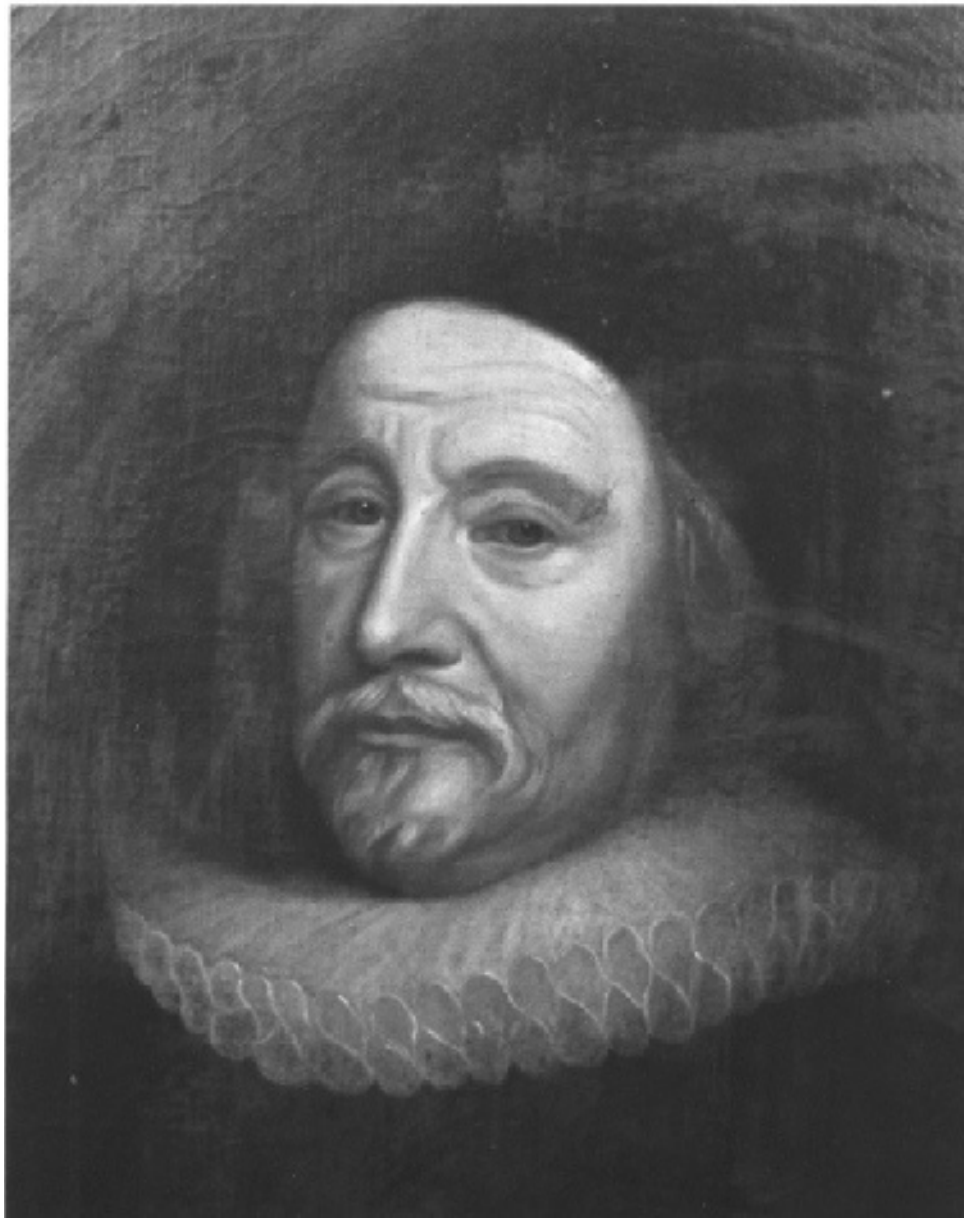
Time and Geology

Chapter 8



James Ussher: suggested the exact day the Earth was formed

4004 B.C. Oct. 26 at 9 am

How did he do it?

Ussher chronology

The Age of the Earth

- Prior to the 19th century, accepted age of Earth based on *religious beliefs*

- *James Hutton* (1726–1797), a Scottish farmer and naturalist, is known as the founder of modern geology.

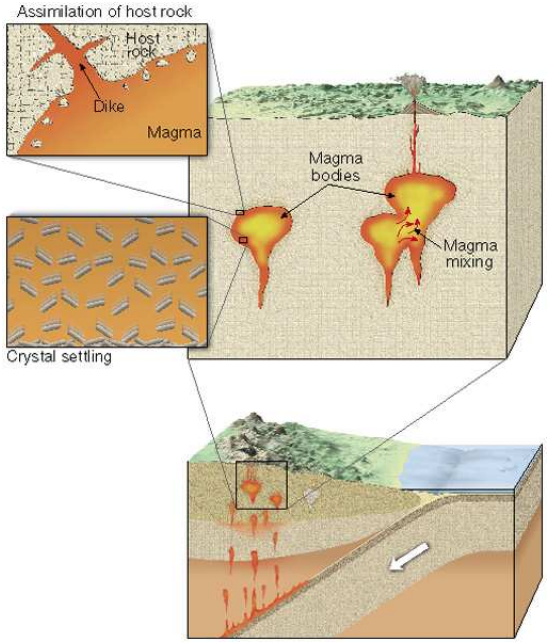
- James Hutton realized that geologic processes require vast amounts of time

- *Charles Lyell* popularized Hutton's concepts in book *Principles of Geology*
  - *Uniformitarianism*: same processes operating in past are operating at present - "*The present is the key to the past*"

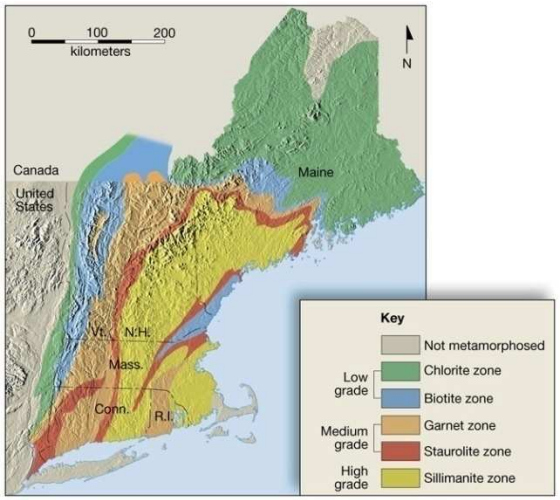
Rocks: Preserve geologic time

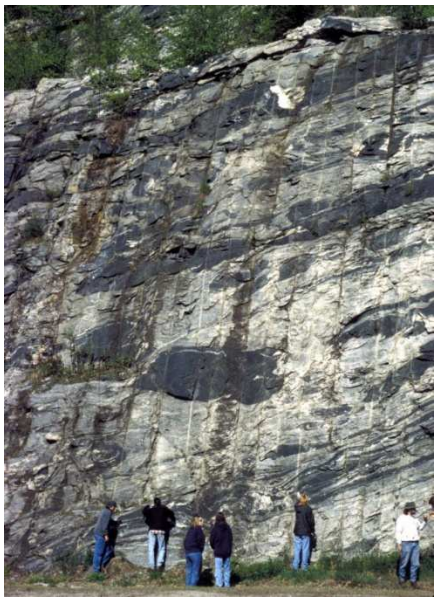
Sedimentary

Igneous



Metamorphic





Rock Formations

Formations - bodies of rock of considerable thickness with recognizable characteristics allowing them to be distinguished from adjacent rock layers

Photo © Craig Aurness/Corbis Images

Relative vs. Numerical Age

- *Relative age* - the order of events or objects, from first (oldest) to last (youngest)
  - Determined by applying simple principles, including *original horizontality, superposition, lateral continuity, cross-cutting relationships, inclusions, and unconformities* of rock units and fossils

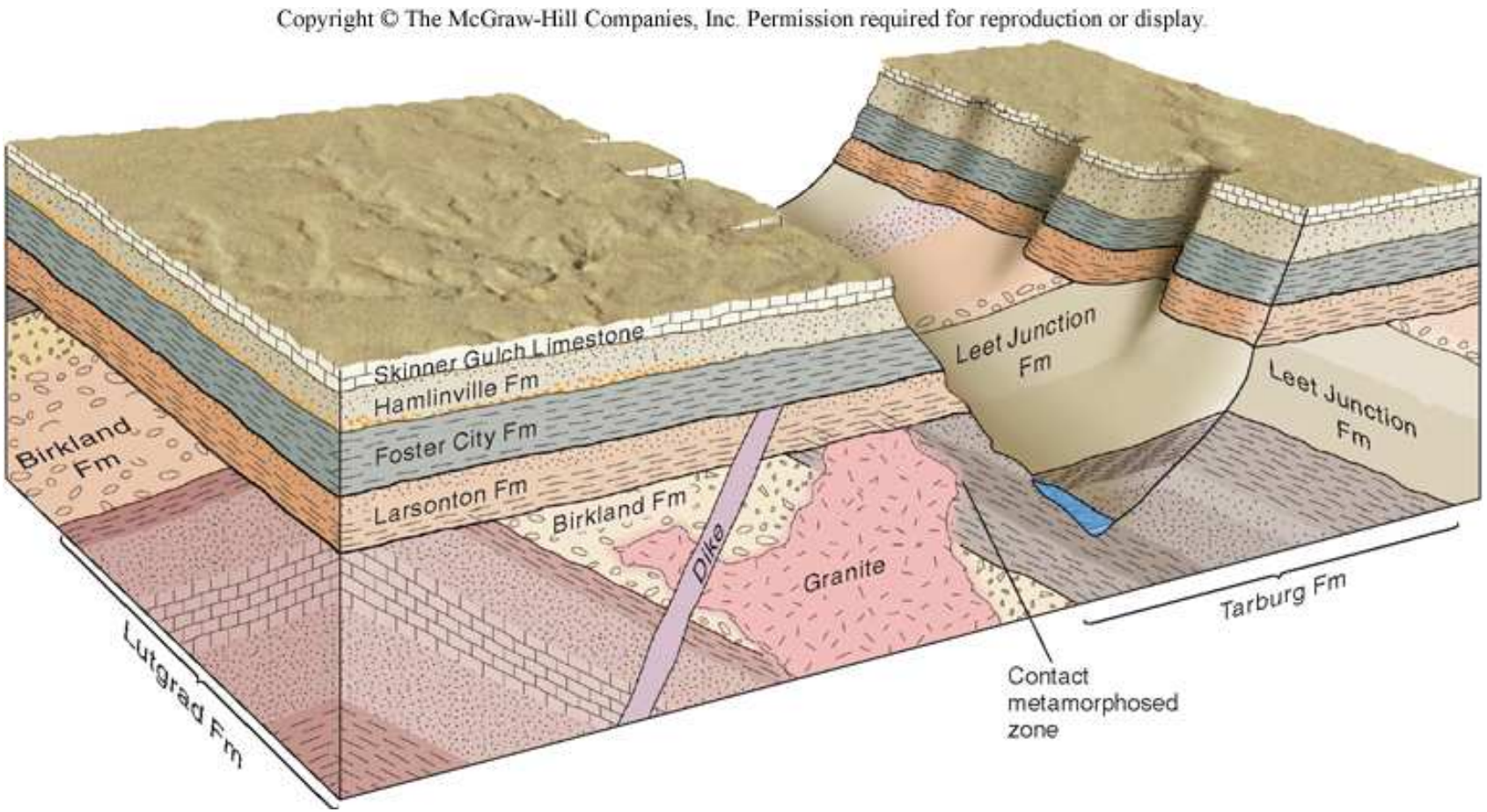
- *Numerical age* - the age of events or objects, expressed as a number or numbers
  - Determined using *radiometric dating* (determining how much radioactive decay of a specific element has occurred since a rock formed or an event occurred)

Principles to Determine Relative Age

- **Superposition**
- **Original Horizontality**
- **Lateral continuity**
- **Cross-cutting**
- **Inclusion**
- **Unconformities**
- **Fossil Succession**

Relative Age Determination

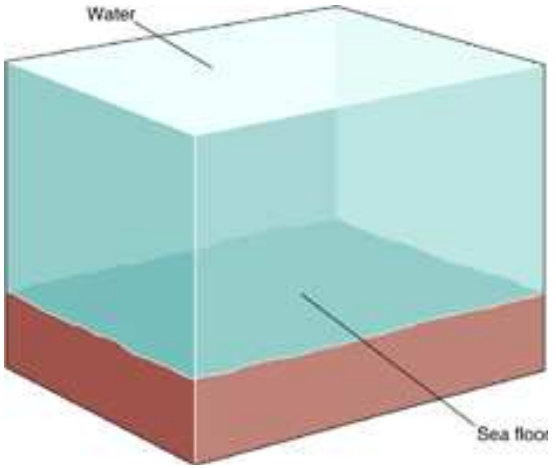
- *Original horizontality* - beds of sediment deposited in water are initially formed as horizontal or nearly horizontal layers

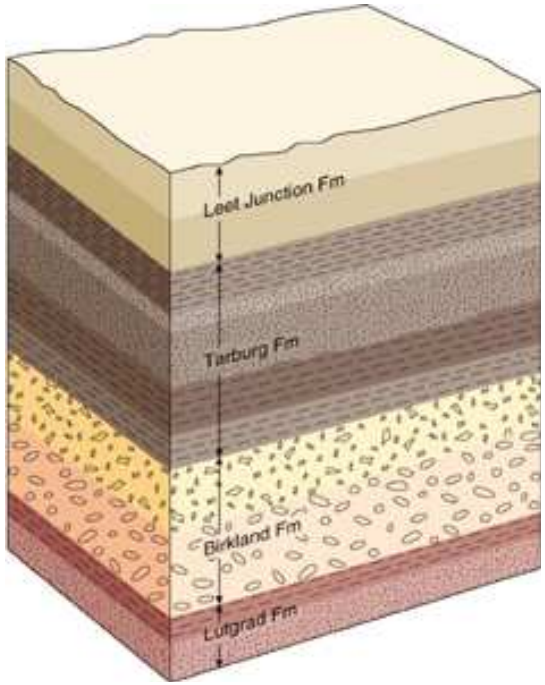


Relative Age Determination

- *Superposition* - within an undisturbed sequence of sedimentary or volcanic rocks, layers get younger from bottom to top

- *Lateral continuity* - original horizontal layer extends laterally until it tapers or thins at its edges





Superposition: oldest on the bottom and youngest on the top.

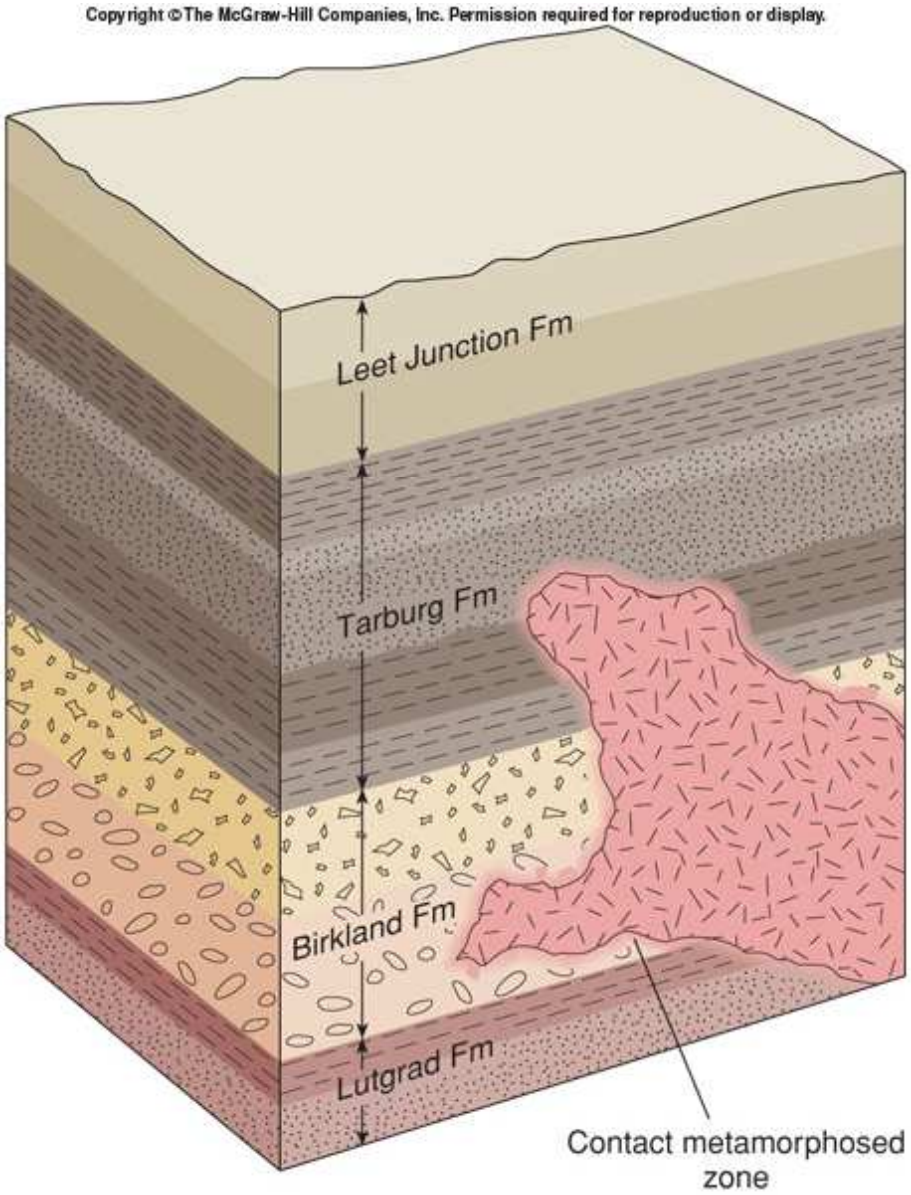
!!!unless the units have been turned completely upside down and thus in reverse chronological order!!!!!

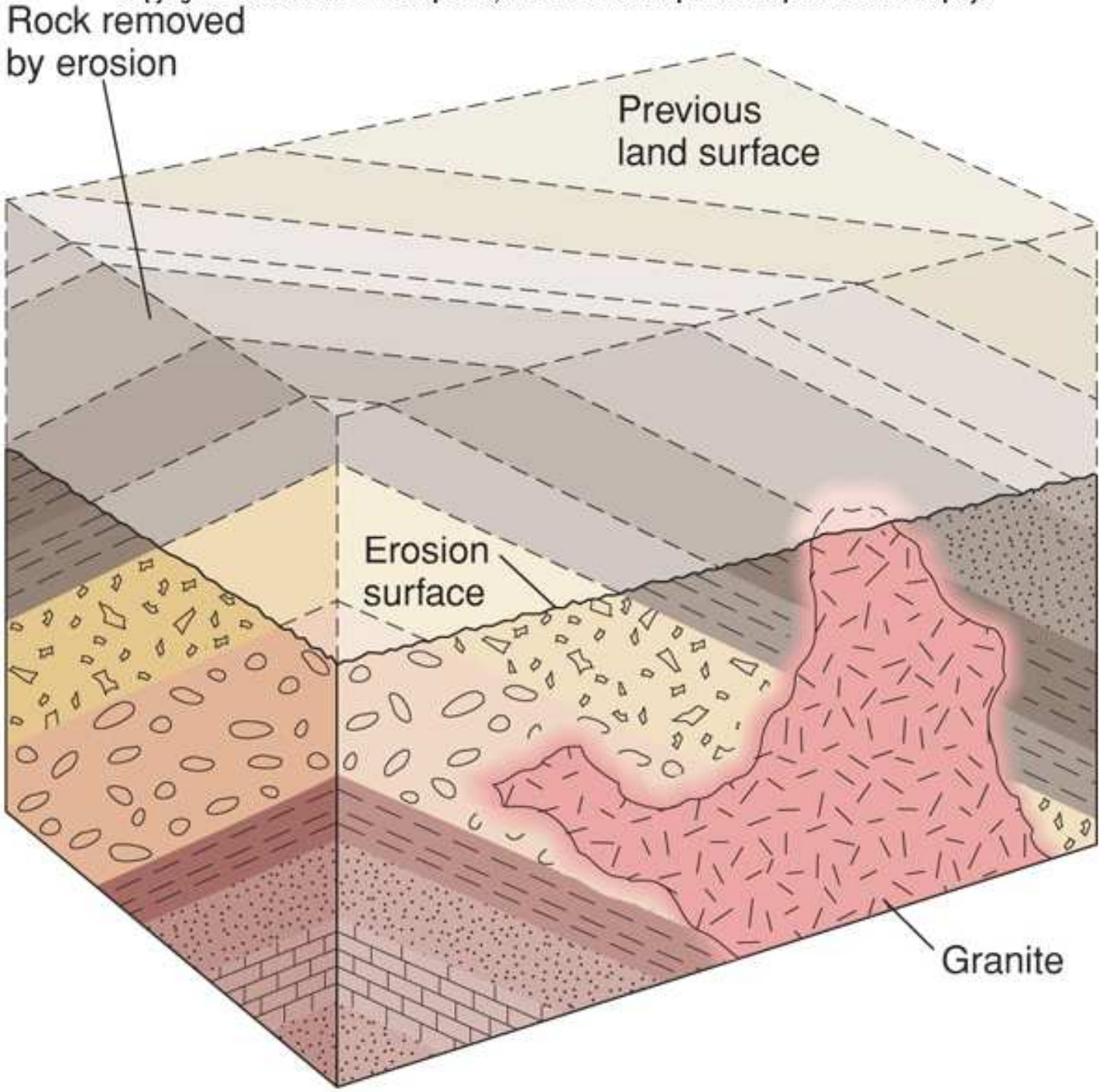
Relative Age Determination

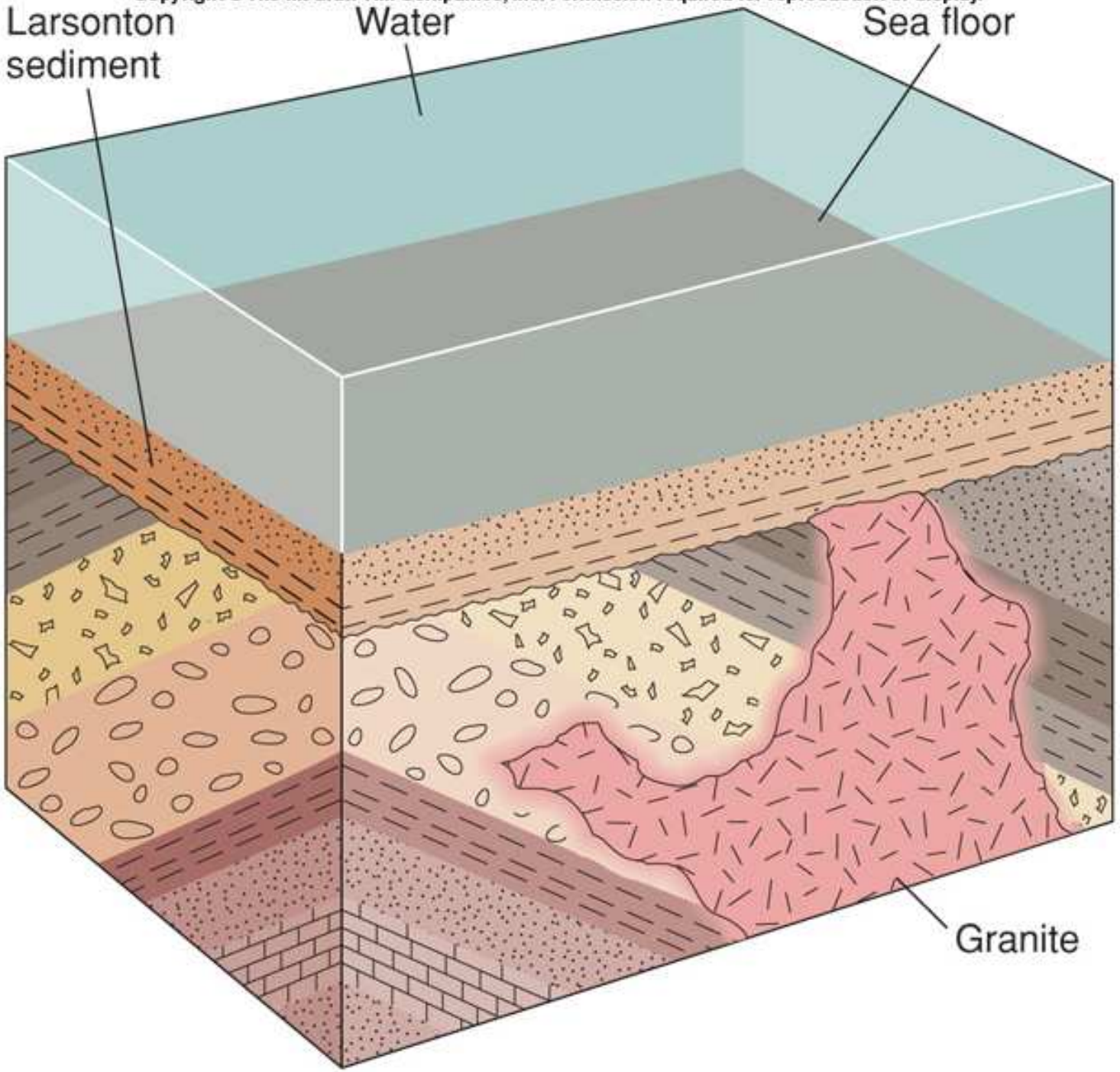
- *Cross-cutting relationships*

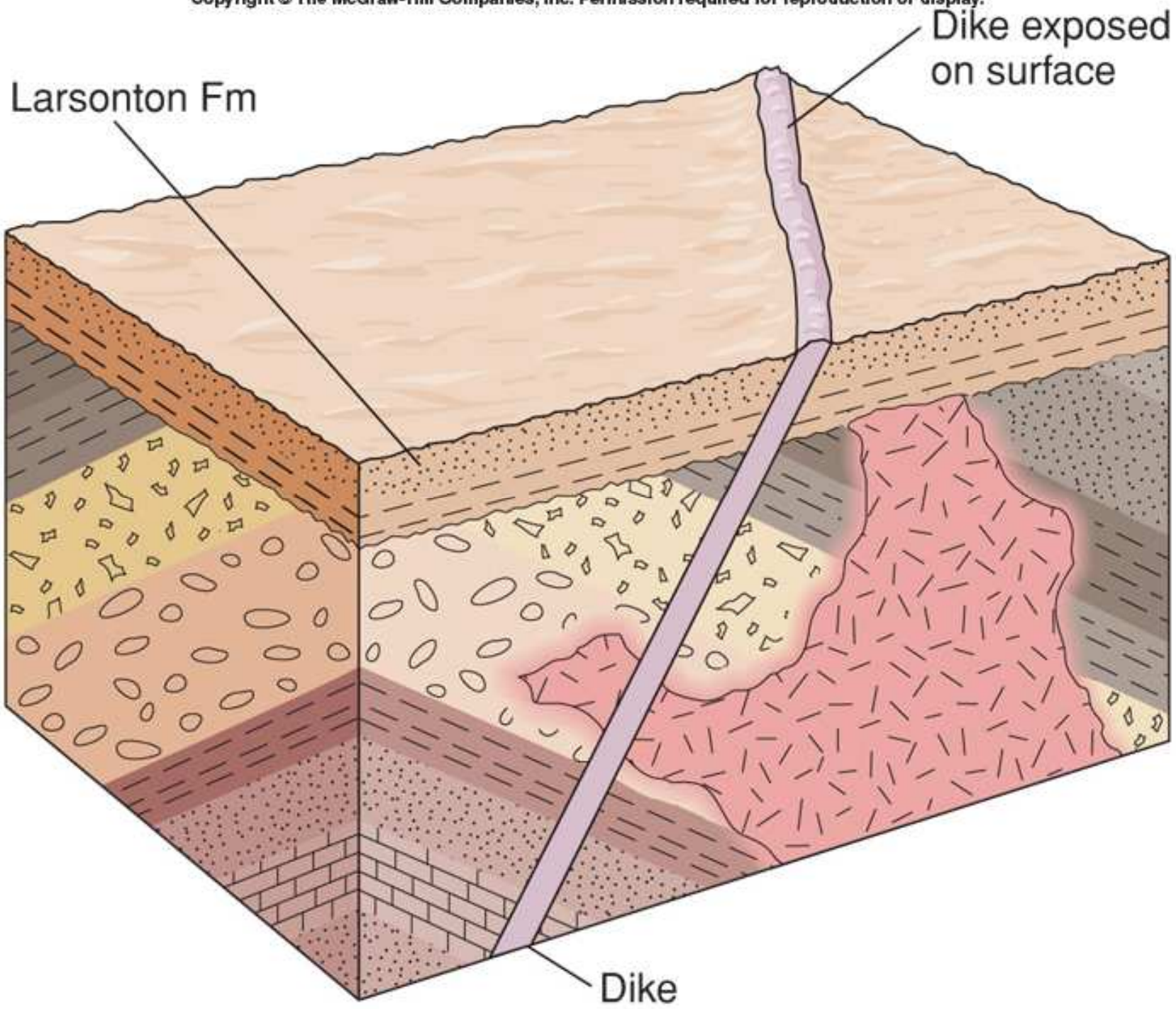
a disrupted pattern is older than the cause of the disruption

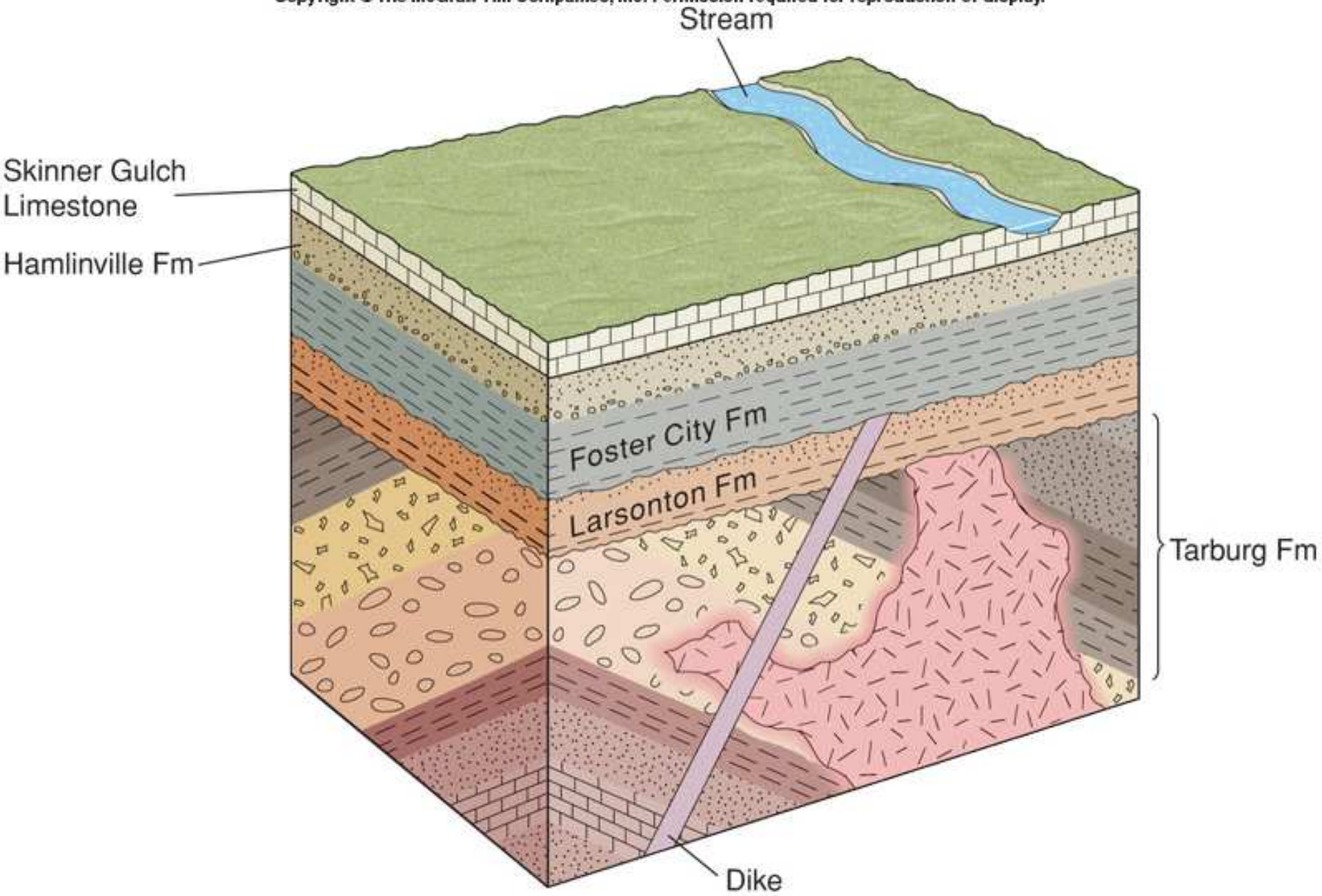
  - *Intrusions* and *faults* are younger than the rocks they cut through





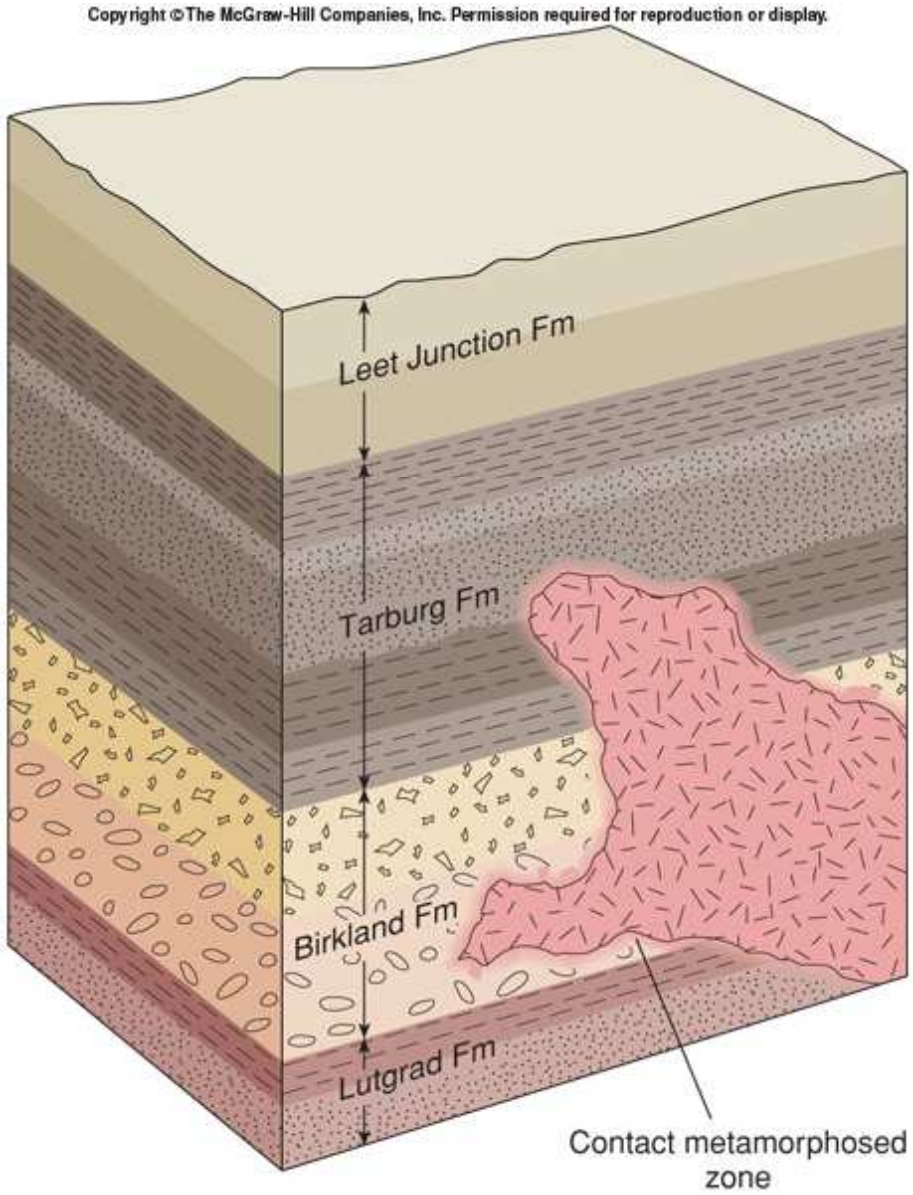






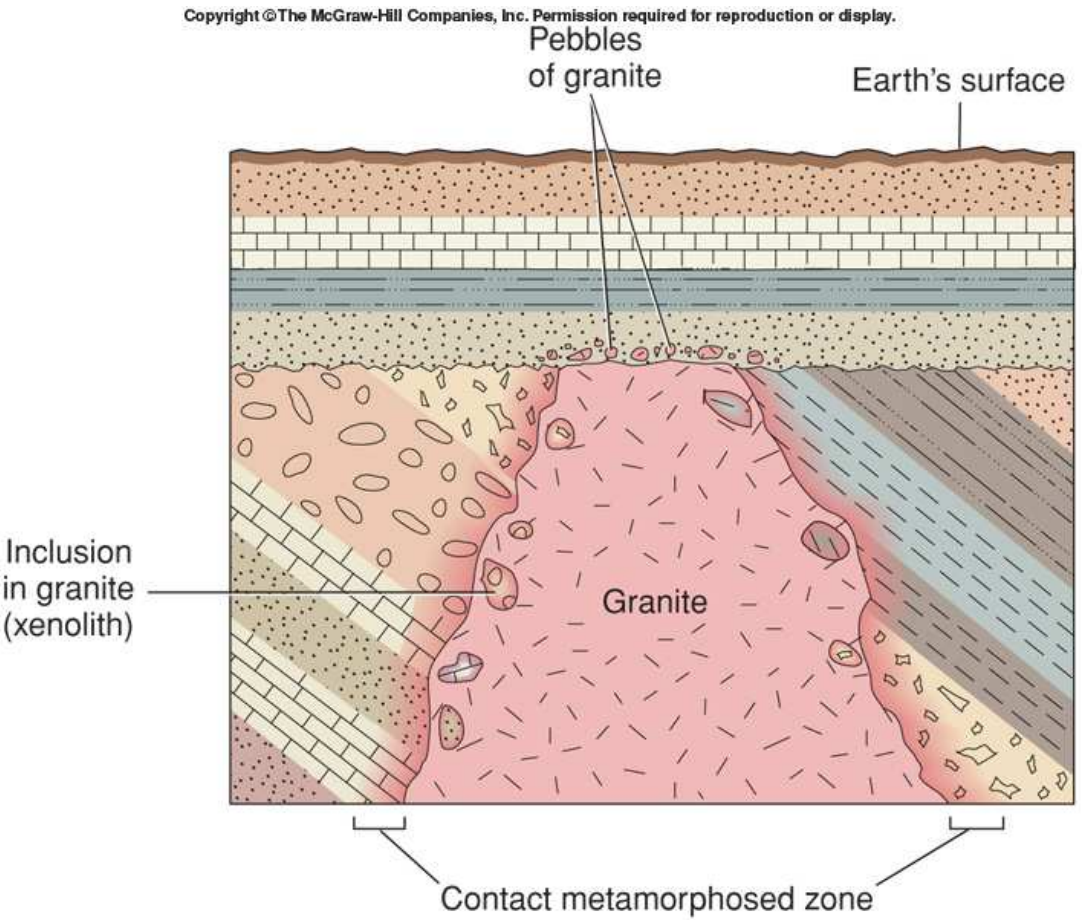
Relative Age Determination

- *Baked contacts* - contacts betwee
  igneous intrusions and surrounding
  rocks, where surrounding rocks hav
  experienced contact metamorphism



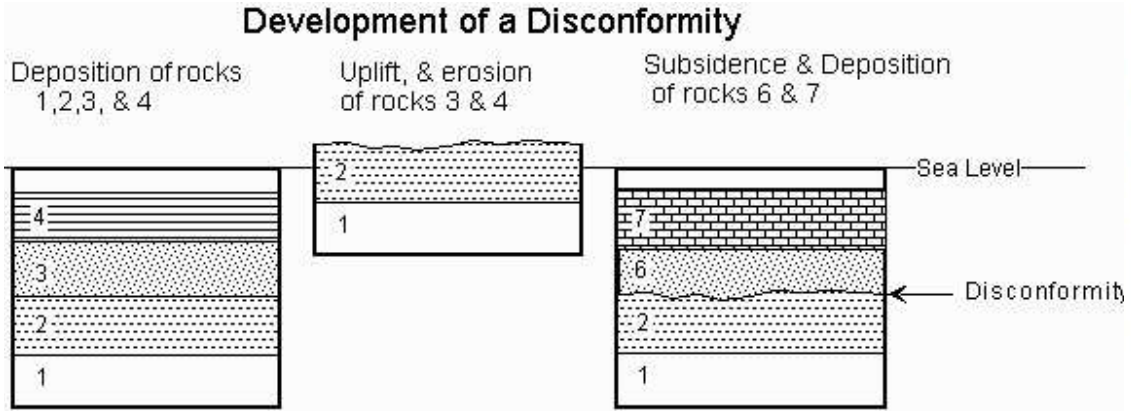
Relative Age Determination

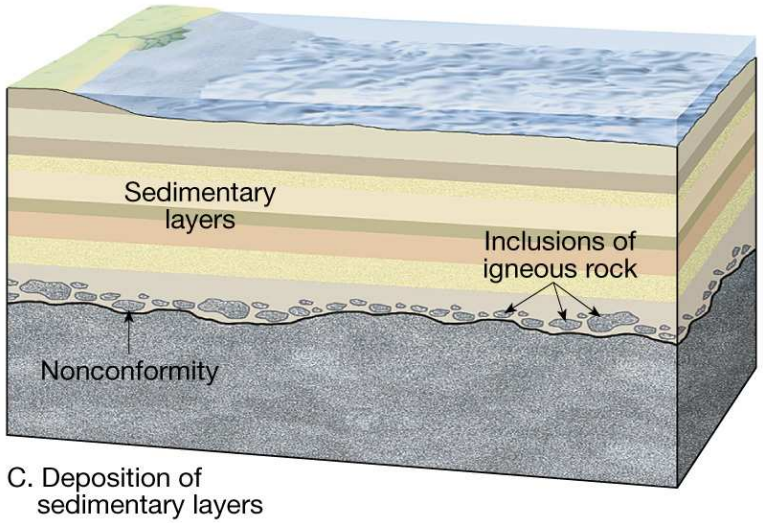
- *Inclusions* - fragments embedded in host rock are older than the host rock

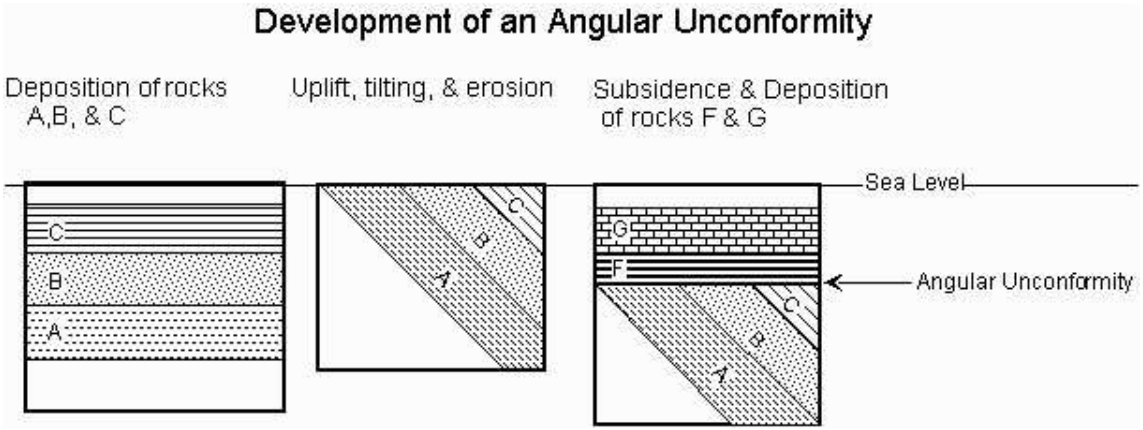


Unconformity

- **Surface that represents a gap in the geologic record**
- **Time in geology is recorded in the rocks, an unconformity marks a time when no rocks were forming at that spot, thus indicating missing time!!**







Types of Unconformities

- **Nonconformity**
  - Metamorphic or igneous (older) rock covered by erosional surface and younger rock (sedimentary)
- **Disconformity**
  - Any erosional surface between rock layers
- **Angular unconformity**
  - Younger rock overlying tilted rock layers

Nonconformity

- *Nonconformity*: A nonconformity exists between sedimentary rocks and metamorphic or igneous rocks when the sedimentary rock lies above and was deposited on the pre-existing and eroded metamorphic or igneous rock.

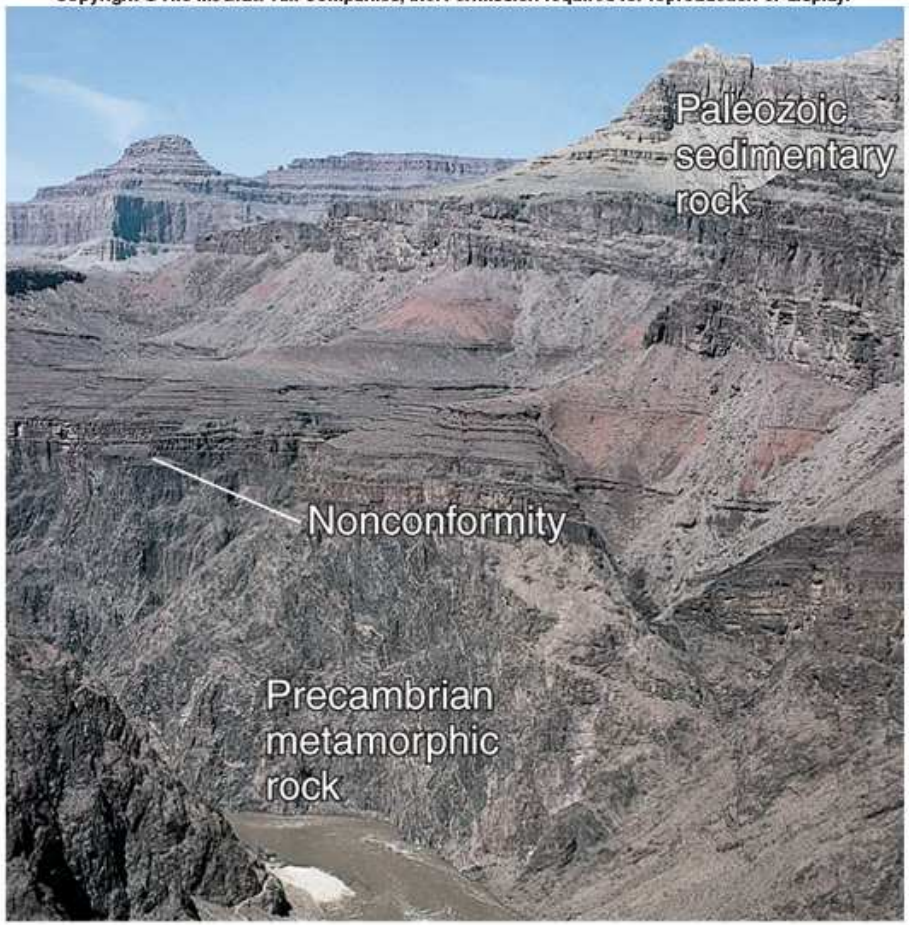


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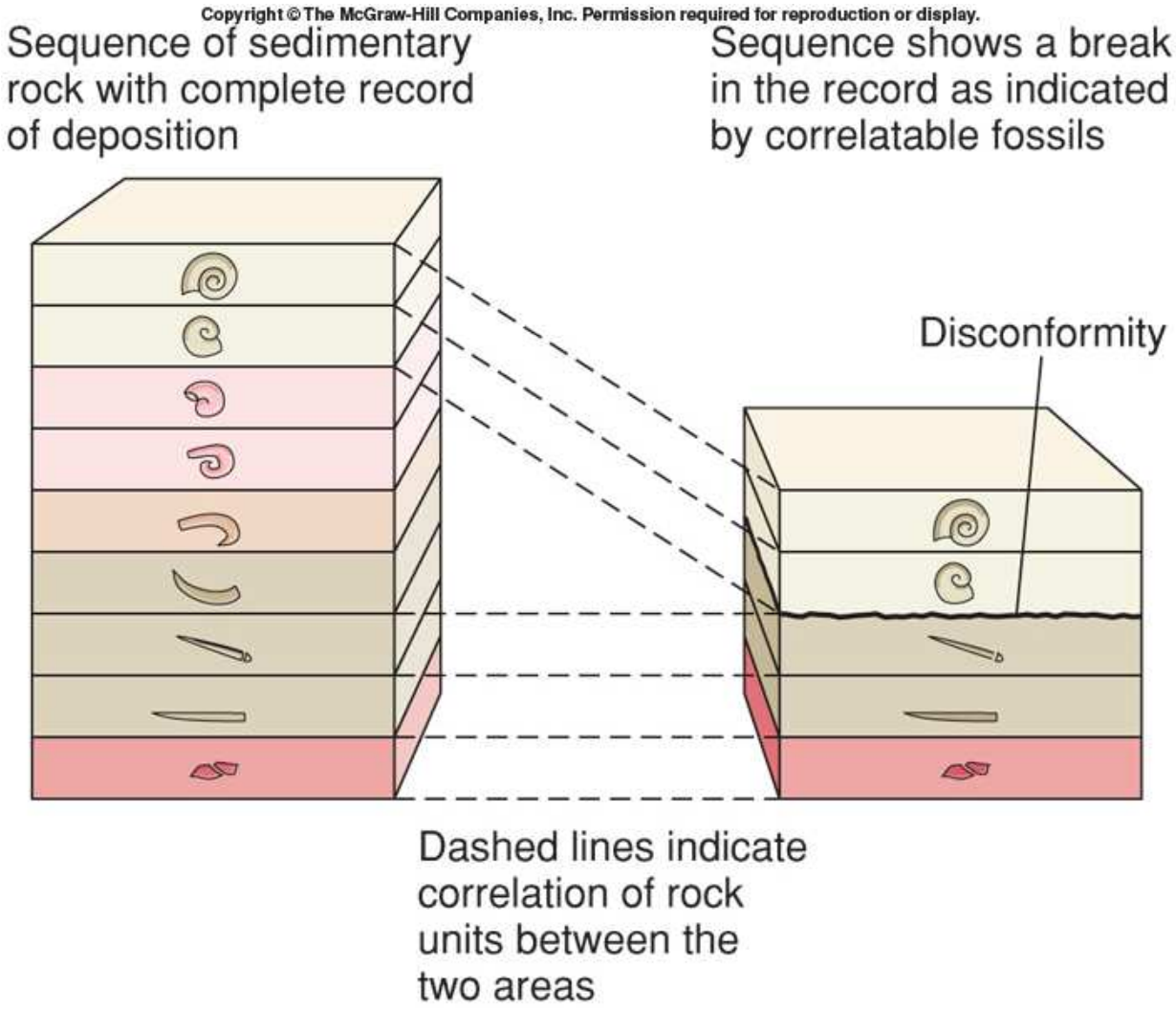
Photo by C.C. Plummer

Disconformity

- *Disconformity* - an unconformity in which the contact representing missing rock layers separates beds that are parallel to each other



Angular unconformity

- *Angular unconformity* - an unconformity in which the contact separates overlying younger layers from eroded tilted or folder layers

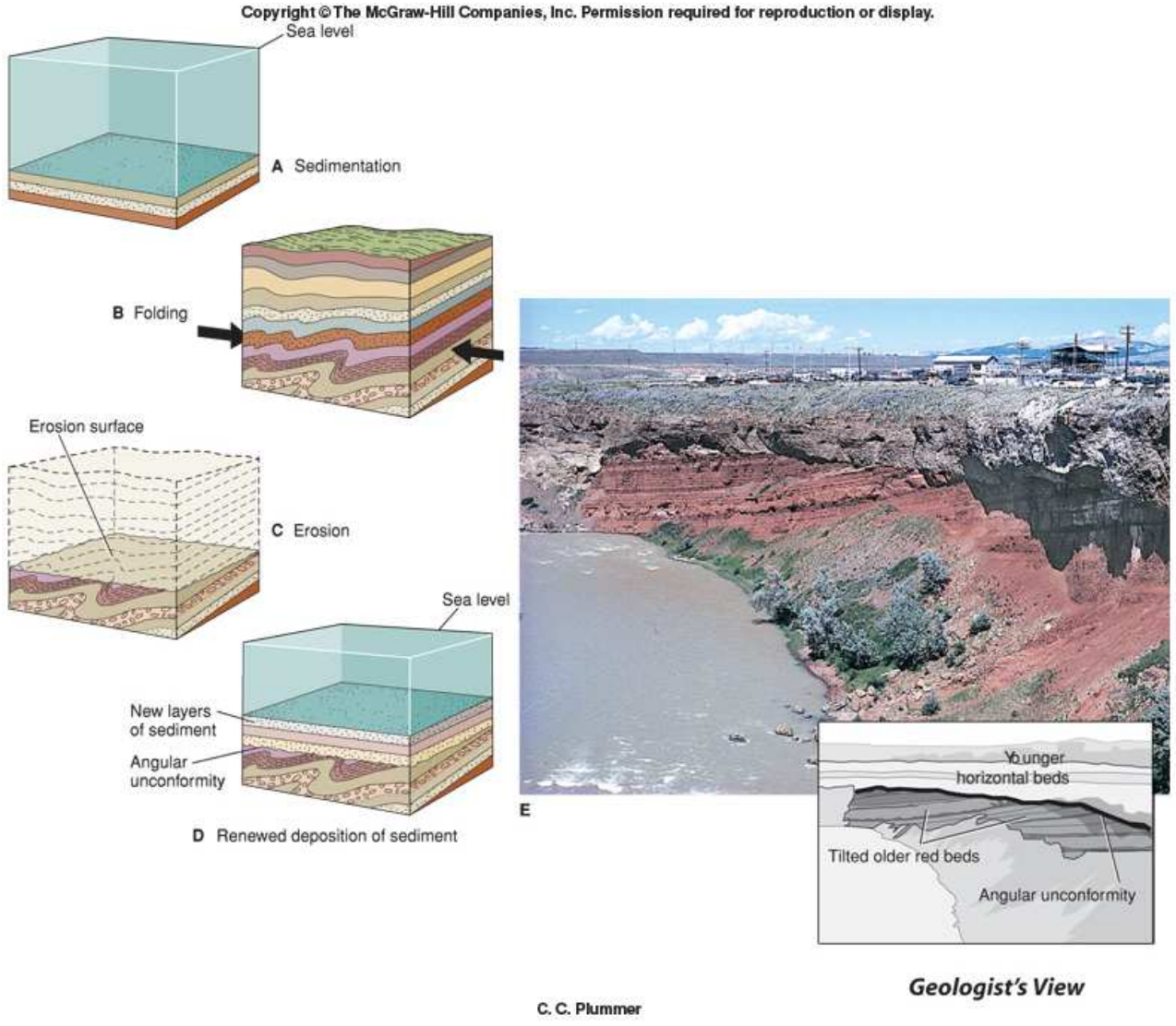


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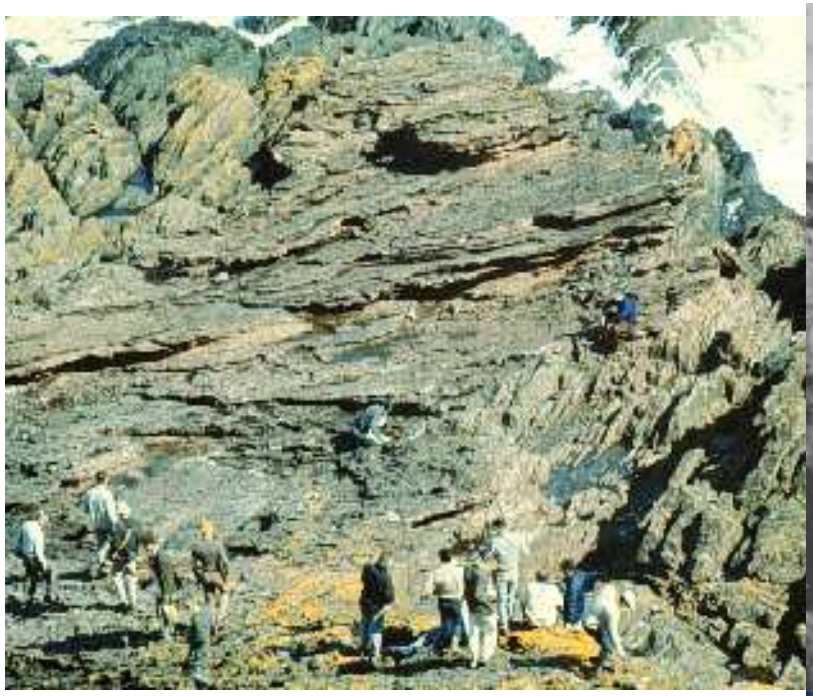
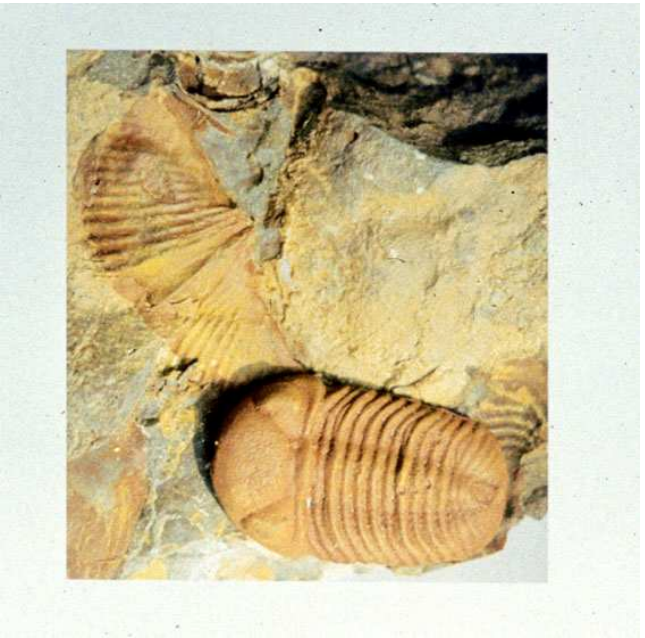
Photo by C.C. Plummer



Siccar Point, Scotland: world famous angular unconformity

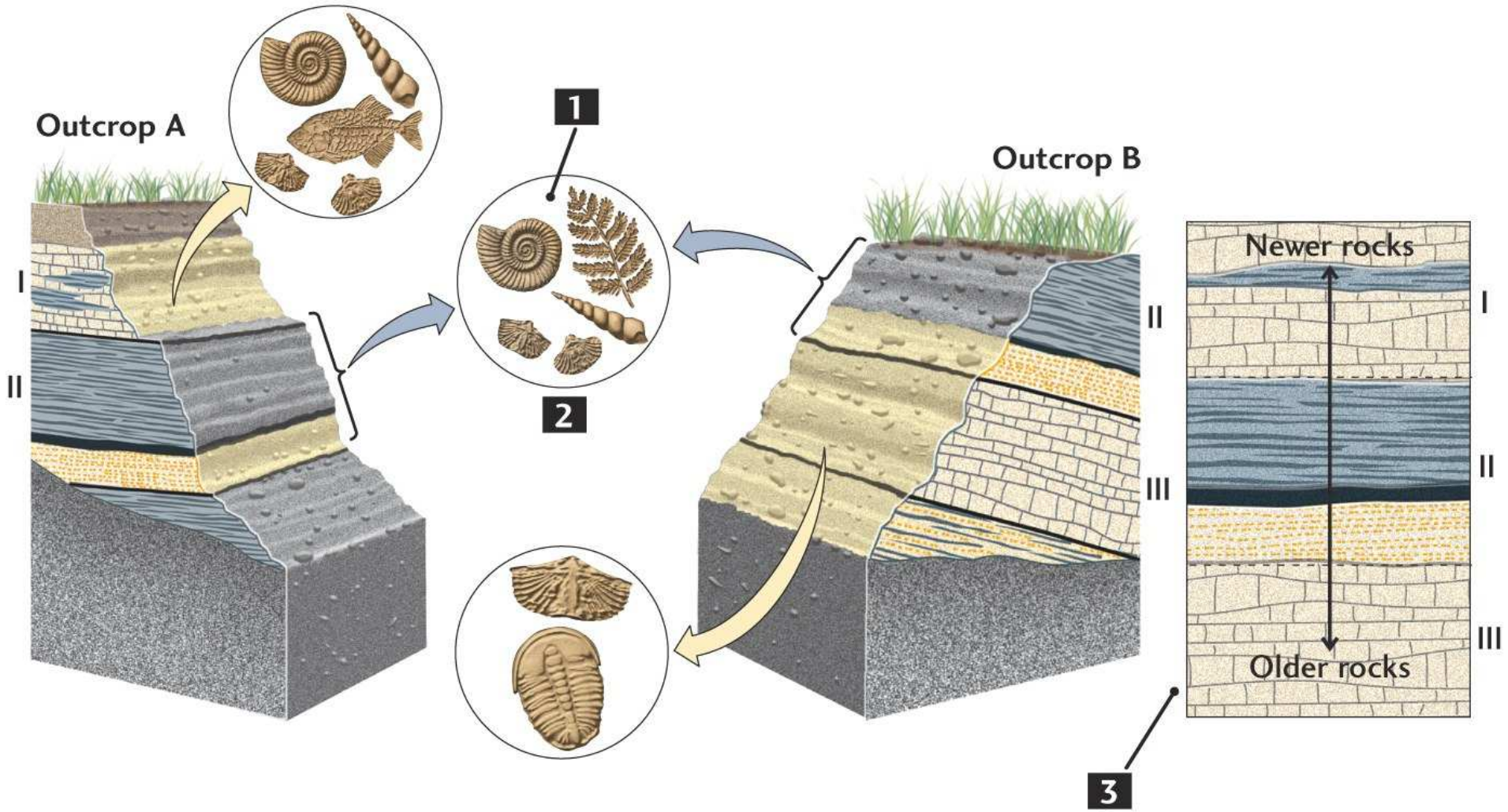
Hutton “upheaval followed by deposition”

William Smith and the Principle of Fossil Succession



Fossil Succession

- Fossil record contained within rock follows the principle of superposition



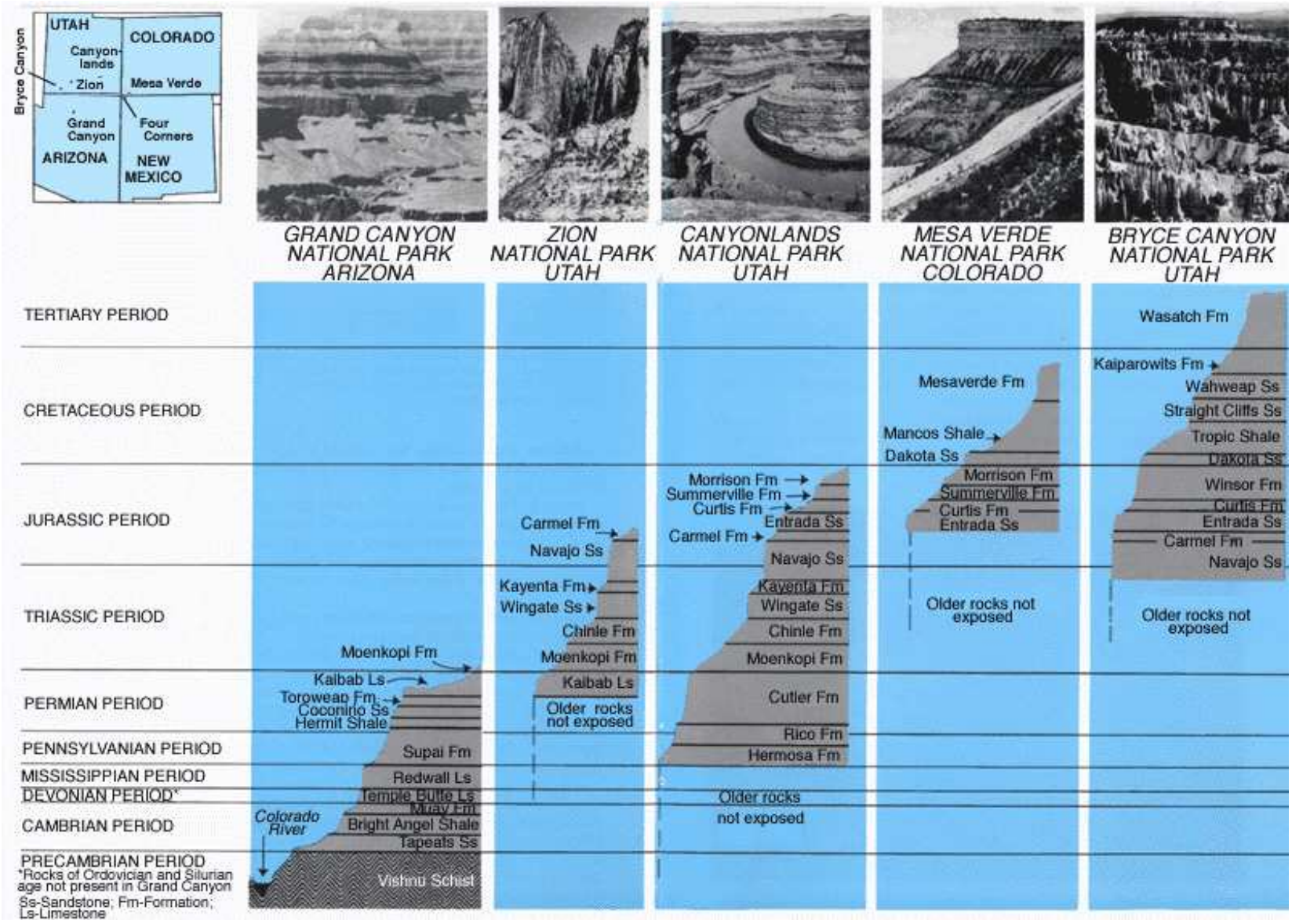
Index Fossil

- Very short lived
- Geographically widespread
- Known to exist during specific time period
- Example: Trilobite

The trilobites disappeared in the mass extinction at the end of the Permian about 250 million years ago.

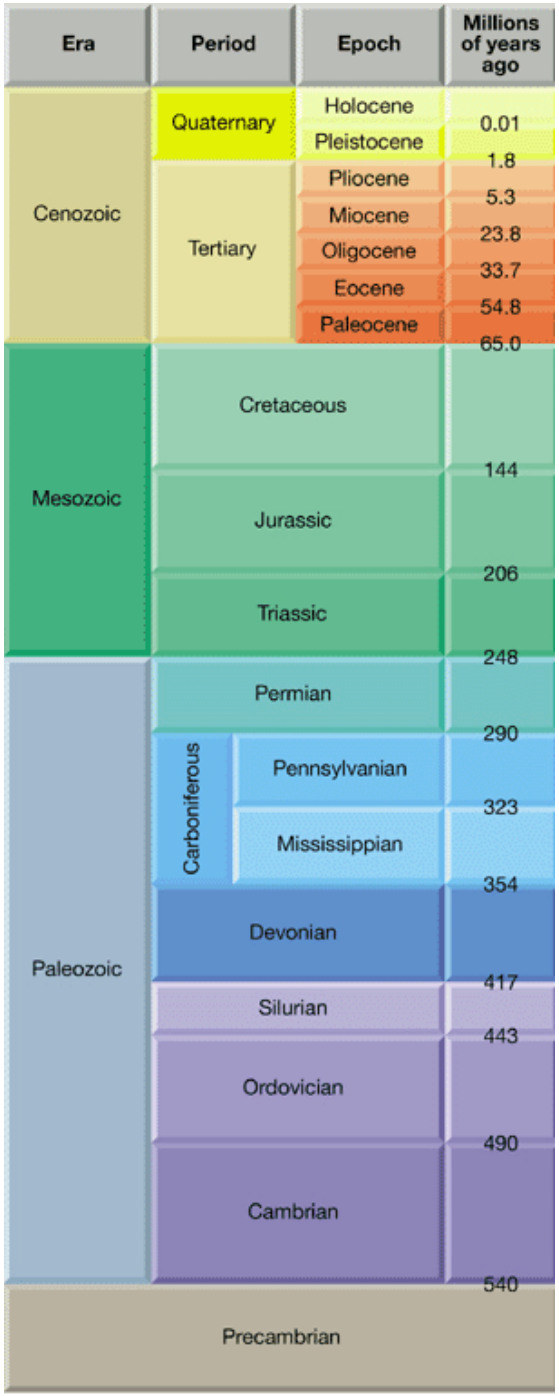
No location on Earth contains a full and complete geologic record for the interval since Earth formation until today

Completing the geologic section requires correlating rocks



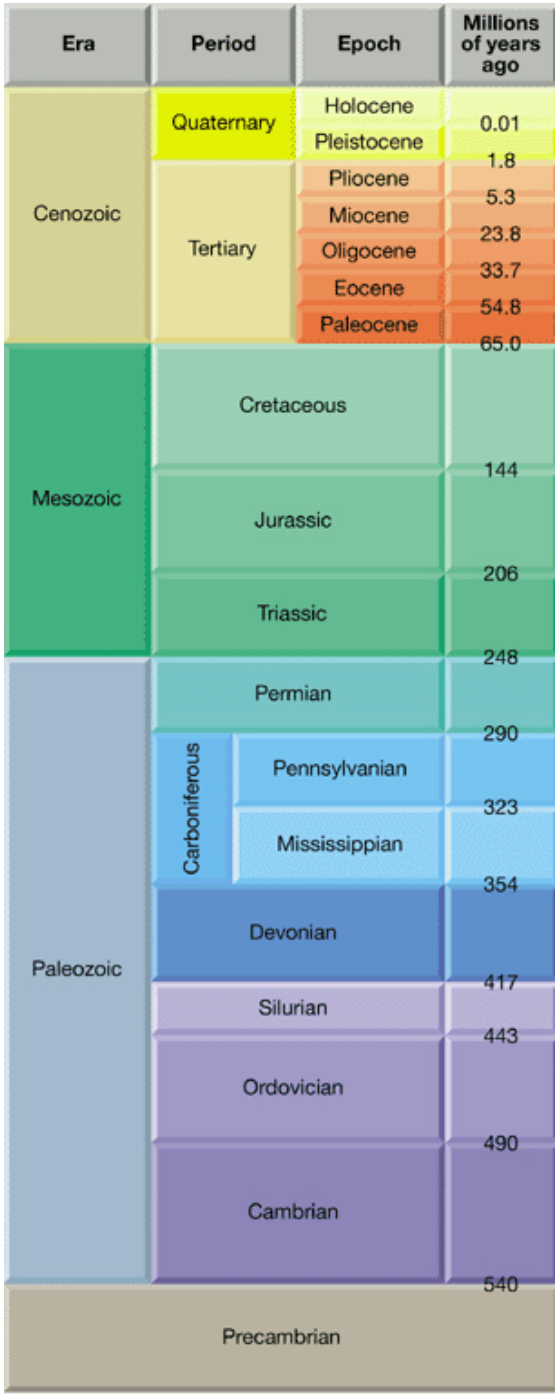
Geologic Time Scale

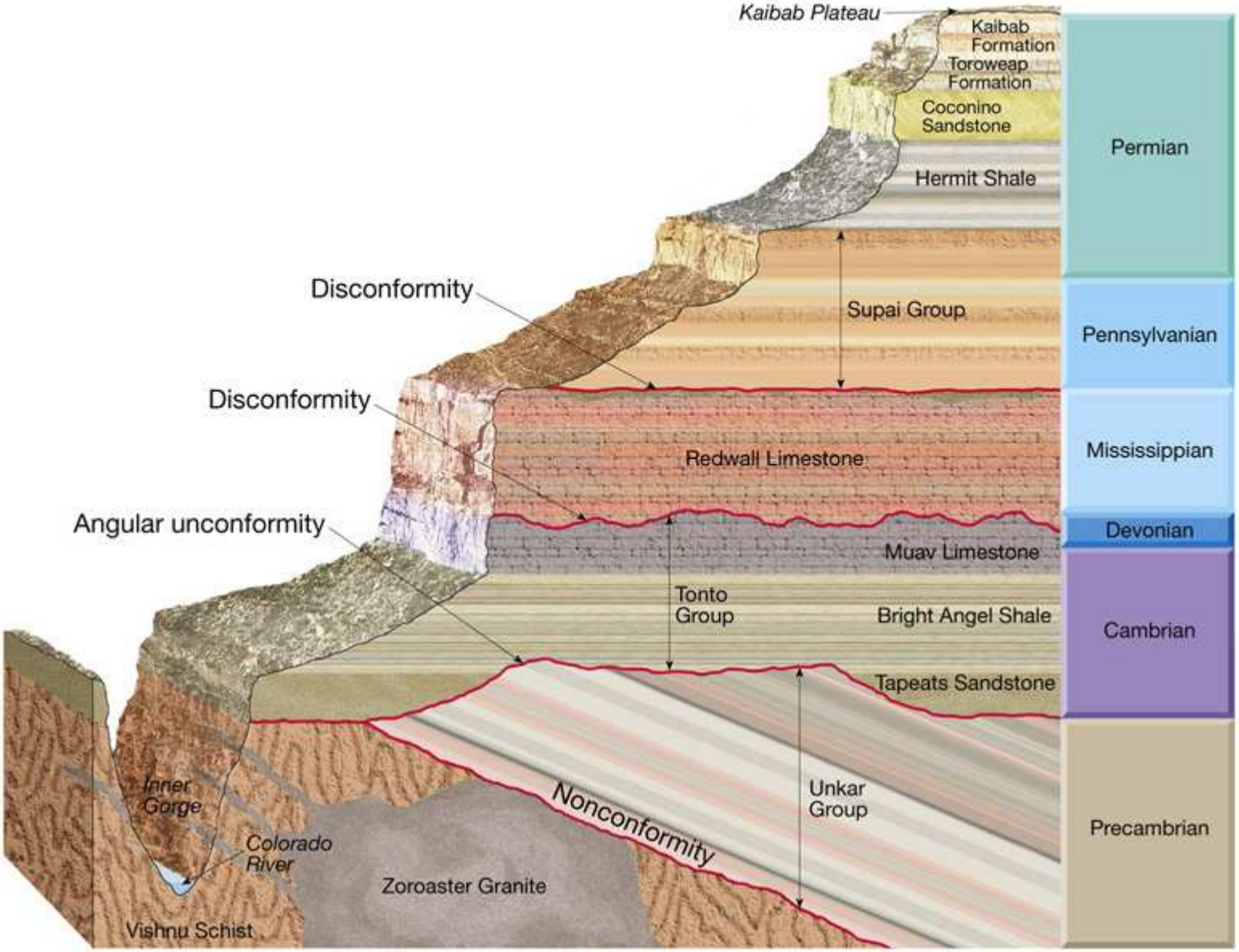
- *Standard geologic time scale*
  - Subdivides geologic time based on fossil assemblages
  - Divided into *eras*, *periods*, and *epochs*
- *Precambrian* - vast amount of time prior to the Paleozoic era; few fossils preserved
- *Paleozoic era* - “old life”
  - appearance of complex life; many fossils



Geologic Time Scale

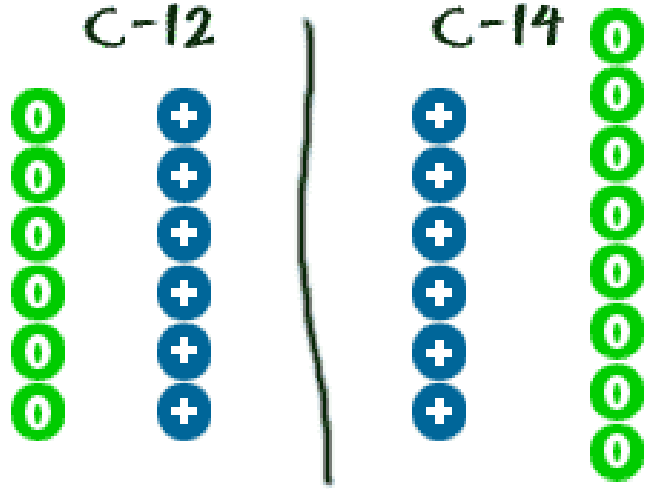
- *Mesozoic era* – "middle life"
  - Dinosaurs abundant on land
  - Period ended by mass extinction
- *Cenozoic era* – "new life"
  - Mammals and birds abundant
  - We are currently in the *Recent* (*Holocene*) *Epoch* of the *Quaternary Period* of the Cenozoic Era
  - Most recent ice ages occurred during the *Pleistocene Epoch* of the Quaternary Period




Kaibab Plateau
Kaibab Formation
Toroweap Formation
Coconino Sandstone
Hermit Shale
Permian
Disconformity
Supai Group
Pennsylvanian
Disconformity
Redwall Limestone
Mississippian
Angular unconformity
Devonian
Muav Limestone
Tonto Group
Bright Angel Shale
Cambrian
Tapeats Sandstone
Inner Gorge
Colorado River
Nonconformity
Unkar Group
Precambrian
Zoroaster Granite
Vishnu Schist

Numerical Age Dating

Adding or removing neutrons from an atom does not create a different element. Rather, it creates a heavier or lighter version of that element. These different versions are called isotopes and most elements are actually a mixture of different **isotopes**.



C-14 is considered an unstable isotope of the element carbon

Unstable isotopes – radioactive decay

Numerical Age Dating

- *Numerical dating* - puts absolute values (e.g., millions of years) on the ages of rocks and geologic time periods
  - Uses *radioactive decay* of *unstable isotopes*
  - Only possible since radioactivity was discovered in 1896
  - Radioactive isotopes decay in predictable manner, giving a characteristic *half-life* (time it takes for a given amount of radioactive isotope to be reduced by half)

Numerical Age Dating

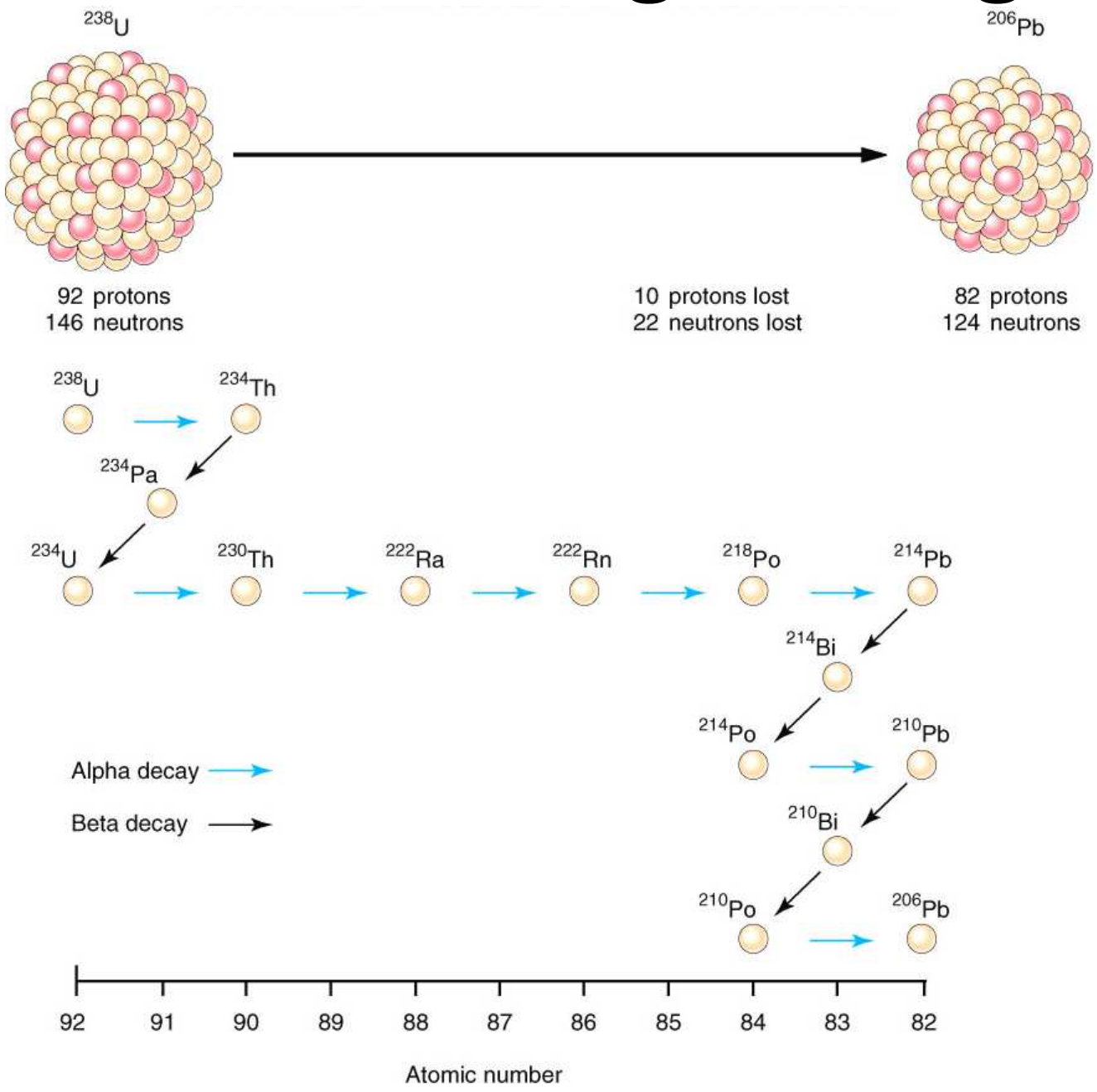
- Isotopes of atoms that occur in nature come in two flavors: stable and unstable (radioactive).

- Some of the unstable isotopes are only moderately unstable and can therefore still persist in nature today.

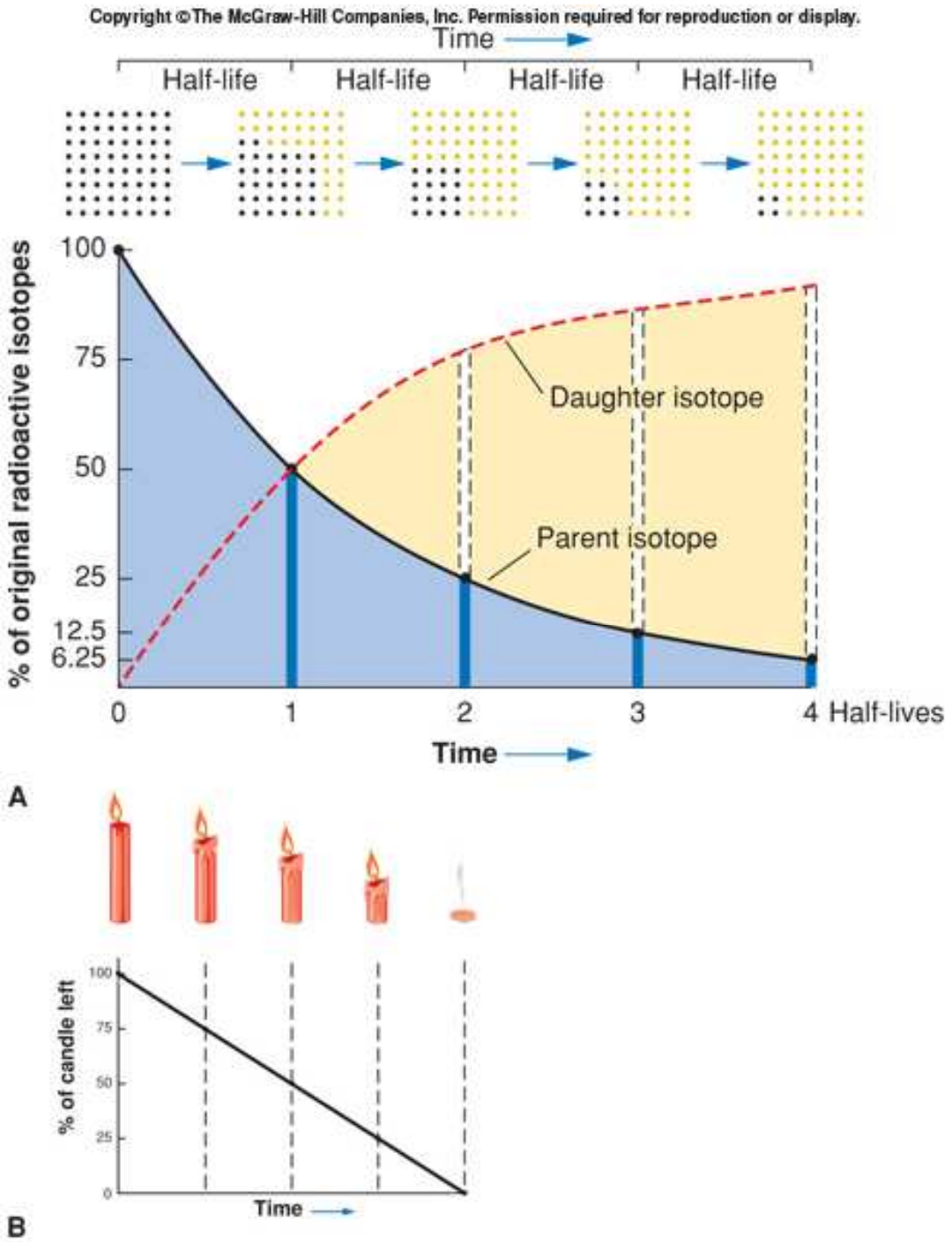
- The isotope 238-U is a good example. It is radioactive but it's half life is 4.43 billion years. The Earth itself is 4.55 billion years old, so we now have roughly half of the 238-U on Earth that we had when Earth was formed.

- When an unstable isotope decays, it makes a new atom of a different element. Stable, isotopes, on the other hand, do not decay.

Numerical Age Dating

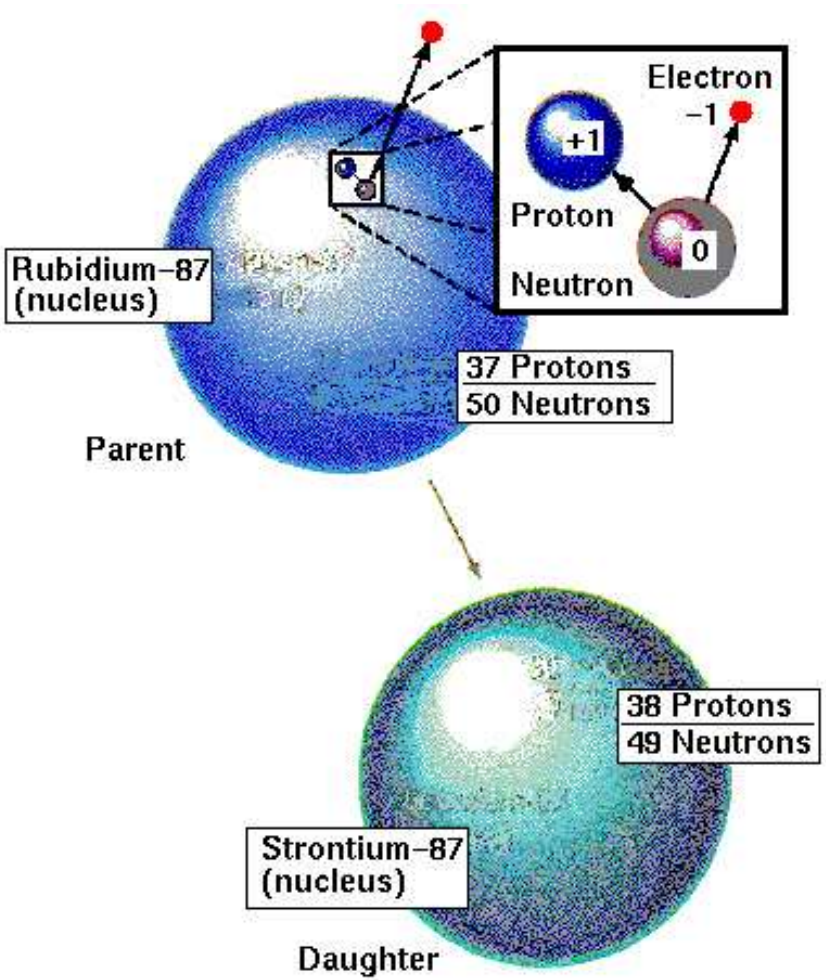


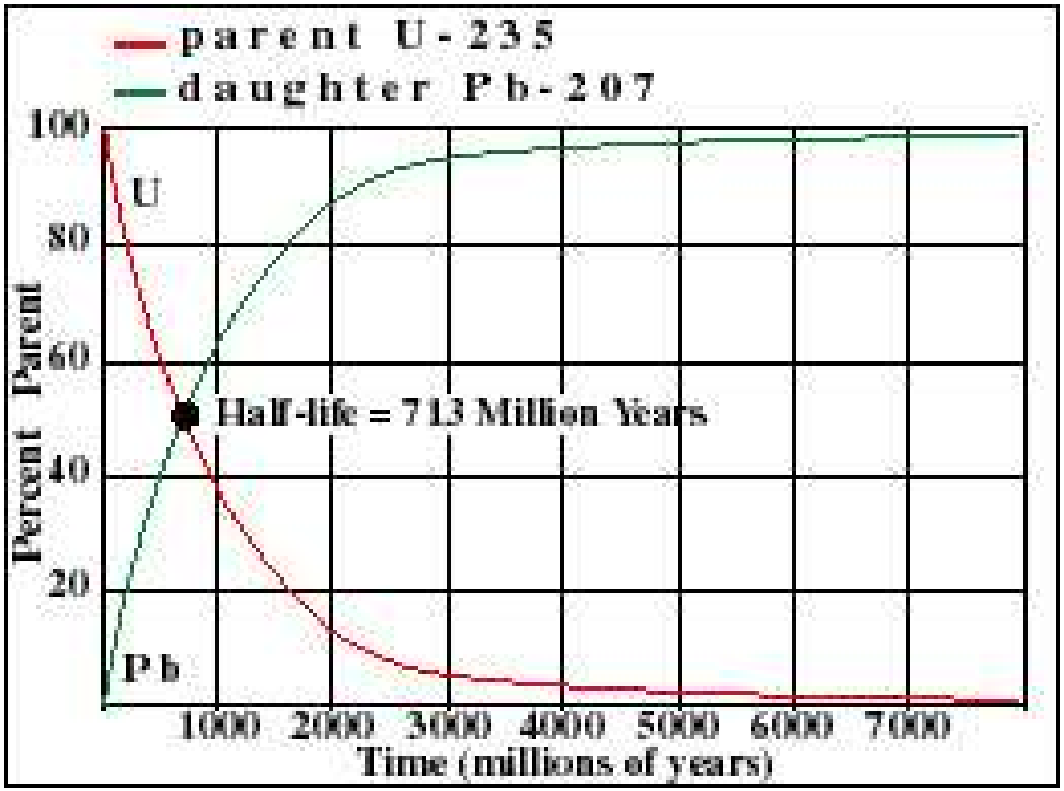
Numerical Age Dating



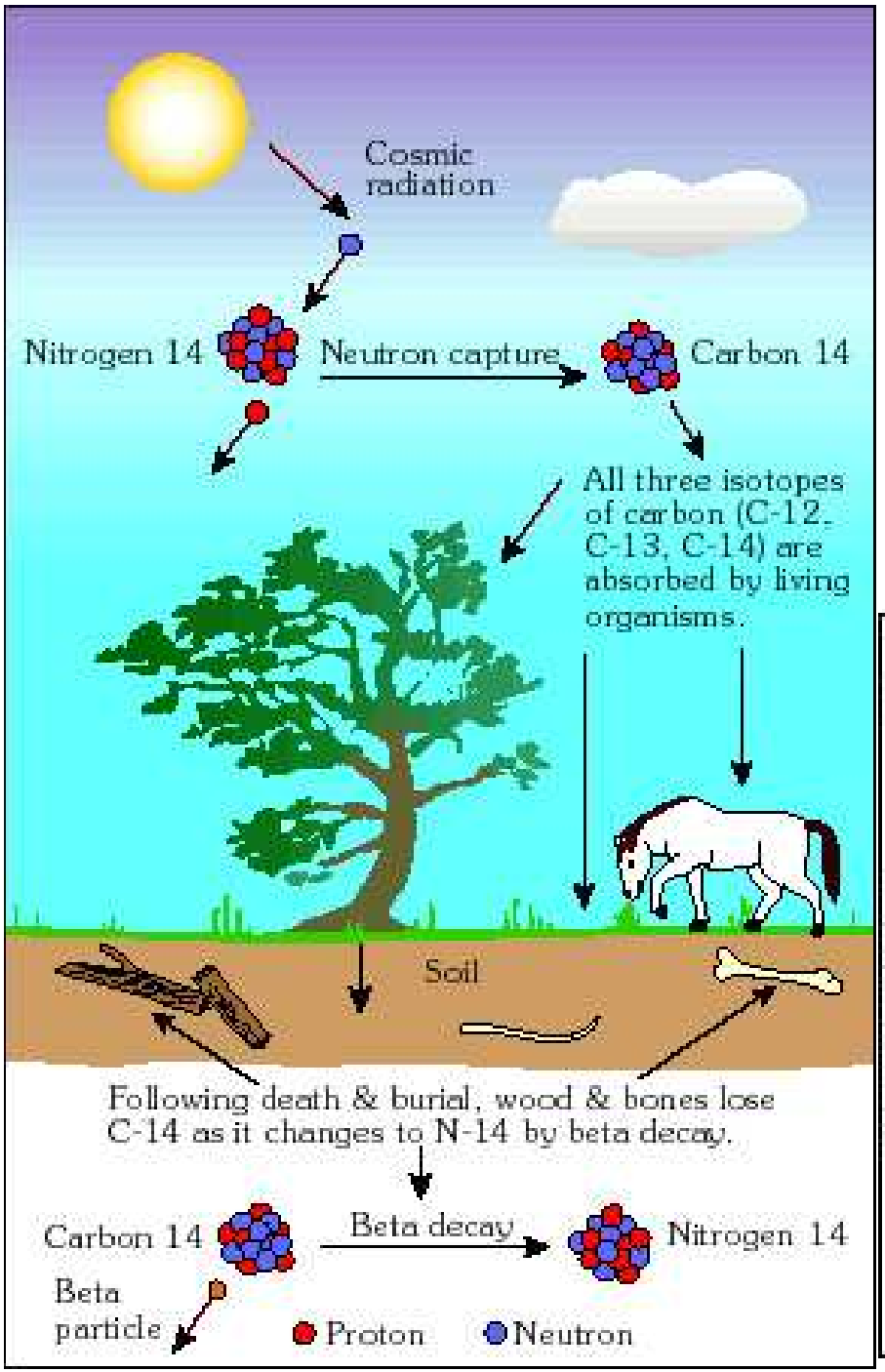
Isotope Age Dating

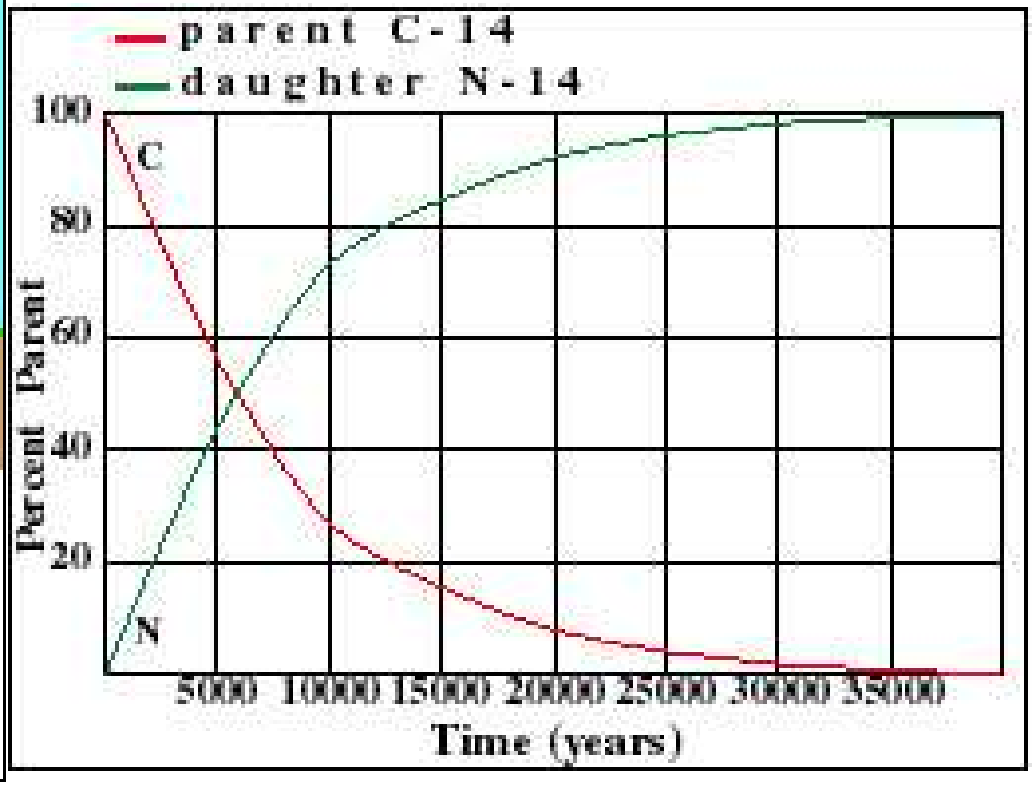
- **Establishes absolute ages**
- **Quantitative measurements of time**





Radiocarbon dating using ^{14}C





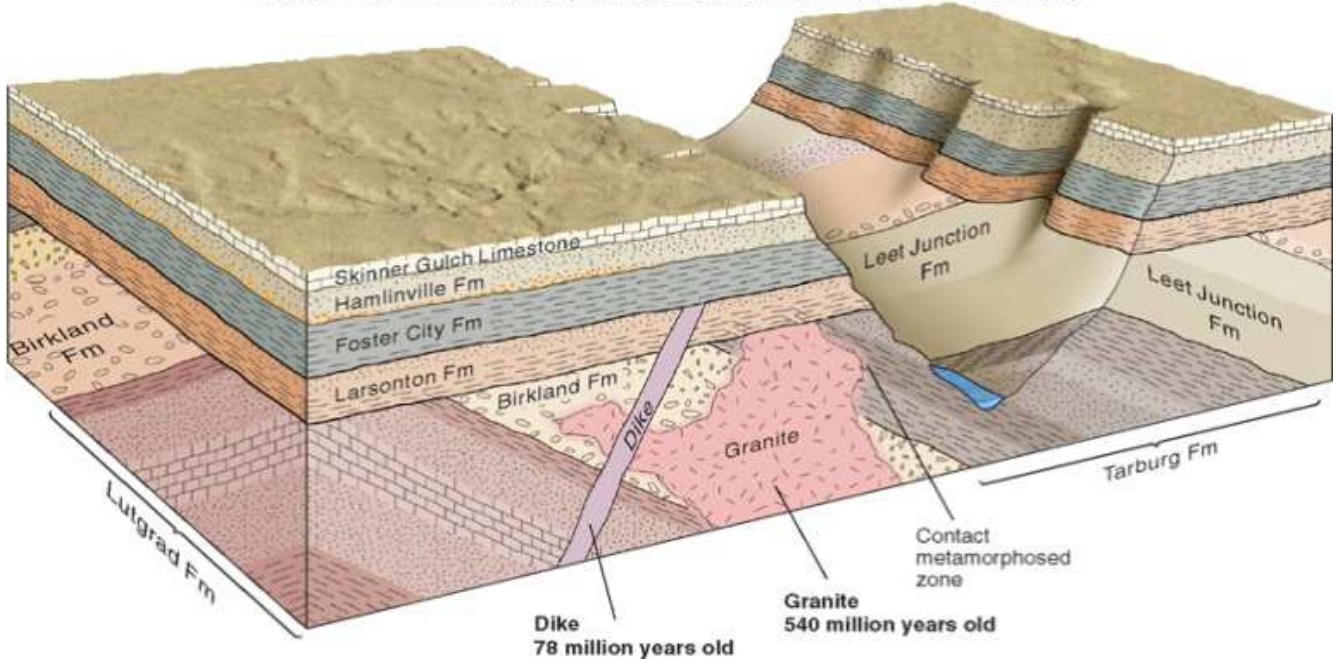
Radiometric Dating

TABLE 8.3 Radioactive Isotopes Commonly Used for Determining Ages of Earth's Materials

Parent Isotope	Half-Life	Daughter Product	Effective Dating Range (years)
K-40 ^{40}K	1.3 billion years	^{40}Ar	100,000–4.6 billion
U-238 ^{238}U	4.5 billion years	^{206}Pb	10 million–4.6 billion
U-235 ^{235}U	713 million years	^{207}Pb	10 million–4.6 billion
Th-232 ^{232}Th	14.1 billion years	^{208}Pb	10 million–4.6 billion
Rb-87 ^{87}Rb	49 billion years	^{87}Sr	10 million–4.6 billion
C-14 ^{14}C	5,730 years	^{14}N	100–40,000

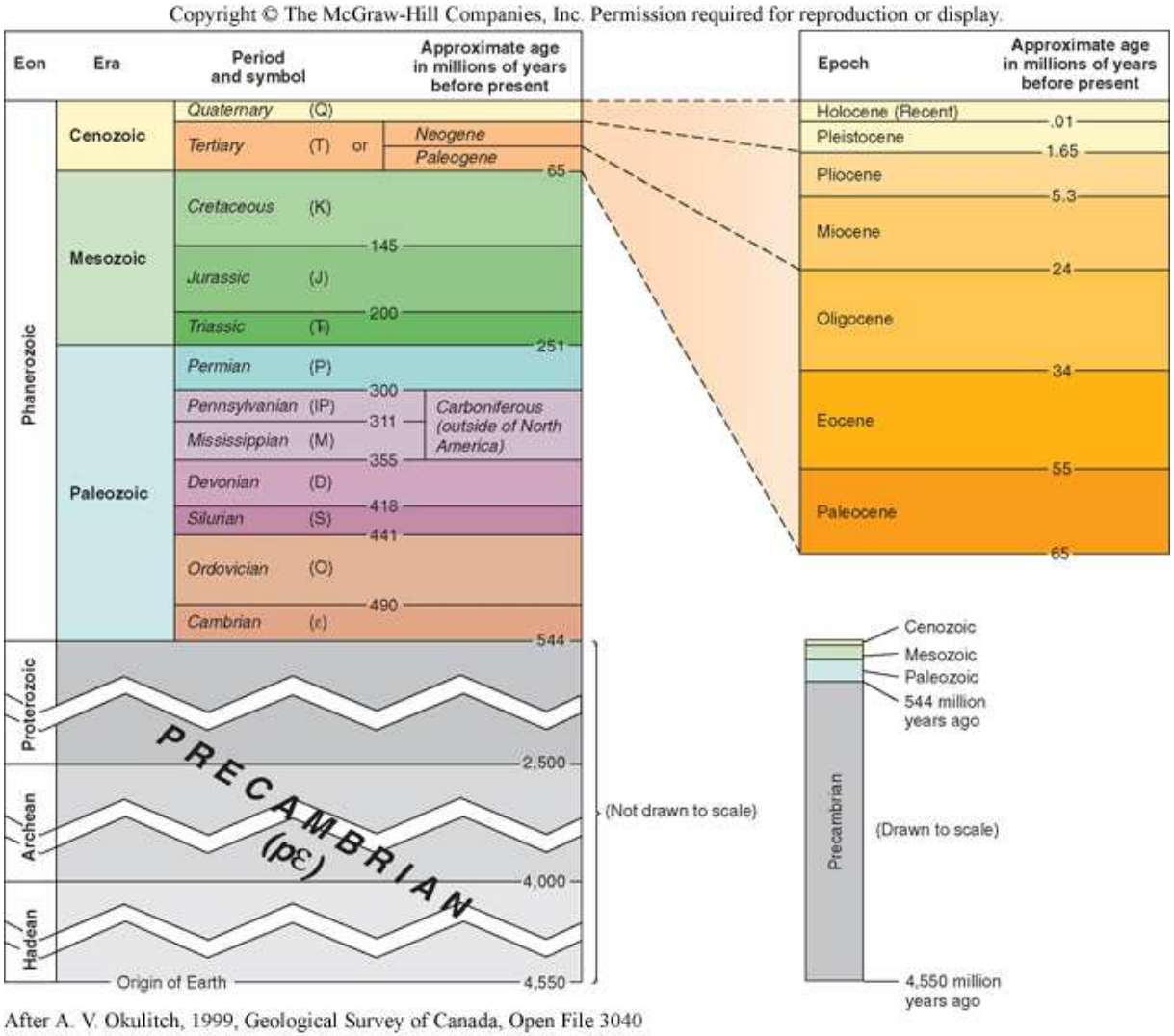
Combining Relative and Numerical Ages

- *Radiometric dating* gives numerical time brackets for events with known relative ages
  - Individual layers may be dated directly
  - Radiometric dating of units above and below, brackets age of units in between



Combining Relative and Numerical Ages

- *Geologic Time Scale*
  - Precambrian (all time prior to Cambrian Period) represents 87% of geologic time)



After A. V. Okulitch, 1999, Geological Survey of Canada, Open File 3040

Age of the Earth

- Numerical dating gives absolute age for Earth of about *4.56 billion years*
  - Oldest age obtained for *meteorites*, believed to have been unchanged since the formation of the solar system
  - Earth and rest of solar system very likely formed at this time
- *Geologic* (*deep*) *time* is ***vast***
  - A long human lifetime (100 years) represents only about *0.000002%* of geologic time

End of Chapter 8