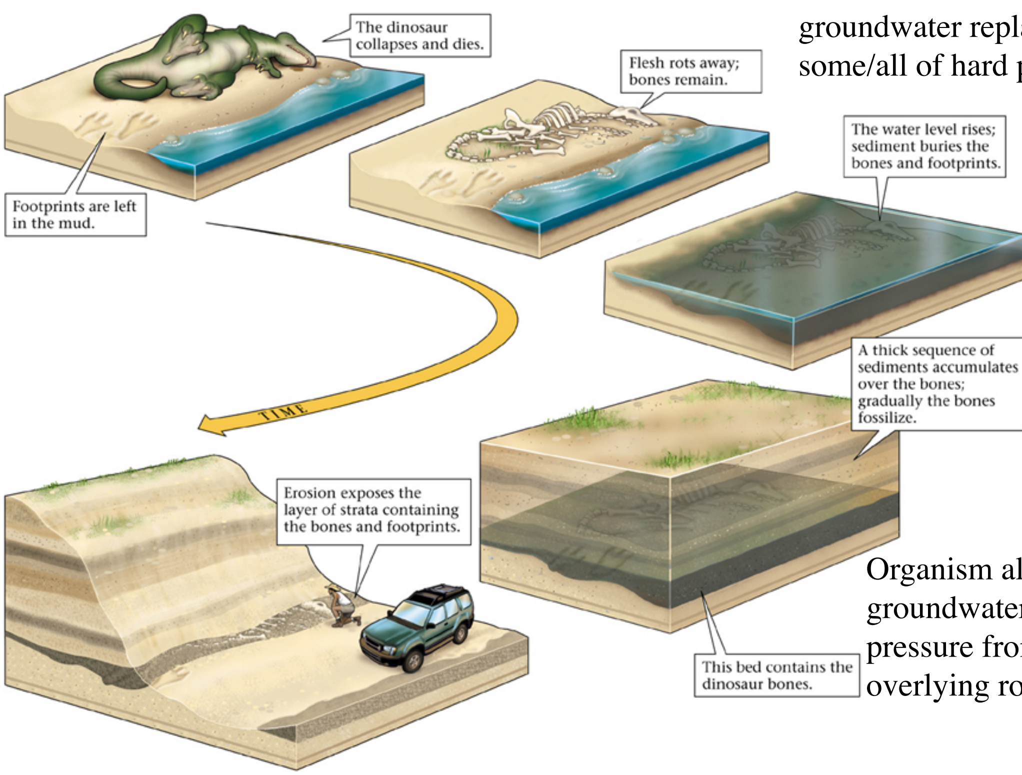
James Hutton's Principle of Uniformitarianism is paraphrased "the present is the key to the past."



His idea was that the processes we see today are the same as those that operated in the past. Geologic change is slow; large changes require a long time.

Fossilization

Minerals from groundwater replace some/all of hard parts.



Organism altered by groundwater and/or pressure from overlying rock.

Fossils

Fossil: remnant or trace of an ancient living organism that is preserved in rock or sediment.

The level at which an organism went extinct represents the time it went extinct.
Most fossils found in sedimentary rocks.

Fossils can survive low level of metamorphism.
Fossils can also occur in volcanic ash (in reality ash is a sediment).
Lava flows can take on the shapes of tree trunks (lava trees).

Fossil Types

Body Fossils: whole bodies or body parts.

Trace Fossils: left by the organism.

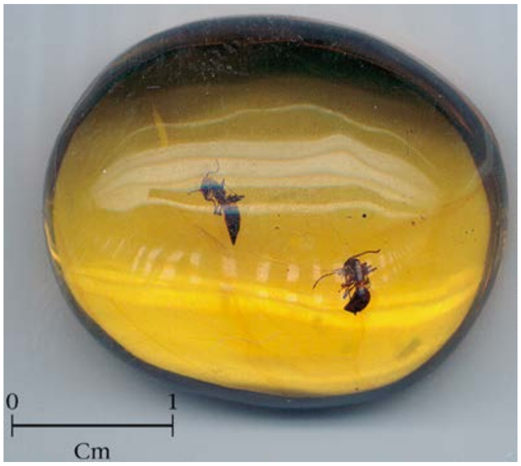
Chemical Fossils: chemicals formed by the organism, now preserved.

Body Fossils

Frozen/Dried: relatively young (thousands not millions of years).

Fossil Types

Preserved in Amber/Tar:



Preserved/Replaced Bones, Teeth, Shells: Bones replaced by silica; Shells = aragonite, which breaks down.

Fossil Types

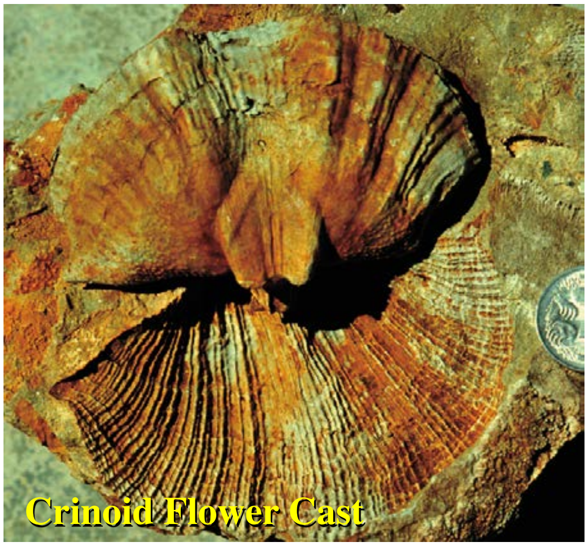
Permineralized Fossils: minerals precipitate in pores; Petrified wood. Cell structure preserved and wood is “turned to stone”. The cell wall remains as an organic film after petrification.

Petrified wood can form from siliceous ash falling on a forest.

Fossil Types

Trace Fossils

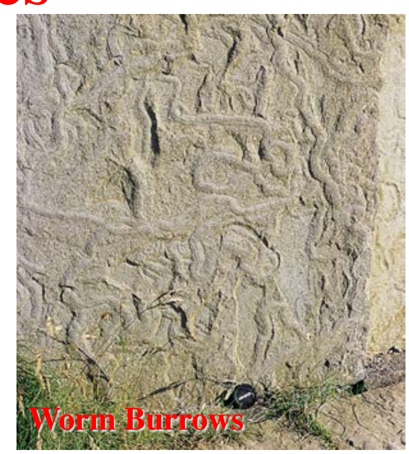
Molds/Casts of Bodies: original part/organism has disappeared, but impression is left.

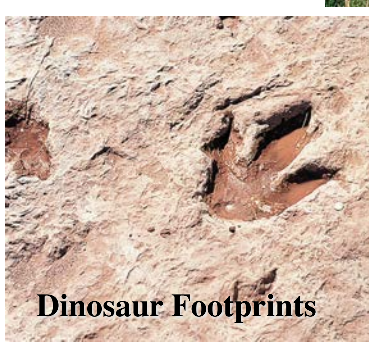


Carbonized Impressions: organism gets flattened between sediment layers. Chemical reactions leave only carbon.

Fossil Types

Trace Fossils:

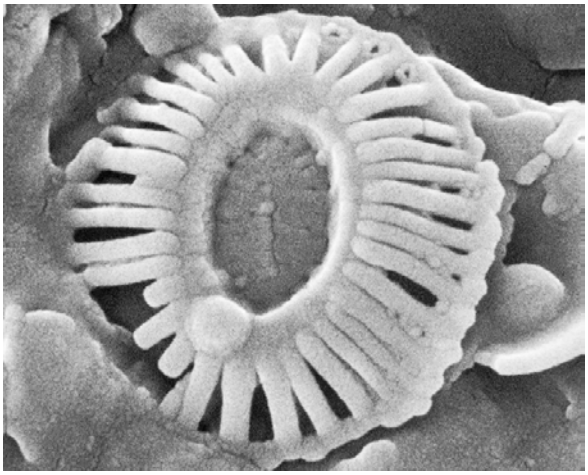




Fossil Types

Chemical Fossils: organisms consist of complex chemicals. During fossilization, some remain intact or break down to form distinctive chemicals.

Fossils also subdivided into ***macrofossils*** and ***microfossils***.



Microfossils: pollen, plankton, algae, bacteria.

Microfossils form deep sea oozes.

Useful for studying climate and climate change.

Fossil Preservation

Few organisms, when they die, leave a fossil. Needs at least one of the following:

- Death in an anoxic (oxygen-poor) environment;
- Rapid burial;
- Presence of hard parts;
- Lack of diagenesis or metamorphism.

Preservation Potential: how likely an organism will become a fossil. Interplay of the four fossilization parameters.

Extraordinary Fossils

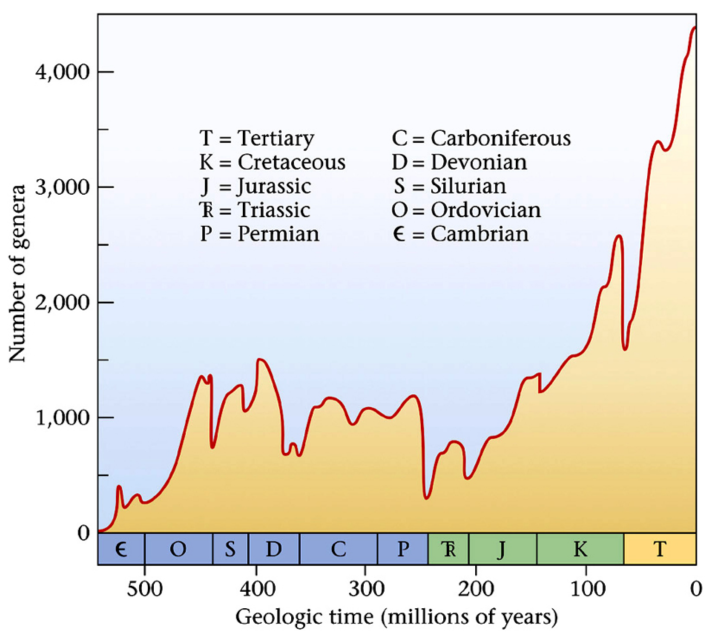
Parts preserved that shouldn't be!
Insects in amber; Anoxic lagoon/lake/ocean floors.

Solenhofen Limestone, Germany (49 Ma): Mammals, amphibians, fish, birds.

Burgess Shale, Canada (510 Ma):
Soft-bodies organisms preserved - no relatives alive present-day.

Extinction

Occurs when the last members of a species die.
Occurs when species cannot adapt to new environmental conditions, or a predator is too efficient (e.g., wooly mammoth).



Extinction

Mass Extinction: many species go extinct at the same time.

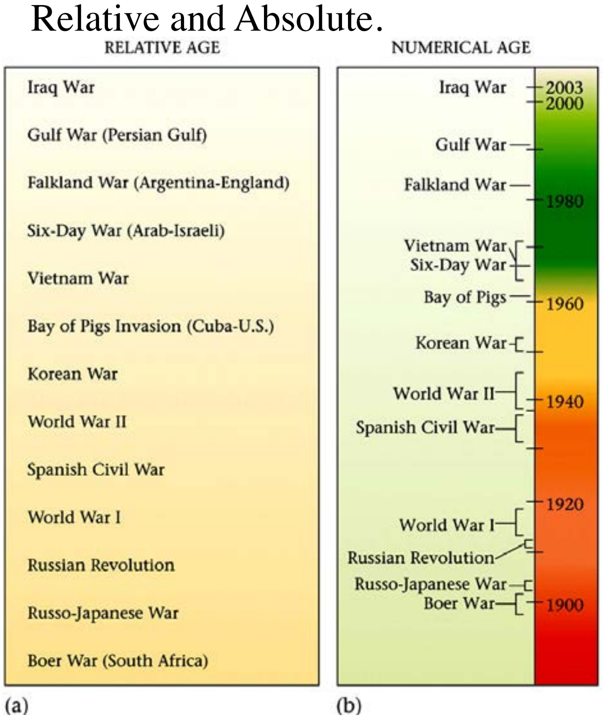
Causes: **Global Climate Changes**;

Tectonic Activity: ocean circulation changes; deserts form due to mountain building, etc.

Asteroid/Comet Impact: Chicxulub.

Geologic Time

Relative and Absolute.

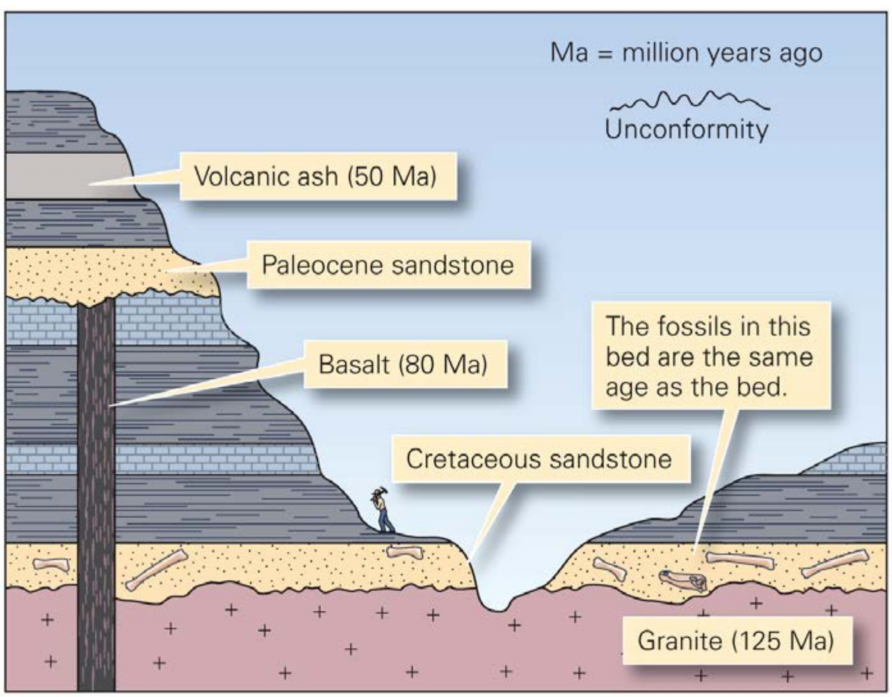


Relative Geologic Time

Concept that a specific sequence of events have resulted in the evolution of the Earth to its current state.

The relative timing of events may be unraveled by careful examination of the "Rock Record".

Relative vs. Numerical Geologic Time

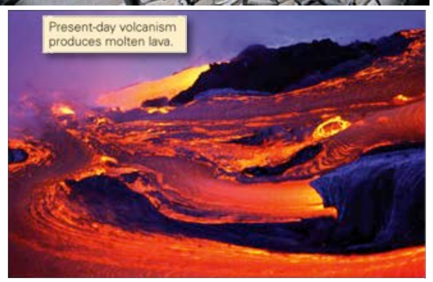


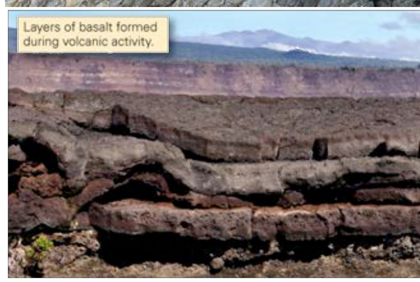
Relative Geological Time

Principles:

Principle of Uniformitarianism:
"The present is the key to the past".

Studying processes today gives insight into past events.

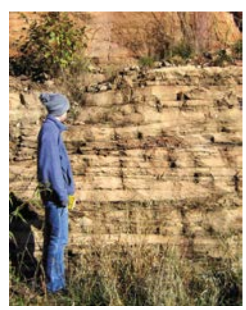




Relative Geological Time

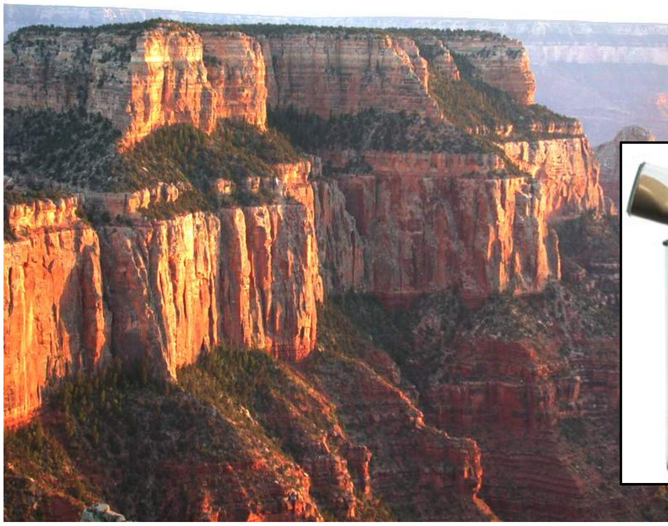
Principles:

Principle of Original Horizontality:
Beds of sedimentary rock are deposited in a horizontal orientation.



Relative Geological Time

Principles:



Principle of Superposition:

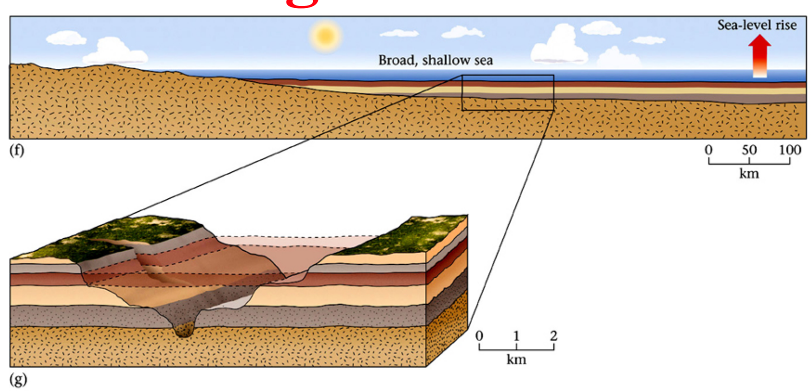
In a sequence of undisturbed sedimentary rocks, the layers get younger upwards.

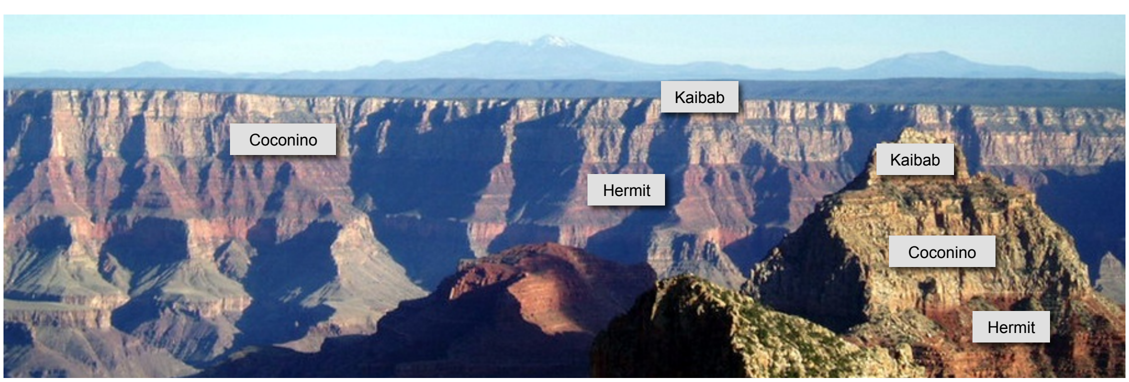
Relative Geological Time

Principles:

Principle of Original Continuity:

Sediments generally accumulate in continuous sheets.



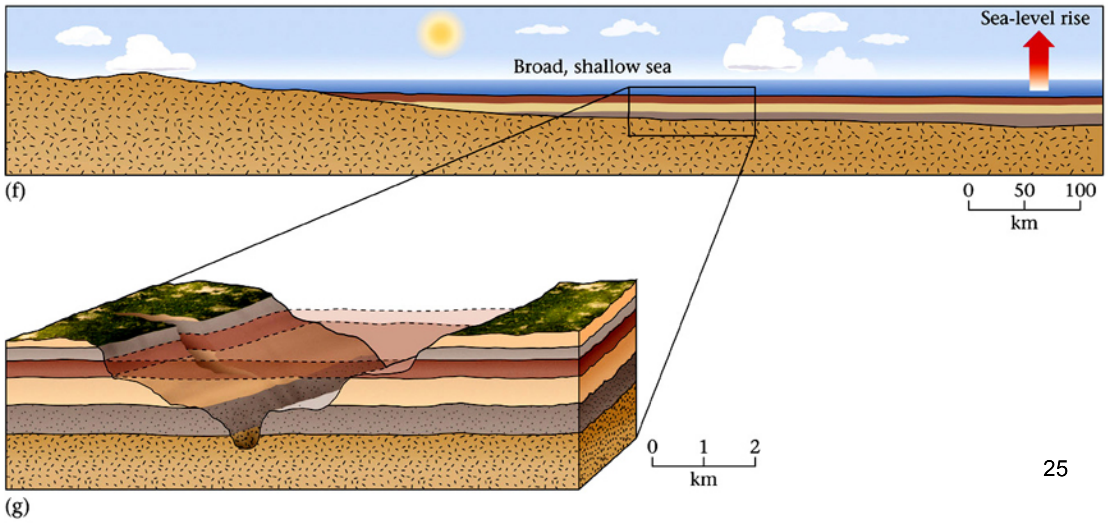


Relative Geological Time

Principles:

Principle of Lateral Continuity:

Original sedimentary layers extend laterally until they thin at its edges.

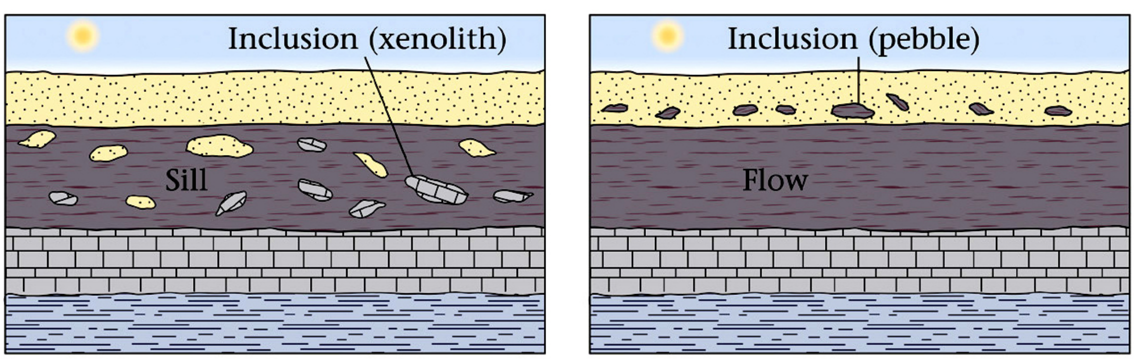


Relative Geological Time

Principles:

Principle of Inclusions:

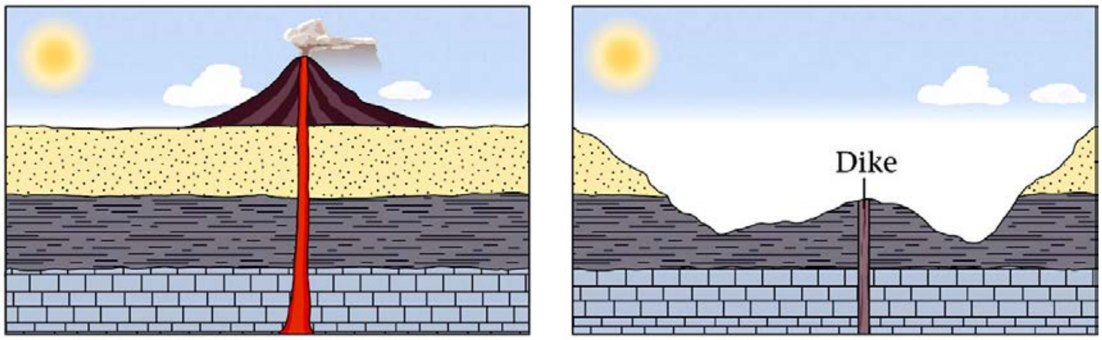
Inclusions are older than the rock in which they are contained.



Relative Geological Time

Principles:

Principle of Cross-Cutting Relations:
A disrupted pattern is older than the cause of the disruption.

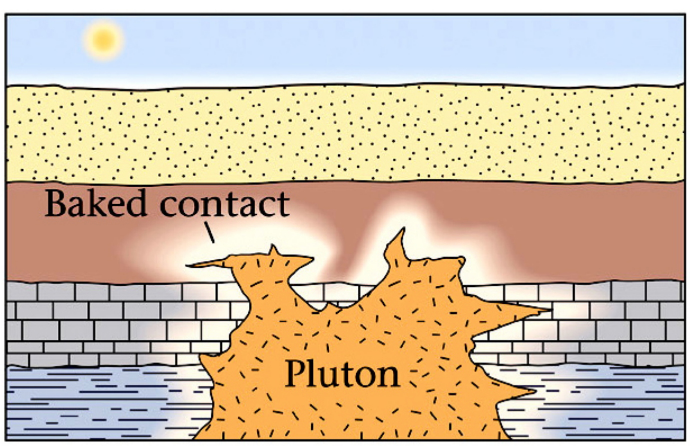


Time 1 Time 2
(h)

Relative Geological Time

Principles:

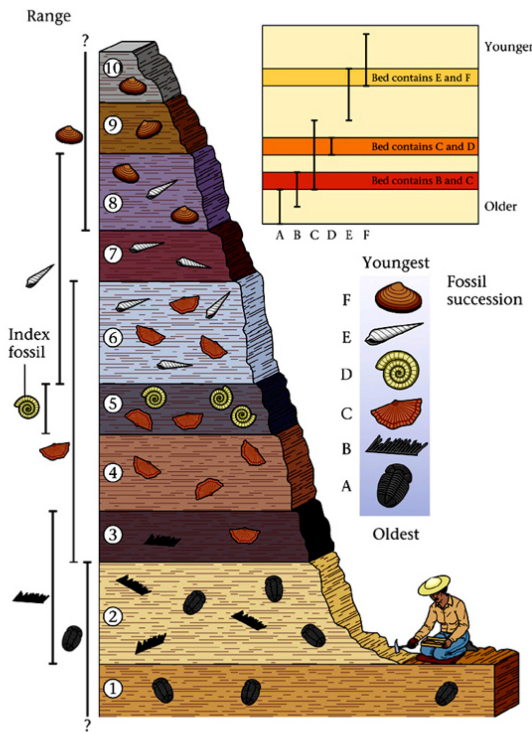
Principle of Baked Contact:
Rocks that have been baked by an igneous intrusion are older than the intrusion.



Relative Geological Time

Principles:

Principle of Fossil Succession:
Fossils contained in strata are related to the age of the rocks.



Unconformities

Surface that represents a break in the geologic record. The rock unit(s) immediately above the break is/are much younger than that/those below.

Usually represent buried erosional surfaces – parcel of geology is missing!
Bedding plane is different - it represents either a small break in sedimentation or a change in sediment type.

Three types of unconformity:
1) Disconformity;
2) Angular unconformity;
3) Nonconformity.

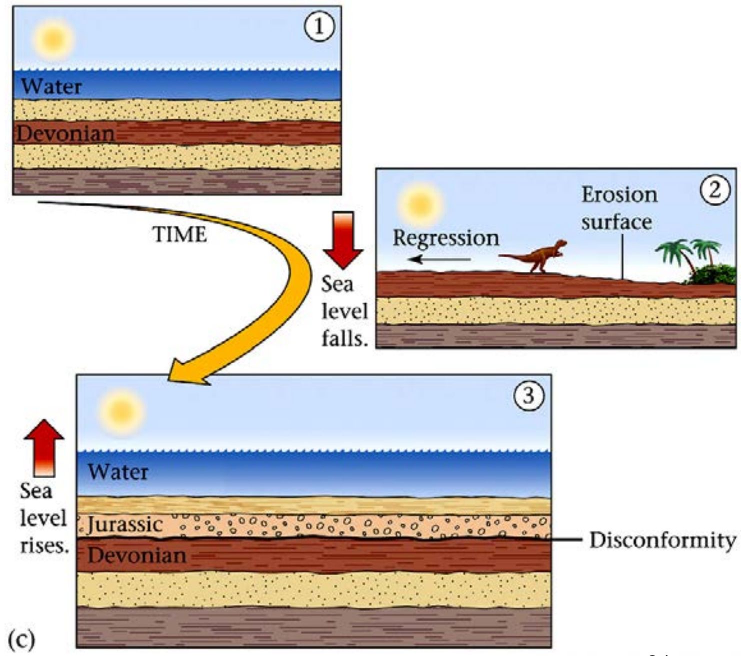
Unconformities

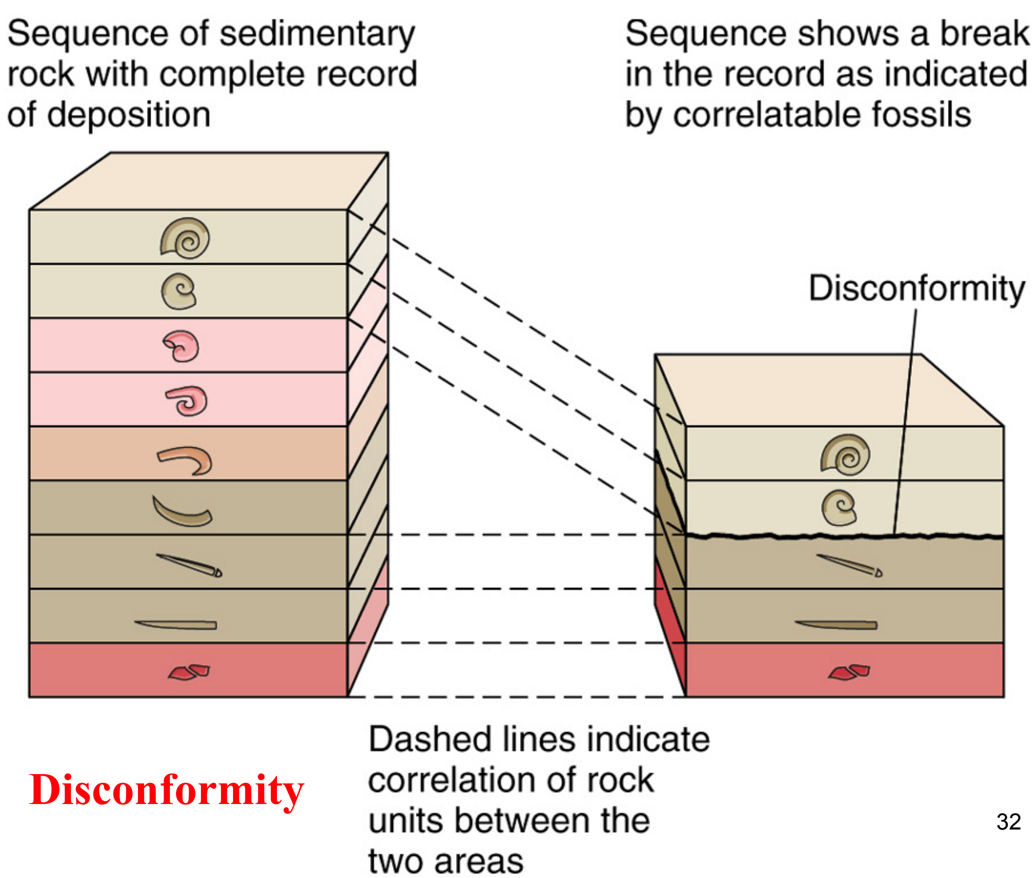
Three types:

1) Disconformity: unconformity is parallel to layering, but there is a gap in the geologic record.

Typically erosional and hard to spot.

Look for weathering surfaces, boulders/ pebbles of older rock in younger.

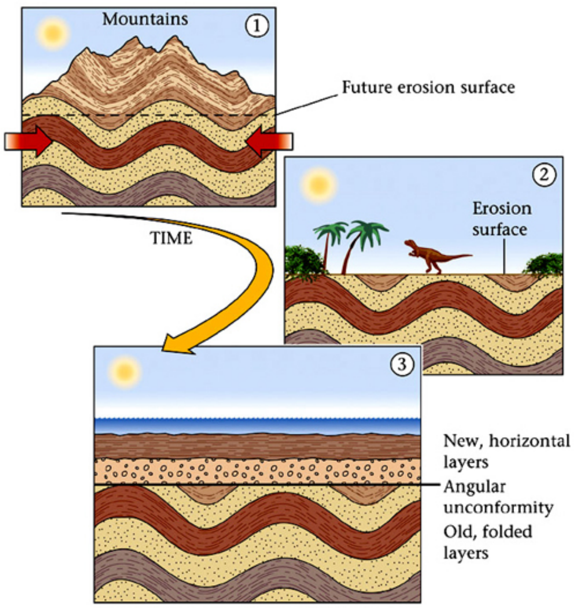


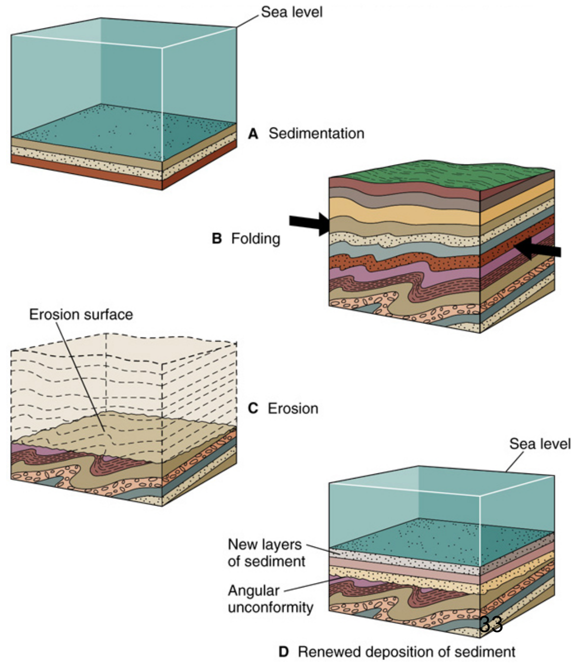


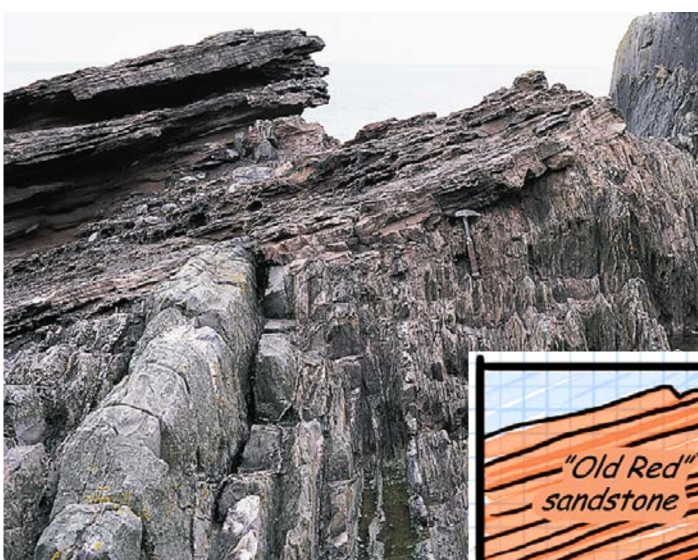
Disconformity

Unconformities

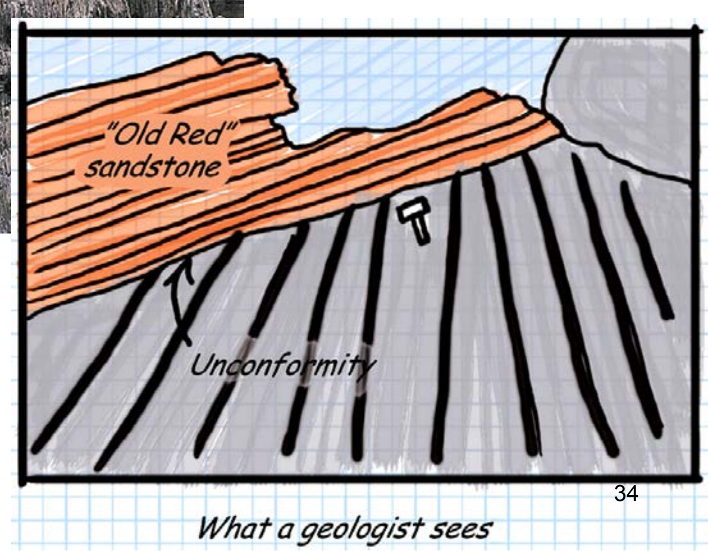
2) __Angular Unconformity__: Younger strata overly older rocks that were tilted/folded.





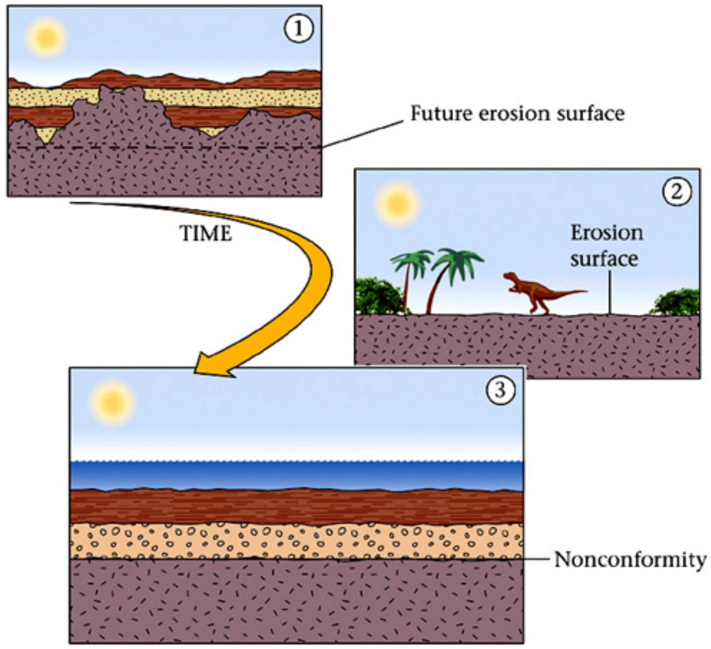


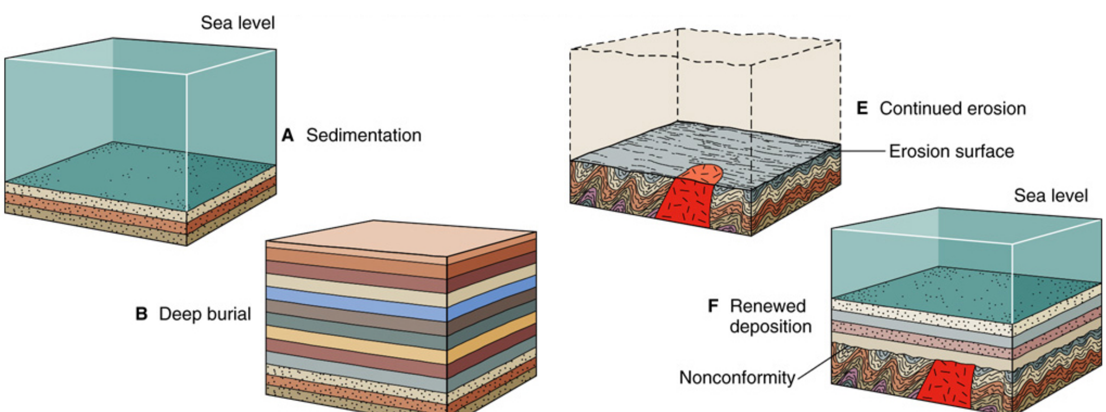
Angular Unconformity

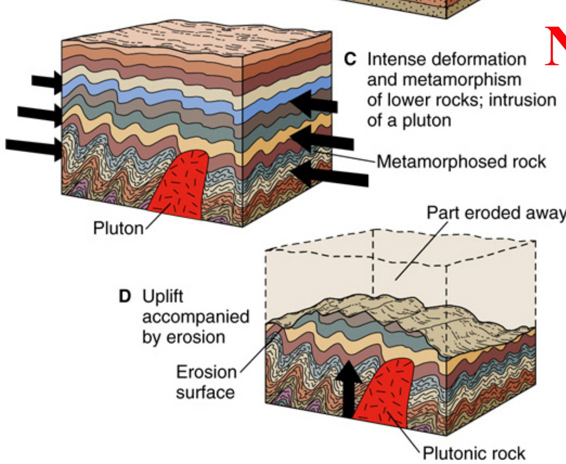


Unconformities

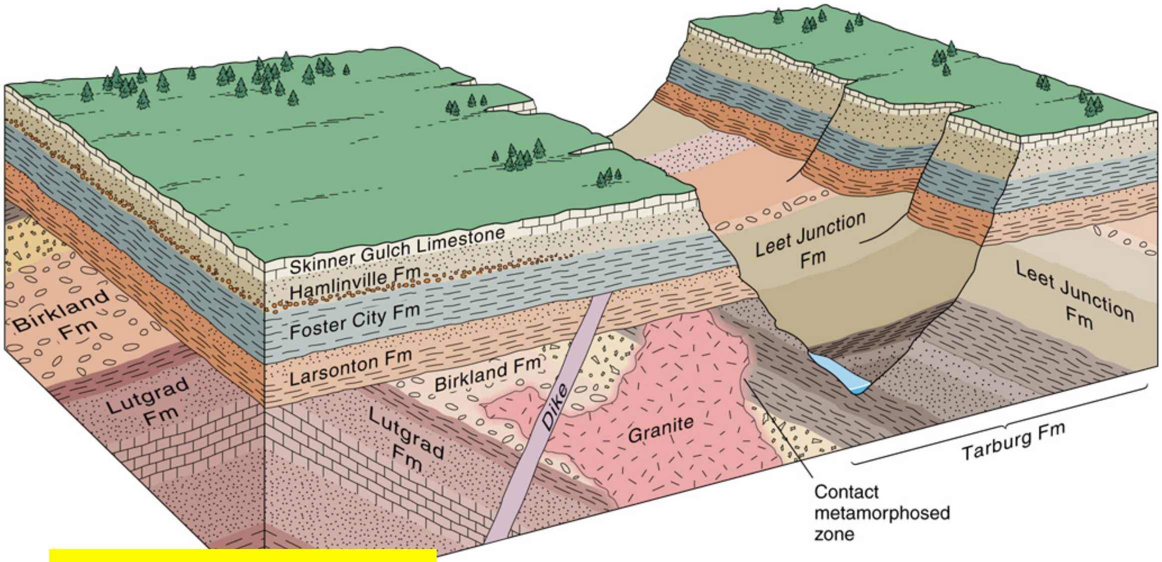
3) <u>Nonconformity</u>: A contact in which an erosional surface on a plutonic or metamorphic rock has been covered by younger sediments or volcanic rocks (i.e., unconformity separates different rock types).







Nonconformity

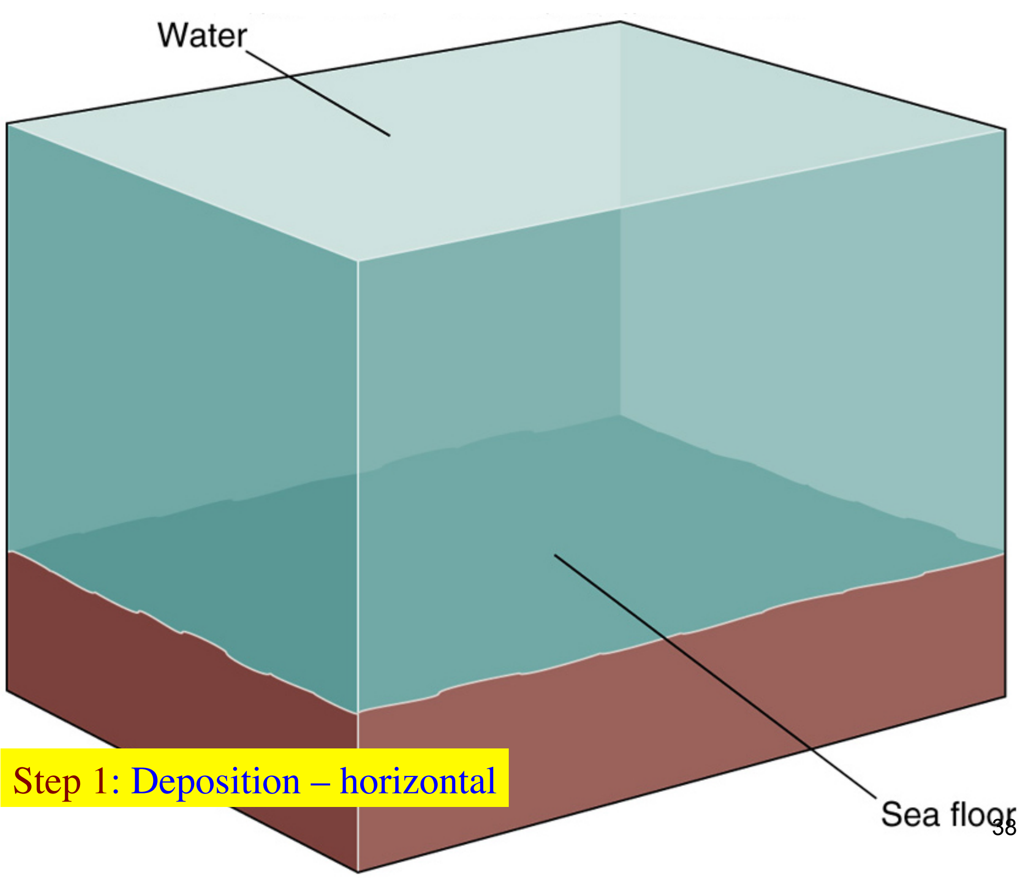


Principles of original horizontality, cross-cutting relations, & superposition.

Block diagram of Miner Canyon contains:

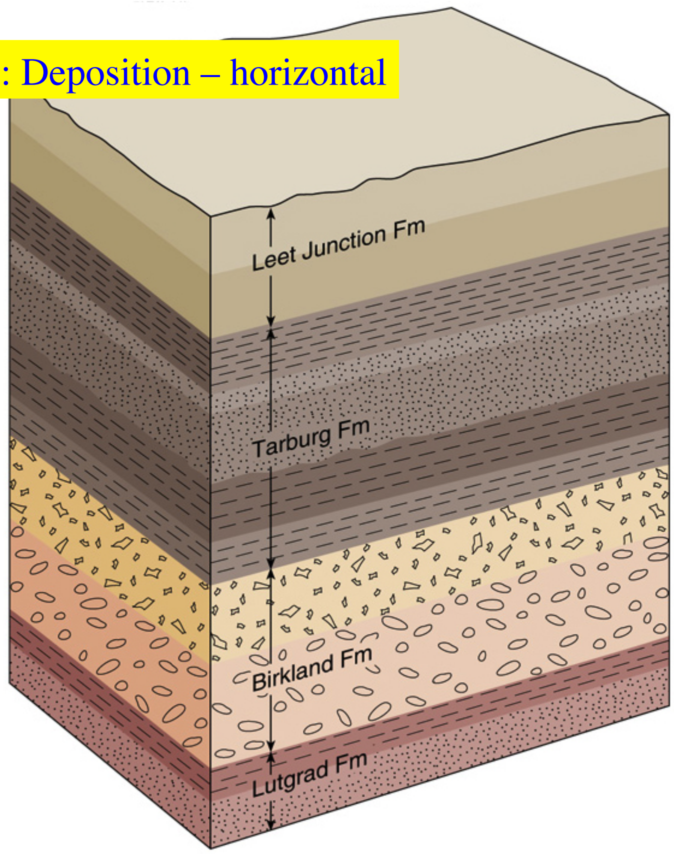
1) Flat-lying sequence of sedimentary rocks;
2) Tilted sequence of sedimentary rocks;
3) Angular unconformity between 1 & 2;
4) Two igneous intrusions – granite and dike.

NOTE: granite is cut by an angular unconformity, so it is therefore older than the event that created the unconformity.



Step 1: Deposition – horizontal

Step 1 (cont.): Deposition – horizontal



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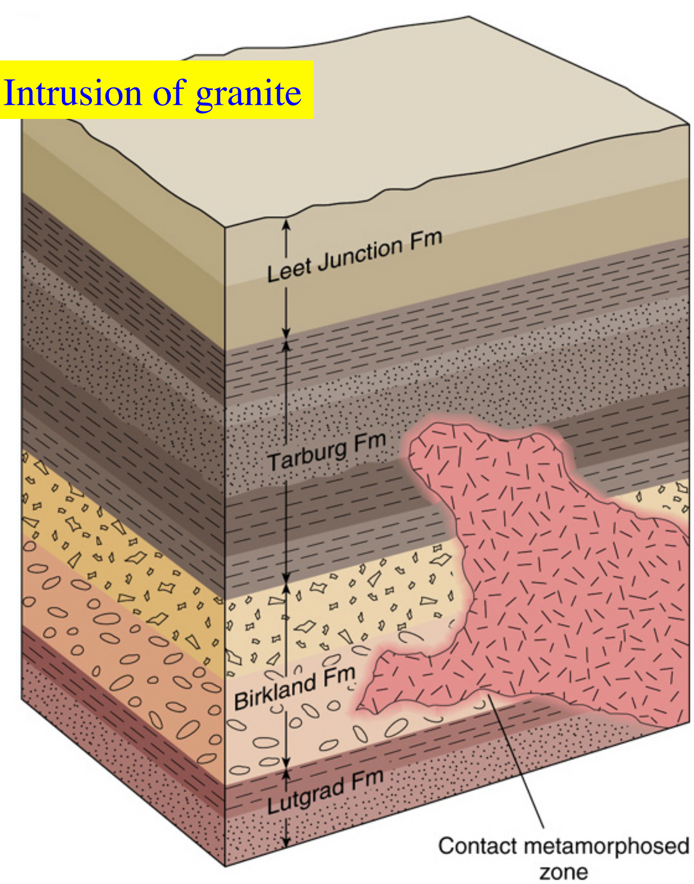
Step 2: Intrusion of granite



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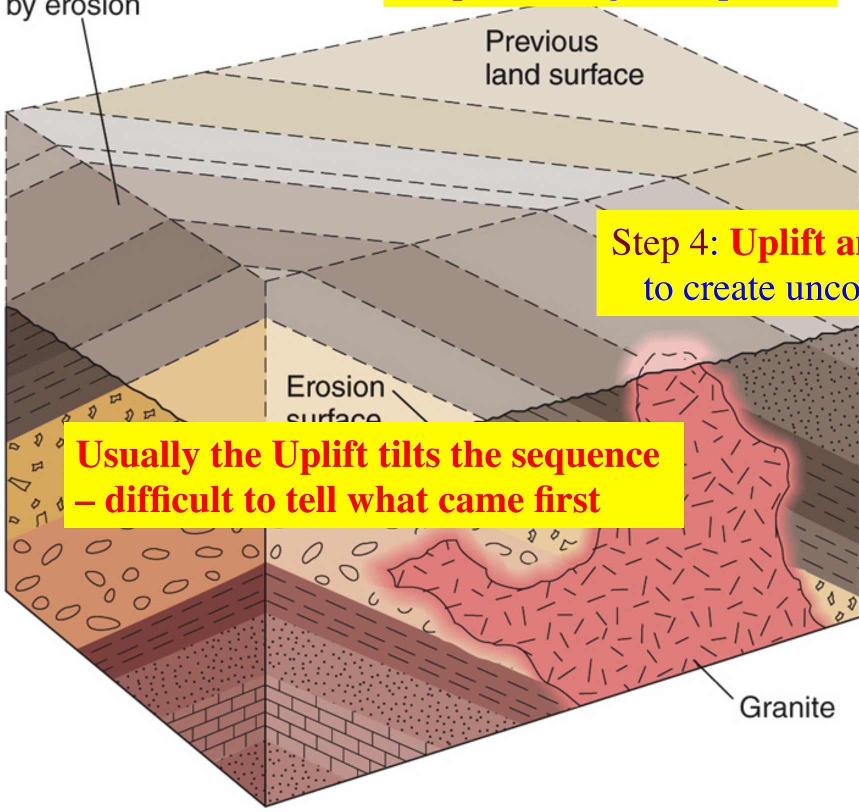
Step 3: Titling of sequence



Step 4: **Uplift and** Erosion to create unconformity

Usually the Uplift tilts the sequence – difficult to tell what came first

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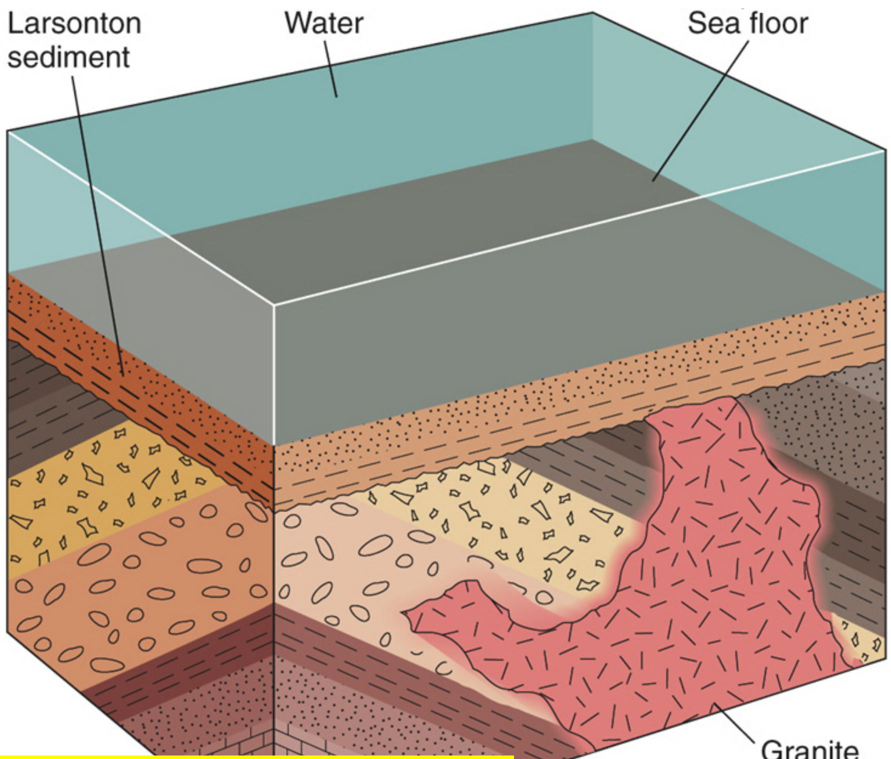

Step 5a: Submergence and deposition of Larsonton Formation and…..

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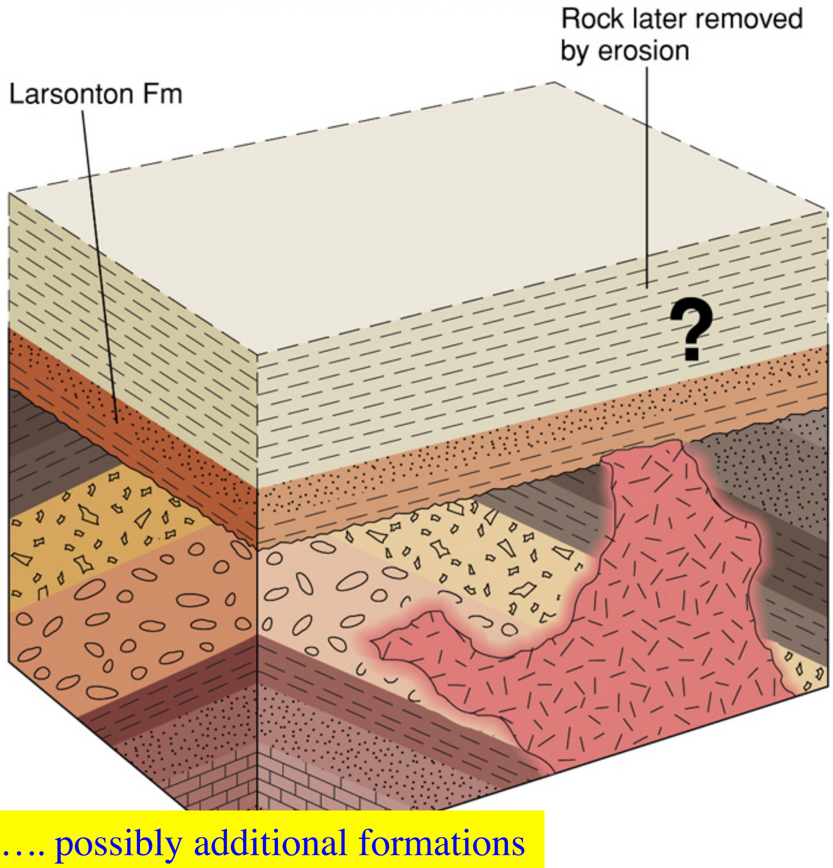
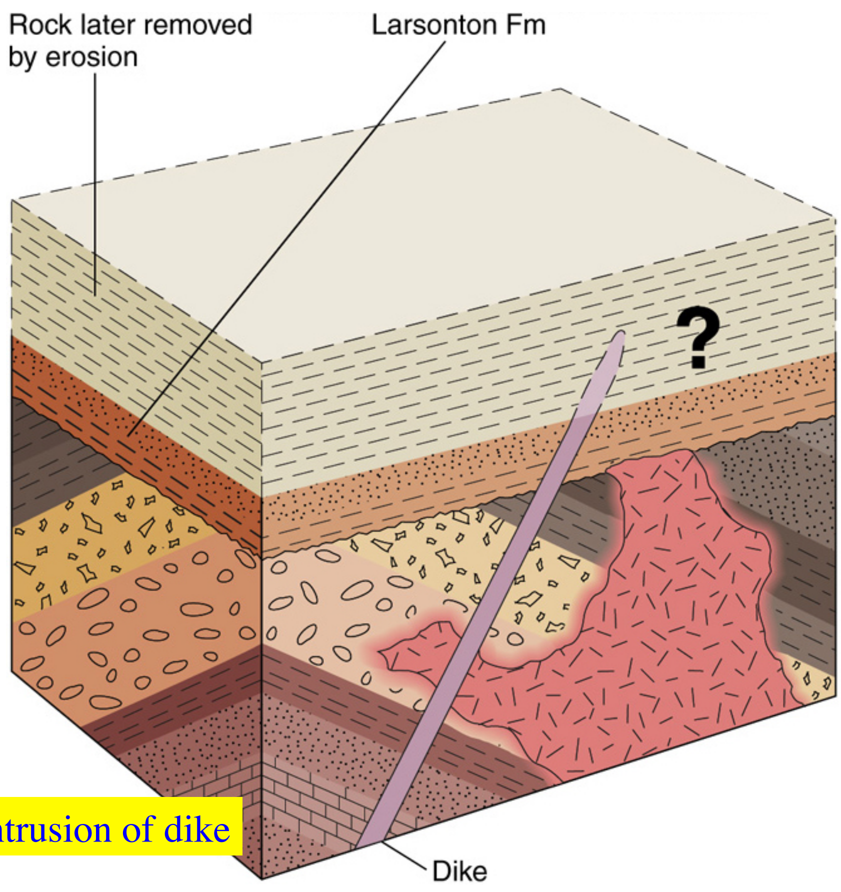
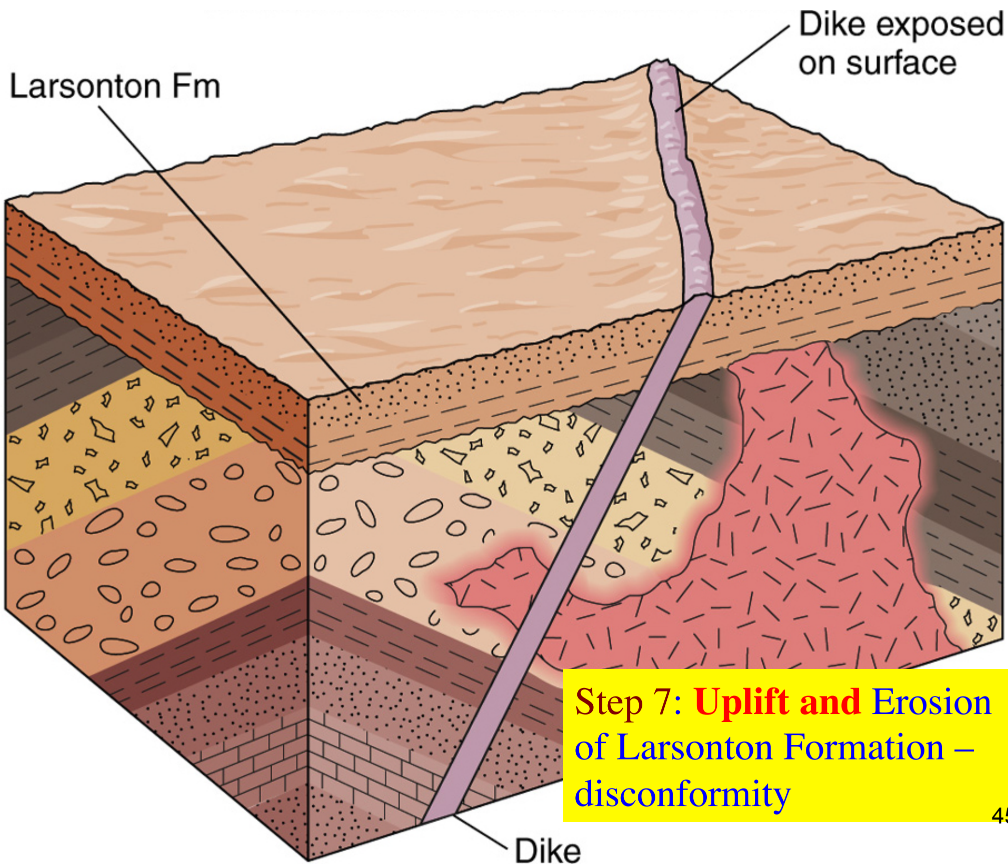


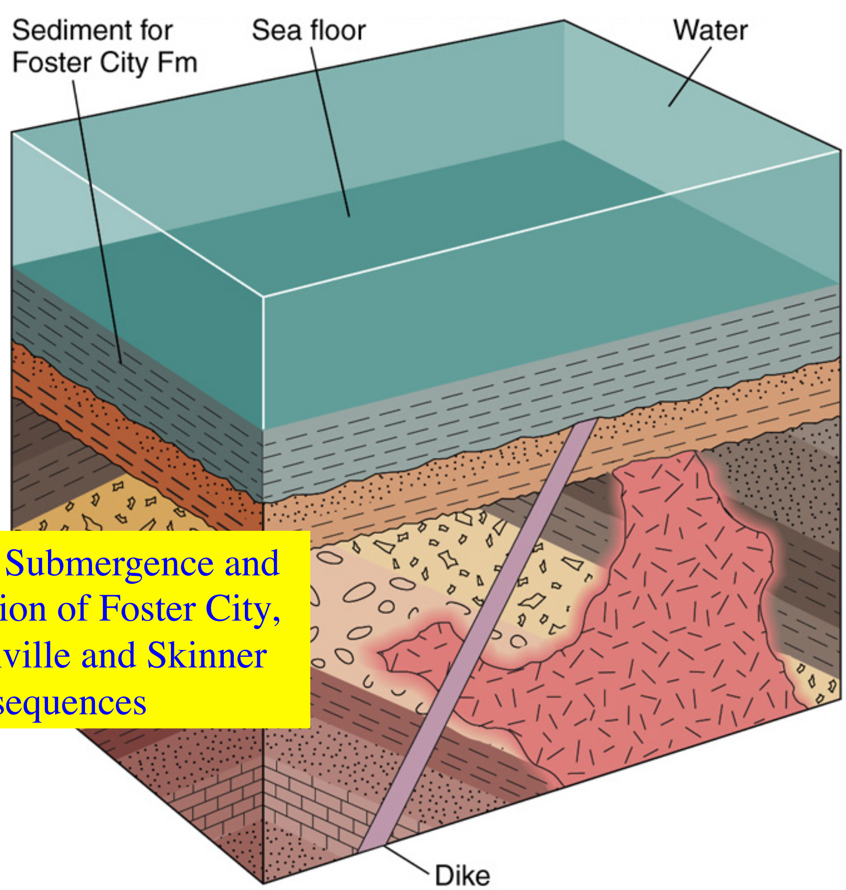
Step 5b: ….. possibly additional formations



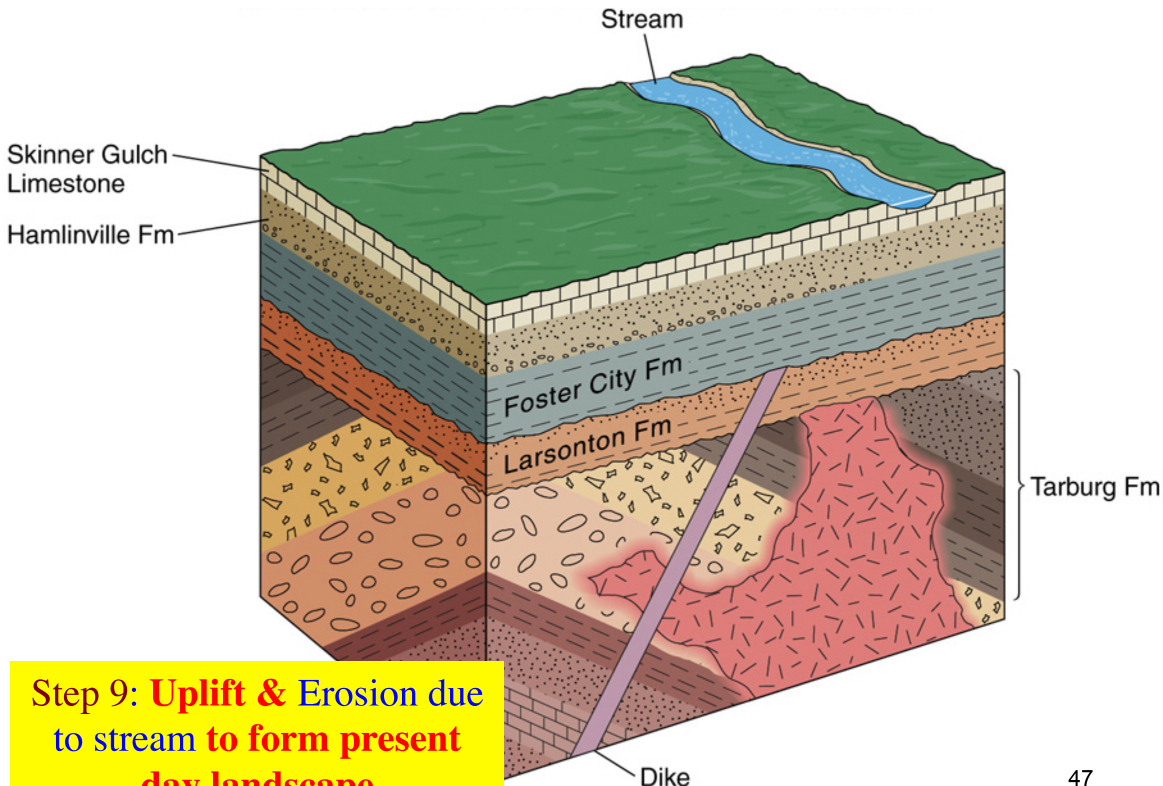
Step 6: Intrusion of dike



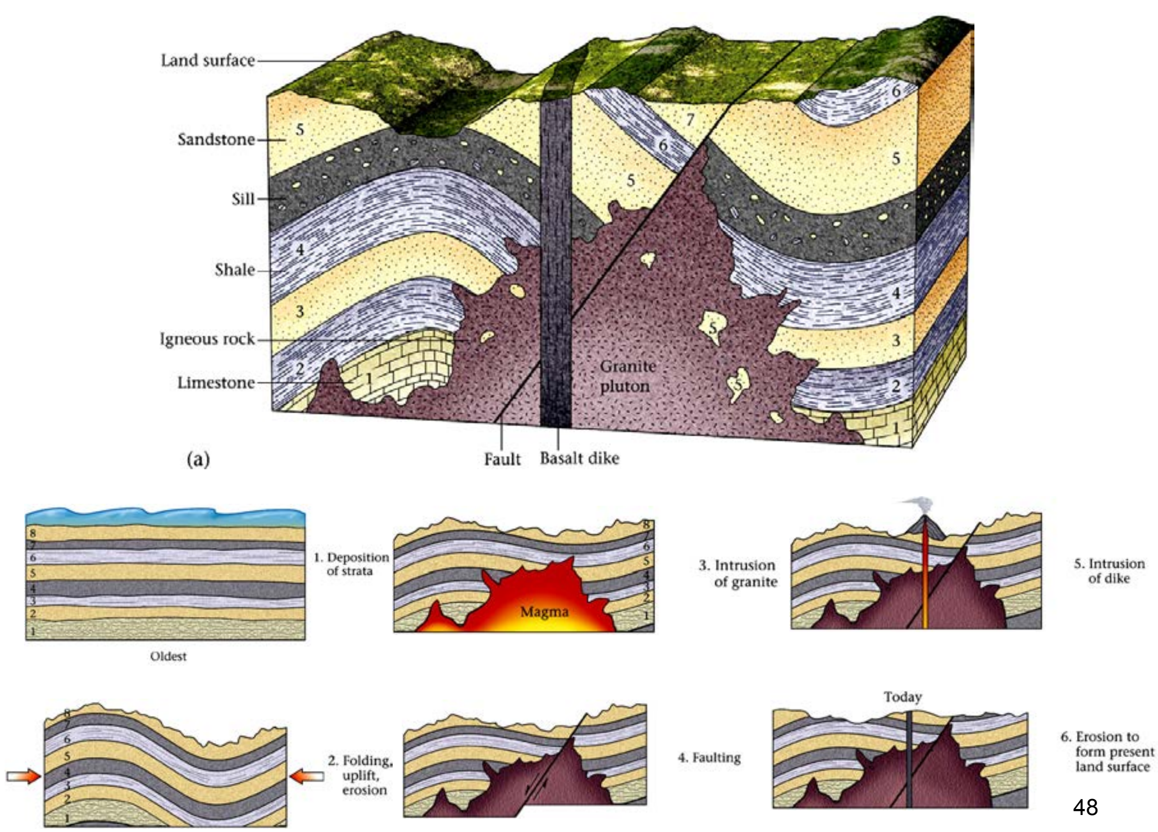
Step 7: **Uplift and** Erosion of Larsonton Formation – disconformity



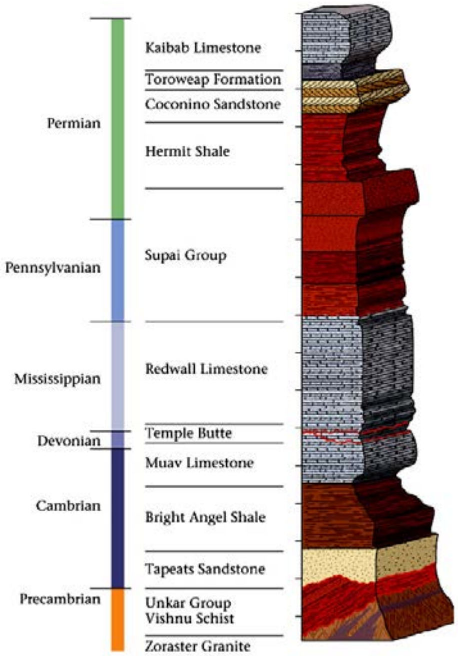
Step 8: Submergence and deposition of Foster City, Hamlinville and Skinner Gulch sequences



Step 9: Uplift & Erosion due to stream to form present day landscape



Stratigraphic Column



Grand Canyon

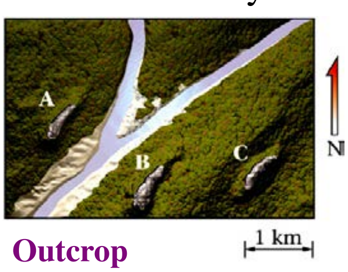
Draw columns to scale (relative thicknesses).

Stratigraphic Formations: recognizable intervals of a specific rock type or group of rock types deposited during a specific time interval. Boundary between formations = ***contact***.

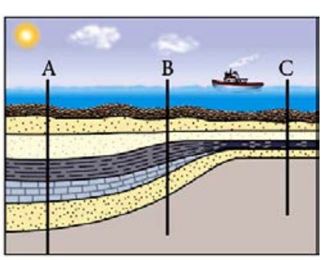
Some formations = one bed; others = several. Typically named after the location where it was first described (e.g., Toroweap Formation). Both words are capitalized.
Group = Several formations.

Correlation

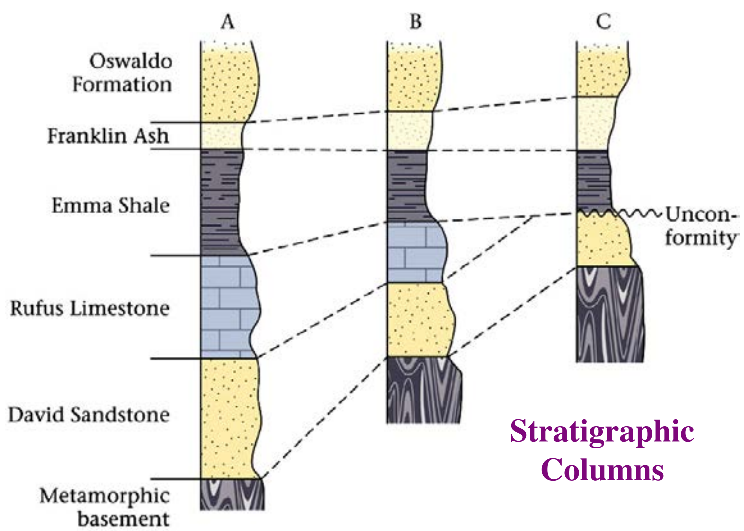
Comparing age relationships of strata at one locality with that at another. Usually use a ***marker bed***, which covers a broad area.



Outcrop



Reconstruction



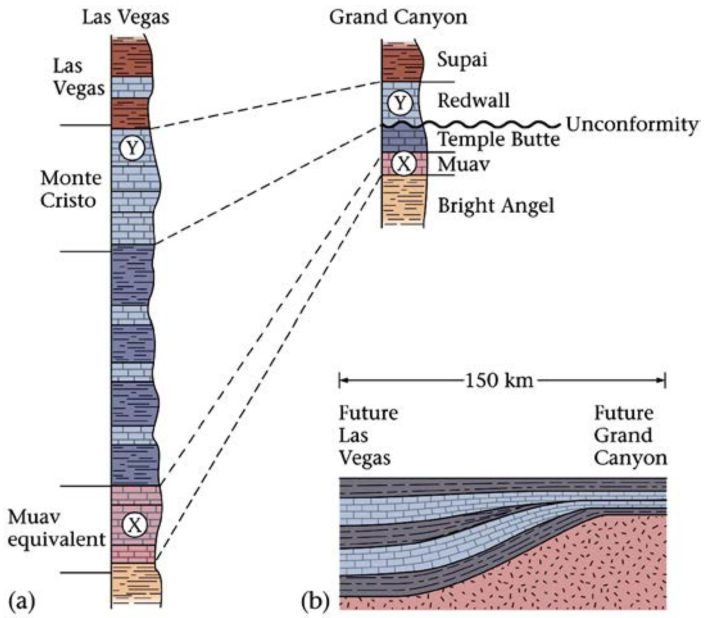
Stratigraphic Columns

Correlation

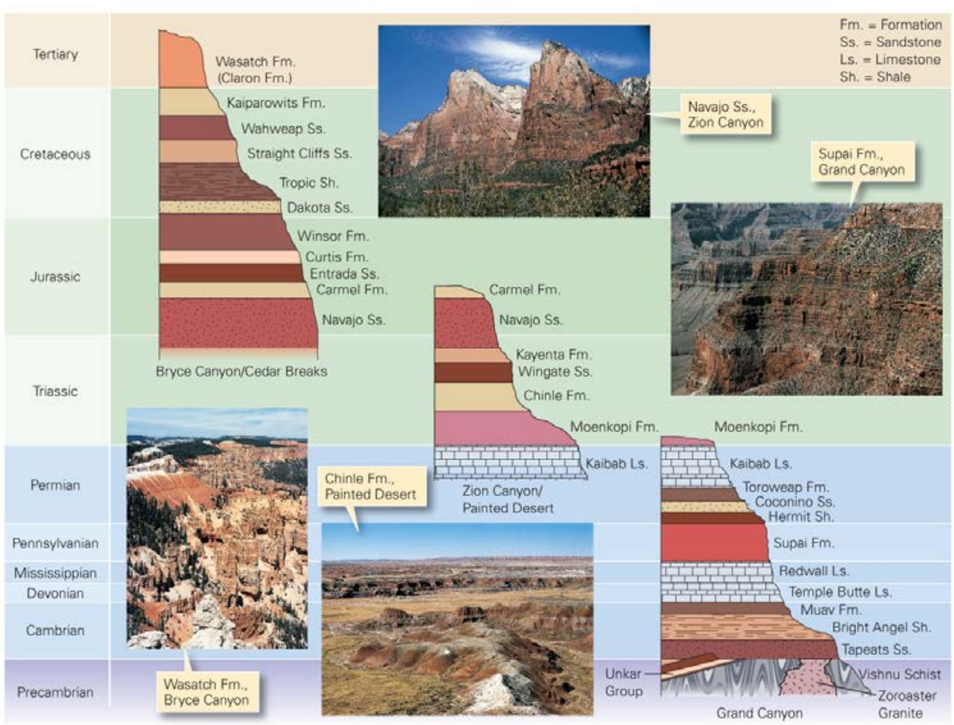
Sediments in the Grand Canyon and those in the mountains 150 km west (N. of Las Vegas).

Monte Cristo Limestone ≡ Redwall Limestone

Based upon fossils.

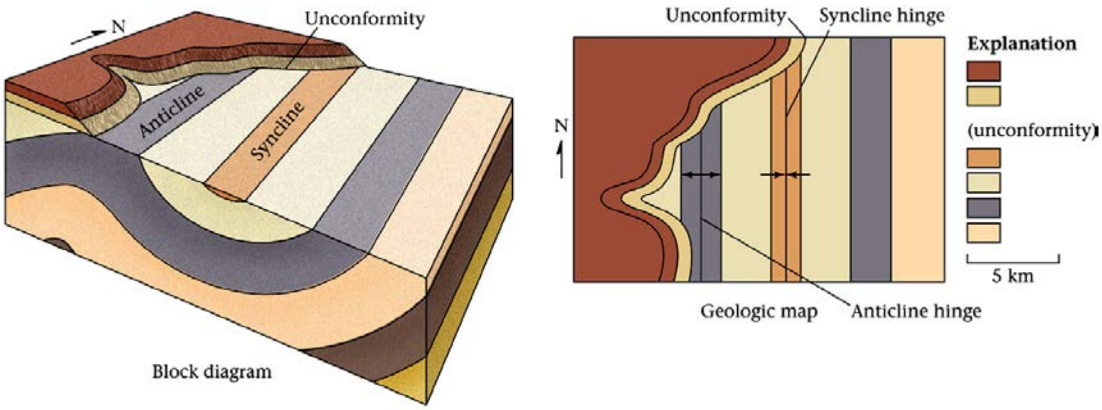


Stratigraphic Correlation



Geologic Map

By correlating strata at many locations, a geologic map can be built up. This portrays rock units at the Earth's surface.



Geologic Time Scale

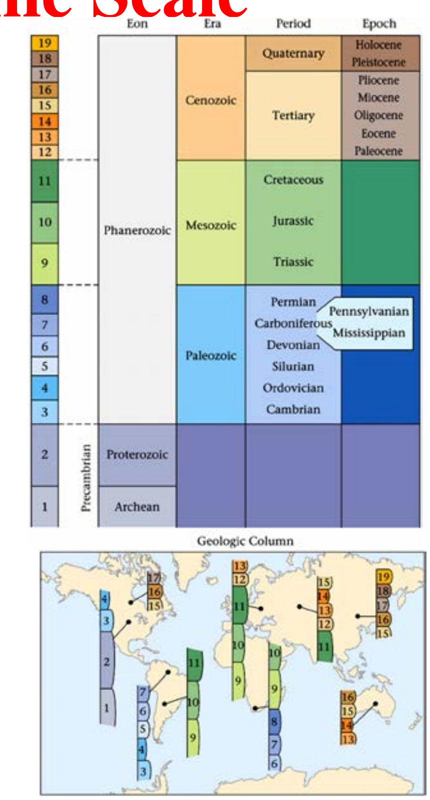
Worldwide relative time scale, based primarily on fossil assemblages.

Consists of **4 EONS**, one of which contains **3 ERAS**, which are subdivided into **PERIODS**, which are in turn divided into **EPOCHS**.

Hadean, Archean, and Proterozoic = Precambrian

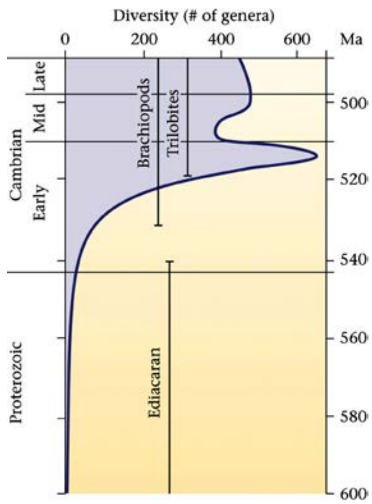
We will consider only "Eras" and "Periods".

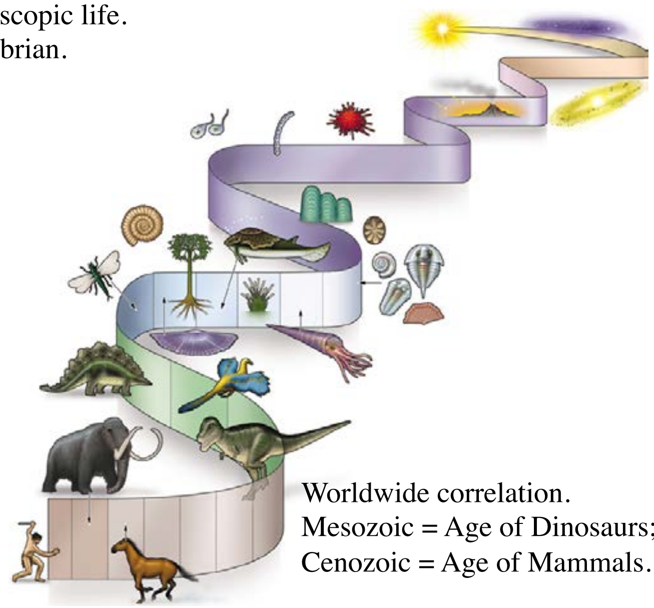
Any rock from anywhere in the world can be placed into this time scale.



Geologic Time Scale

Cambrian explosion = widespread macrscopic life.
Microscopic life know from the Precambrian.





Worldwide correlation.
Mesozoic = Age of Dinosaurs;
Cenozoic = Age of Mammals.

Absolute Time

Use of absolute dates rather than relative events.

(A) Genealogy: Archbishop Ussher, Ireland, mid-1600s. Biblical chronology – Earth formed at 9 a.m., October 26th, 4,004 B.C.

(B) Heat Loss: assume a molten Earth – calculate the time it would take to cool:

(i) 1700s – 75,000 years (Buffon, France);
(ii) 1800s – 25,000,000 years (Kelvin, England);

Was the Earth ever completely molten?

Other heat sources (other than collisional from accretion) = radioactivity.

(C) Salinity of the Oceans: Assume oceans were originally made of freshwater; 1900s = ~100,000,000 years (Joly, Ireland) – ignored salt tied up in rocks.

(D) Sedimentation Rates: depended upon assumed rates –
1800s: 3 m.y. to 1.5 b.y.

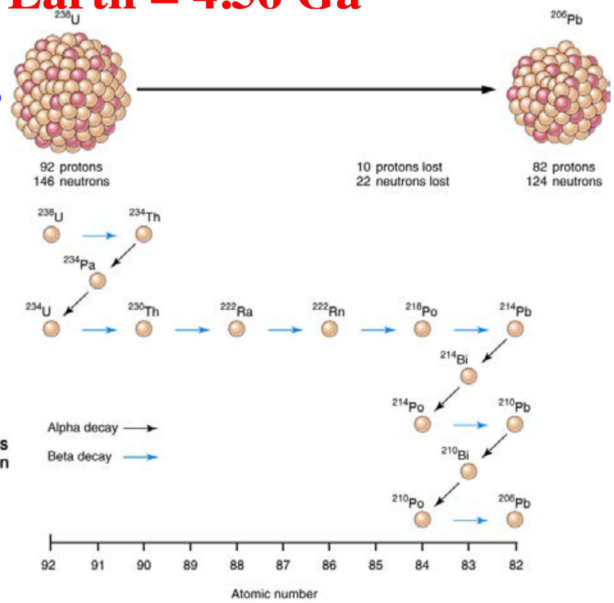
Absolute Time

E) Radiometric Dates: Earth = 4.56 Ga

Radioactive Decay: spontaneous nuclear breakdown of parent element to form daughter element with emission of:

Particles – alpha particles or helium nuclei = α; electrons or ß particles;

Electromagnetic radiation of γ rays.



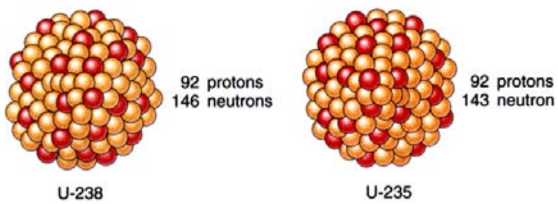
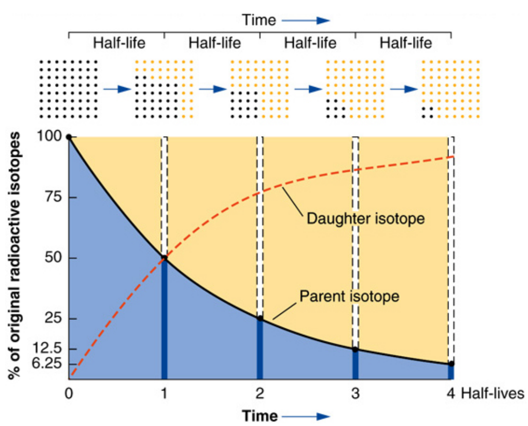


Figure 8.22

Nuclei of isotopes of U-238 and U-235.

Isotope: same proton #, different neutron #.

Half Life



Half life or $t^{1/2}$: time after which half of the parent element atoms have decayed to form daughter elements.

Half life is constant for a given parent element (isotope). Therefore, ratio of parent/daughter in a rock can provide the absolute age of a rock.

Cannot tell which parent will decay at a given time: Probability.

Radiometric Dating Techniques

TABLE 12.1 Isotopes Used in the Radiometric Dating of Rocks

Parent → Daughter	*Half-Life (years)*	*Minerals in Which the Isotopes Occur*
$^{147}Sm \rightarrow {}^{143}Nd$	106 billion	Garnets, micas
$^{87}Rb \rightarrow {}^{87}Sr$	48.8 billion	Potassium-bearing minerals (mica, feldspar, hornblende)
$^{238}U \rightarrow {}^{206}Pb$	4.5 billion	Uranium-bearing minerals (zircon, uraninite)
$^{40}K \rightarrow {}^{40}Ar$	1.3 billion	Potassium-bearing minerals (mica, feldspar, hornblende)
$^{235}U \rightarrow {}^{207}Pb$	713 million	Uranium-bearing minerals (zircon, uraninite)

Sm = samarium, Nd = neodymium, Rb = rubidium, Sr = strontium, U = uranium, Pb = lead, K = potassium, Ar = argon

1. Collect the Rocks;
2. Separate the Minerals;
3. Extract Parent & Daughter Isotopes;
4. Analyze P-D Ratio.

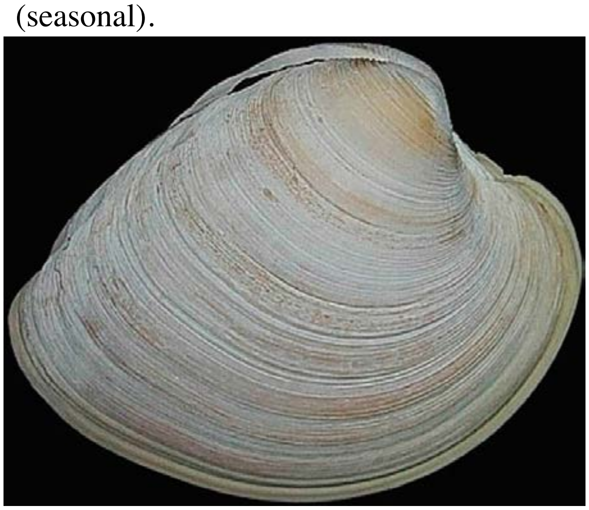
Uncertainty in measurement;
Accuracy and Precision;
Standards.
Radiometric Age = Blocking Temperature.

Other Dating Techniques

Annual fluctuations in sedimentation (flood/drought).

Growth rates of chemical sediments (seasonal) - e.g., travertine.

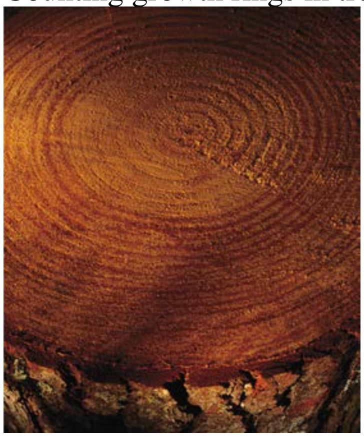
Growth rate of shell-secreting organisms (seasonal).

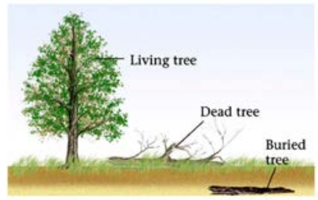


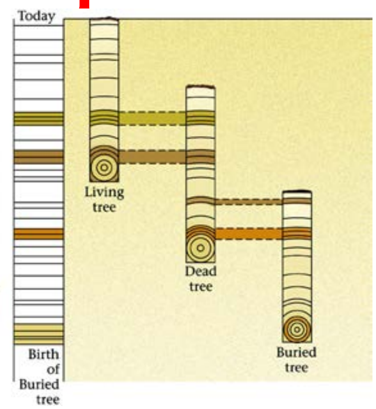
Layers in ice (seasonal).

Other Dating Techniques

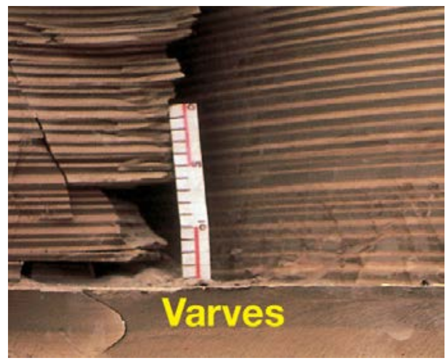
Counting growth rings in trees.





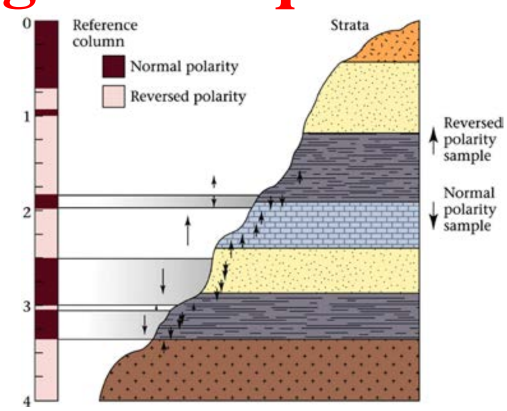


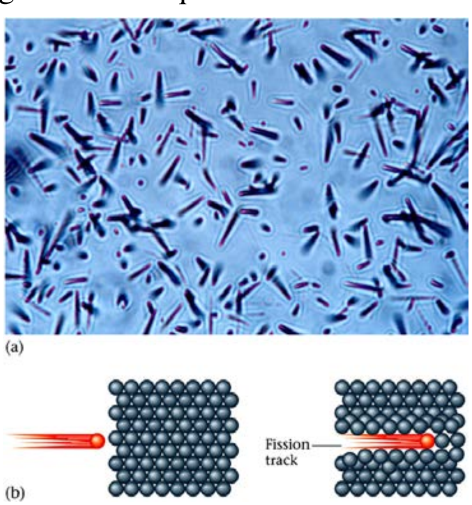
Counting layers in lake sediments (organic productivity).



Other Dating Techniques

Magnetostratigraphy: reversals of the Earth's magnetic field is recorded in the rocks. A reference framework has been devised to compare patterns of reversals in a given rock sequence to this framework.





Fission Track Dating: particles emitted during decay damage the crystal lattice. The greater the number of "fission tracks" the older the sample..

Carbon-14

Gives the age of organic material.

^{14}C produced in the atmosphere by variety of reactions due to interactions of cosmic-ray produced neutrons with the stable isotopes of C, N, O.

Most important reaction = ^{14}N:

$$n + {}^{14}_{7}N \rightarrow {}^{14}_{6}C + {}^{1}_{1}H$$

Decay takes place by emission of a ß emission and forms stable ^{14}N:

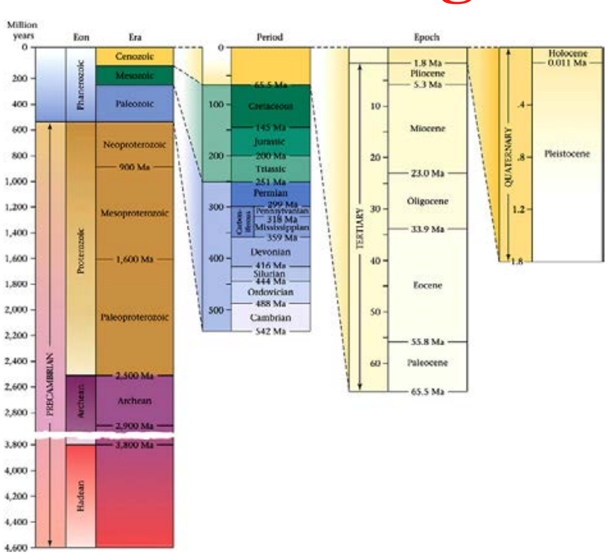
$$^{14}_{6}C \rightarrow {}^{14}_{7}N + \beta^{-}$$

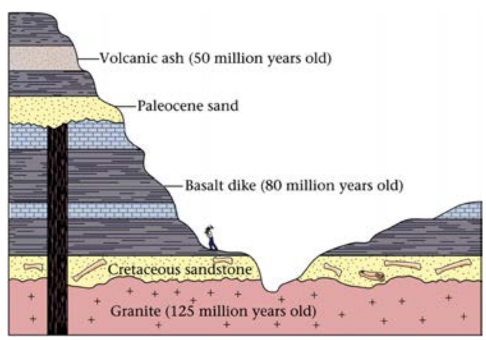
T_{half} ^{14}C = 5730 ± 40 years.

^{14}C incorporated into CO_2, rapidly mixed throughout the atmosphere and hydrosphere, reaching a steady state equilibrium. Maintained by its production and continuous decay.

Plants and animals contain ^{14}C at a constant level, until death, then it declines through natural decay - calculate time since death.

Geologic Time Scale





Putting absolute ages on the geologic time scale is done using datable igneous/metamorphic rocks and their cross-cutting relationships with sedimentary strata.

Age of the Earth

Age of the Earth = Age of Meteorites, the oldest parts of the solar system.

Oldest rocks on Earth ~**4.28** Ga.

Oldest mineral = **4.4 Ga**

Consider **ZIRCON** – $ZrSiO_4$

Nesosilicate – sites are compatible with U^{4+}, but not Pb^{2+}.

When Zircon forms, it can contain substantial U but no Pb.

All Pb in Zircon is due to decay and is relative to absolute age.

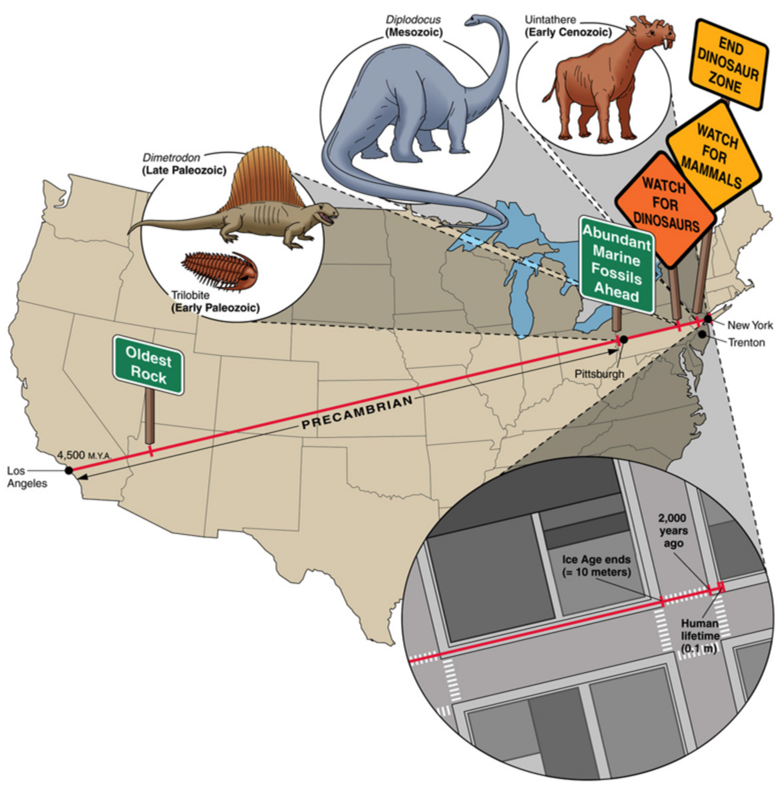
Zircons are very durable – can survive several cycles of erosion/ depositions: "**Zircons are Forever**"!!!!!

Radiometric dating measures when the clock was set/reset.

Clock can be reset after formation (e.g., metamorphism).

Allows absolute ages to be put on the relative time scale.

Comprehending Geologic Time



Summary

Fossils: Body, Trace, Chemical.

Preservation.

Extraordinary Fossils.

Extinction/Mass Extinction.

Relative & Absolute Geologic Time.

Relative Geological Time Principles: Uniformitarianism; Original Horizontality; Superposition; Original Continuity; Lateral Continuity; Inclusions; Cross-Cutting Relationships; Baked Contacts; Fossil Succession.

Unconformities: Disconformity; Angular Unconformity; Nonconformity.

Stratigraphic Column: Formations, Groups.

Correlation: Marker Bed.

Geologic Maps.

Geologic Time Scale: Eons, Eras, Periods, Epochs.

Absolute Time.

Radiometric Dating: Half Life; Dating Techniques.

Other Dating Techniques: Growth Rings; Seasonal Deposition; Magnetostratigraphy; Fission Track; Carbon 14.

Age of the Earth & Comprehending Geologic Time.