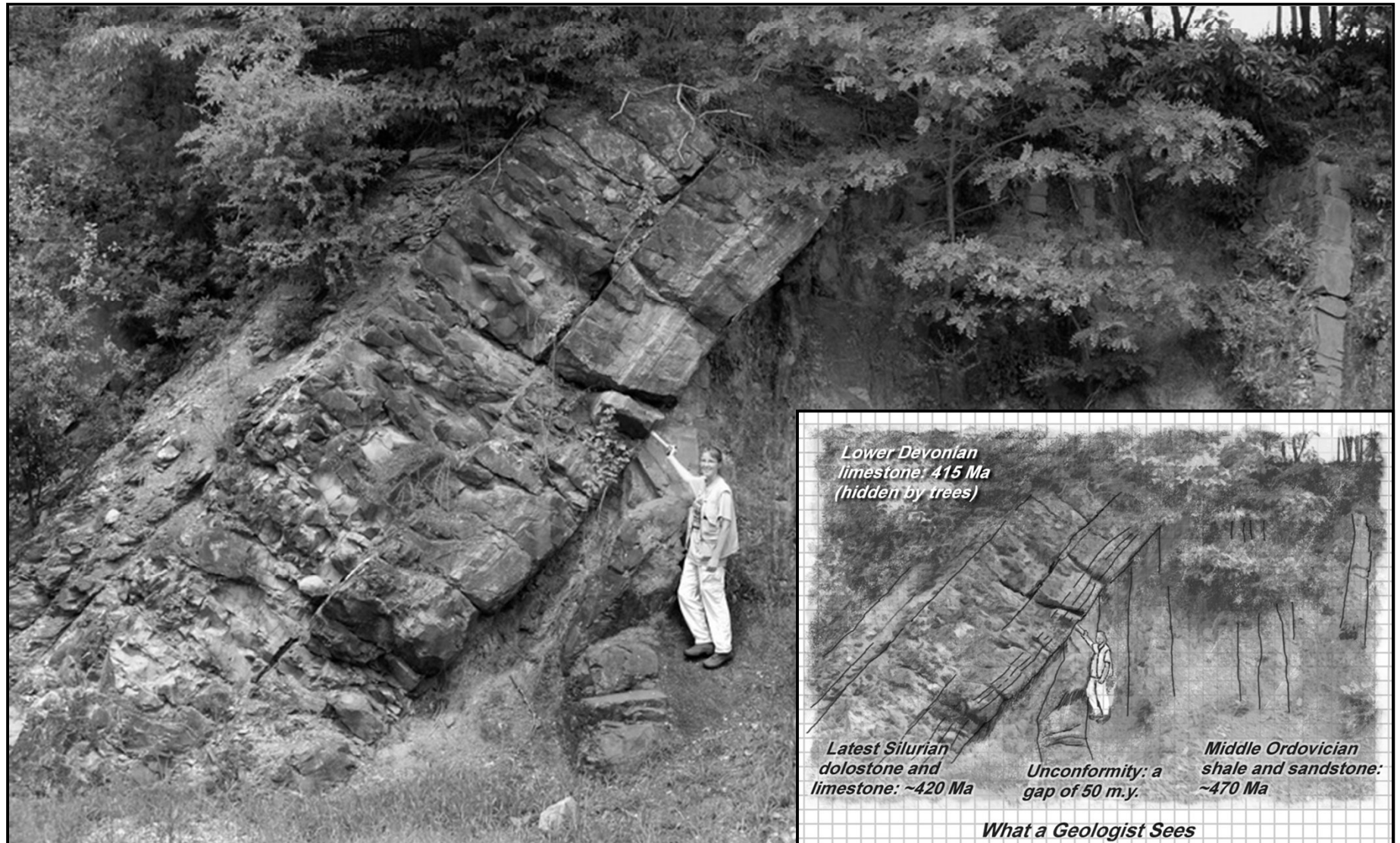


PHYS 3800 Physical Geology

Chapter 10: Deep Time: How Old Is Old?



Thought for the Day



Geologic Time

- Earth has a history that is billions of years old.
- Discovering this was a major step in human history.
- It changed our perception of time and the Universe.



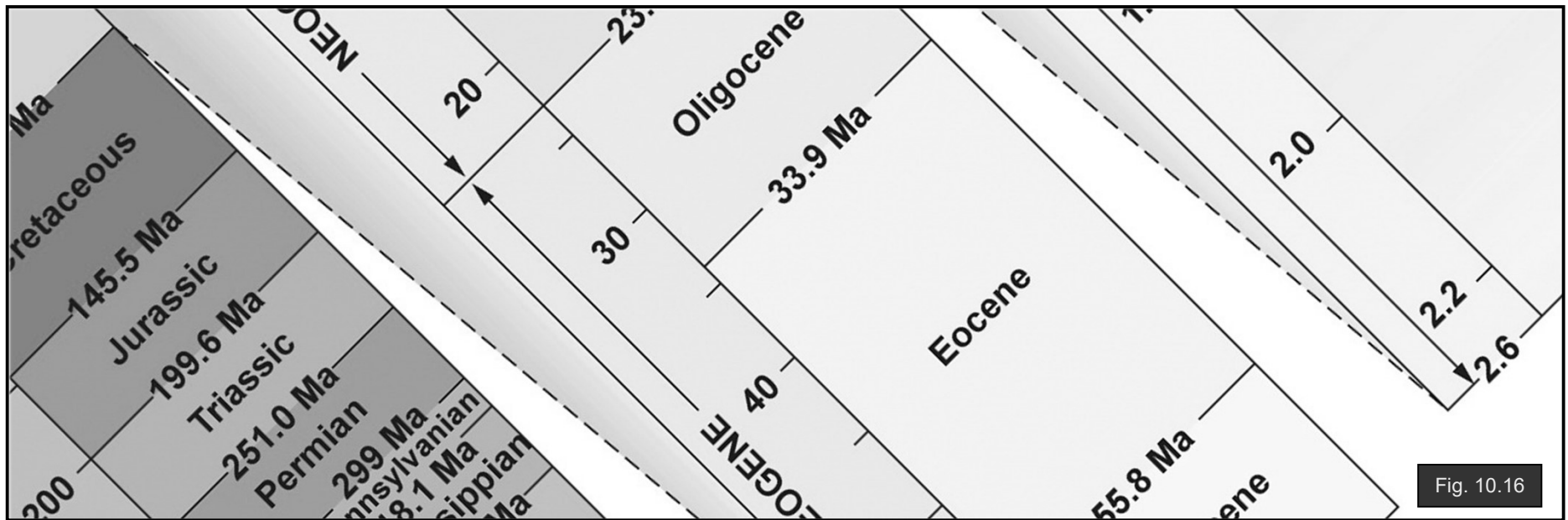
Geologic Time

- Provides a frame of reference for understanding:
 - Rocks
 - Fossils
 - Geologic structures
 - Landscapes
 - Tectonic events
 - Change



Geologic Time

- Deep time—the immense span of geologic time
- The concept is so vast, it is difficult for people to grasp.
 - We think of time in terms of our lives:
 - Our parents and grandparents
 - Our children or grandchildren
- Human history is minuscule against geologic time.



Geologic Time

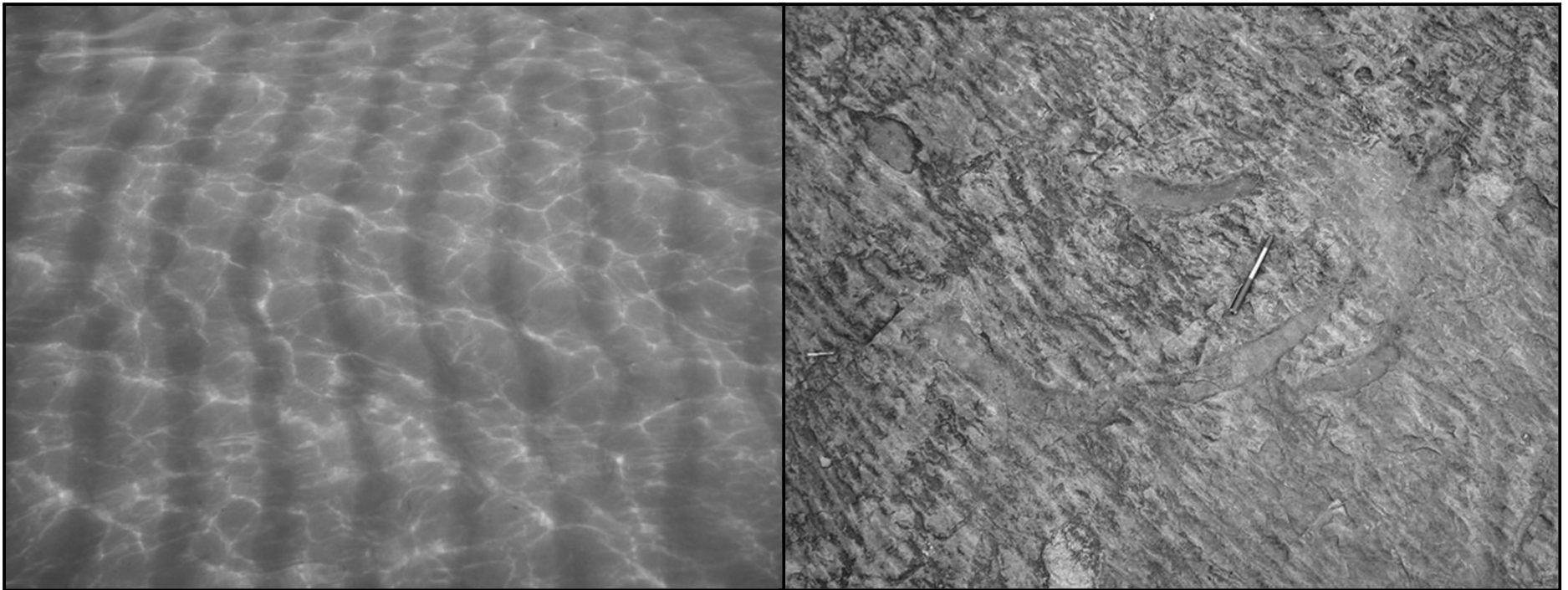
- **James Hutton (1726–97), Scottish physician and farmer.**
 - He is called “the father of modern geology.”
 - Identified features in rocks that resembled features forming in modern sedimentary environments.
 - The first to articulate the “principle of uniformitarianism”



Geologic Time

■ James Hutton's principle of uniformitarianism

- “The present is the key to the past.”
 - ▶ Processes seen today are the same as those of the past.
 - ▶ Geologic change is slow; large changes require a long time.
 - ▶ Therefore, there must have been a long time before humans.



Geologic Time

- There are two ways of dating geological materials.
 - Relative ages—based upon order of formation
 - Qualitative method developed hundreds of years ago.
 - Permit determination of older vs. younger relationships.
 - Numerical ages—actual number of years since an event
 - Quantitative method developed recently.

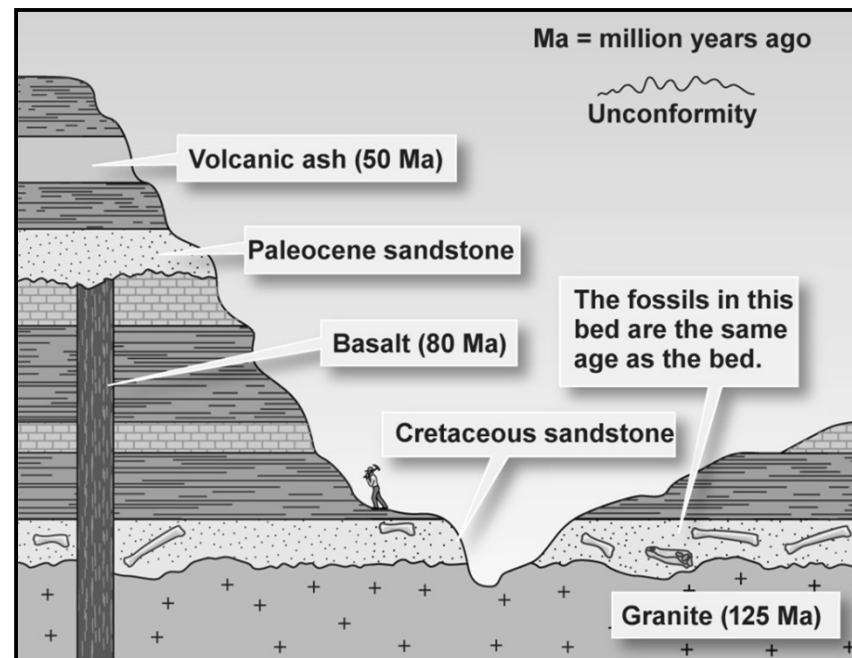


Fig. 10.15

Physical Principles

- Sir Charles Lyell wrote *Principles of Geology* in 1830–33.
 - Laid out a set of principles for deciphering Earth history.
 - Used to establish relative ages of Earth materials.
 - The principle of uniformitarianism
 - ▶ Processes observed today were the same in the past.
 - ▶ Mudcracks in old sediments formed like mudcracks today.



Physical Principles

- The principle of original horizontality
 - Sediments settle out of a fluid by gravity.
 - This causes sediments to accumulate horizontally.
 - Sediment accumulation is not favored on a slope.
 - Hence, tilted sedimentary rocks must be deformed.

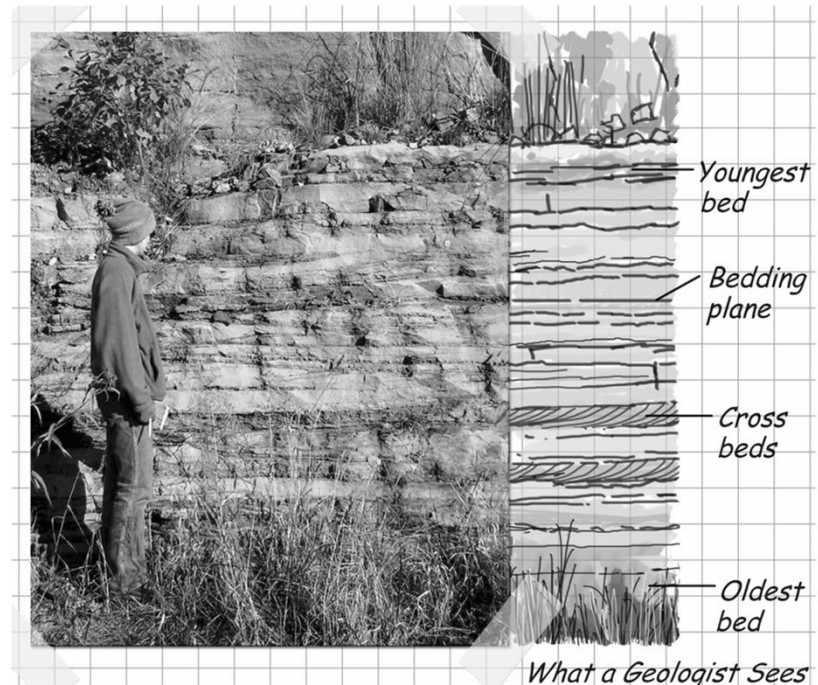


Fig. 10.1b, c

Physical Principles

- The principle of superposition
 - In an undeformed sequence of layered rocks:
 - Each bed is older than the one above and younger than the one below.
 - Younger strata are on top, older strata on bottom.

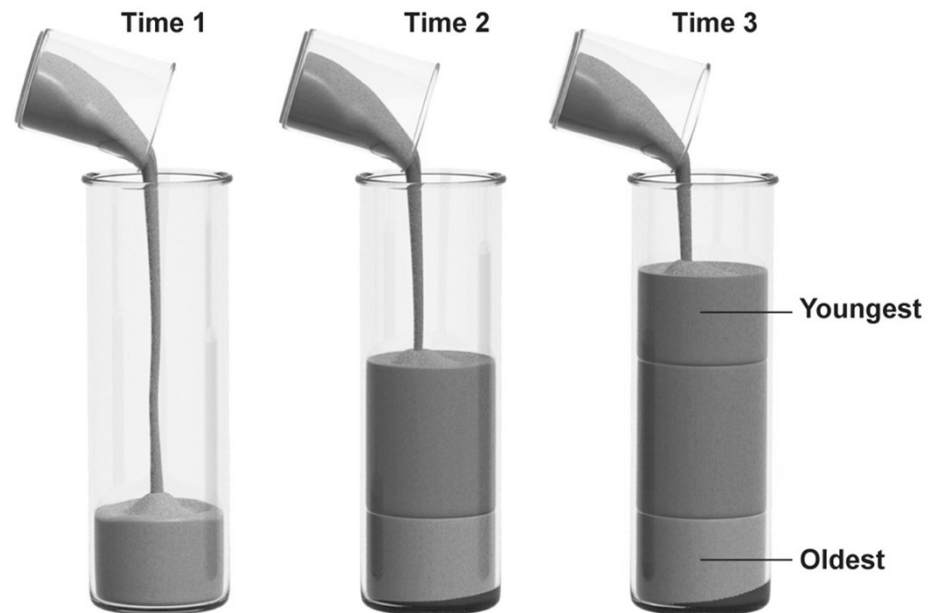
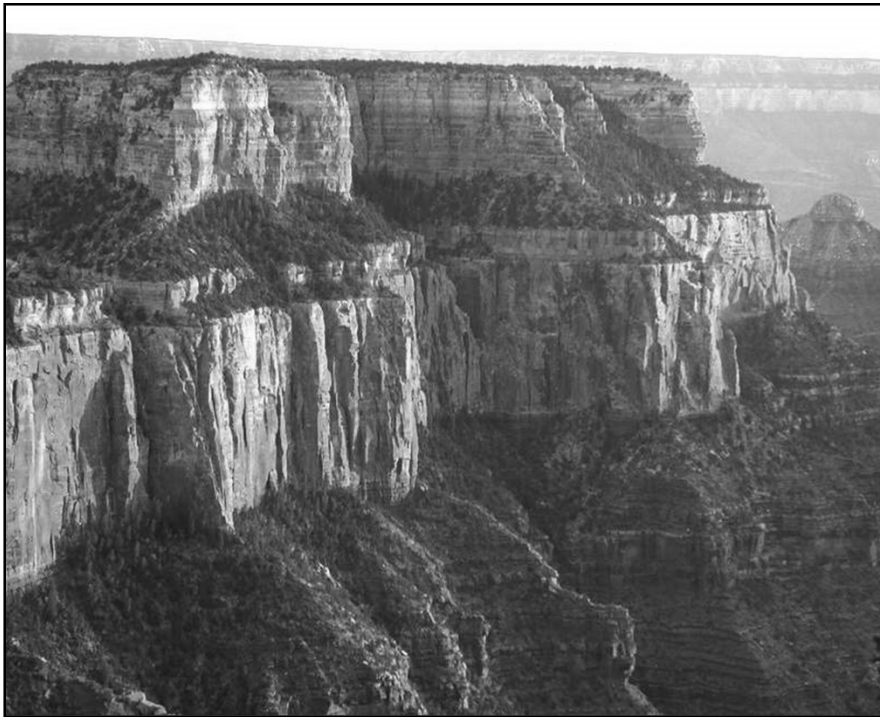


Fig. 10.1d

Physical Principles

■ The principle of lateral continuity

- Strata often form laterally extensive horizontal sheets.
- Subsequent erosion dissects once-continuous layers.
- Flat-lying rock layers are unlikely to have been disturbed.



Fig. 10.1e



Physical Principles

- The principle of cross-cutting relations
 - Younger features truncate (cut across) older features.
 - Faults, dikes, erosion, etc., must be younger than the material that is faulted, intruded, or eroded.
 - A volcano cannot intrude rocks that aren't there.

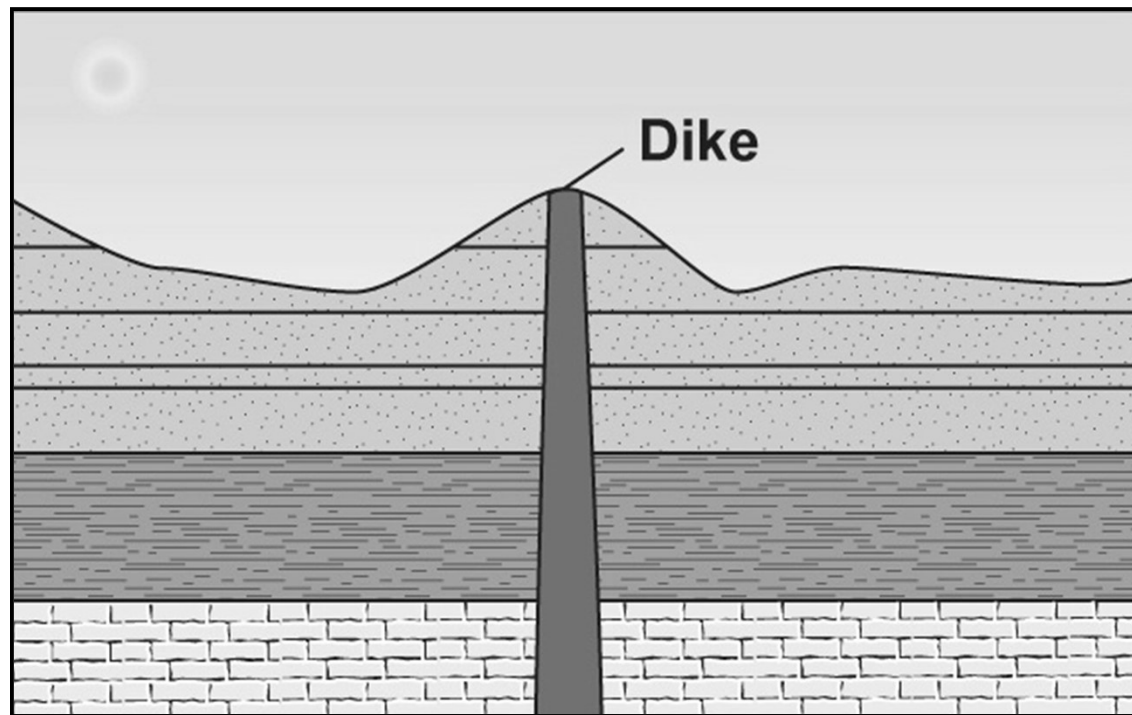


Fig. 10.1f

Physical Principles

- The principle of baked contacts
 - An igneous intrusion cooks the invaded country rock.
 - The baked rock must have been there first (it is older).

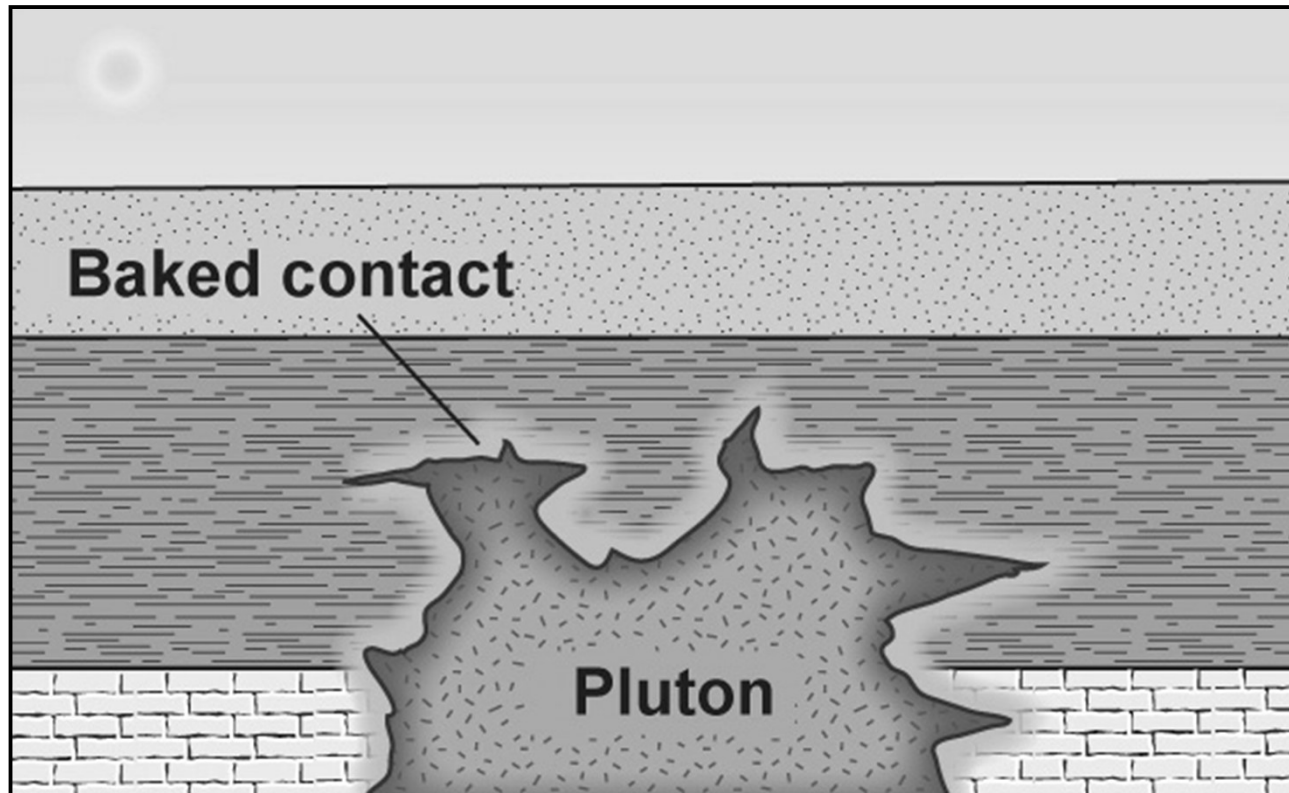
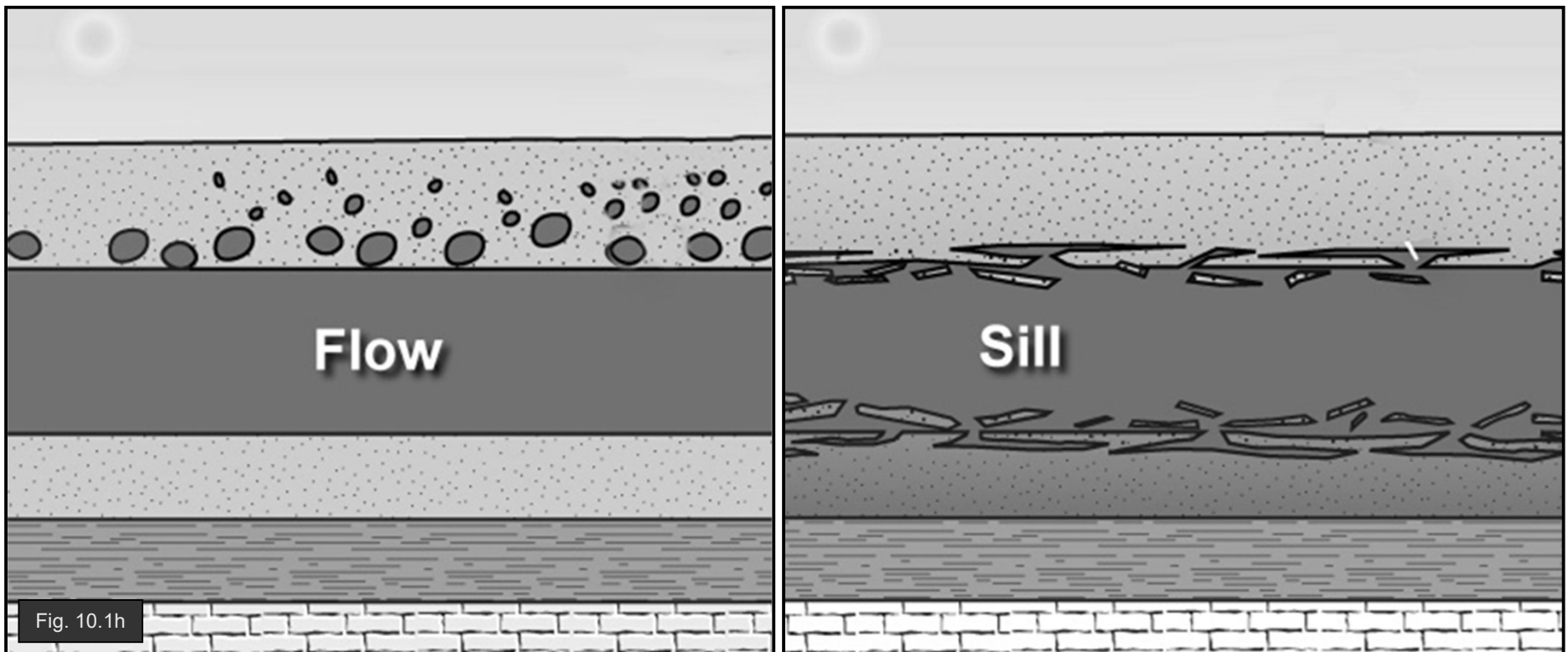


Fig. 10.1g

Physical Principles

- Principle of inclusions—a rock fragment within another
- Inclusions are always older than the enclosing material.
 - Weathering rubble must have come from older rock.
 - Fragments (xenoliths) are older than igneous intrusion.



Physical Principles

- Physical principles allow us to sort out relative age.
- This is possible even in complex situations.
- Consider this block of geologic history. We see:
 - Folded sediments
 - Intrusions
 - Granite
 - Basalt
 - A fault
 - Xenoliths
 - Inclusions
 - Baked contact
- Easily deciphered!

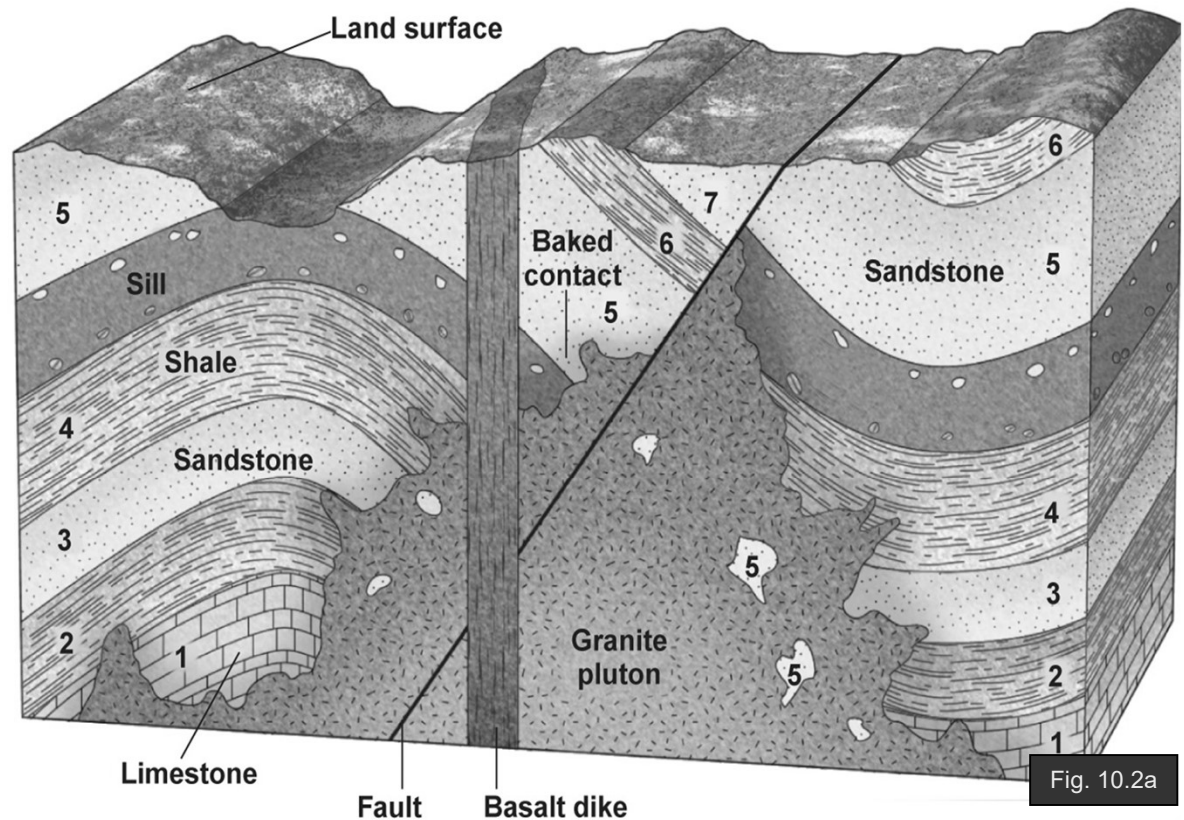


Fig. 10.2a

Geologic History

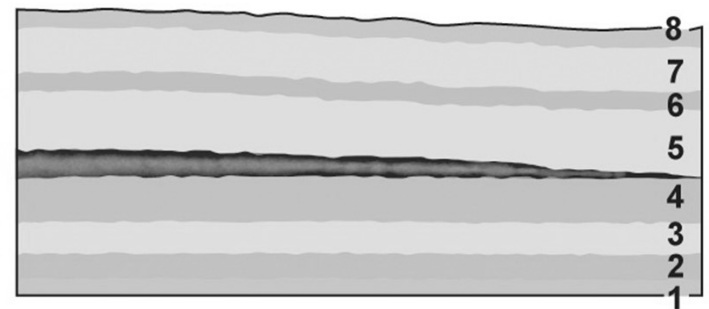
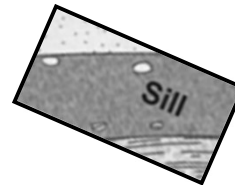
- A sequence of horizontal strata accumulates.

- Superposition (1 oldest)



- An igneous sill intrudes.

- Inclusions of 4 and 5 in sill confirm it is younger.



- Folding, uplift, and erosion take place.

- Folding occurs before intrusion.

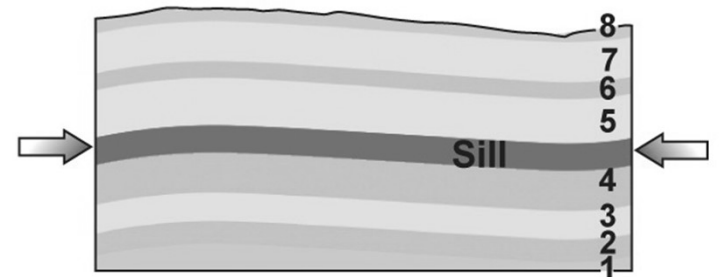
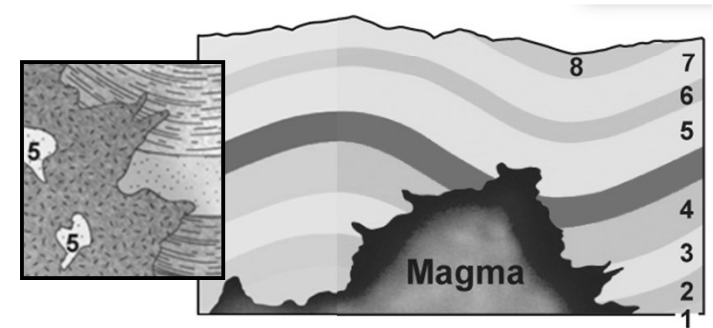


Fig. 10.2b

Geologic History

■ A granitic pluton intrudes the folded sediments.

- Granite cuts folded layers.
- Baked contact caused by heat.
- Xenoliths fall into magma.



■ A fault cuts the granite and folded sediments.

■ A basalt dike cuts across the block.

- The dike cools and the surface volcano is eroded.

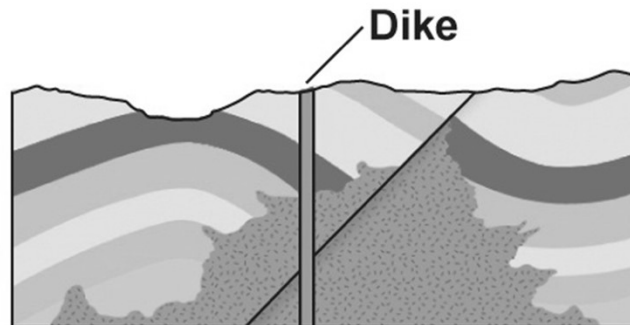
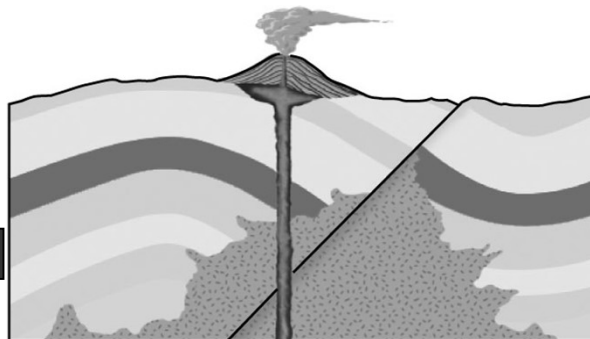
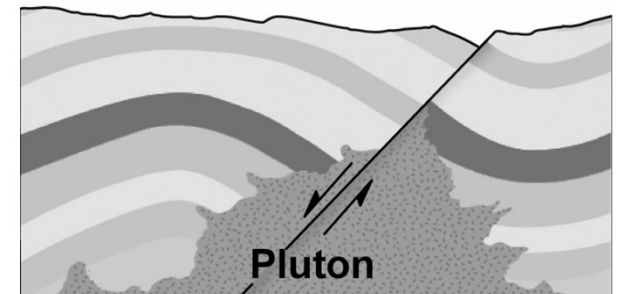
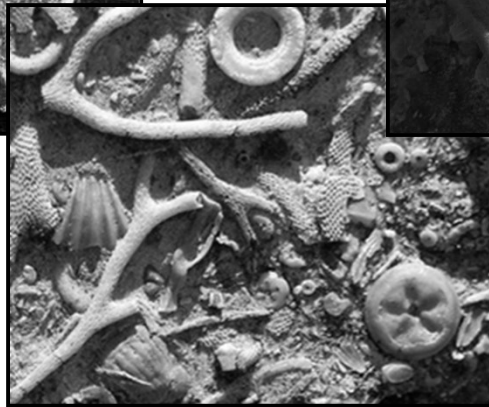
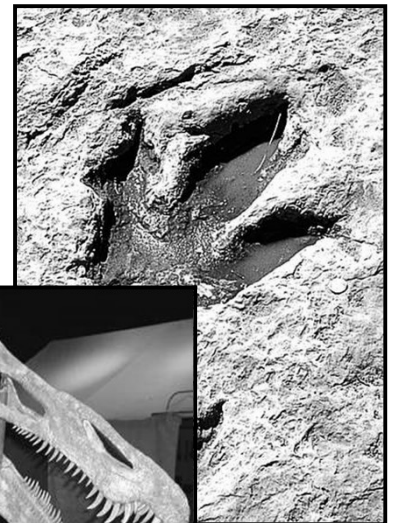
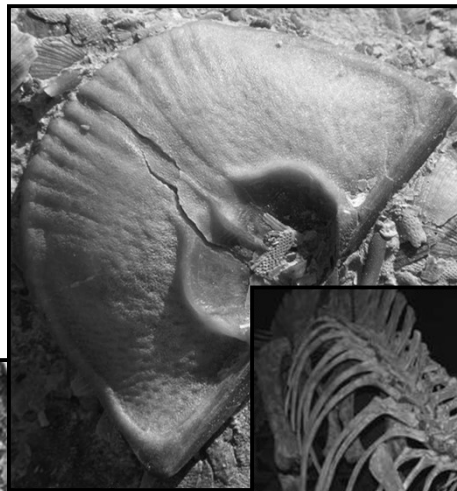
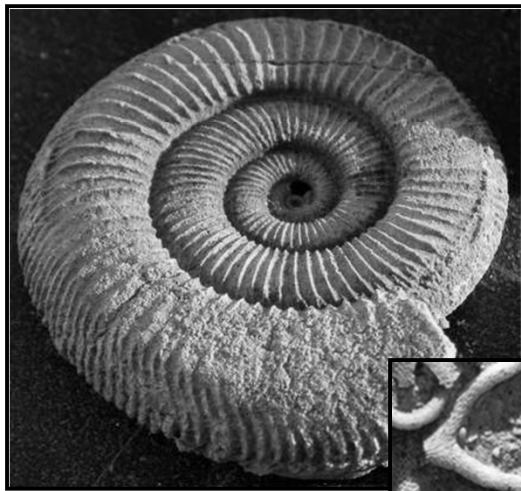


Fig. 10.2b

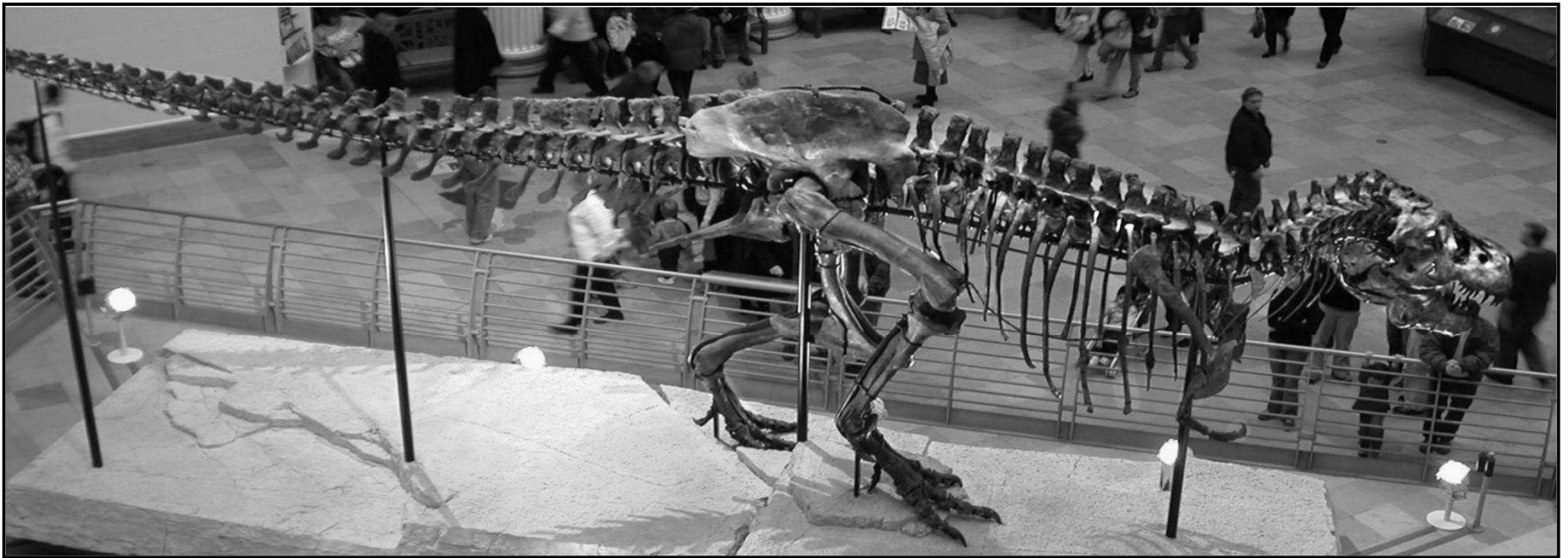
The Principle of Fossil Succession

- Fossils are often preserved in sedimentary rocks.
- Fossils are time markers useful for relative age-dating.
 - Fossils speak of past depositional environments.
 - Specific fossils are only found within a limited time range.



The Principle of Fossil Succession

- Species evolve, exist for a time, and then disappear.
- First appearance, range, and extinction are used for dating.
- Fossils succeed one another in a known order.
- A time period is recognized by its fossil content.



The Principle of Fossil Succession

- Fossil range—the first and last appearance
 - Each fossil has a unique range.
 - Range overlap narrows time.
- Index fossils are diagnostic of a particular geologic time.
- Fossils correlate strata:
 - Locally
 - Regionally
 - Globally

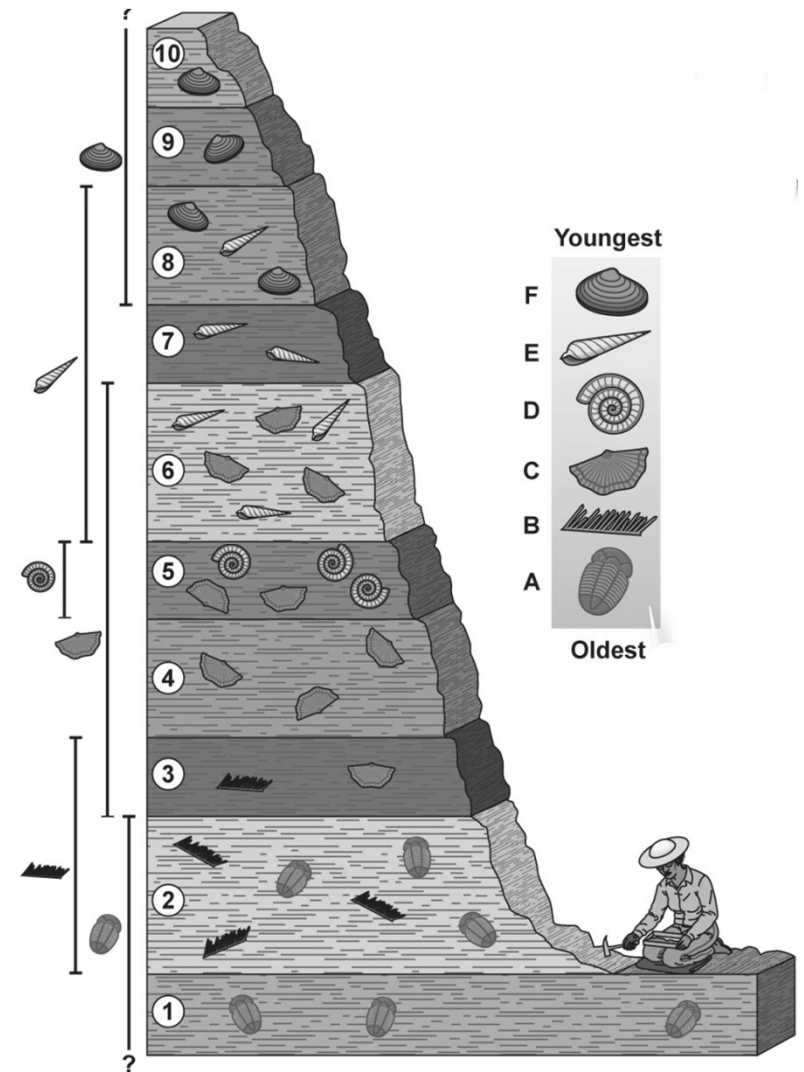


Fig. 10.3

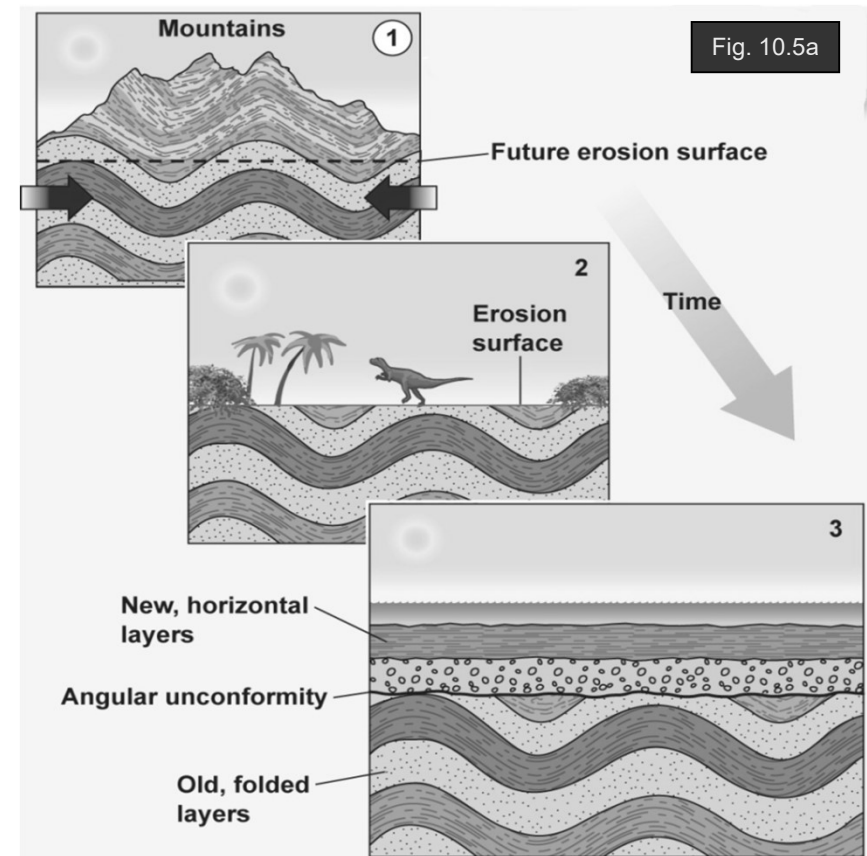
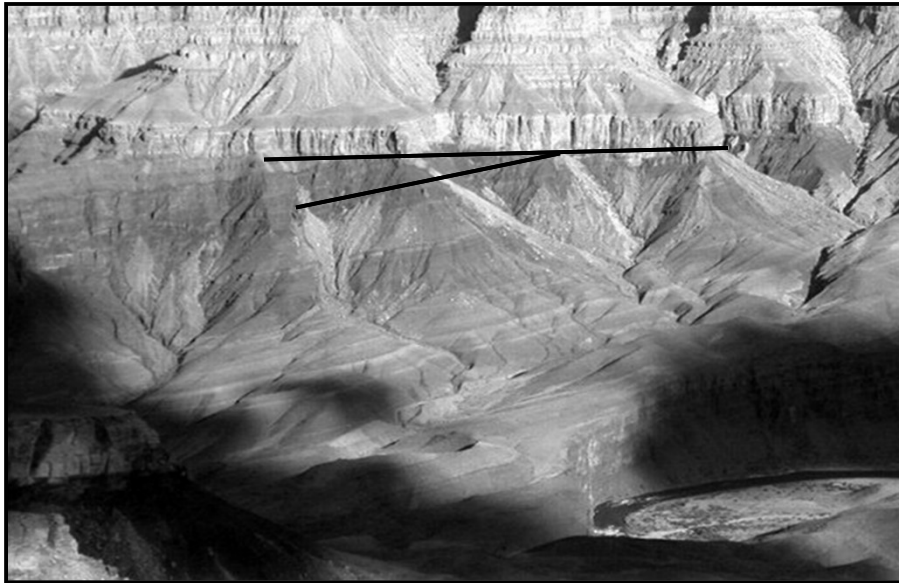
Unconformities

- An unconformity is a time gap in the rock record, from:
 - Erosion
 - Nondeposition
- James Hutton was the first to recognize their significance.
- Three types of unconformity:
 - Angular unconformity
 - Nonconformity
 - Disconformity



Angular Unconformity

- An angular unconformity represents a huge gulf in time.
 - Horizontal marine sediments deformed by orogenesis
 - Mountains eroded completely away
 - Renewed marine invasion
 - New sediments deposited.



Angular Unconformity

- **Hutton's Unconformity, Siccar Point, Scotland**
 - A common destination for geologists
 - Vertical beds of Ordovician sandstone
 - Overlain by gently dipping Devonian redbeds
 - Missing time: ~ 50 million years

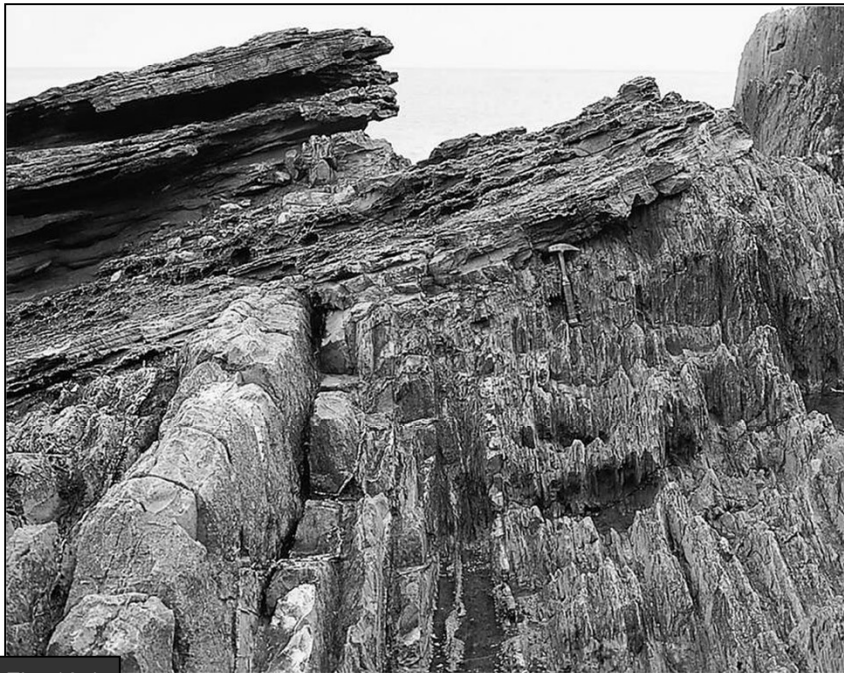
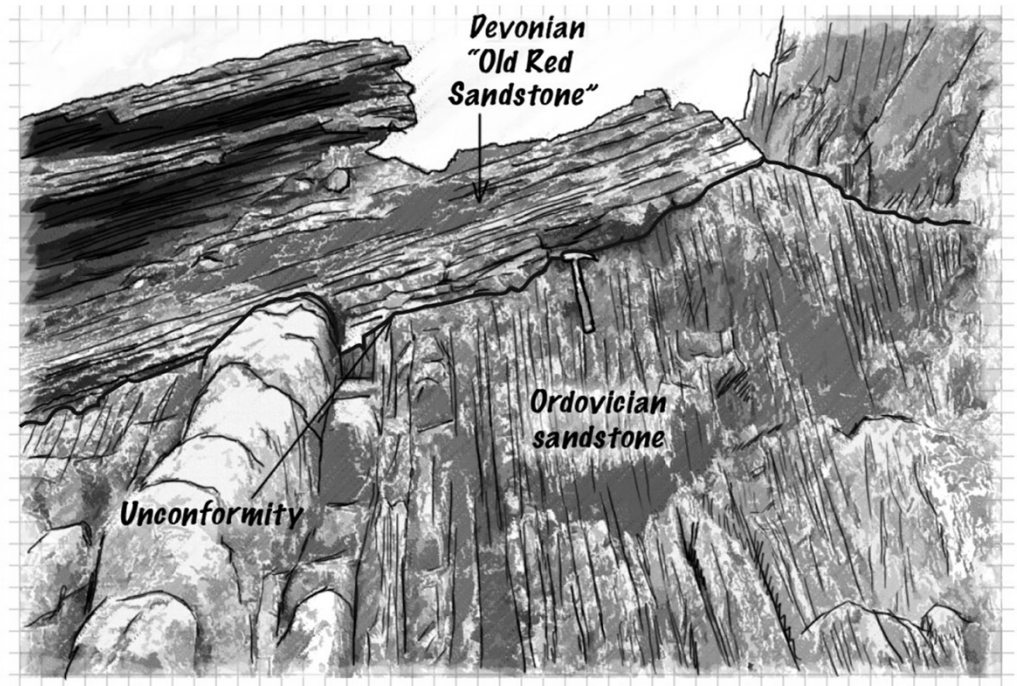


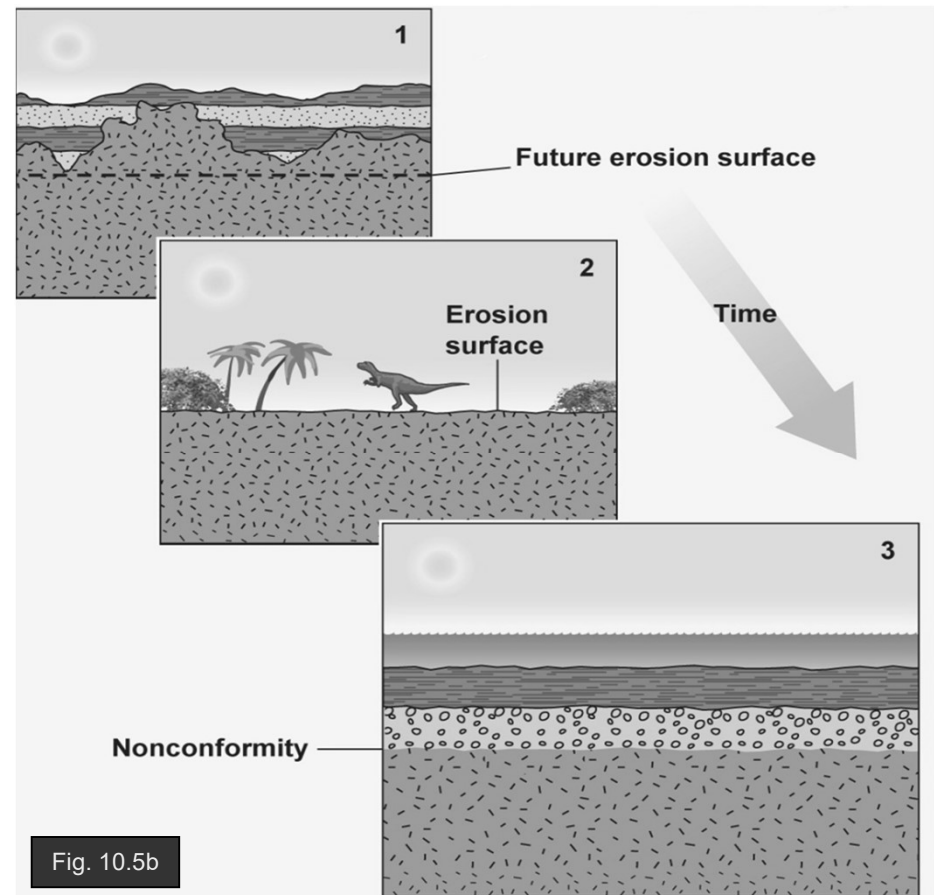
Fig. 10.4



What a Geologist Sees

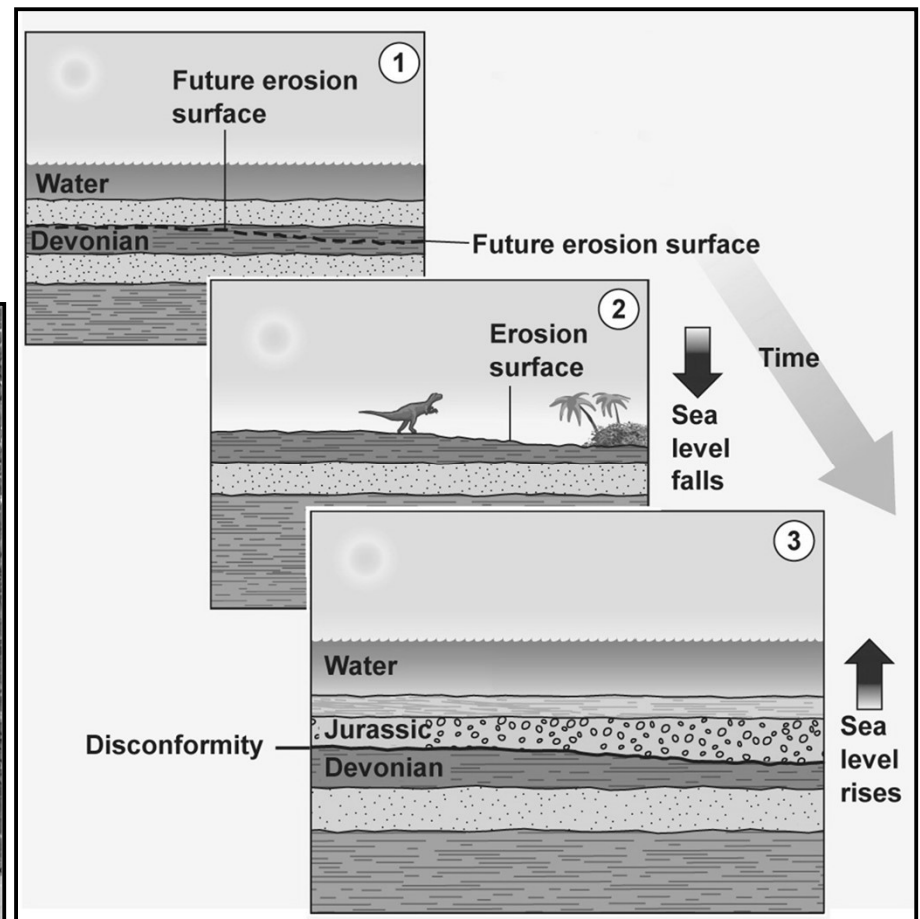
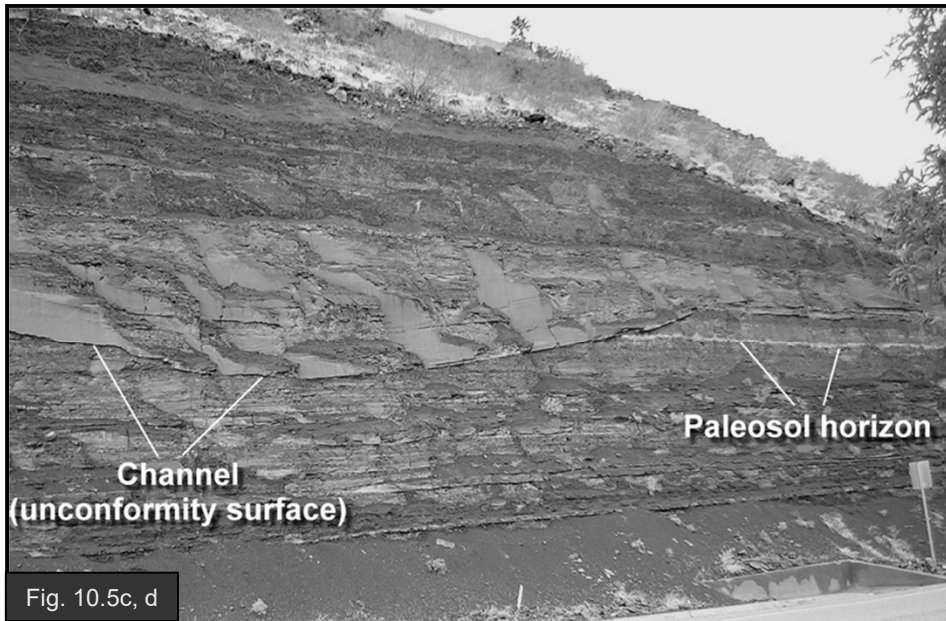
Unconformities

- **Nonconformity**—igneous/metamorphic rocks capped by sedimentary rocks
 - Igneous or metamorphic rocks were exposed by erosion.
 - Sediment was deposited on this eroded surface.



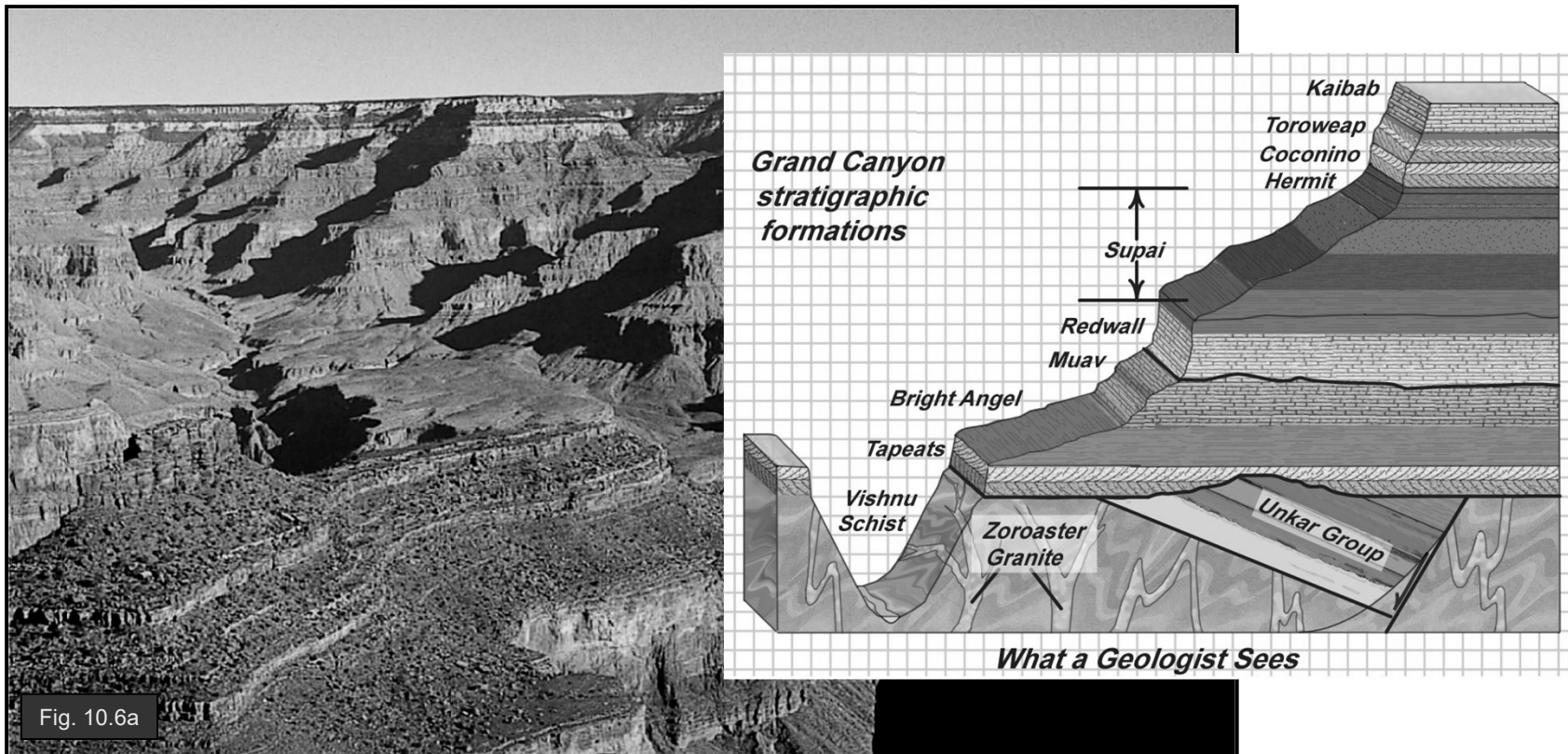
Unconformities

- **Disconformity**—parallel strata bounding nondeposition
 - Due to an interruption in sedimentation:
 - Pause in deposition
 - Sea level falls, then rises
 - Erosion
 - Often hard to recognize



Correlating Formations

- Earth history is recorded in sedimentary strata.
- The Grand Canyon has thick layers of strata and numerous gaps.
 - Formations can be correlated over long distances.



Correlating Formations

- A stratigraphic column describes the sequence of strata.
 - Formations can be traced over long distances.
 - Contacts define boundaries between formations or beds.
 - Several formations may be combined as a group.

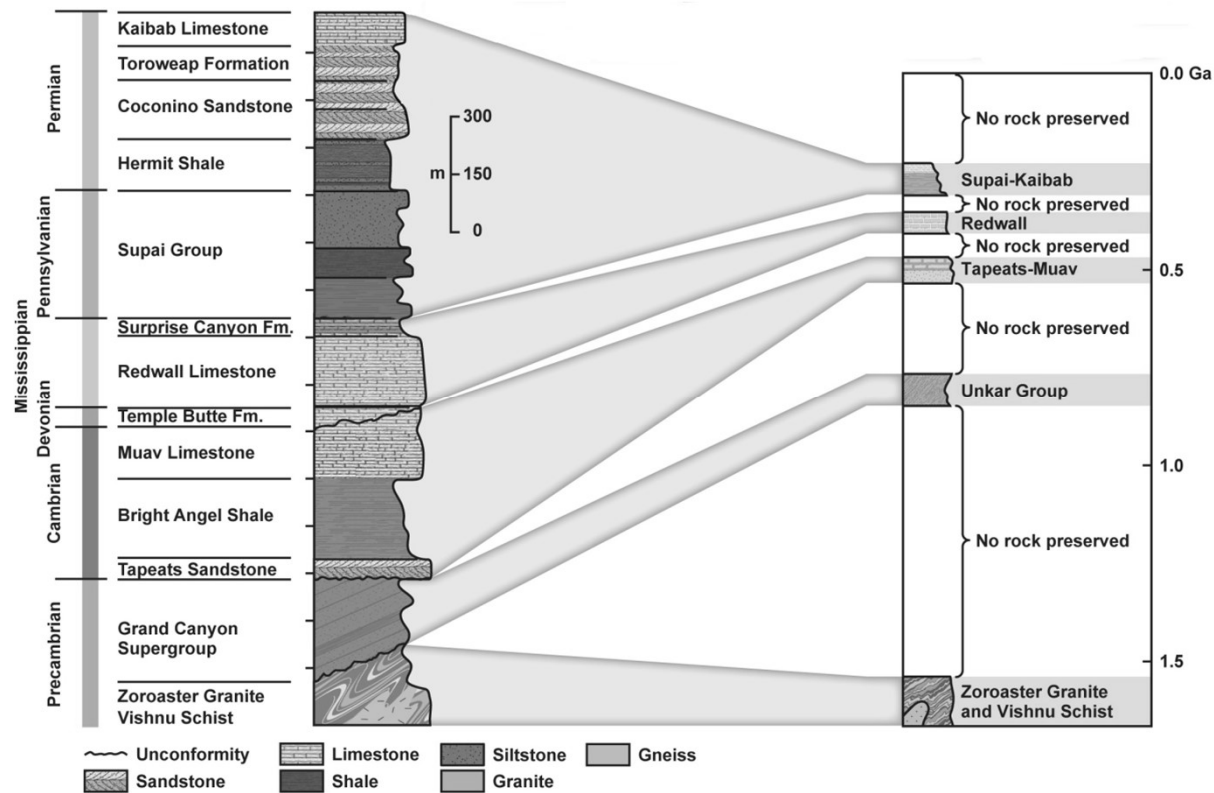


Fig. 10.6b, c

Stratigraphic Correlation

- Lithologic correlation (based on rock type) is regional.
 - Sequence is the relative order in which the rocks occur.
 - Marker beds have unique characteristics to aid correlation.
- Fossil correlation is based on fossils within the rocks.
 - Applicable to much broader areas.

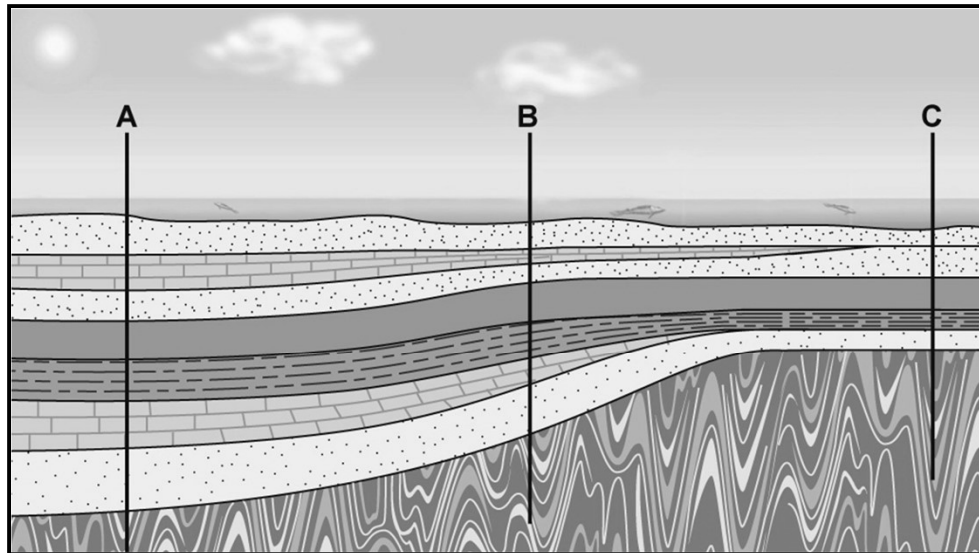
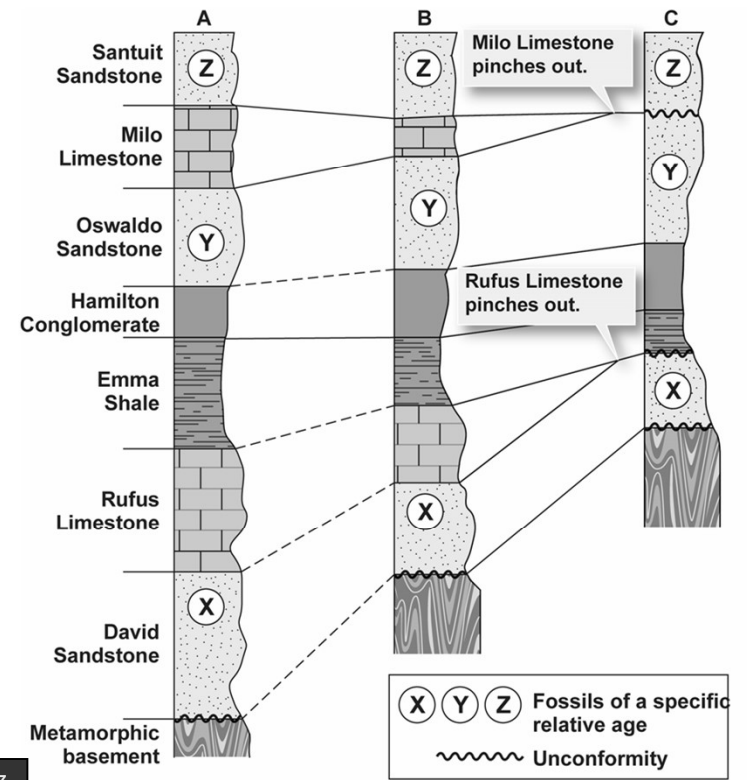


Fig. 10.7



Geologic Maps

- William “Strata” Smith was the first to note that strata could be matched across distances.
 - Similar rock types in a similar order.
 - Rock layers contained the same distinctive fossils.
- After years of work, he made the first geologic map.

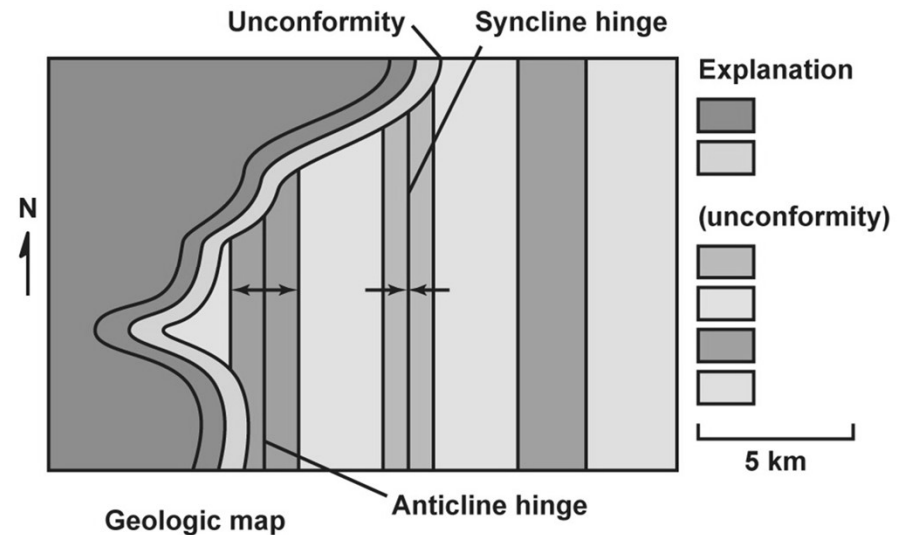
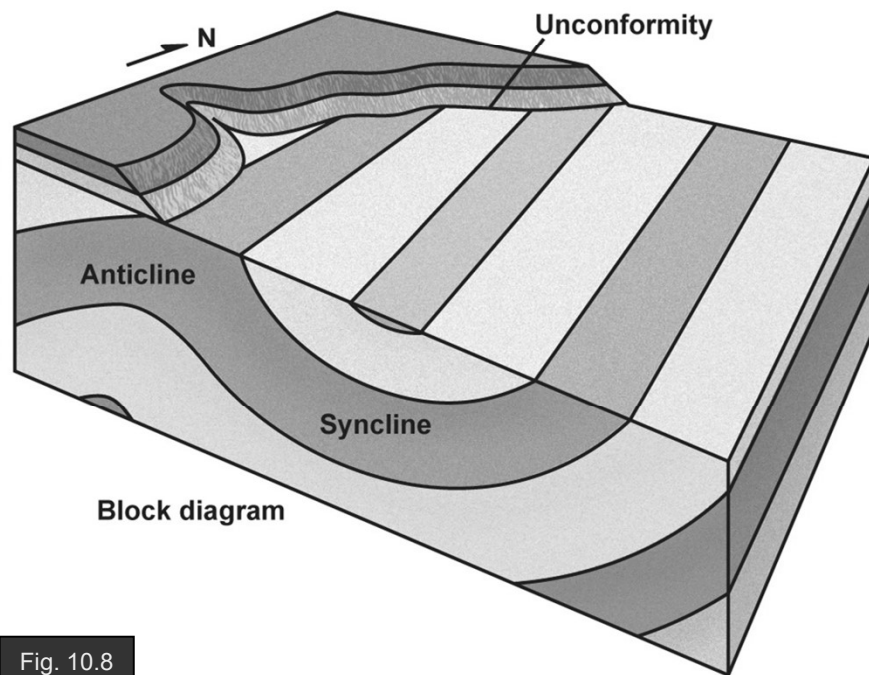
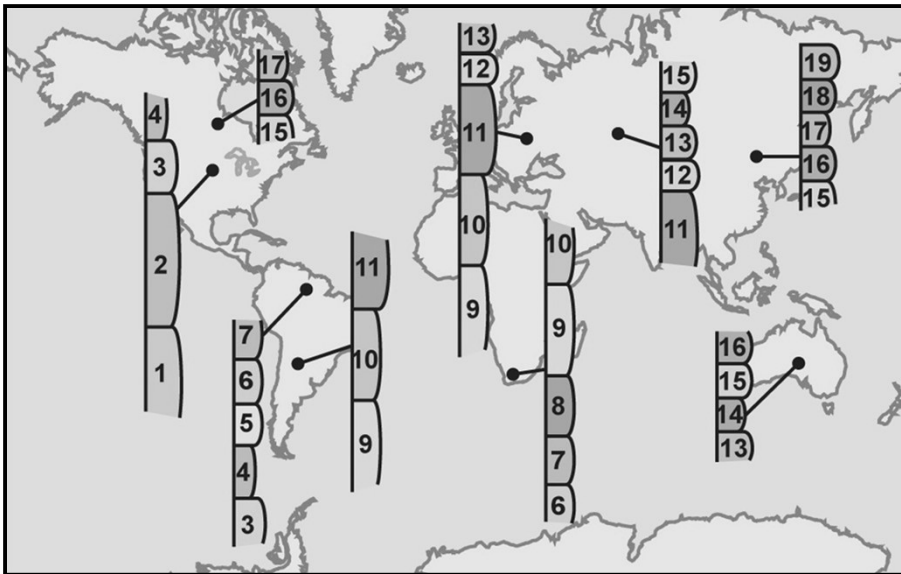


Fig. 10.8

The Geologic Column

- A composite stratigraphic column can be constructed.
 - Assembled from incomplete sections across the globe.
 - It brackets almost all of Earth history.



	Eon	Era	Period	Epoch
19	Phanerozoic	Cenozoic	Quaternary	Holocene
18				Pleistocene
17			Neogene	Pliocene
16				Miocene
15			Tertiary	Oligocene
14				Eocene
13				Paleocene
12		Mesozoic	Cretaceous	
11				
10				
9			Jurassic	
8	Precambrian	Paleozoic	Triassic	
7			Permian	Pennsylvanian
6			Carboniferous	Mississippian
5			Devonian	
4			Silurian	
3			Ordovician	
2			Cambrian	
1				
		Proterozoic		
		Archean		

Fig. 10.9

The Geologic Column

- The composite column is divided into time blocks.
- This is the geologic time scale, Earth's “calendar.”
 - Eons—the largest subdivision of time (hundreds to thousands of Ma)
 - Eras—subdivisions of an eon (65 to hundreds Ma)
 - Periods—subdivisions of an era (2 to 70 Ma)
 - Epochs—subdivisions of a period (0.011 to 22 Ma).

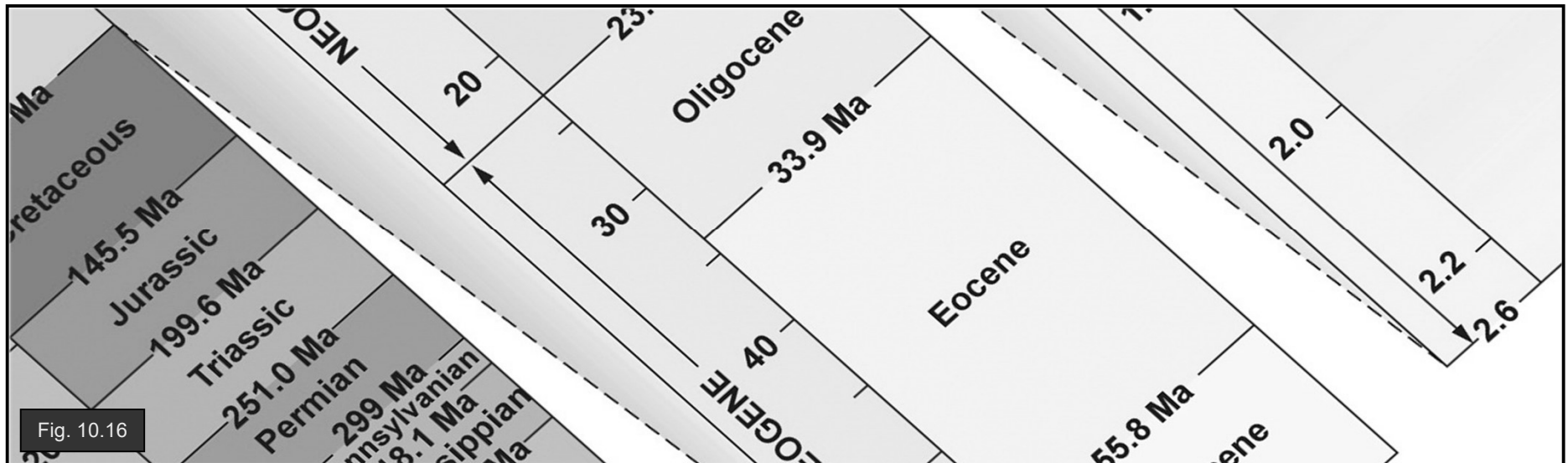


Fig. 10.16

The Geologic Time Scale

■ Names of the Eons

- **Phanerozoic**—"visible life" (542 to 0 Ma)
- **Proterozoic**—"before life" (2.5 to 0.542 Ga)
- **Archean**—"ancient" (3.8 to 2.5 Ga)
- **Hadean**—"hell" (4.6 to 3.8 Ga)

■ Names of the Eras

- **Cenozoic—“recent life”**
- **Mesozoic—“middle life”**
- **Paleozoic—“ancient life”**

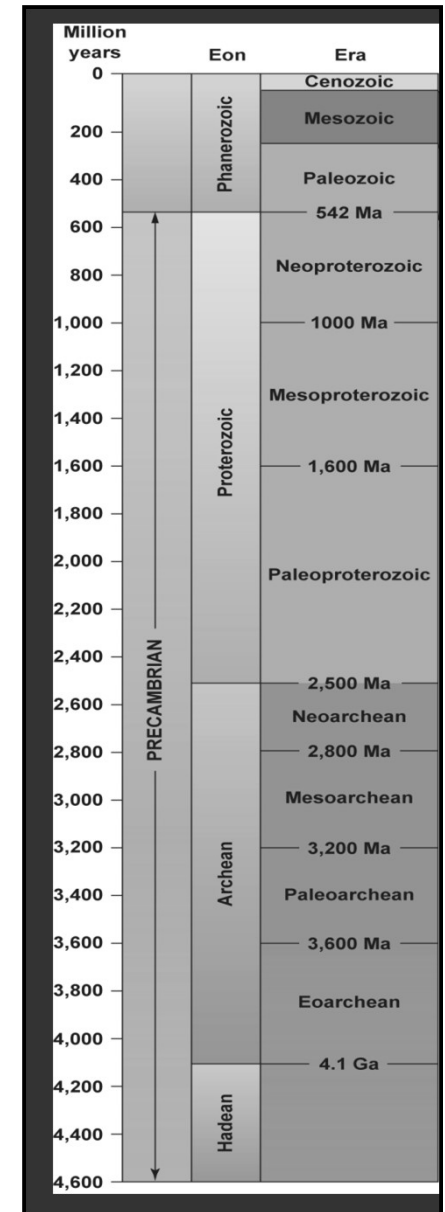


Fig. 10.16

Geologic Time

- Time-scale subdivisions are variously named.
 - The nature of life—“zoic” means life (i.e., Proterozoic)
 - A characteristic of the time period (i.e., Carboniferous)
 - A specific locality (i.e., Devonian)



Geologic Time and Life

- Life first appeared on Earth ~3.8 Ga.
- Early life consisted of single-celled organisms.
- O₂ from cyanobacteria built up in atmosphere by 2 Ga.
- Around 700 Ma, multicellular life evolved.
- Around 542 Ma marks the first appearance of invertebrates.
 - Shells increased fossil preservation.
 - Life diversified rapidly as the “Cambrian Explosion.”

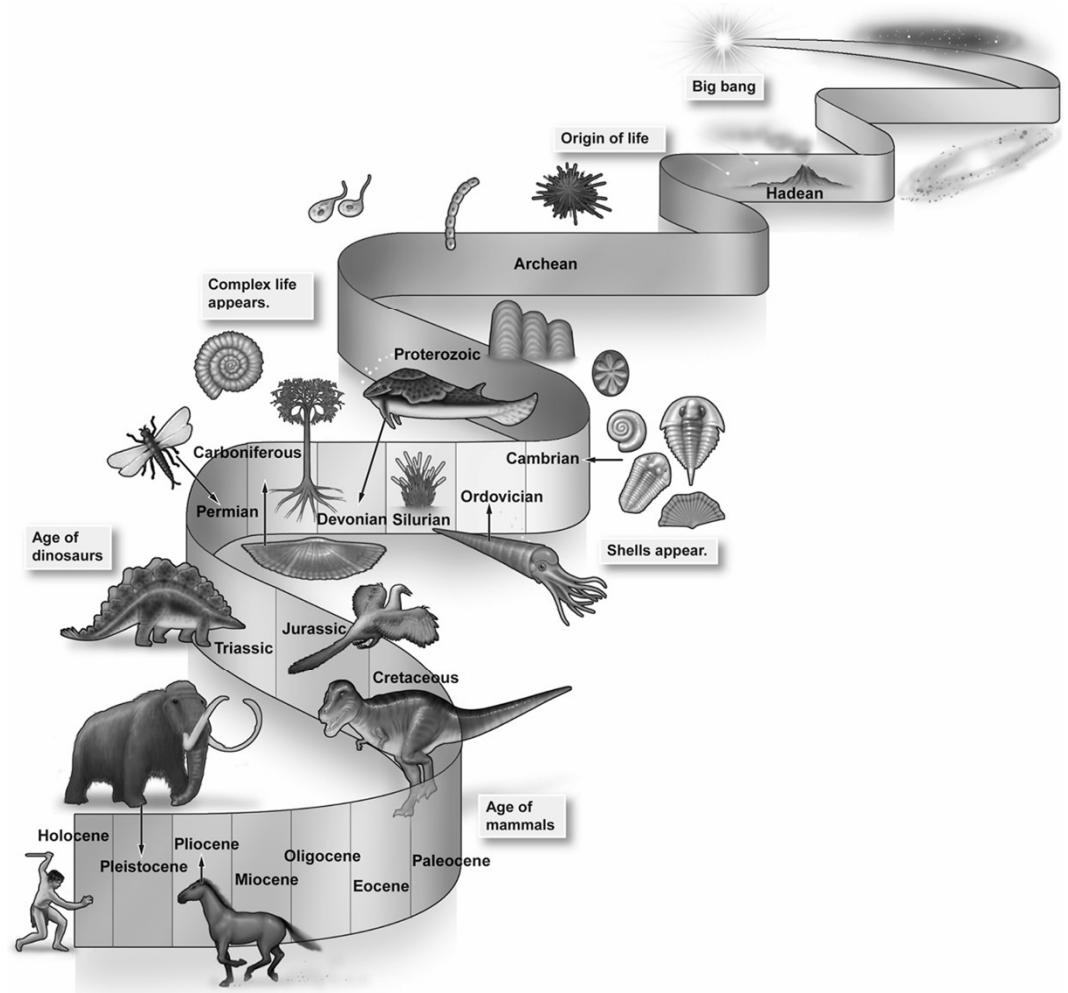


Fig. 10.10

Stratigraphic Correlation

■ National Parks of Arizona and Utah

- Formations can be traced over long distances.
- Overlap is seen in the sequences of rock types.
- Overlapping rock columns are used to build a composite.

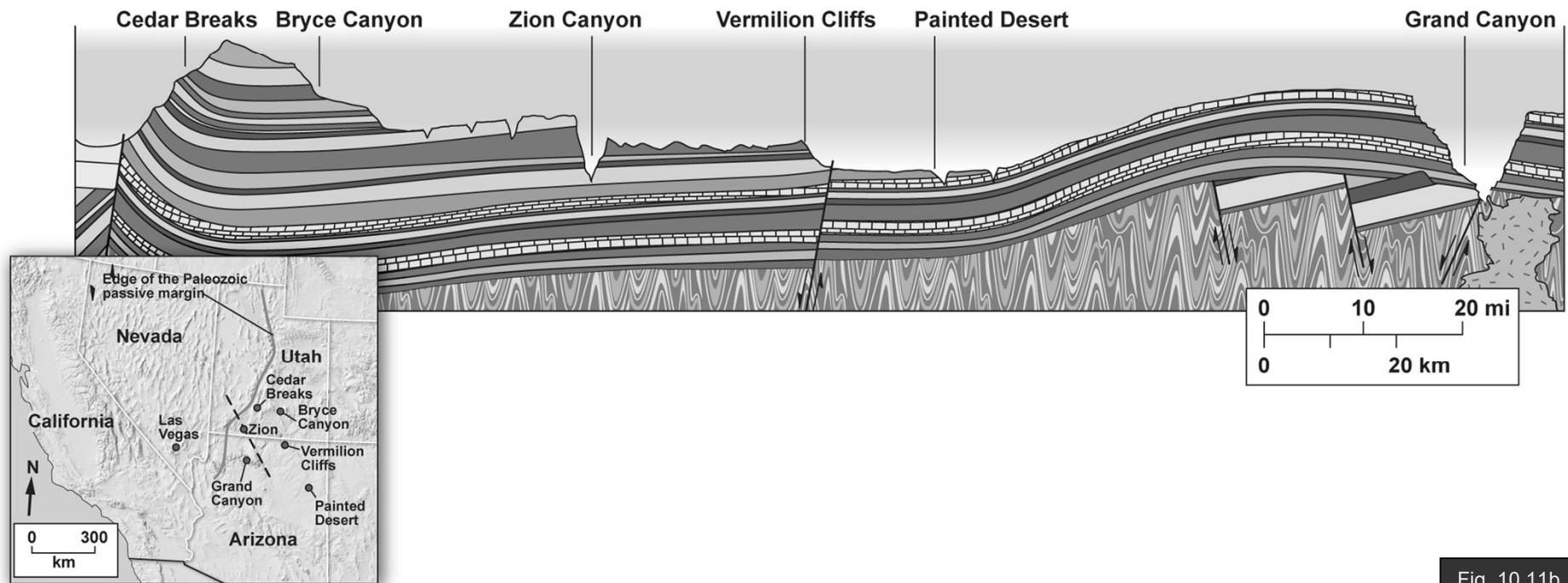


Fig. 10.11b

Numerical Age

- Numerical ages give age of rocks in years.
- Based on radioactive decay of atoms in minerals.
 - Radioactive decay proceeds at a known, fixed rate.
 - Radioactive elements act as internal clocks.
- Numerical age study is also called geochronology.



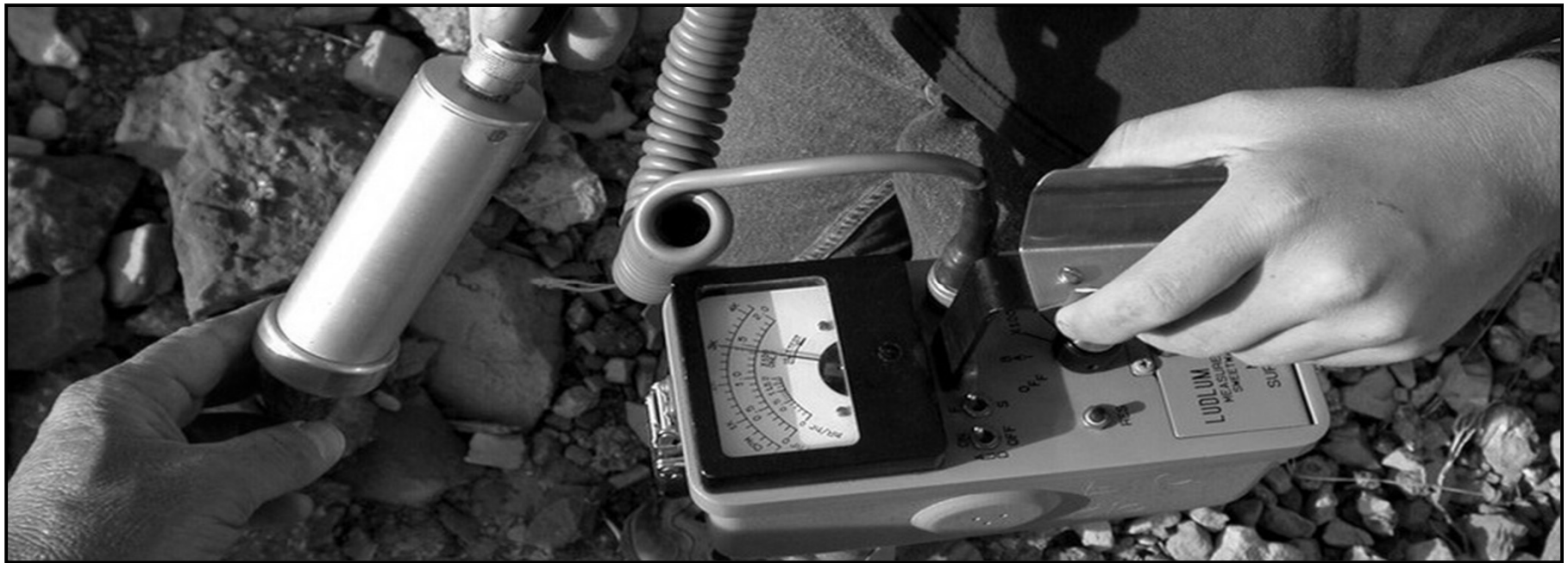
Radioactive Decay

- **Isotopes—elements that have varying numbers of neutrons**
- **Isotopes have similar but different mass numbers.**
 - **Stable—**isotopes that never change (i.e., ^{13}C)
 - **Radioactive—**isotopes that spontaneously decay (i.e., ^{14}C)



Radioactive Decay

- Radioactive decay progresses along a decay chain.
 - Decay creates new unstable elements that also decay.
 - Decay proceeds to a stable element endpoint.
- Parent isotope—the isotope that undergoes decay
- Daughter isotope—the product of this decay



Radioactive Decay

- **Half-life ($t_{1/2}$)**—time for half of the unstable nuclei to decay
 - The half-life is a characteristic of each isotope.
 - After one $t_{1/2}$, one-half of the original parent remains.
 - After three $t_{1/2}$, one-eighth of the original parent remains.
- As the parent disappears, the daughter “grows in.”

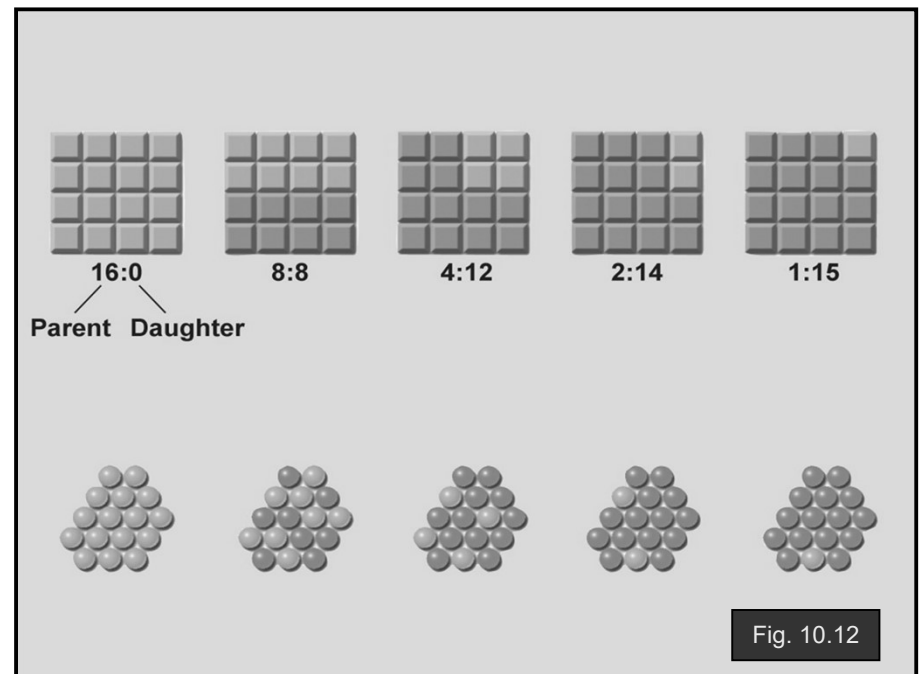
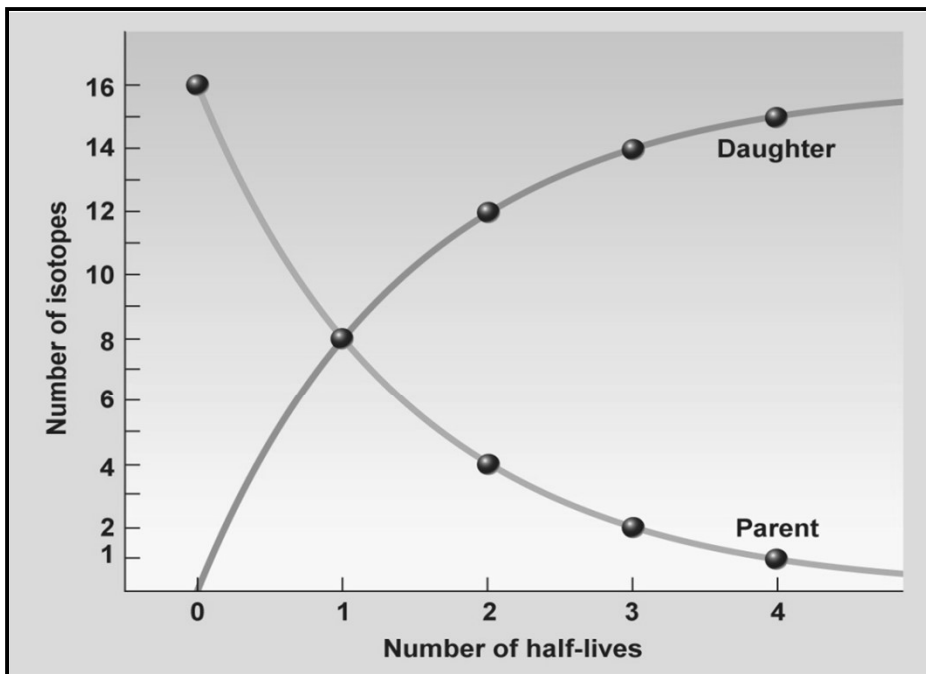


Fig. 10.12

Isotopic Dating

- The age of a mineral can be determined by:
 - Measuring the ratio of parent to daughter isotopes
 - Calculating the amount of time by using the known $t_{1/2}$
- Different radioactive isotopes have different half-lives.
- Isotopic dating is time-consuming and expensive.

Table 10.1 Isotopes Used in the Isotopic Dating of Rocks

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

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

Isotopic Dating

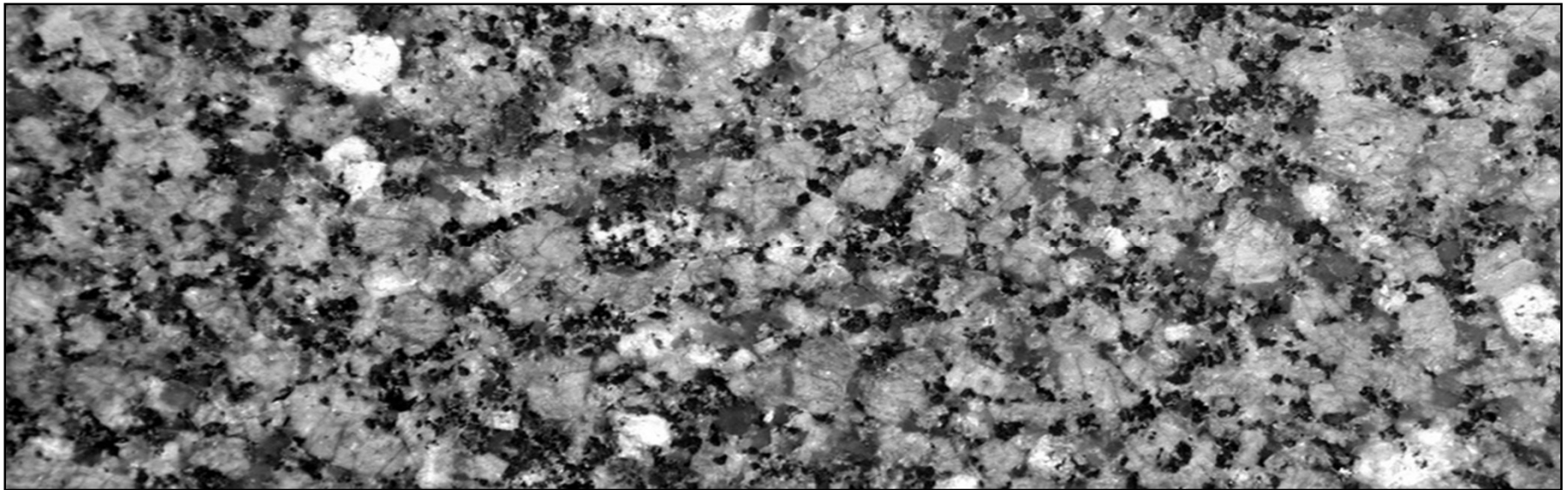
- **How is an isotopic date obtained?**
 - **Collect unweathered rocks with appropriate minerals.**
 - **Crush and separate desired minerals.**
 - **Extract parent and daughter isotopes.**
 - **Analyze the parent-daughter ratio.**
- **Geochronology requires analytical precision.**
 - **Mass-spectrometers are used to measure isotopes.**



Fig. 10.13

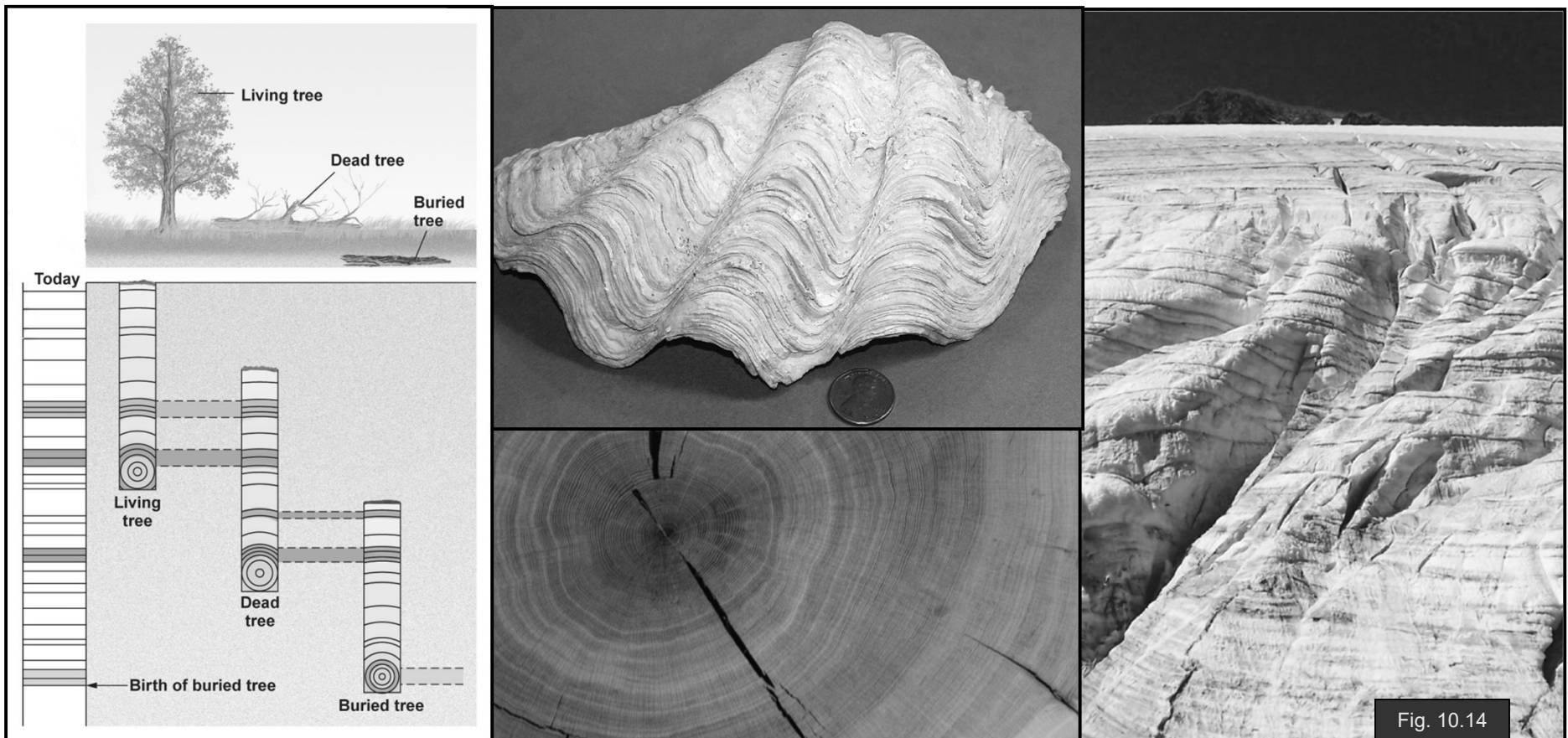
What Does an Isotopic Date Mean?

- Isotopic dating gives the time a mineral cooled below its “closure temperature.”
 - Cooling of magma or lava to solid, cool igneous rock
 - Metamorphic rock temperatures drop below closure temp
- Sedimentary rocks cannot be directly dated.



Other Numerical Ages

- Numerical ages are possible without isotopes.
 - Growth rings—annual layers from trees or shells
 - Rhythmic layering—annual layers in sediments or ice



Numerical Ages and Geologic Time

- Geochronology is less useful for sedimentary deposits.
- Sediment ages can be bracketed by numerical ages.
 - Date adjacent igneous and metamorphic rocks.
 - Apply principle of cross-cutting relationships.
 - Age ranges narrow as data accumulate.
- Geologic time scale dated in this way.

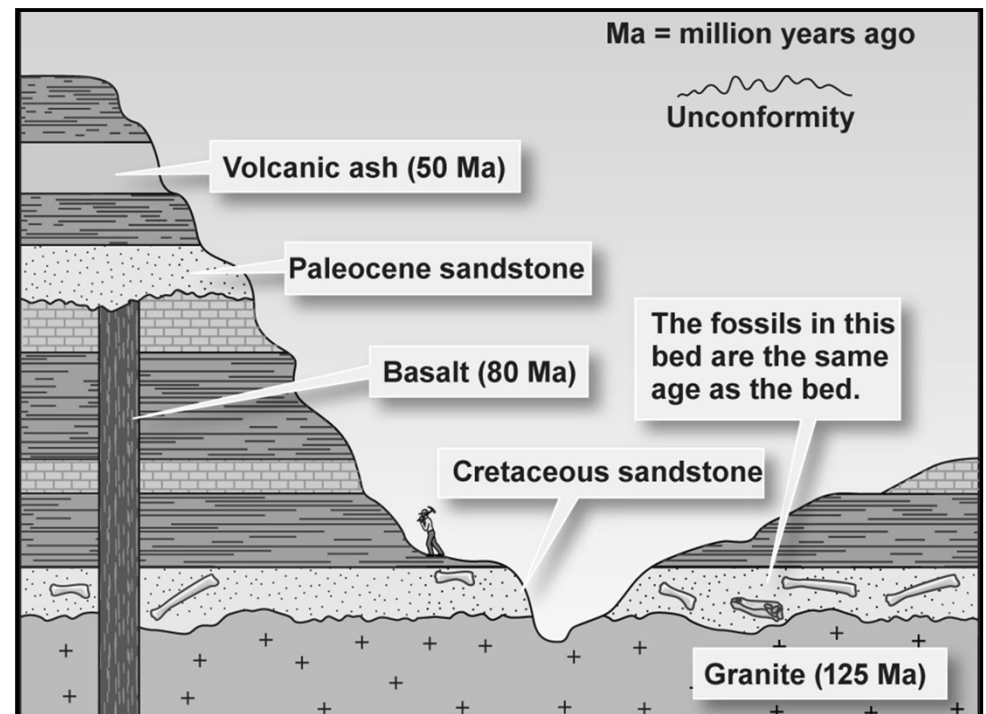
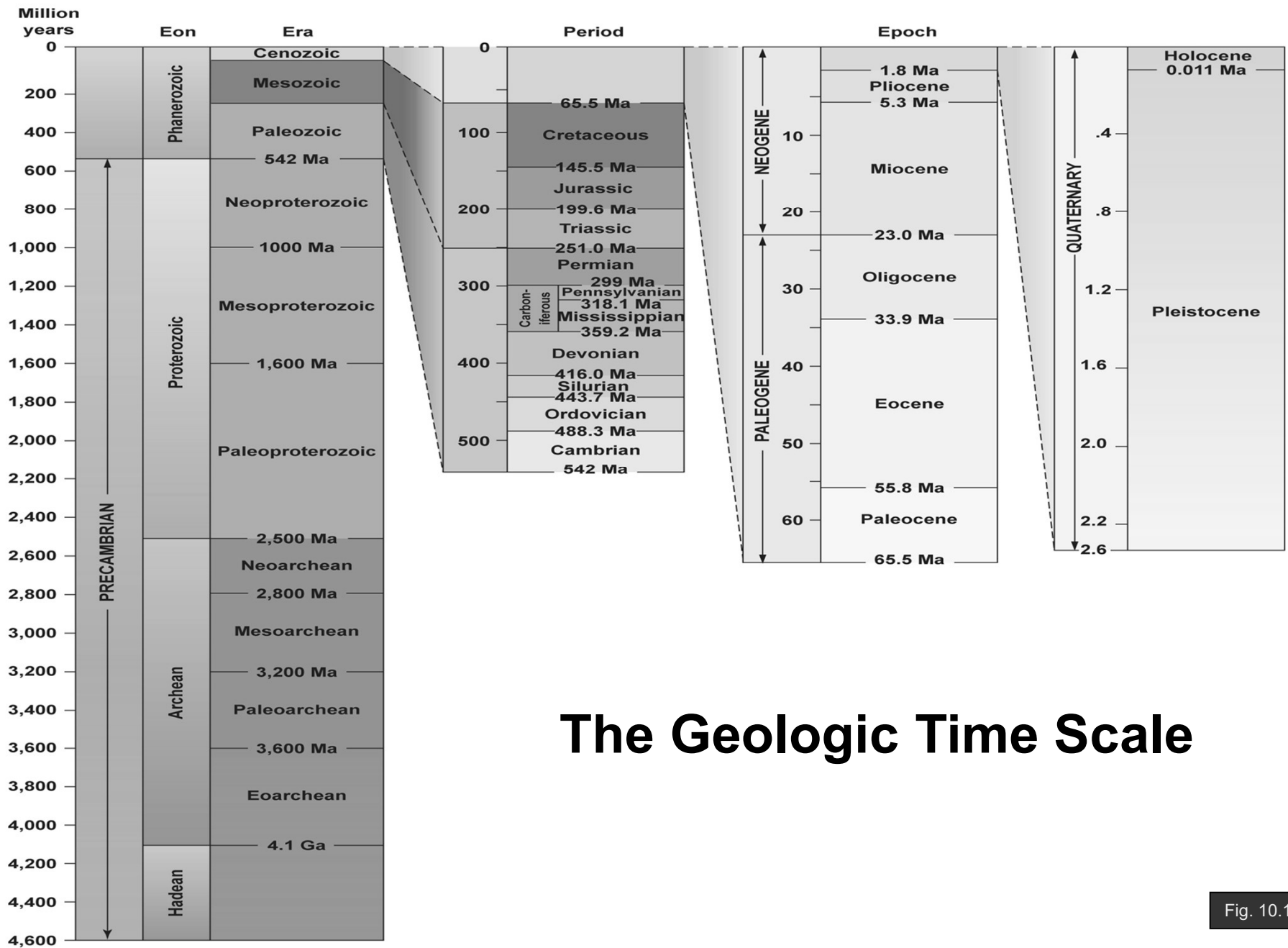


Fig. 10.15



The Geologic Time Scale

Fig. 10.16

The Age of the Earth

- Before radiometric dating, age estimates varied widely.
 - Lord Kelvin estimated Earth cooling at ~20 Ma.
 - Uniformitarianism and evolution indicated an Earth much older than ~100 Ma.
- Radioactivity discovered in 1896 by Henri Becquerel.
 - Led to isotopic dating beginning in 1950s.



The Age of Earth

- The oldest rocks on Earth's surface date to 4.03 Ga.
- Zircons in ancient sandstones date to 4.4 Ga.
- Age of Earth is 4.57 Ga, based on correlation with:
 - Meteorites
 - Moon rocks

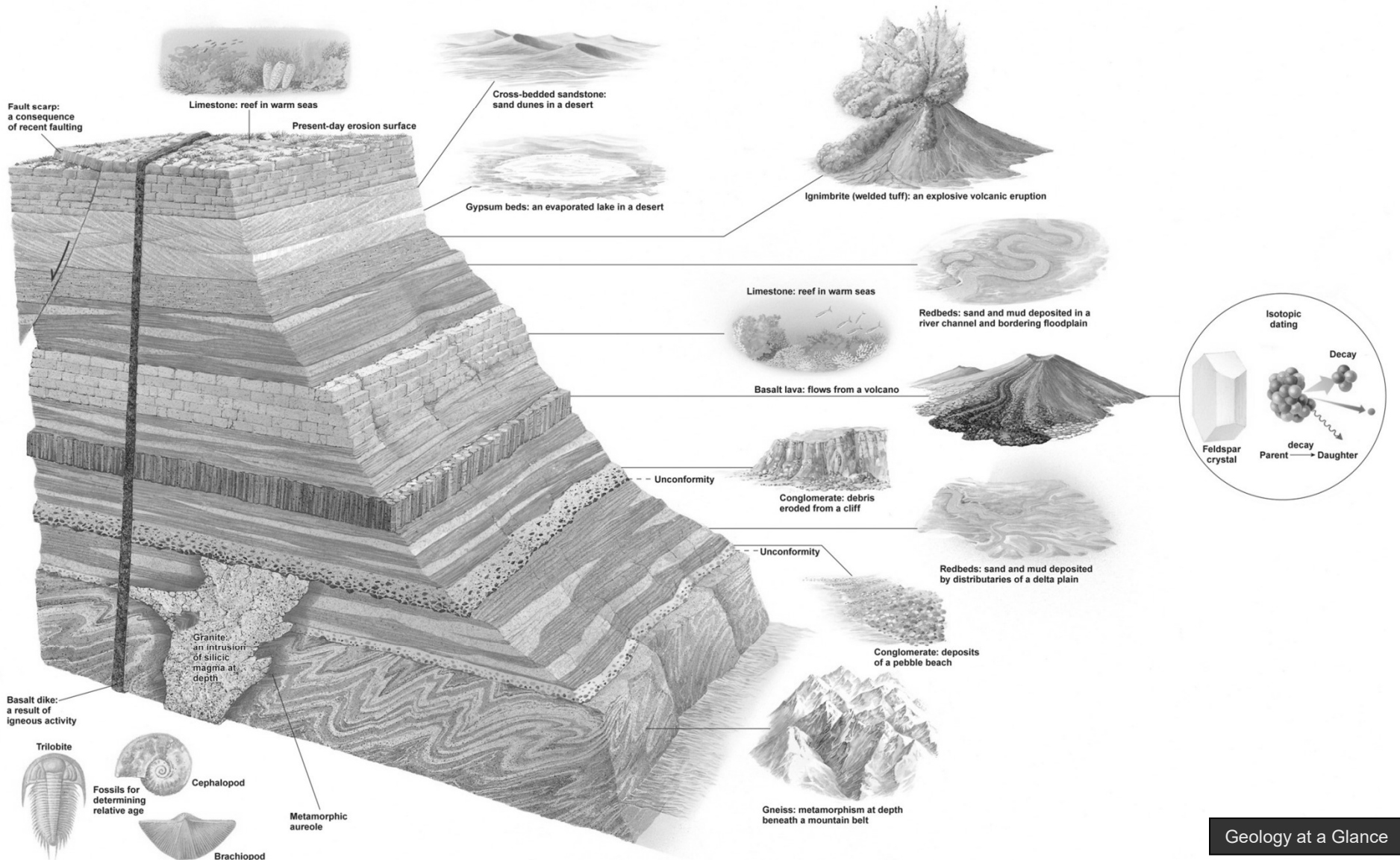


Geologic Time

- The immensity of time is beyond comprehension.
- Metaphors illustrate the scale of time.
 - The age of Earth (4.6 Ga) can be compared to pennies.
 - Lined up, 4.6 billion pennies would be 87,400 km long.
 - This is more than twice Earth's circumference.
- Humans occupy 0.000001% of Earth history.



Geologic Time



Useful Web Resources

- **USGS Geologic Time Online Edition**
 - <http://pubs.usgs.gov/gip/geotime/>
- **Geological Society of America (GSA) Printable Time Scale**
 - www.geosociety.org/science/timescale/
- **CHRONOS Cyberinfrastructure Site**
 - www.chronos.org/
- **Deep Time: A History of the Earth—Interactive Infographic**
 - <http://deeptime.info/>
- **Exploring Time**
 - <http://exploringtime.org/?page=segments>
- **Smithsonian National Museum of Natural History, Geologic Time**
 - <http://paleobiology.si.edu/geotime/index.htm>