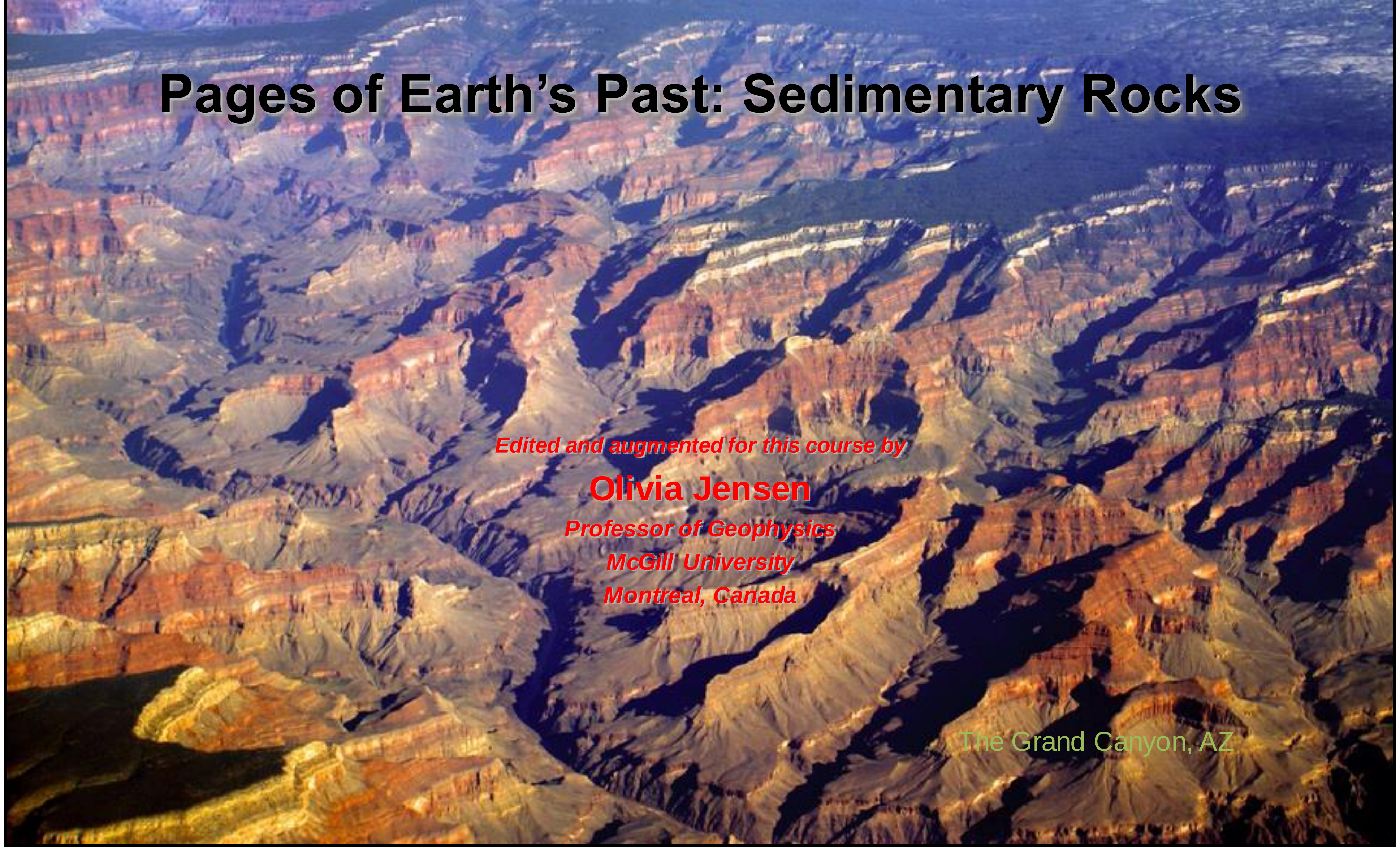
# Pages of Earth's Past: Sedimentary Rocks



The Grand Canyon, AZ

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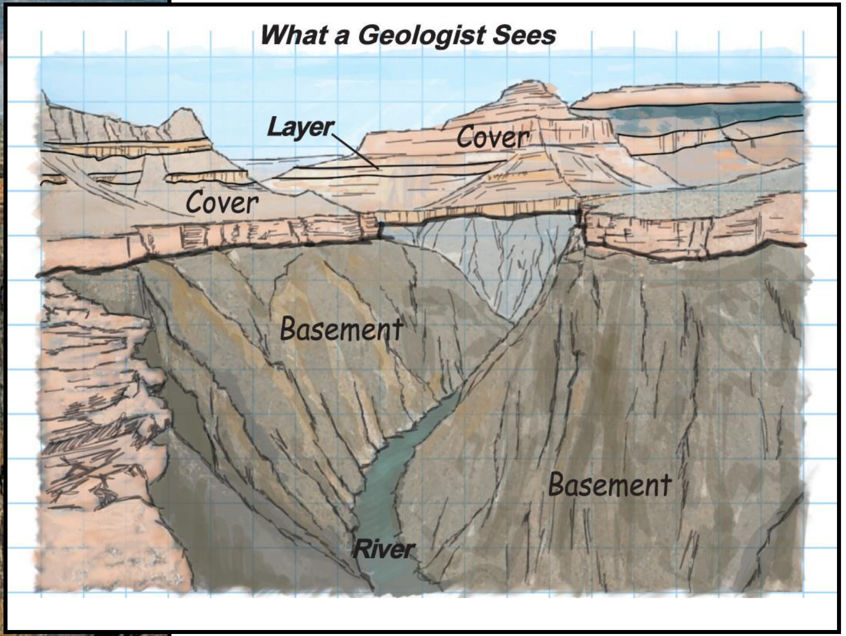
# Introduction

- **Sedimentary Rock:**
  - **Forms at or near Earth's surface in one of several ways.**
    - **Cementing loose clasts (fragments) of preexisting rock.**
    - **Cementing together loose shells and shell fragments.**
    - **Accumulation of organic matter from living organisms.**
    - **Precipitation of minerals dissolved in water.**

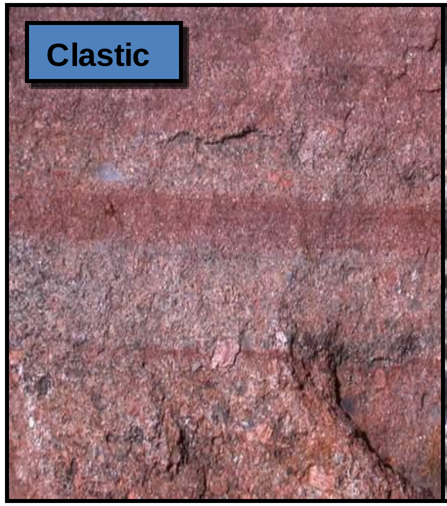
# Introduction

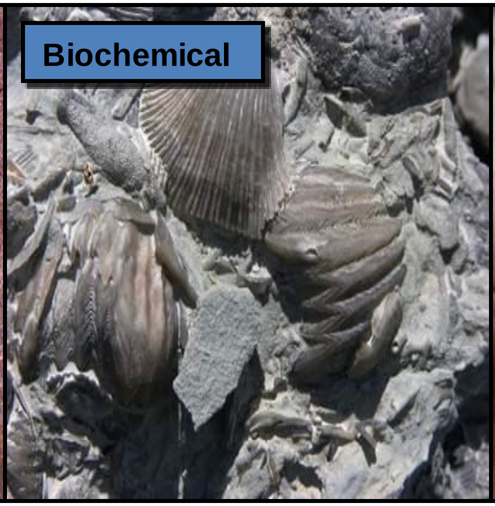
- Sedimentary rocks form layers like the pages of a book.
  - The layers record a history of ancient environments.
  - The layers occur only in the upper part of the crust.
- Sedimentary rocks cover underlying basement rock.

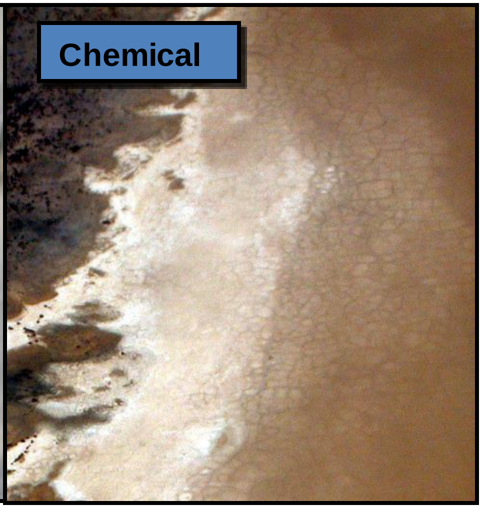


# Classes of Sedimentary Rock

- **Geologists define four classes of sedimentary rock:**
  - **Clastic—loose rock fragments (clasts) cemented together.**
  - **Biochemical—cemented shells of organisms.**
  - **Organic—carbon-rich remains of once living organisms.**
  - **Chemical—minerals that crystallize directly from water.**
- **Physical and chemical weathering provide the raw material for all sedimentary rocks.**

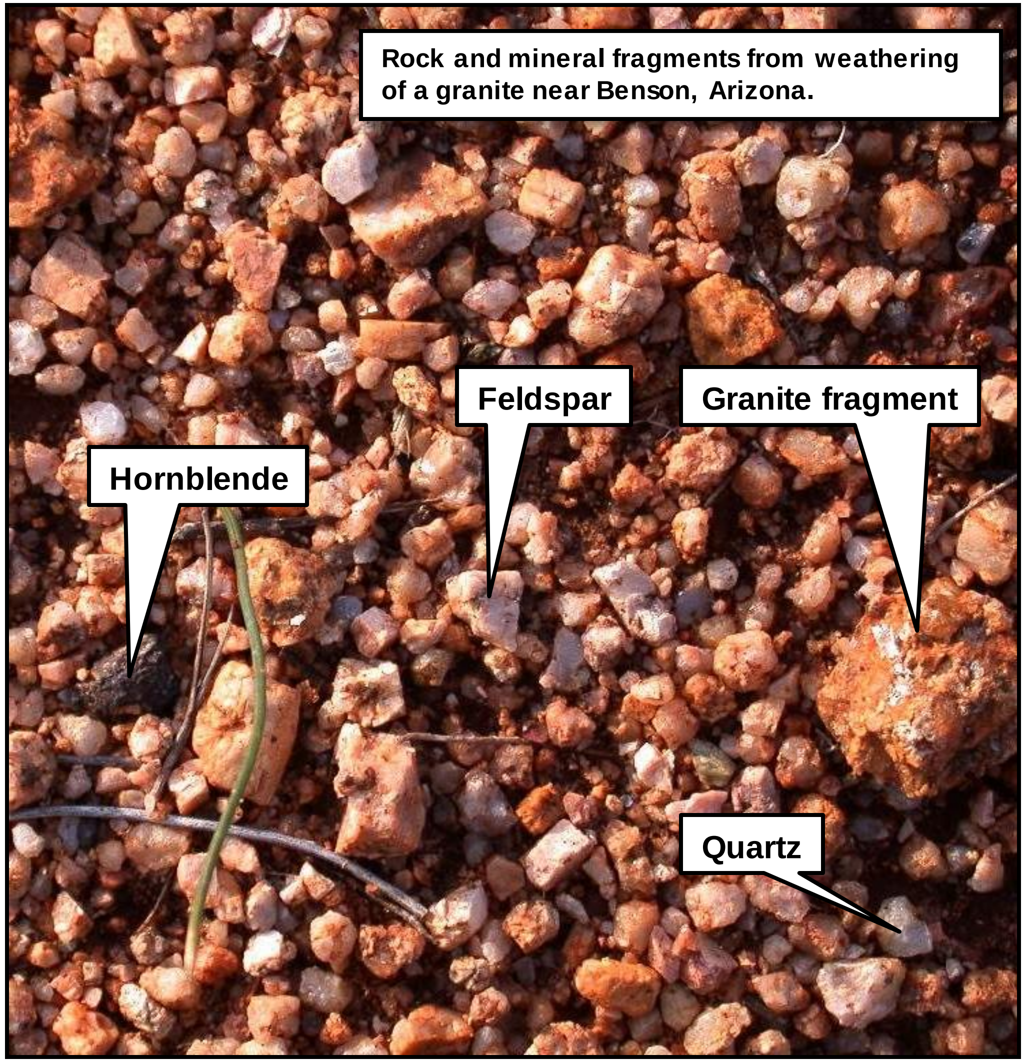






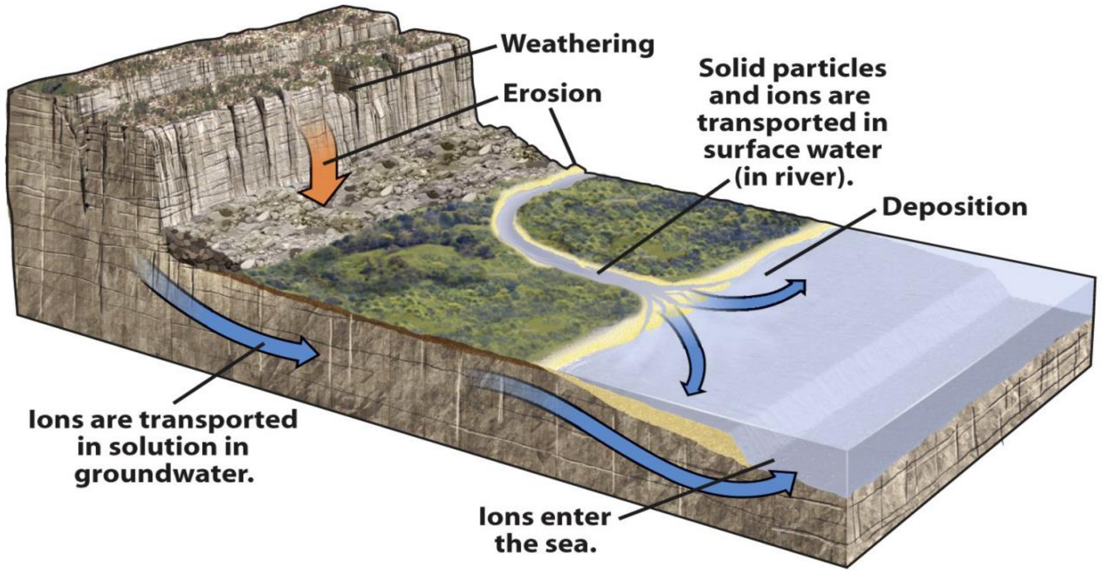
# Clastic Sedimentary Rocks

- Detrital (or clastic) sedimentary rocks consist of:
  - Detritus (loose clasts).
    - Mineral grains.
    - Rock fragments.
  - Cementing material.
    - Often quartz or calcite.



# Clastic Sedimentary Rocks

- Clastic sedimentary rocks are created by:
  - Weathering—generation of detritus via rock disintegration.
  - Erosion—removal of sediment grains from parent rock.
  - Transportation—dispersal by gravity, wind, water, and ice.
  - Deposition—settling out of the transporting fluid.
  - Lithification—transformation into solid rock.



# Classifying Clastic Sedimentary Rocks

- Classified on the basis of texture and composition.
  - Clast (grain) size.
  - Clast composition.
  - Angularity and sphericity.
  - Sorting.
  - Character of cement.
- These variables produce a diversity of clastic rocks.

# Classifying Clastic Sedimentary Rocks

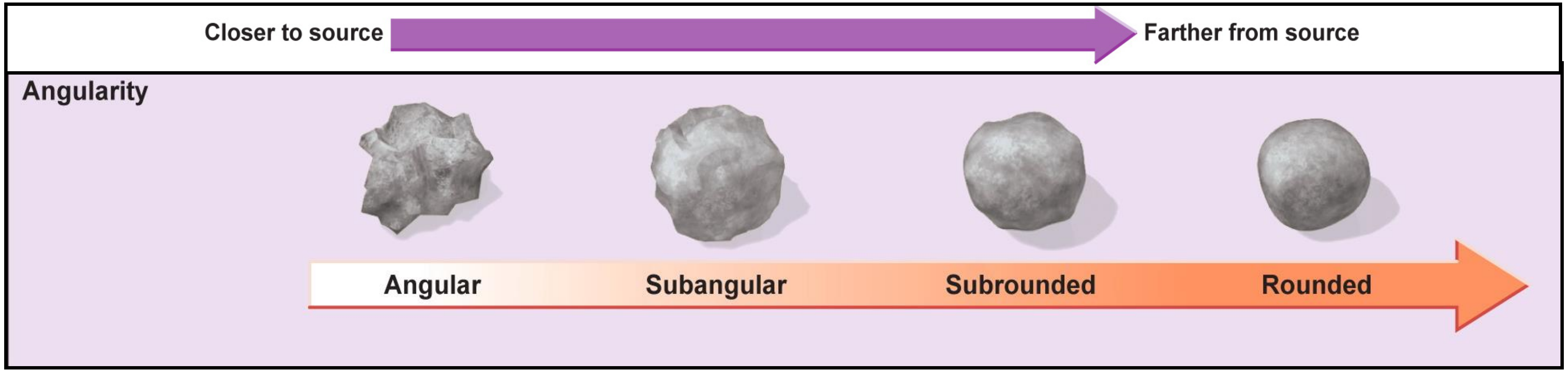
- Clast size—the diameter of fragments or grains.
  - Range from very coarse to very fine.
  - Boulder, cobble, pebble, sand, silt, and clay.
    - Gravel—coarse-grained sed (boulder, cobble, pebble).
    - Mud—fine-grained (silt and clay).

# Classifying Clastic Sedimentary Rocks

- **Clast composition—the mineral makeup of sediments.**
  - **May be individual minerals or rock fragments.**
  - **Composition tells the story about the original source rock.**

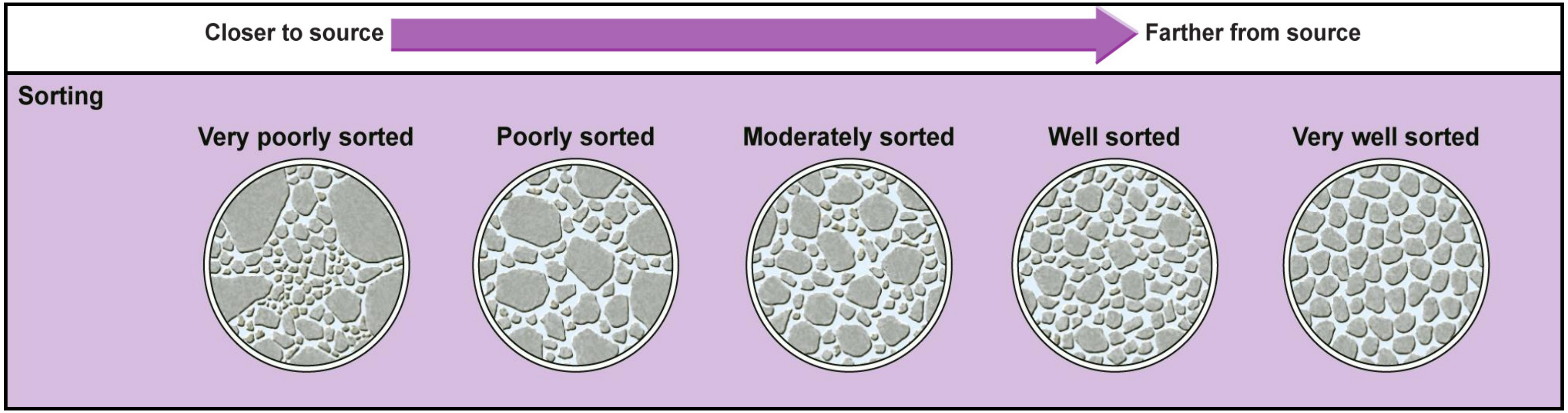
# Classifying Clastic Sedimentary Rocks

- Angularity—the degree of edge or corner smoothness.
- Sphericity—degree to which a clast nears a sphere.
  - Fresh detritus is usually angular and nonspherical.
  - Grain roundness and sphericity increases with transport.
    - Well-rounded—long transport distances.
    - Angular—negligible transport.



# Classifying Clastic Sedimentary Rocks

- Sorting—the uniformity of grain size.
  - Well-sorted—all clasts have nearly the same grain size.
  - Poorly sorted—clasts show a wide variety of grain sizes.
  - Size sorting occurs along stream flow (OJ).

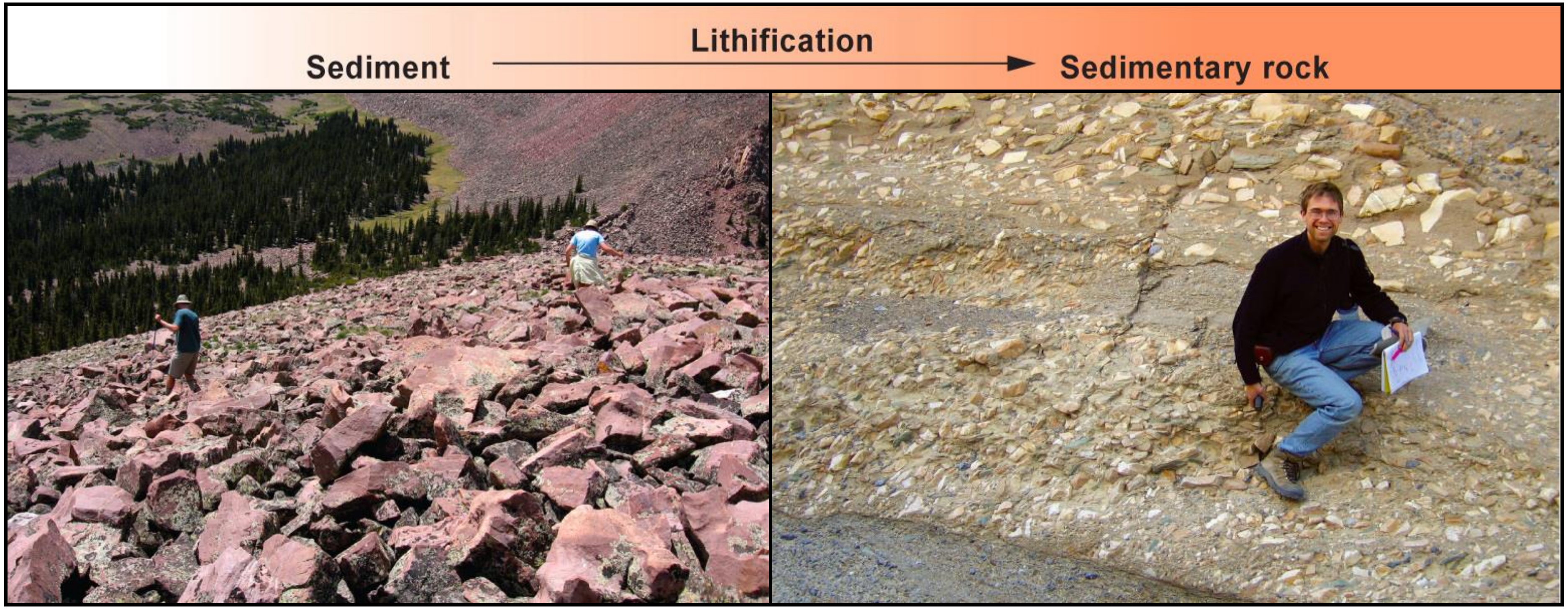


# Classifying Clastic Sedimentary Rocks

- Character of cement – minerals that fill sediment pores.
- Different clastic sedimentary rocks have different cement.
  - Quartz and calcite are the most common cements.

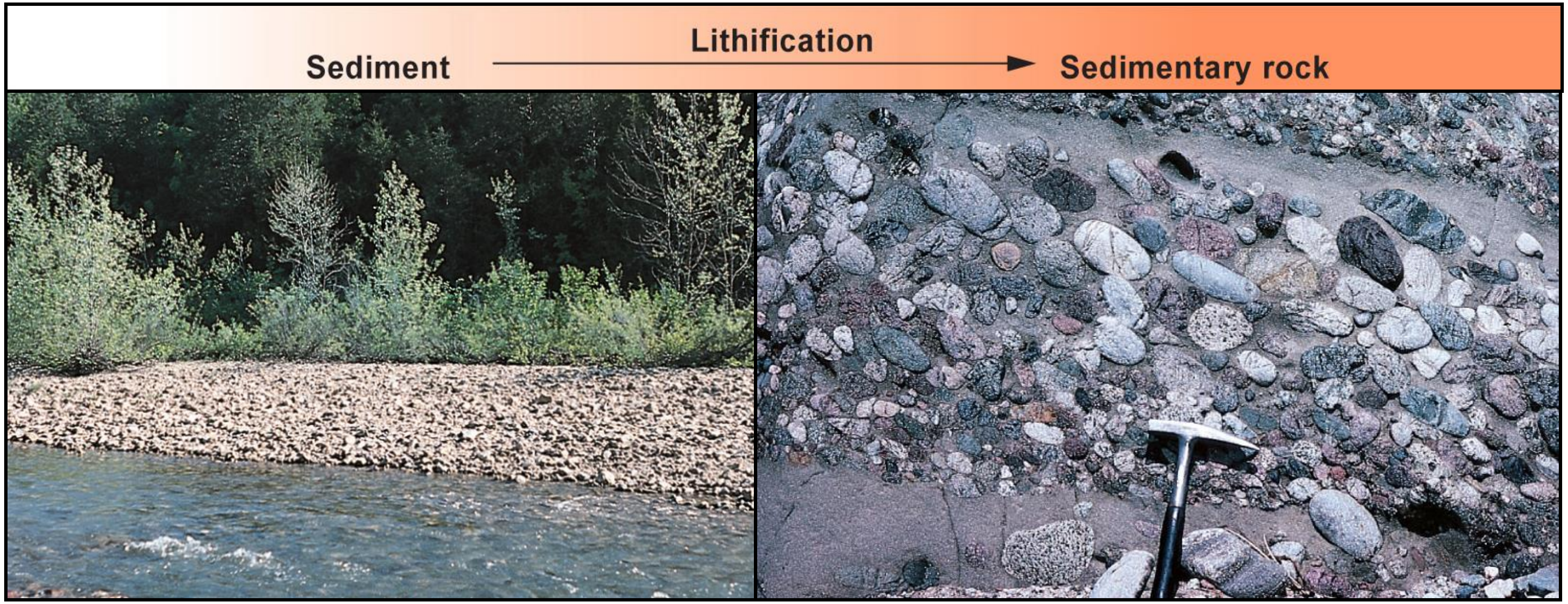
# Clastic Sedimentary Rocks

- Coarse clastics—gravel-sized clasts.
  - Breccia—angular rock fragments.
    - Angularity indicates the absence of rounding by transport.
    - Deposited relatively close to clast source.
    - Example: Talus or "Scree" under a cliff face (Black Tusk)



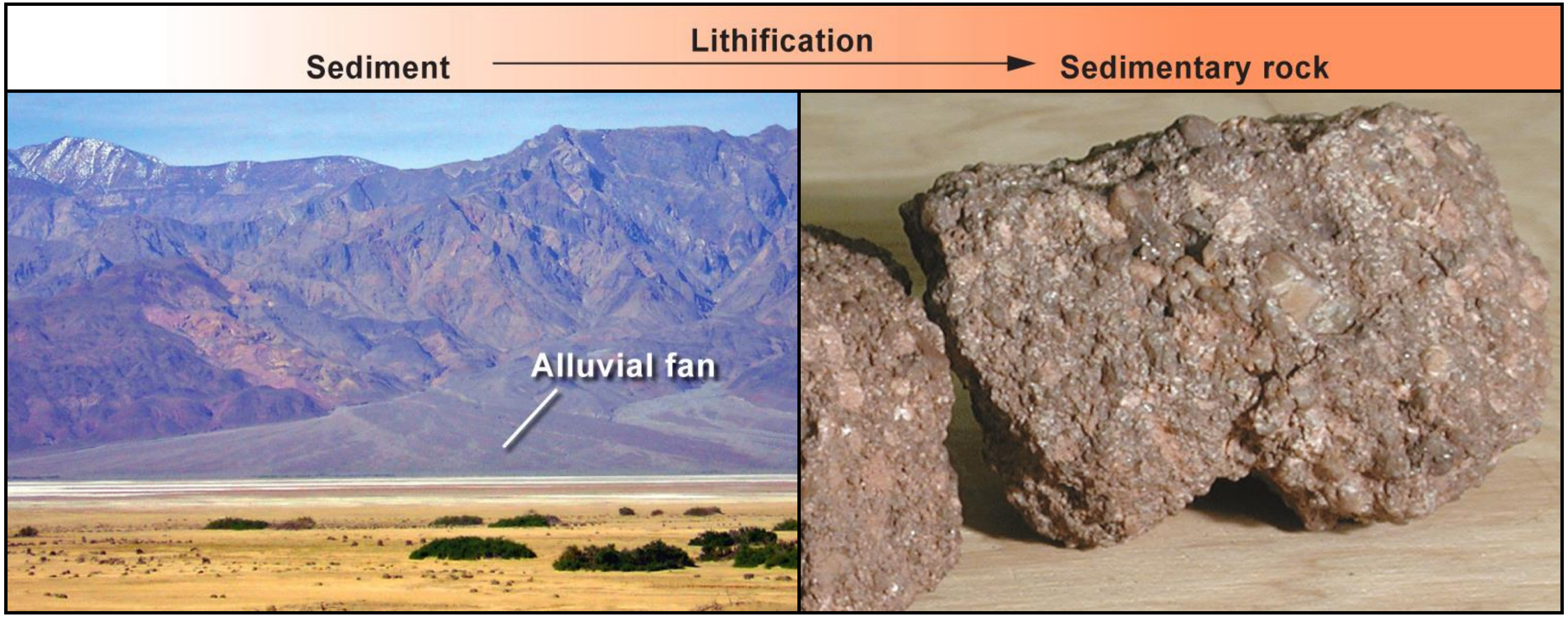
# Clastic Sedimentary Rocks

- **Coarse clastics—gravel-sized clasts.**
  - **Conglomerate—rounded rock clasts.**
    - **Clasts rounded as flowing water wears off corners and edges.**
    - **Deposited farther from the source than breccia.**
    - **Example: River channel**



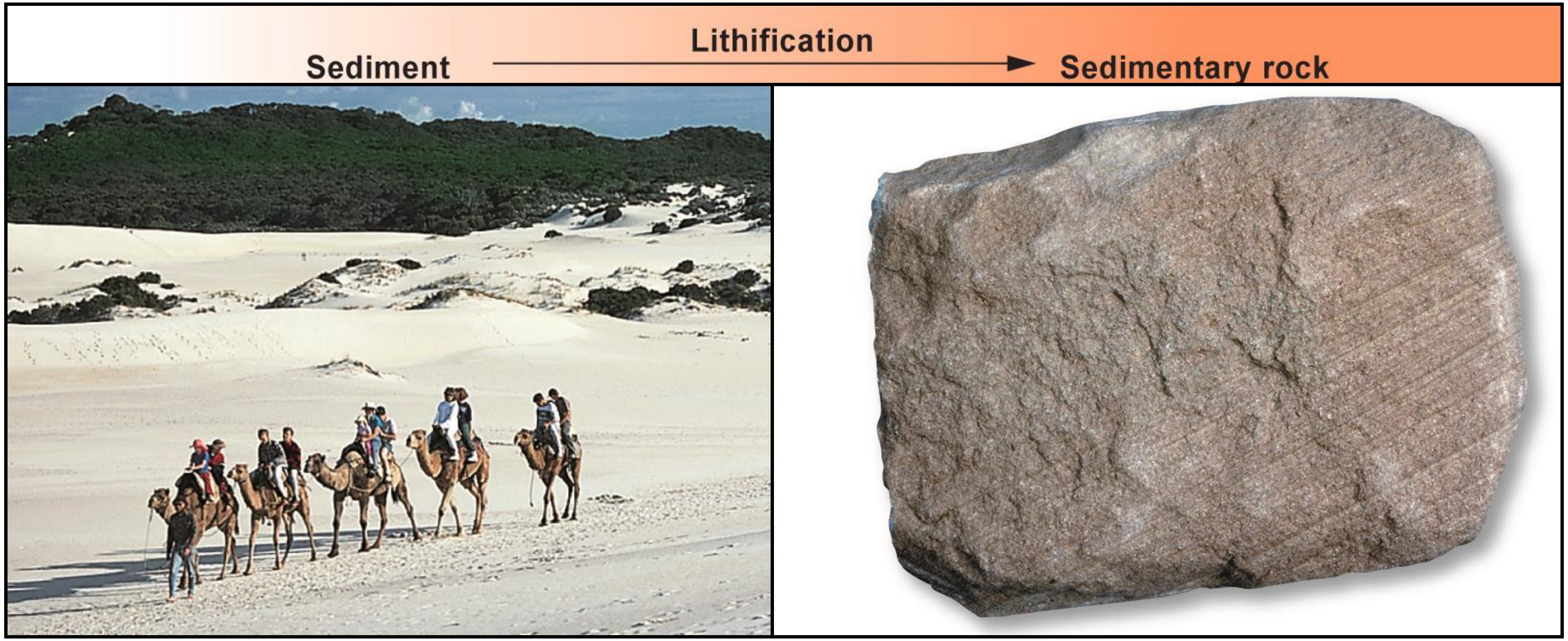
# Clastic Sedimentary Rocks

- Coarse clastics—sand and gravel-sized clasts.
  - Arkose—sand and gravel with abundant feldspar.
    - Commonly deposited in alluvial fans.
    - Feldspar indicates short transport.



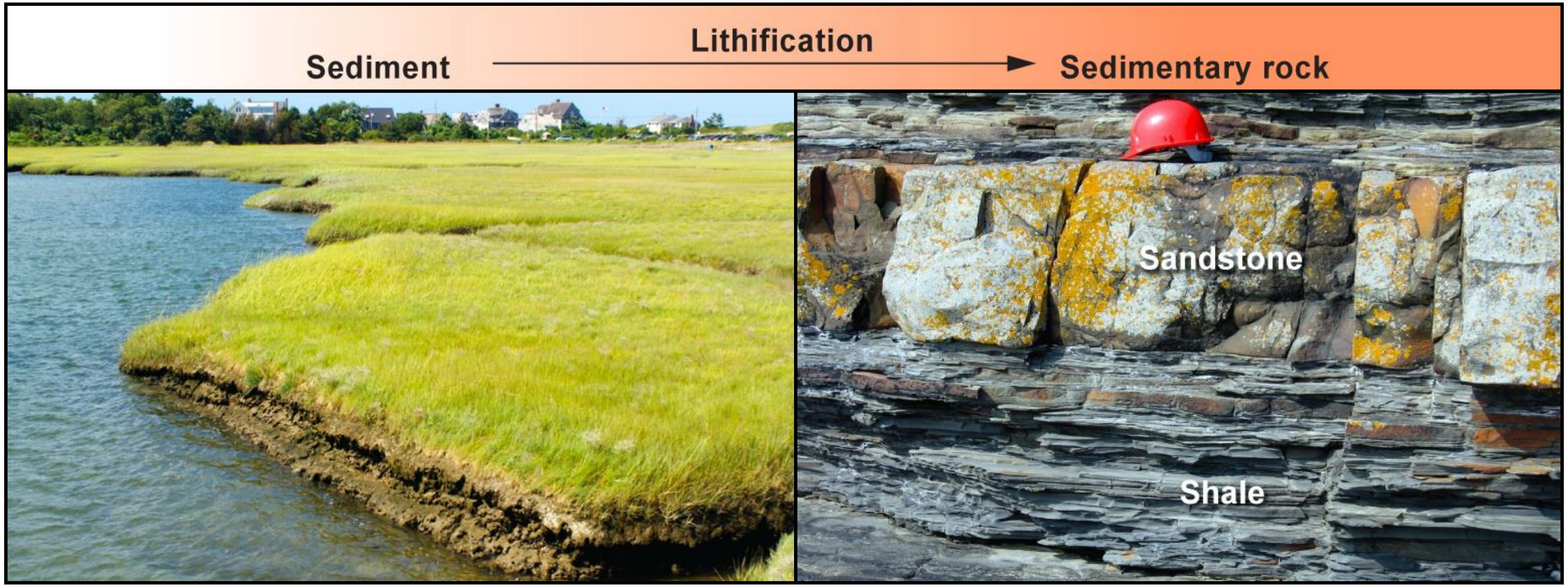
# Clastic Sedimentary Rocks

- Sandstone—clastic rock made of sand-sized particles.
  - Common in beach and dune settings.
  - Quartz is, by far, the most common mineral in sandstones.



# Clastic Sedimentary Rocks

- Fine clastics are deposited in quiet water settings.
  - Floodplains, lagoons, mudflats, deltas, deep-water basins.
- Silt, when lithified*, becomes siltstone.
- Mud, when lithified, becomes mudstone or shale.
  - * lithification: to make into rock



# Biochemical Sedimentary Rocks

- Sediments derived from the shells of living organisms.
  - Hard mineral skeletons accumulate after death.
  - Different sedimentary rocks are made from these materials.
    - Calcite and Aragonite ($CaCO_3$) -- limestone.
    - Silica ($SiO_2$) -- chert

# Biochemical Sedimentary Rocks

- **Limestone -- sedimentary rocks made of $CaCO_3$.**
  - **Fossiliferous limestone -- contains visible fossil shells.**
  - **Micrite -- fine carbonate mud.**
  - **Chalk -- made up of plankton shells**
    - **White Cliffs of Dover**

# Biochemical Sedimentary Rocks

- Chert—rock made of cryptocrystalline quartz; Opal?
  - Silica ($SiO_2$) skeletons of some marine plankton.
  - After burial, silica in bottom sediments dissolves.
  - Silica in pore fluids solidifies into a gel.
  - The silica gel precipitates chert as nodules or beds – also in fossilized trees


# Organic Sedimentary Rocks

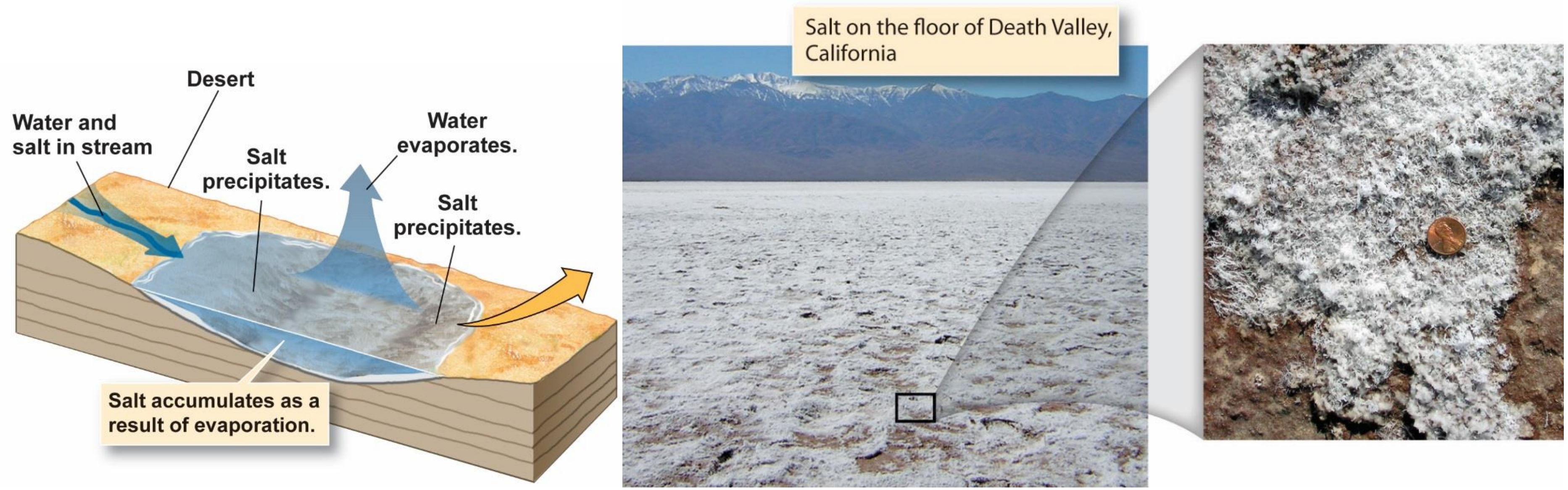
- Made of organic carbon, the soft tissues of living things.
  - Coal—altered remains of fossil vegetation.
    - Black, combustible sedimentary rock
    - Over 50–90% carbon
    - Has fueled industry since the industrial revolution began.

# Chemical Sedimentary Rocks

- Comprised of minerals precipitated from water solution.
  - Have a crystalline (interlocking) texture.
    - Initial crystal growth in solution.
    - Recrystallization during burial -- neocrystalization.
- There are several classes.
  - Evaporites
  - Travertine
  - Replacement chert
  - Dolostone: $CaMg(CO_3)_2$
    - The hard cap of the Niagara escarpment

# Chemical Sedimentary Rocks

- Evaporites—rock from evaporated sea or lake water.
  - Evaporation triggers deposition of chemical precipitates.
  - Thick deposits require large volumes of water.
  - Evaporite minerals include halite (rock salt) and gypsum.



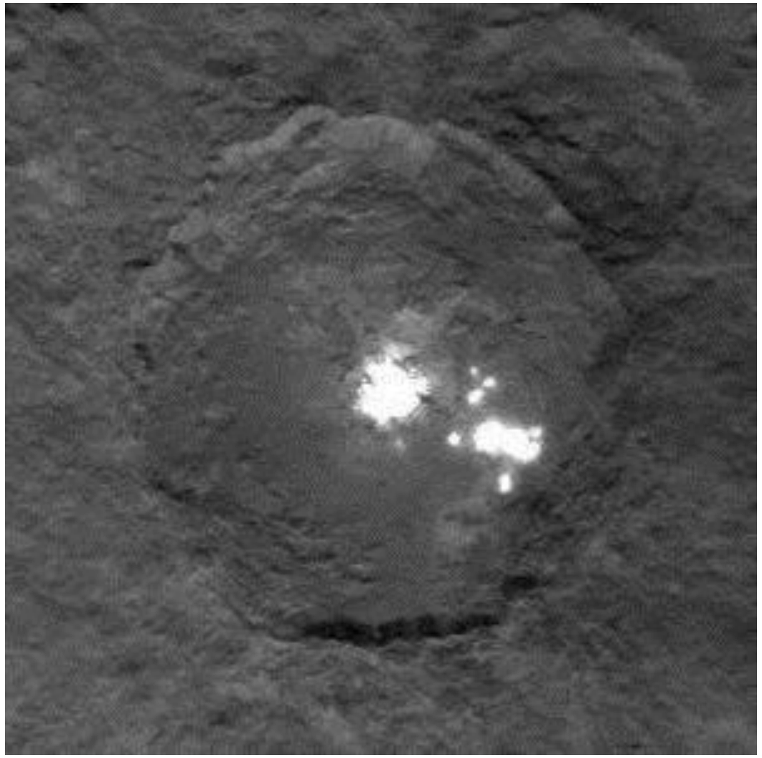
# Salts accumulation means water

- **Formed by the evaporation of saline waters, it is sometimes surprising where we find them.**

  - **The Giant Salt City 1200ft Beneath Detroit**
  - **Salt beds in the Mediterranean basin**
  - **Valles Marineris region of Mars**
  - **Meteorites and asteroids**
  - **Occator crater on Ceres, the largest asteroid**

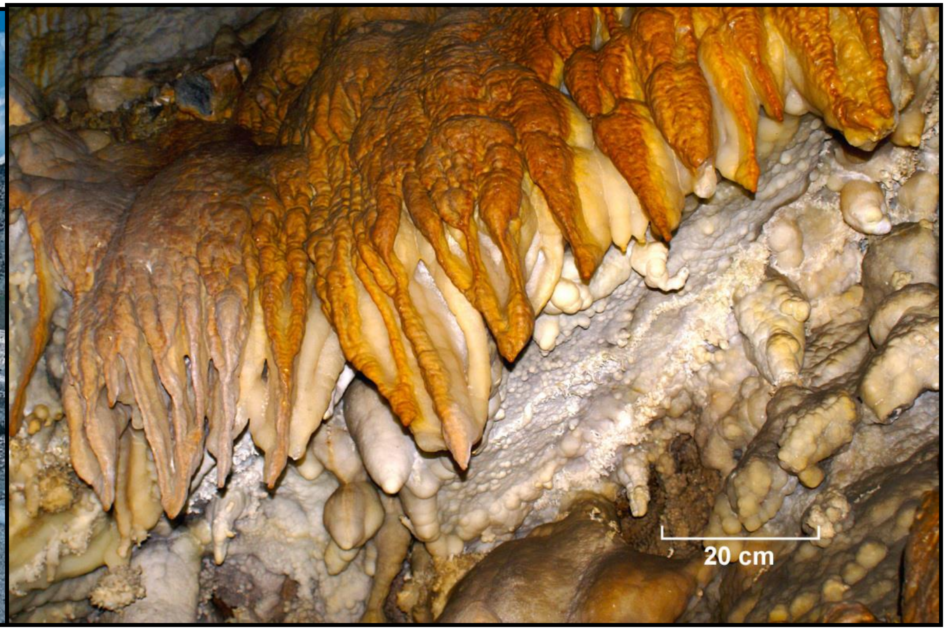
# Salts accumulation means water

- **Salts tell us of past water.**
  - **Occator crater on Ceres, the largest asteroid**



# Chemical Sedimentary Rocks

- **Travertine—calcium carbonate ($CaCO_3$) precipitated from ground water where it reaches the surface.**
  - **$CO_2$ expelled into the air causes $CaCO_3$ to precipitate.**
    - **Thermal (hot) springs.**
    - **Caves—speleothems.**

# Chemical Sedimentary Rocks

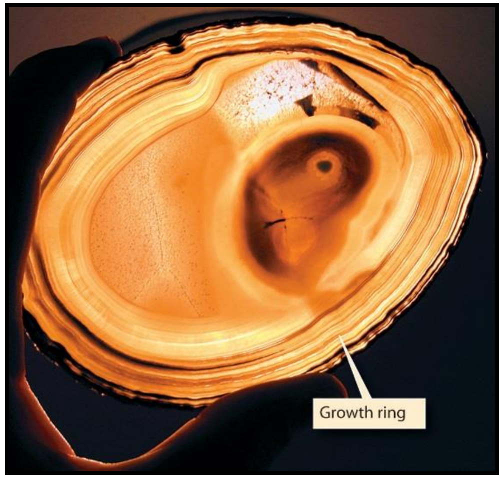
- Dolostone—limestone altered by Mg-rich fluids.
  - $CaCO_3$ altered to dolomite $CaMg(CO_3)_2$ by $Mg^{2+}$-rich water.
  - Diagenisis, dolomitization

# Diagenesis

- Physical, chemical, and biological changes to sediment.
  - Lithification is one aspect of diagenesis
- As sediments are buried, pressure and temperature rise.
  - Temps between burial and metamorphism (~300ºC).
  - Interactions with hot groundwater—chemical reactions.
  - Cements may precipitate or dissolve.
  - At higher pressure & temperature, metamorphism begins.

# Chemical Sedimentary Rocks

- Replacement chert—nonbiogenic
  - Cryptocrystalline silica gradually replaced calcite, long after limestone was deposited.
- Many colors and varieties.
  - Flint—colored black or gray from organic matter.
  - Agate—precipitates in concentric rings.
  - Petrified wood—wood grain preserved by silica.



# Sedimentary Structures

- Features imparted to sediments at or near deposition.
  - Bedding and stratification.
  - Surface features on bedding layers.
  - Arrangement of grains within bedding layers.
- Provide strong evidence about conditions at deposition.

# Bedding and Stratification

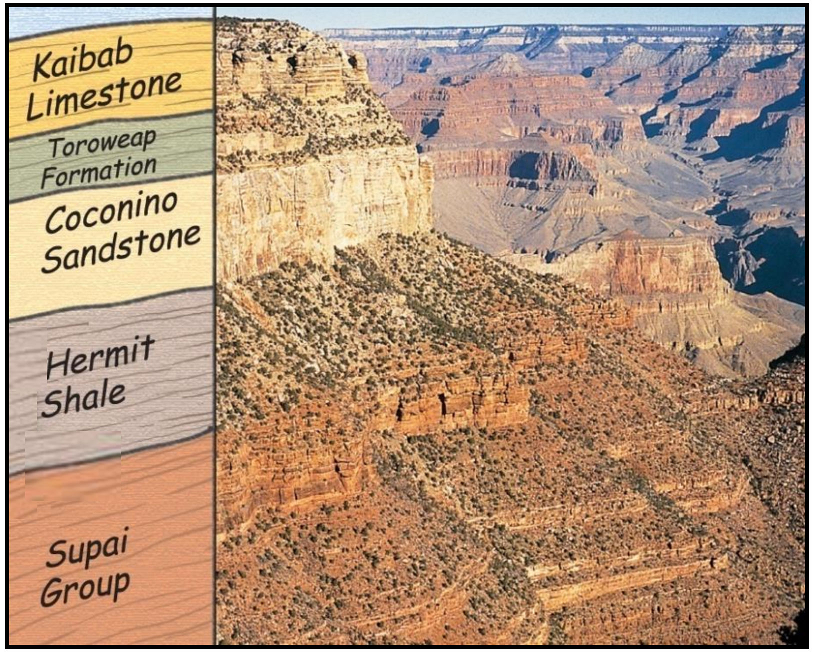
- Sedimentary rocks are usually layered or stratified.
  - Arranged in planar, close-to-horizontal beds.
  - The boundary between two beds is a bedding plane.
  - Several beds together constitute strata.
  - A sequence of beds is called bedding or stratification.

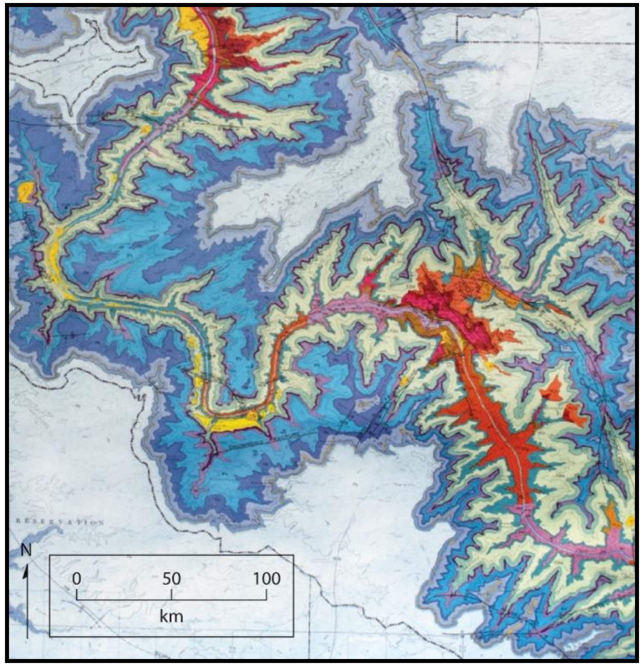
# Sedimentary Structures

- Beds have a definable thickness that can change.
- Bedding forms due to changes in:
  - Climate
  - Water depth of deposition
  - Current velocity
  - Sediment source
  - Sediment supply

# Bedding and Stratification

- Depositional changes vary the stacking of rock features.
  - Creates unique packages recognizable over a region.
  - This distinct rock package is called a formation.
    - Formations are able to be mapped.
    - Formations are named for places they are best exposed.
- Geologic maps display the distribution of formations.



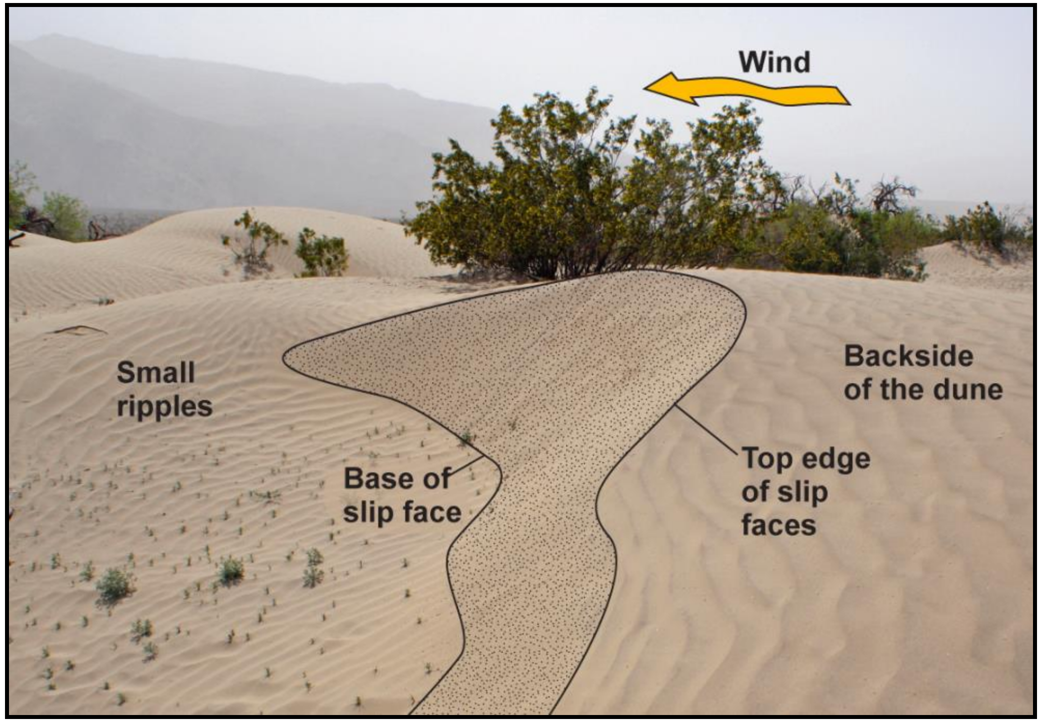



# Current Deposition

- Water or wind flowing over sediment creates bedforms.
- Bedform character is tied to flow velocity and grain size.
  - Ripple marks—cm-scale ridges and troughs.
    - Develop perpendicular to flow.
    - Ripple marks are frequently preserved in sandy sediments.
    - Found on modern beaches
    - Found on bedding surfaces of ancient sedimentary rocks

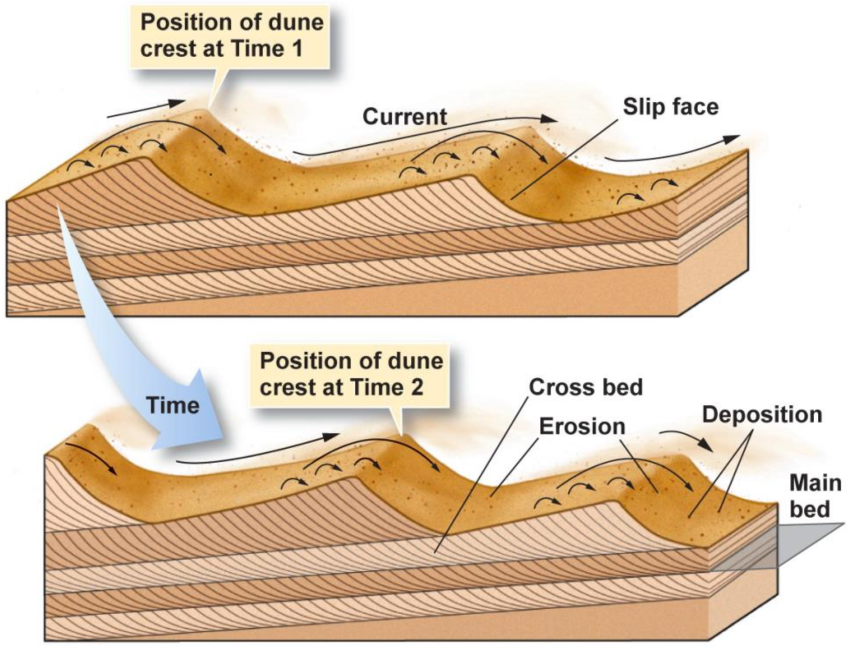
# Current Deposition

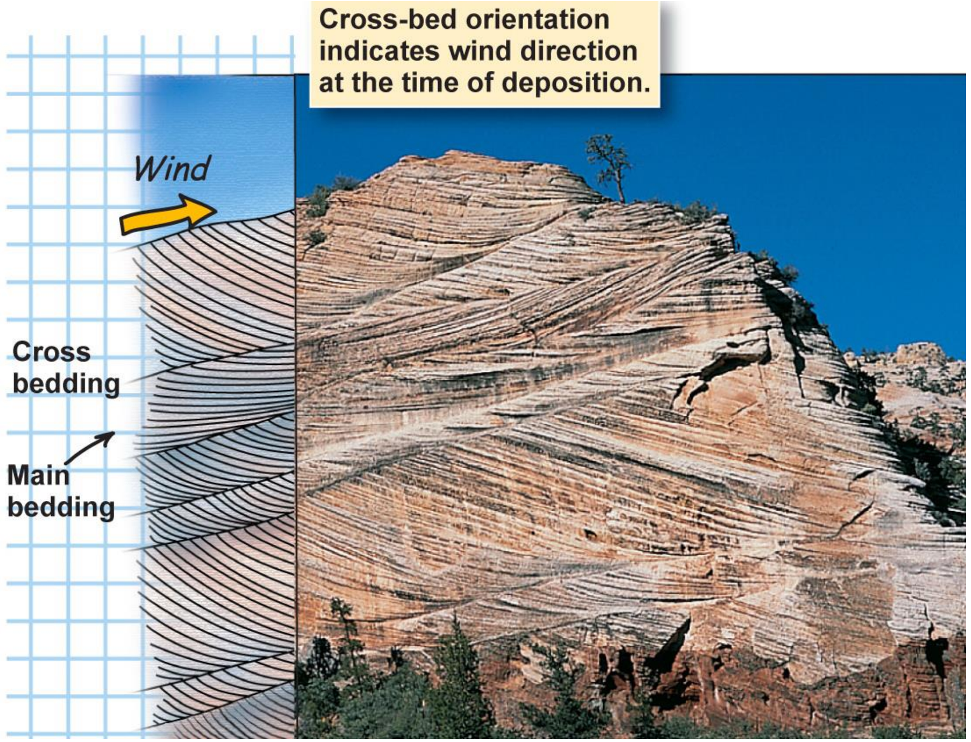
- **Dunes—similar to ripples except much larger.**
  - **Form from water or wind transported sand.**
  - **Occur in streams and in desert or beach regions.**
  - **Range in size from tens of cm to hundreds of m.**
  - **Often preserve large internal cross beds.**



# Current Deposition

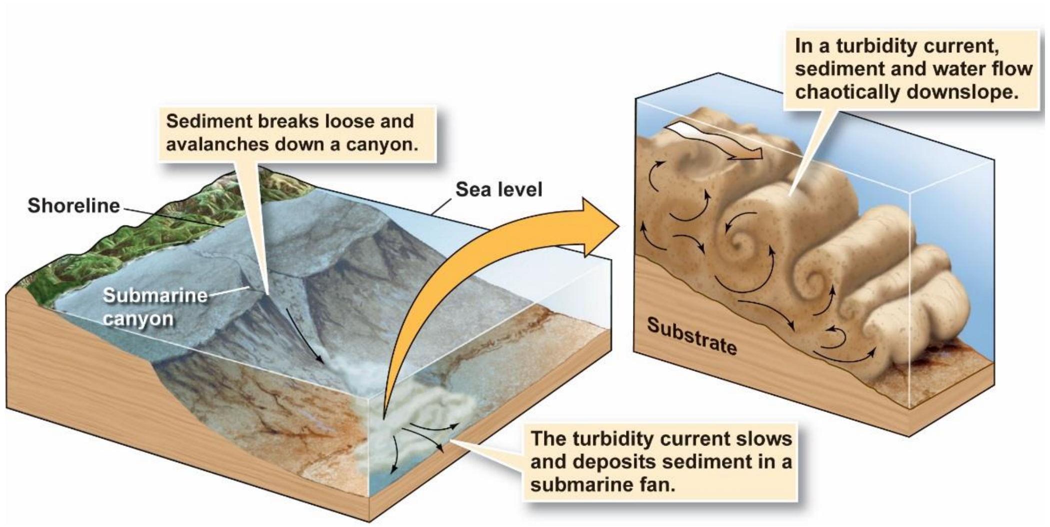
- Cross beds—created by ripple and dune migration.
  - Sediment moves up the gentle side of a ripple or dune.
  - Sediment piles up, then slips down the steep face.
    - The slip face continually moves downcurrent.
    - Added sediment forms sloping cross beds.

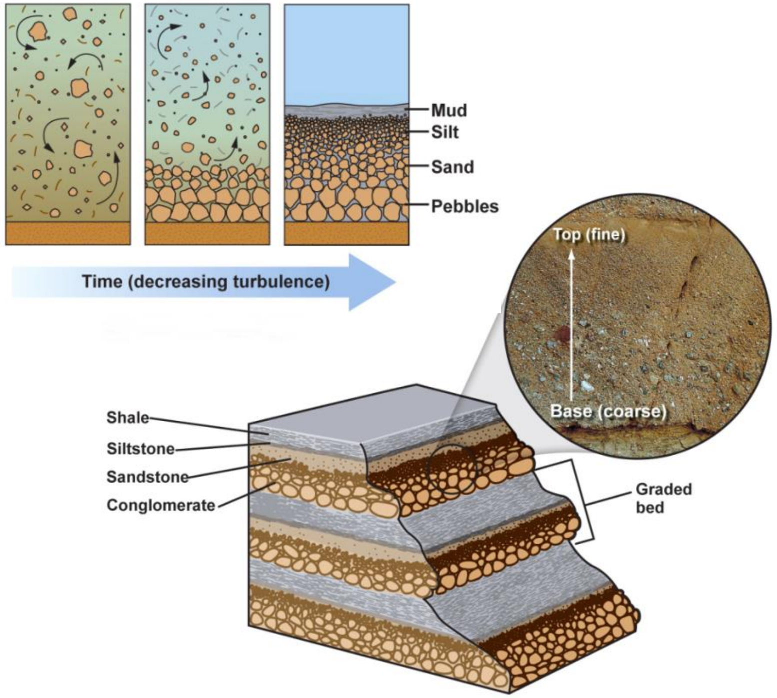


# Current Deposition

- Turbidity currents and graded beds.
  - Sediment moves on a slope as a pulse of turbid water.
  - As pulse wanes, water loses velocity and grains settle.
  - Coarsest material settles first, medium next, then fines.
- This process forms graded beds in turbidite deposits.



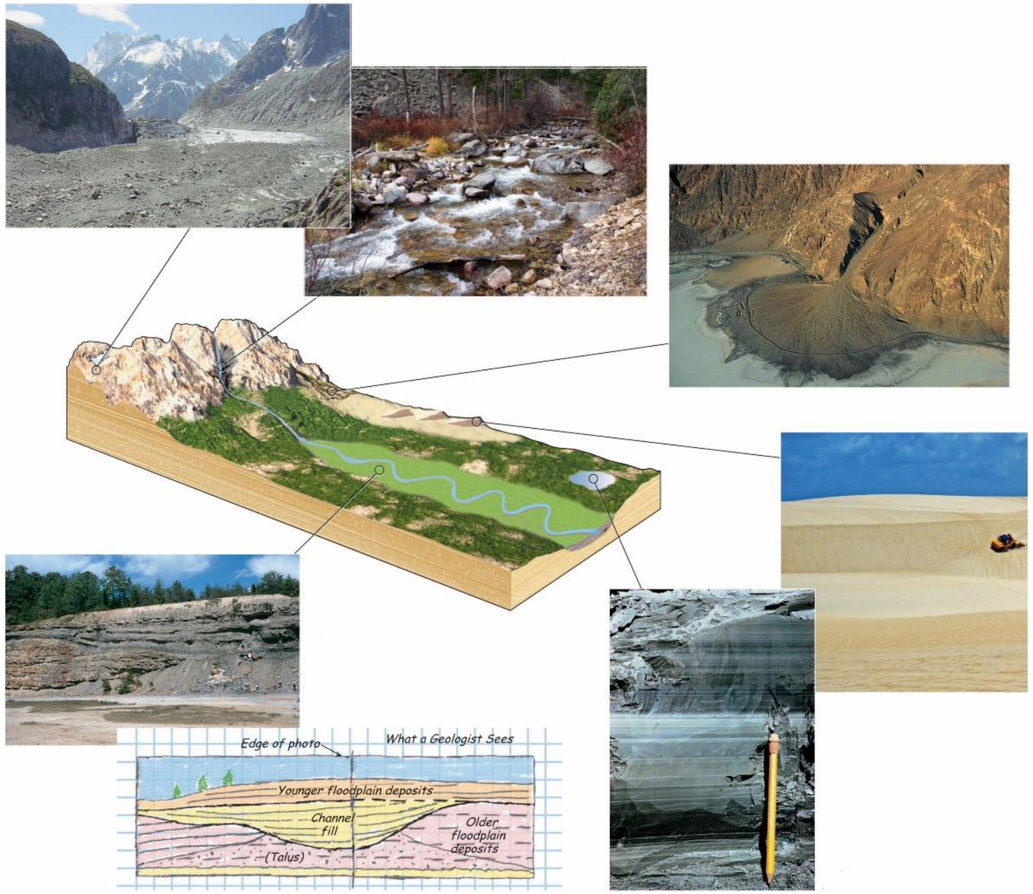



# Bed Surface Markings

- Occur after deposition while sediment is still soft.
  - Mudcracks—polygonal desiccation features in wet mud.
    - Indicate alternating wet and dry terrestrial conditions
  - Scour marks—troughs eroded in soft mud by current flow
  - Fossils—evidence of past life
    - Footprints
    - Shell impressions


# Depositional Environments

- Locations where sediment accumulates. They differ in:
  - Chemical, physical, and biological characteristics.
  - Sediment delivery, transport, and depositional conditions.
  - Energy regime.
- Environments include:
  - Terrestrial
  - Coastal
  - Marine.



# Depositional Environments

- Terrestrial Environments—deposited above sea level.
  - Glacial environments—due to movement of ice.
    - Ice carries and dumps every grain size.
    - Creates glacial till; poorly sorted gravel, sand, silt, and clay.

# Depositional Environments

- Terrestrial Environments—deposited above sea level.
  - Mountain stream environments.
    - Fast-flowing water carries large clasts during floods.
    - During low flow, these cobbles and boulders are immobile.
    - Coarse conglomerate is characteristic of this setting.

# Depositional Environments

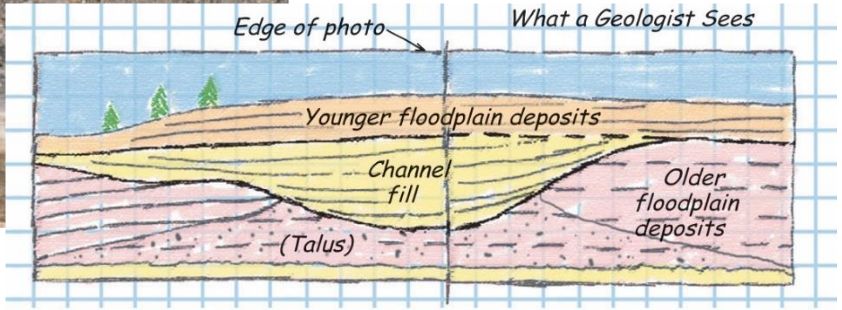
- Terrestrial environments—deposited above sea level.
  - Alluvial fan—sediments that pile up at a mountain front.
    - Rapid drop in stream velocity creates a cone-shaped wedge.
    - Sediments become conglomerate and arkose.

# Depositional Environments

- Terrestrial environments—deposited above sea level.
  - Sand-dune environments—wind-blown, well-sorted sand – aeolian deposition.
    - Dunes move according to the prevailing winds.
    - Result in uniform sandstones with gigantic cross beds.

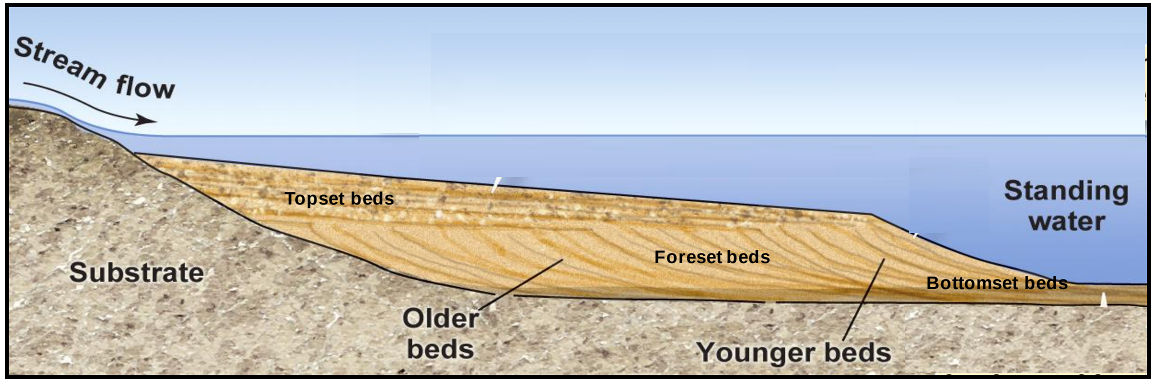
# Depositional Environments

- Terrestrial environments—deposited above sea level.
  - River environments—channelized sediment transport.
    - Sand and gravel fill concave-up channels.
    - Fine sand, silt, and clay are deposited on nearby flood plains.



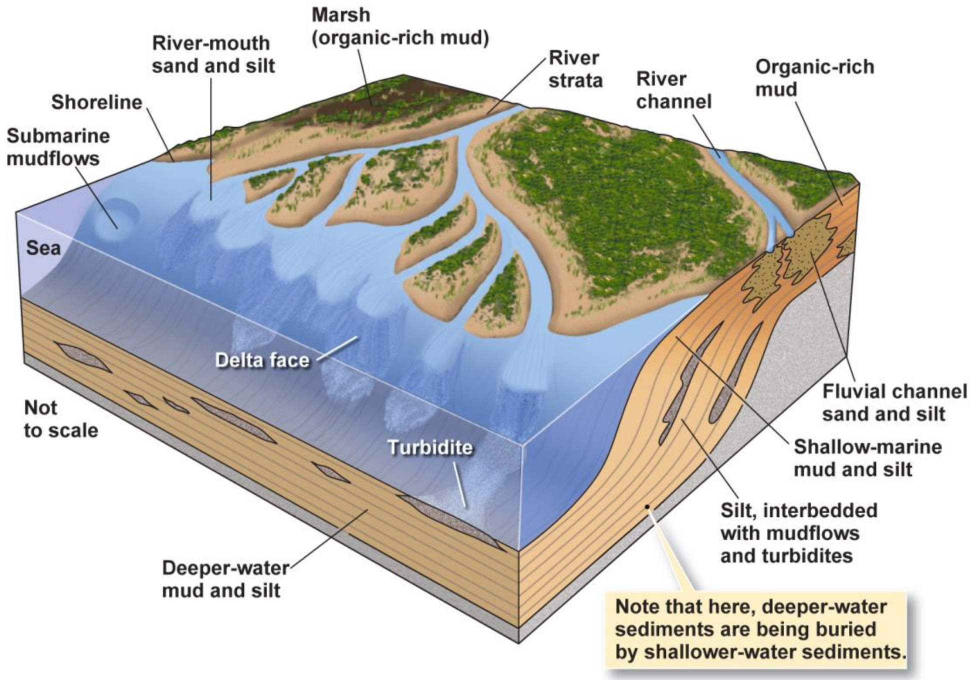
# Depositional Environments

- Terrestrial environments—deposited above sea level.
  - Lake—large ponded bodies of water.
    - Gravels and sands trapped near shore.
    - Well-sorted muds deposited in deeper water.
  - Delta—sediment piles up where a river enters a lake.
  - Often topset, foreset, bottomset (Gilbert-type) geometry.



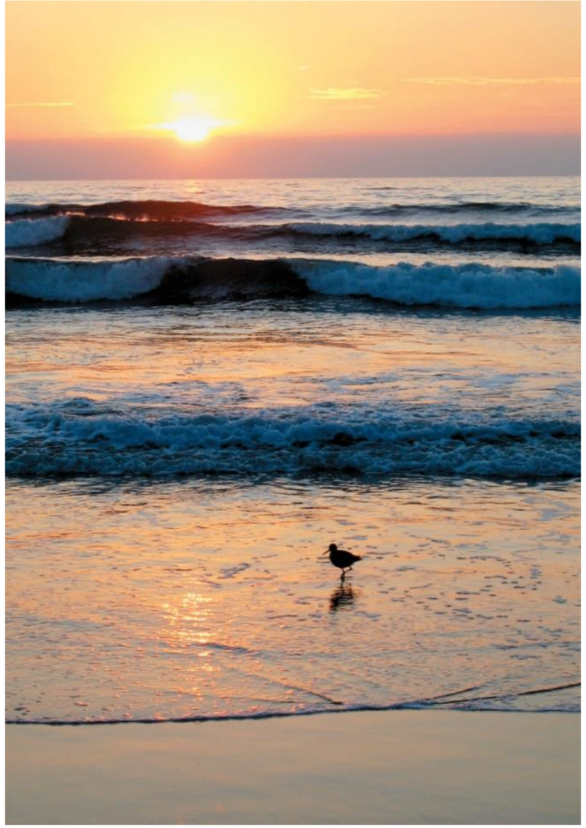

# Depositional Environments

- Marine delta environments—deposited at sea level.
  - Delta—sediment accumulates where a river enters the sea.
    - Sediment carried by the river is dumped when velocity drops.
    - Deltas grow over time, building out into the basin.
    - Much more complicated than simple lake deltas.
    - Many sub-environments present.



# Depositional Environments

- Marine environments—deposited at or below sea level.
  - Coastal beach sands—sand is moved along the coastline.
    - Sediments are constantly being processed by wave action.
    - A common result? Well-sorted, well-rounded medium sand.
    - Beach ripples often preserved in sedimentary rocks.

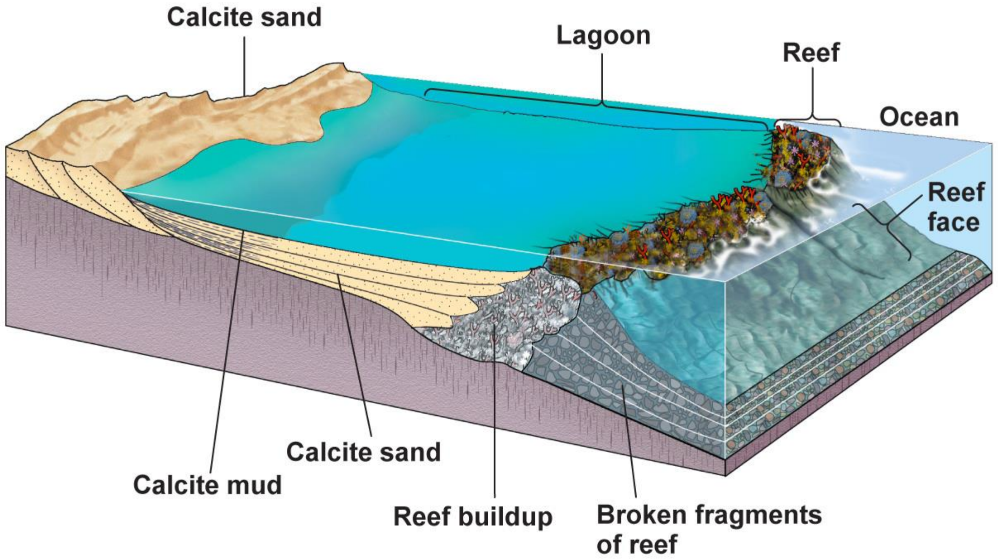


# Depositional Environments

- Marine environments—deposited at or below sea level.
  - Shallow-marine clastic deposts—finer sands, silts, muds.
    - Fine sediments deposited offshore where energy is low.
    - Finer silts and muds turn into siltstones and mudstones.
    - Usually supports an active biotic community.

# Depositional Environments

- Marine environments—deposited at or below sea level.
  - Shallow water carbonate environments.
    - Most sediments are carbonates—shells of organisms.
    - Warm, clear, marine water, relatively free of clastic sediments.
    - Protected lagoons accumulate mud.
    - Wave-tossed reefs are made of coral and reef debris.
    - Source of limestones.

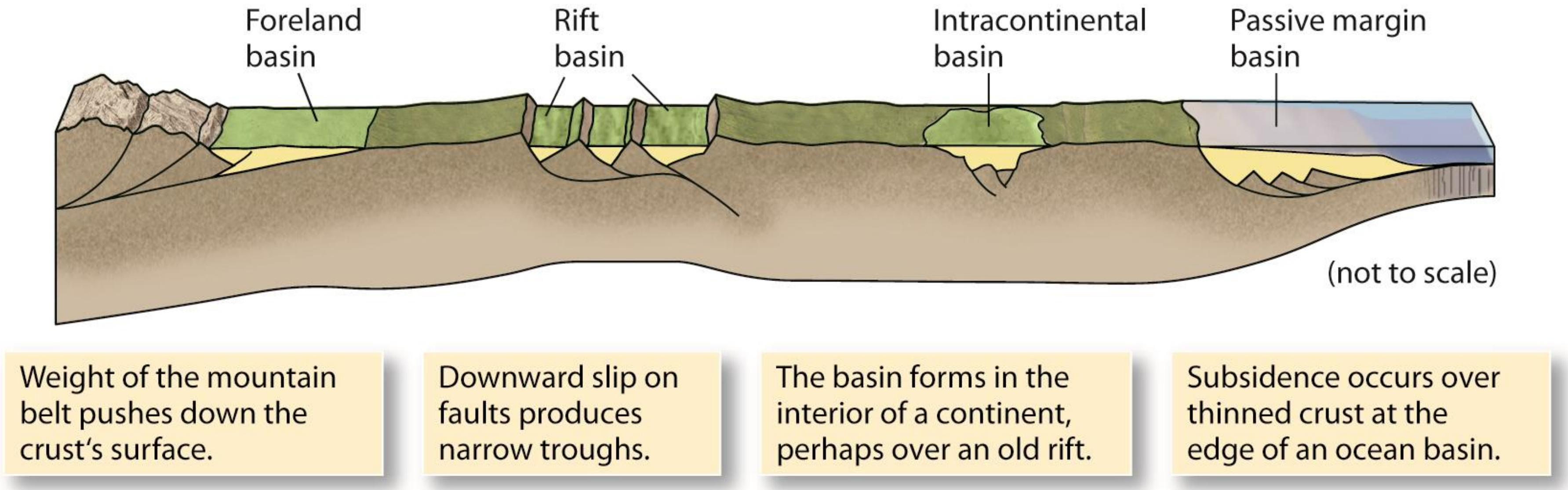



# Depositional Environments

- **Marine environments—deposited at or below sea level.**
  - **Deep marine deposits—fines settle out far from land.**
    - **Skeletons of planktonic organisms make chalk or chert.**
    - **Fine silt and clay lithifies into shale.**

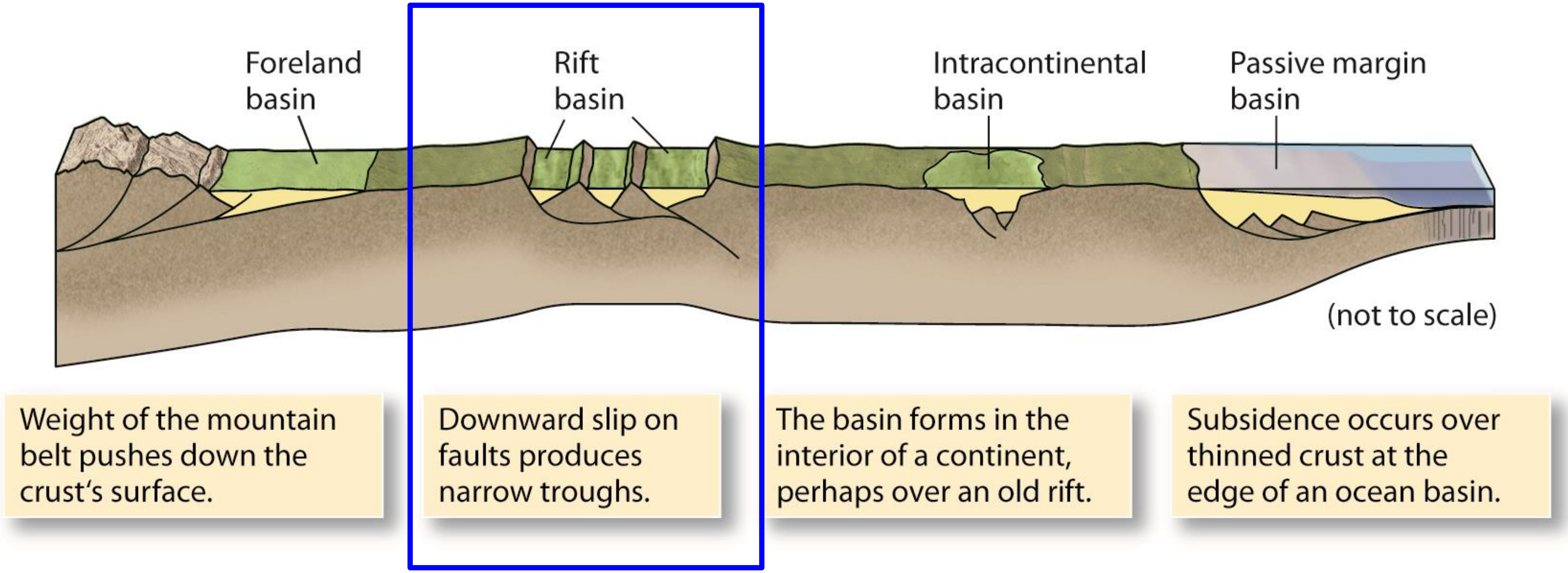
# Sedimentary Basins

- Sediments vary in thickness across Earth's surface.
  - Thin to absent where nonsedimentary rocks outcrop.
  - Thicken to 10–20+ km in sedimentary basins.
- Subsidence—sinking of the land during sedimentation.
- Basins are special places that accumulate sediment.



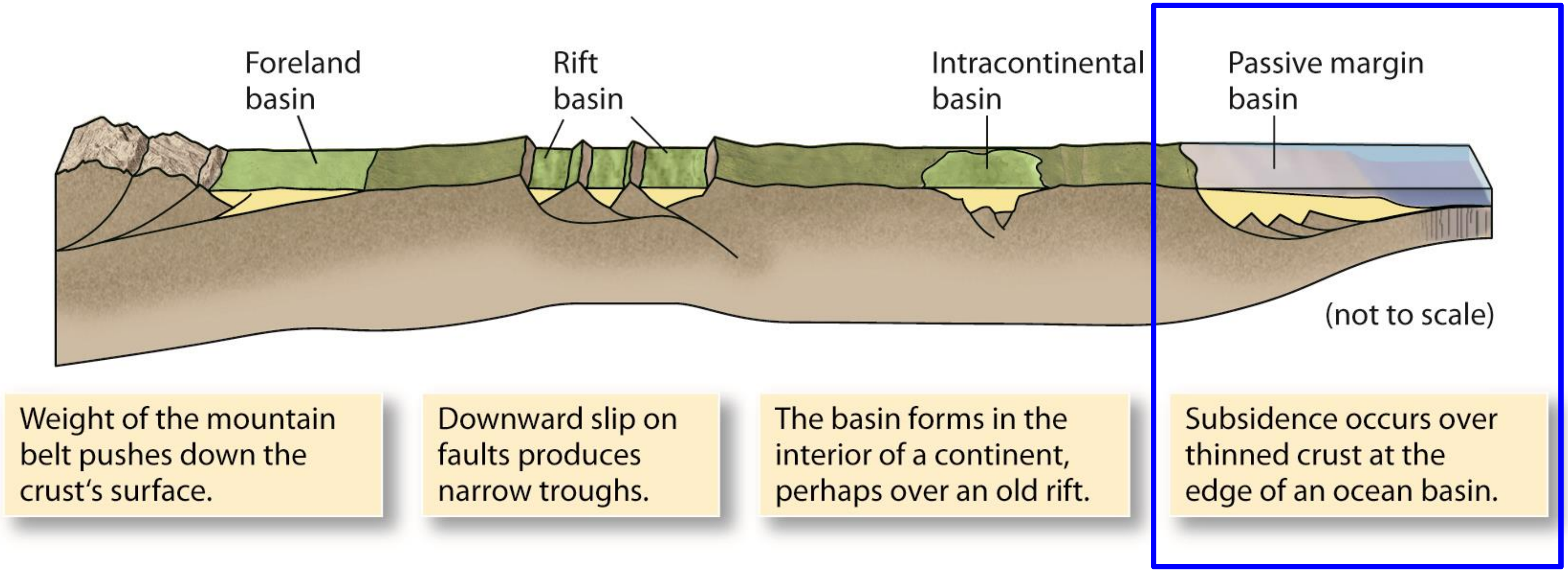
# Sedimentary Basins

- Basins form where tectonic activity creates space.
  - Rift basins—divergent (pull-apart) plate boundaries.
    - Crust thins by stretching and rotational normal faulting.
    - Thinned crust subsides.
    - Sediment fills the down-dropped troughs.



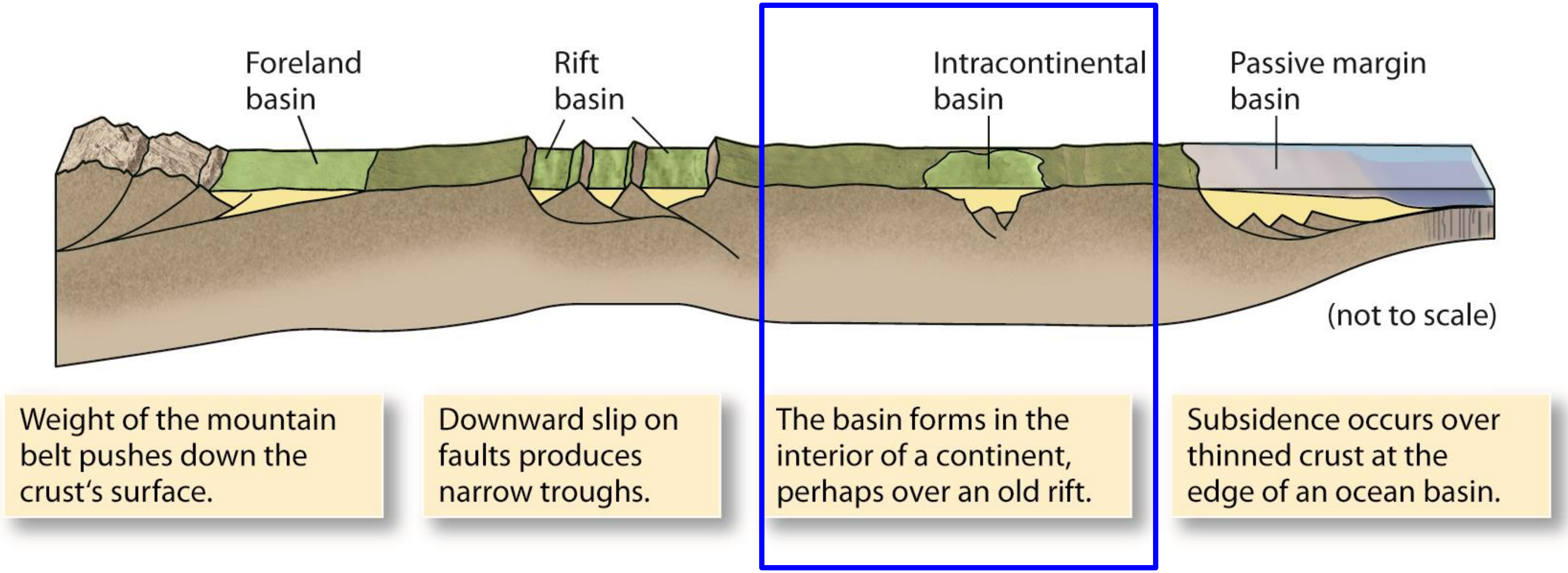
# Sedimentary Basins

- Basins form where tectonic activity creates space.
  - Passive margins—continental edge far from plate boundary.
    - Underlain by crust thinned by previous rifting.
    - Thinned crust subsides as it cools.
    - Subsiding basin fills with sediment from rivers entering sea.



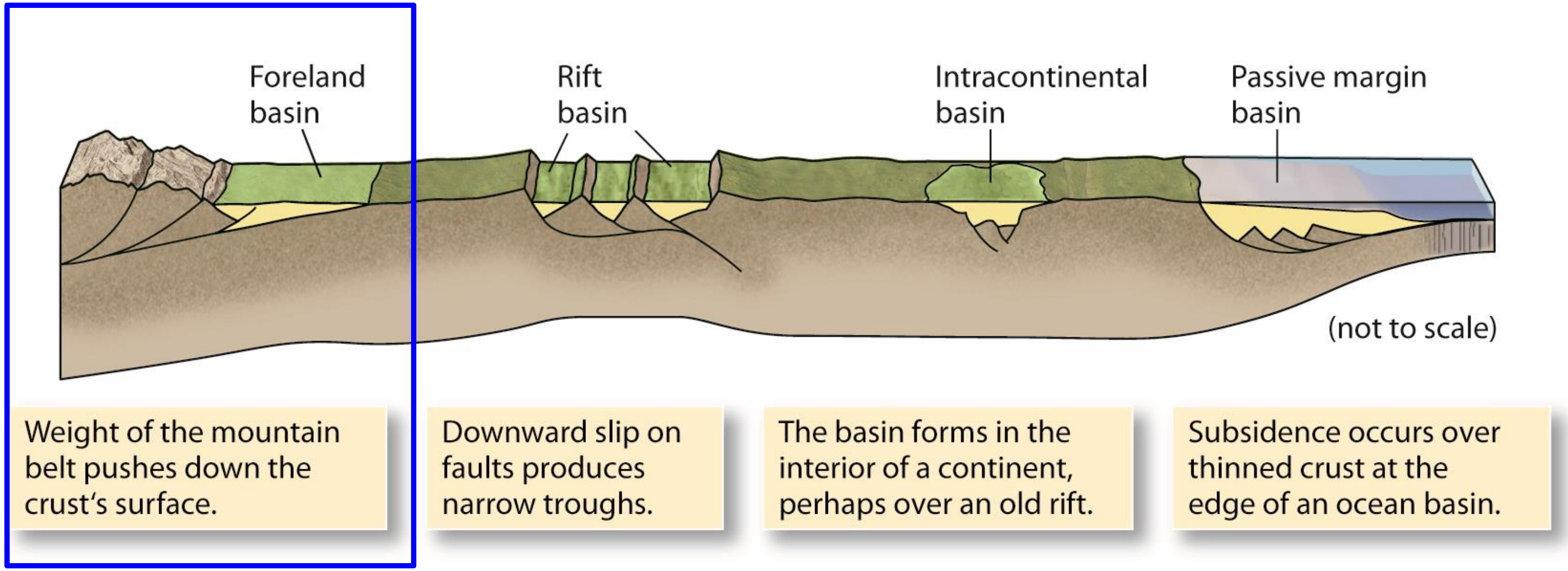
# Sedimentary Basins

- Basins form where tectonic activity creates space.
  - Intracontinental basins—interiors far from margins.
    - May be linked to failed crustal rifts.
    - Continue to subside for millions of years after formation.



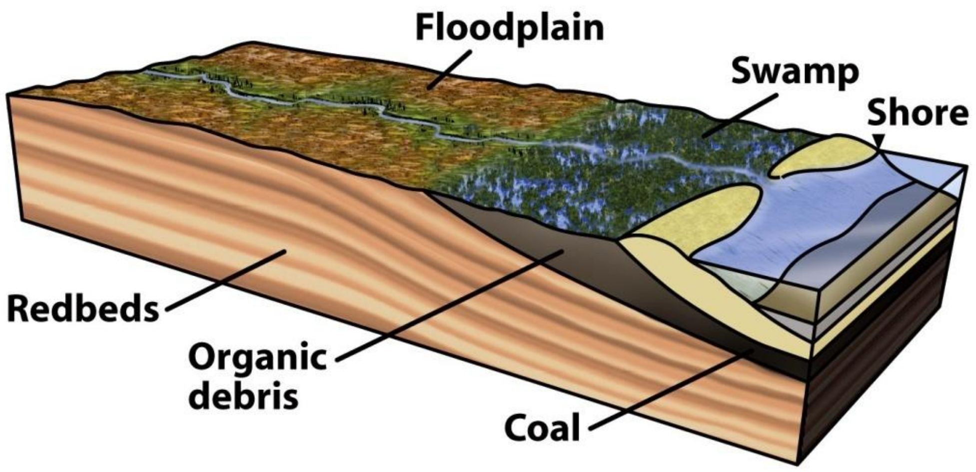
# Sedimentary Basins

- Basins form where tectonic activity creates space.
  - Foreland basins—craton side of collisional mountain belt.
    - Flexure of the crust from loading creates a downwarp.
    - Fills with debris eroded off of the mountains.
    - Fluvial, deltaic, and lake sediments fill foreland basins.



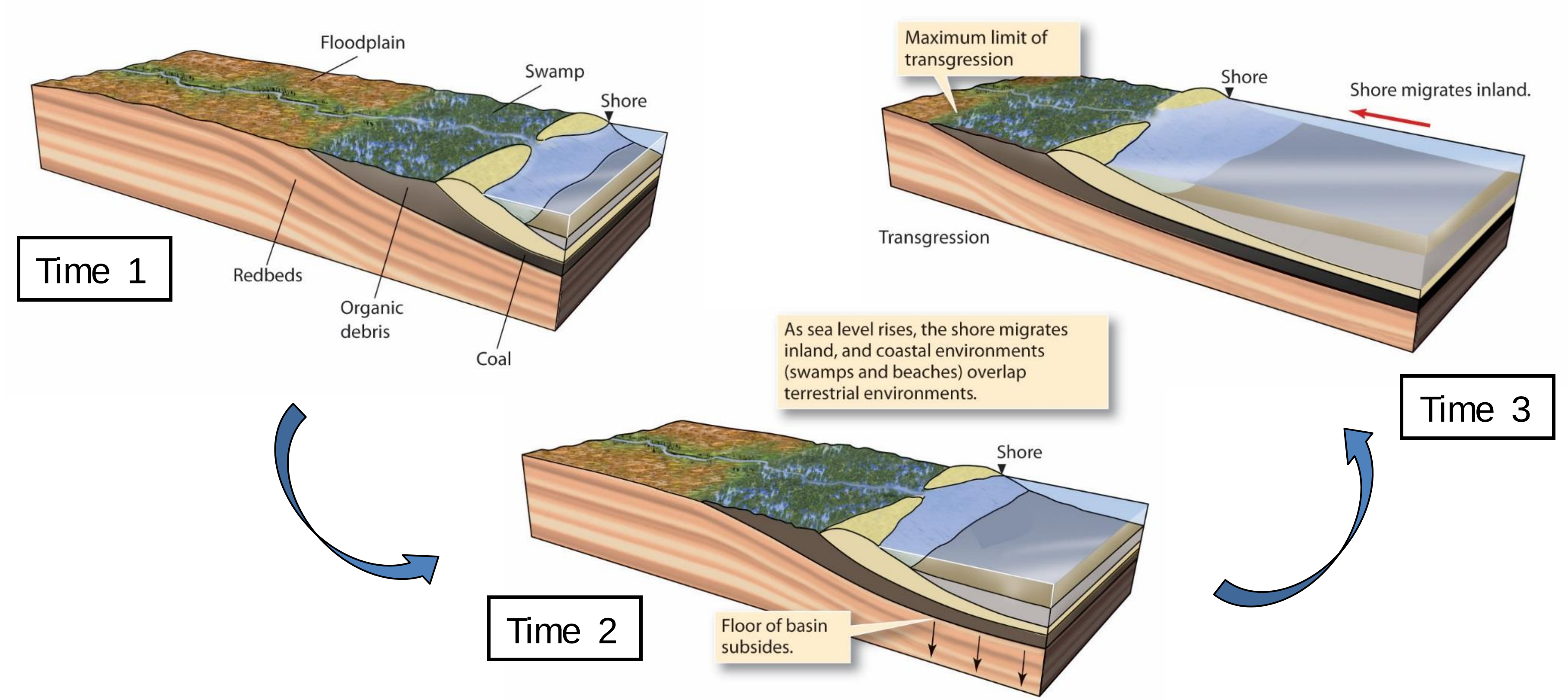
# Transgression–Regression

- Sea level changes.
  - Sedimentary deposition is strongly linked to sea level.
  - Changes in sea level are commonplace geologically.
    - Sea level rises and falls up to hundreds of meters
      - Changes in climate, tectonic processes
    - Depositional belts shift landward or seaward in response.
    - Layers of strata record deepening or shallowing upward.



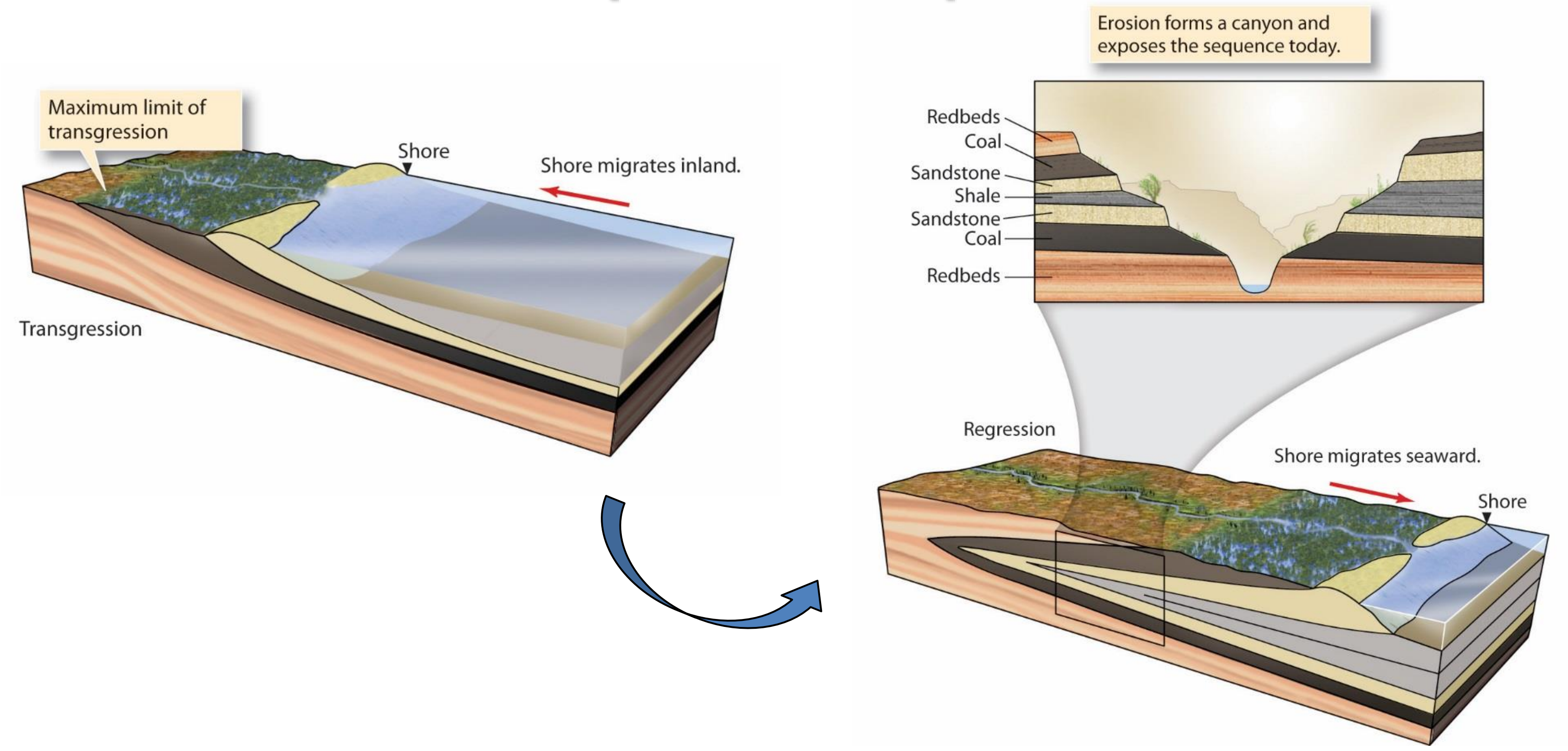
# Transgression–Regression

- Sea level changes.
  - Transgression—flooding due to sea-level rise.
    - Sediment belts shift landward; strata “deepen” upward.



# Transgression–Regression

- **Regression – exposure due to sea level fall.**
  - **Depositional belts shift seaward; strata "shallow upward."**
  - **Regression tied to erosion; less likely to be preserved.**
- **Sea level rise and fall creates a predictable pattern.**



# Deep Time: How Old Is Old?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# Geologic Time

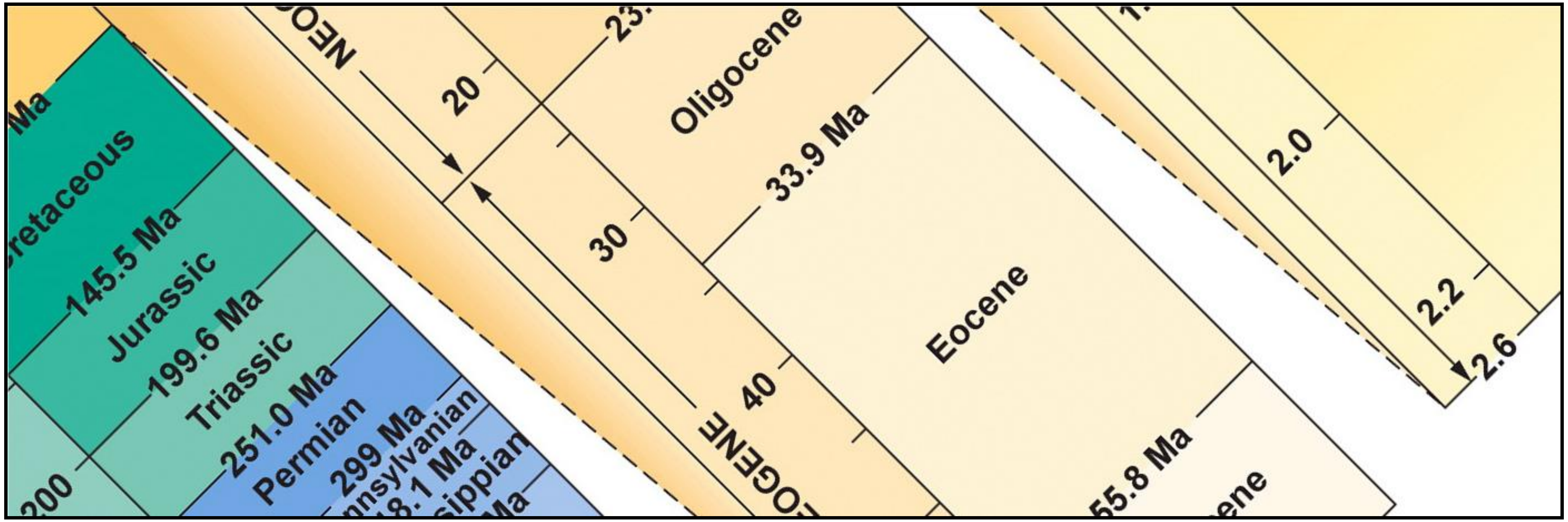
- Earth has a history that is billions of years old.
- Discovering this was a major step in human history.
- It changed our perception of time and the Universe.

# 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.

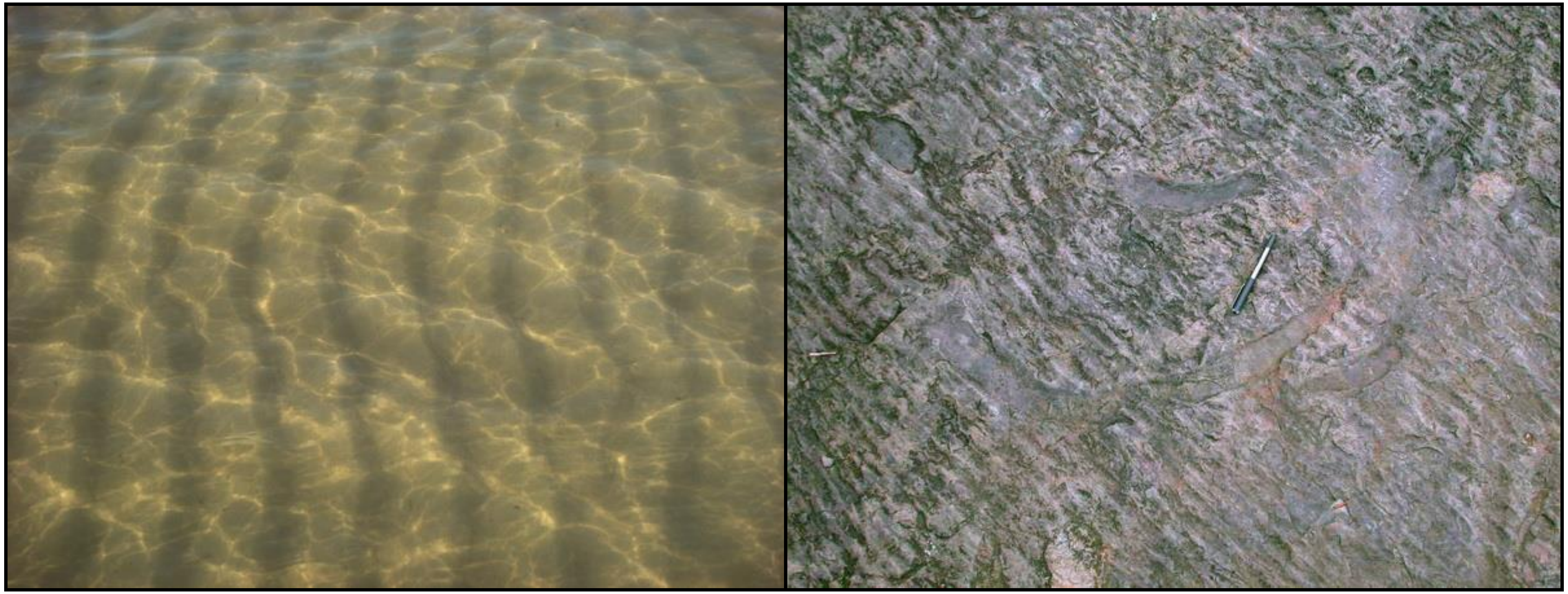


# Geologic Time

- 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"

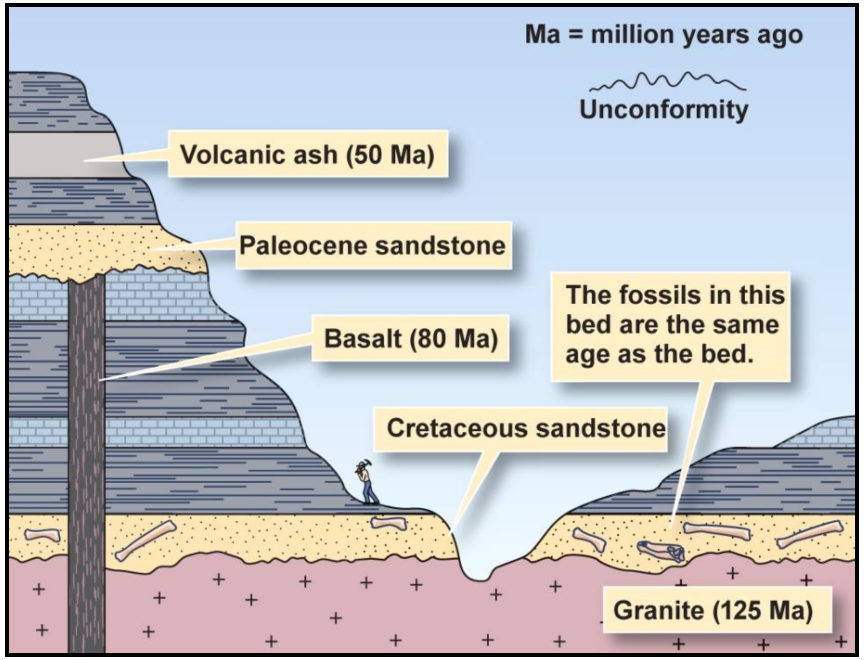
# Geologic Time

- 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.

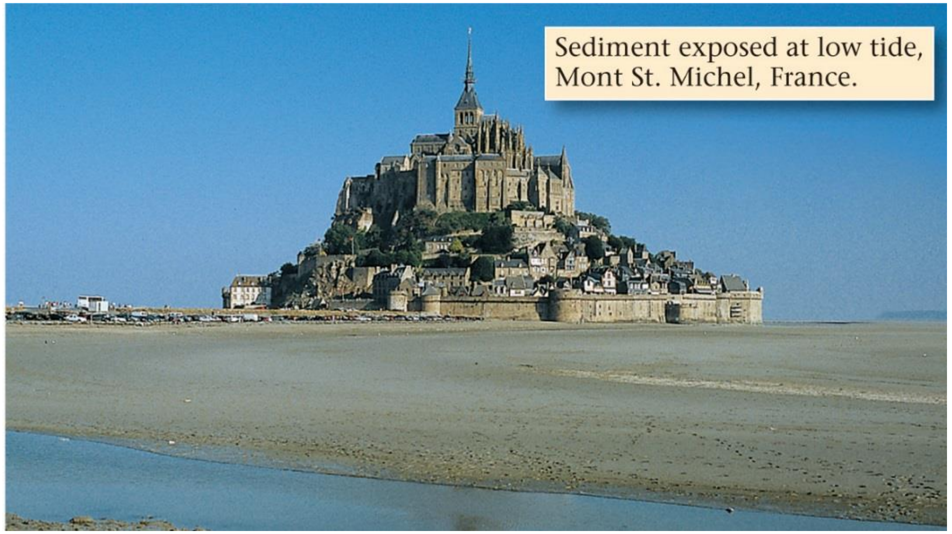


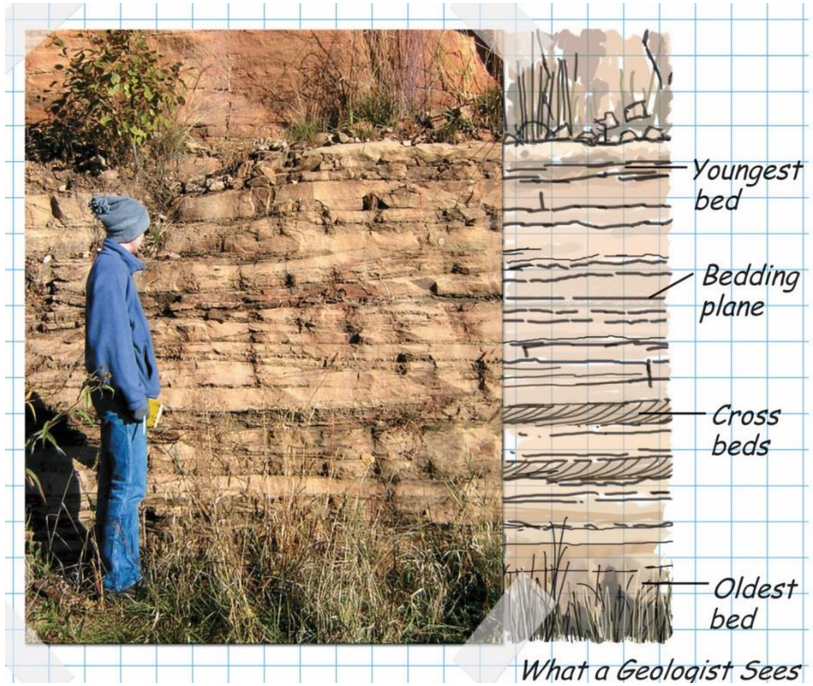
# Physical Principles

- 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

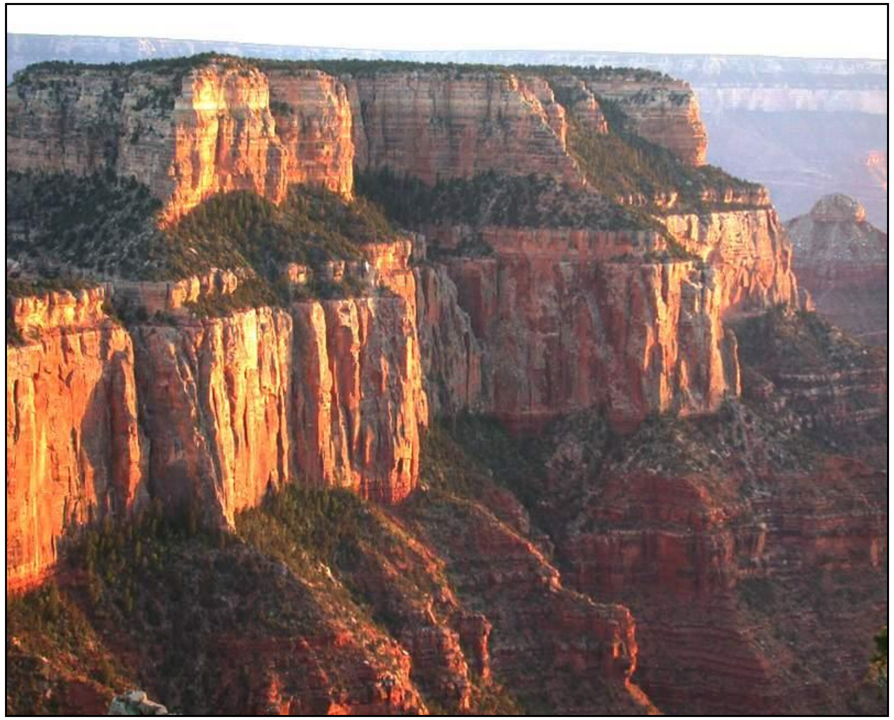
- The principle of original horizontality
  - Sediments settle out of a fluid by gravity.
  - This causes sediments to accumulate horizontally.
  - Sediment accumulation is not favored on a slope.
  - Hence, tilted sedimentary rocks must be deformed.

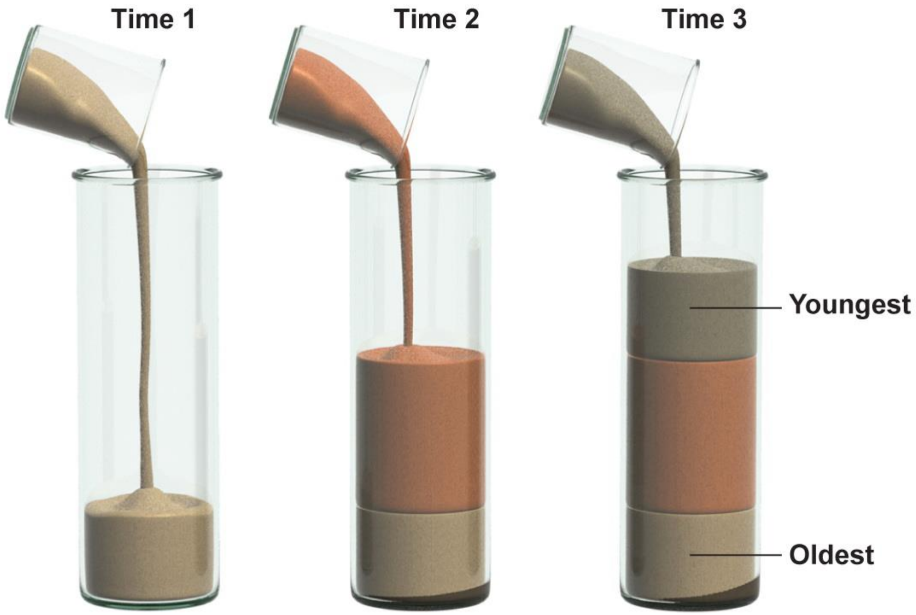


# Physical Principles

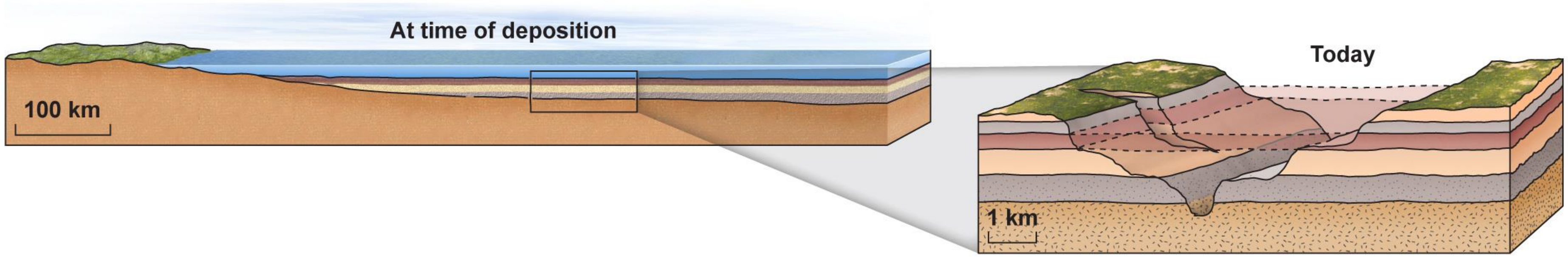
- The principle of superposition
  - In an undeformed sequence of layered rocks:
    - Each bed is older than the one above and younger than the one below.
  - Younger strata are on top, older strata on bottom.





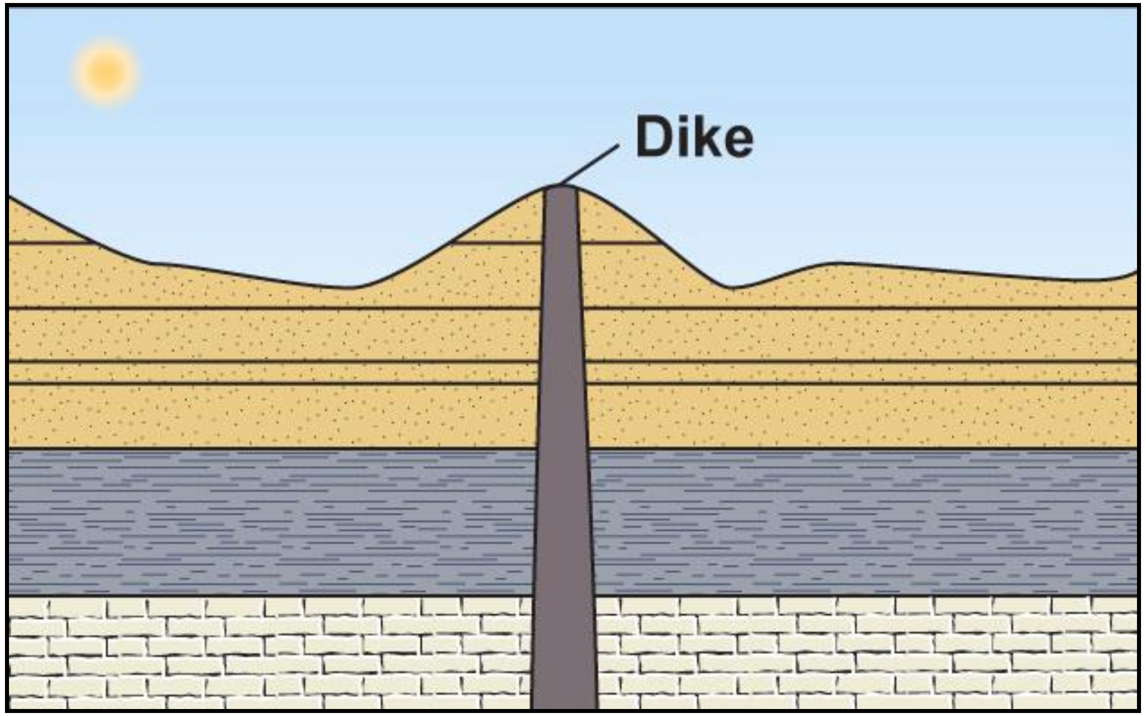
# Physical Principles

- 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.



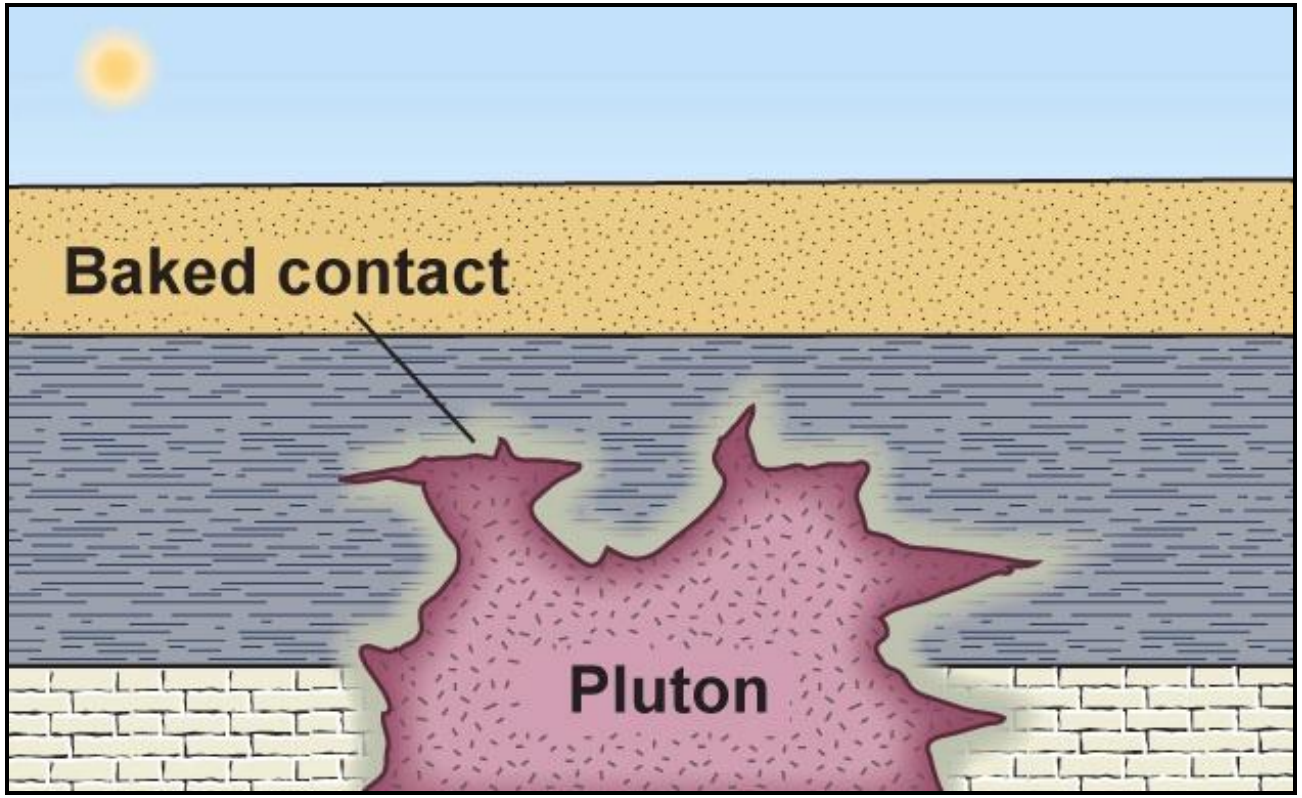

# Physical Principles

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



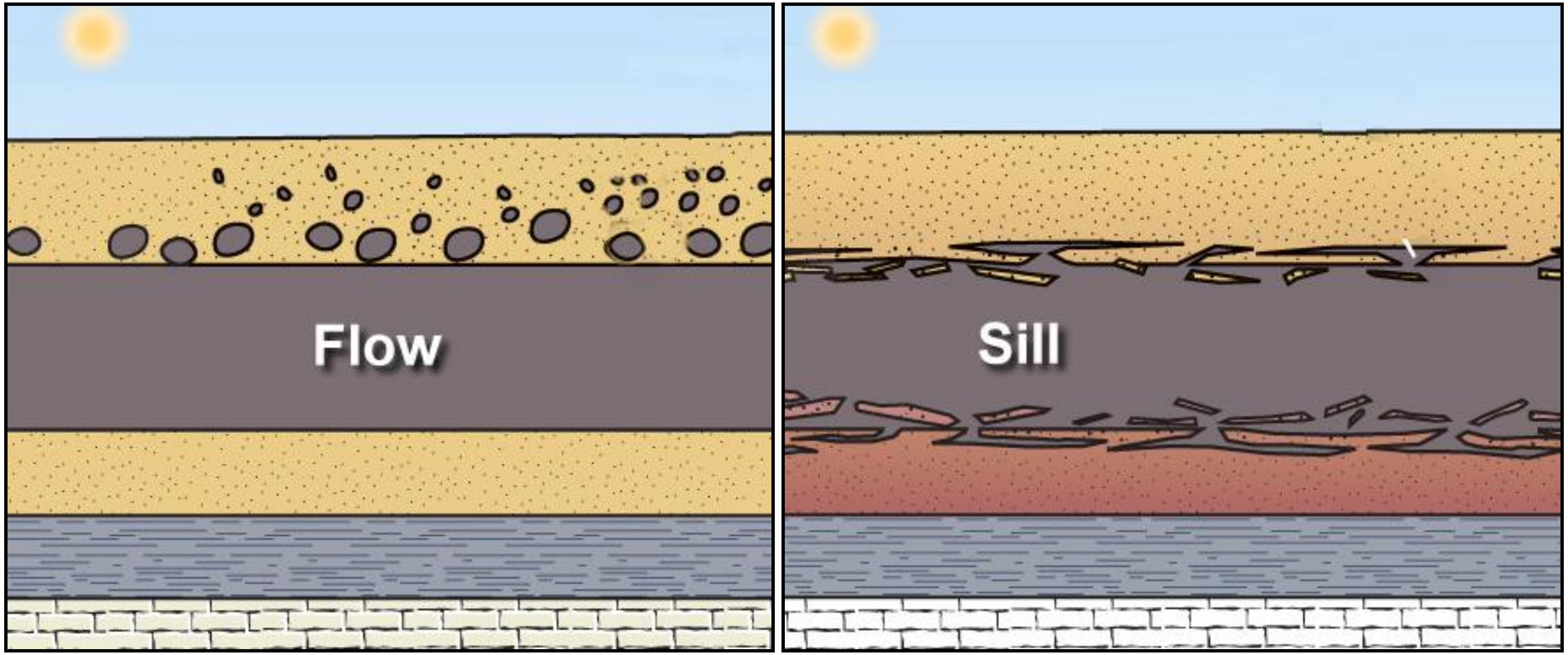
# Physical Principles

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



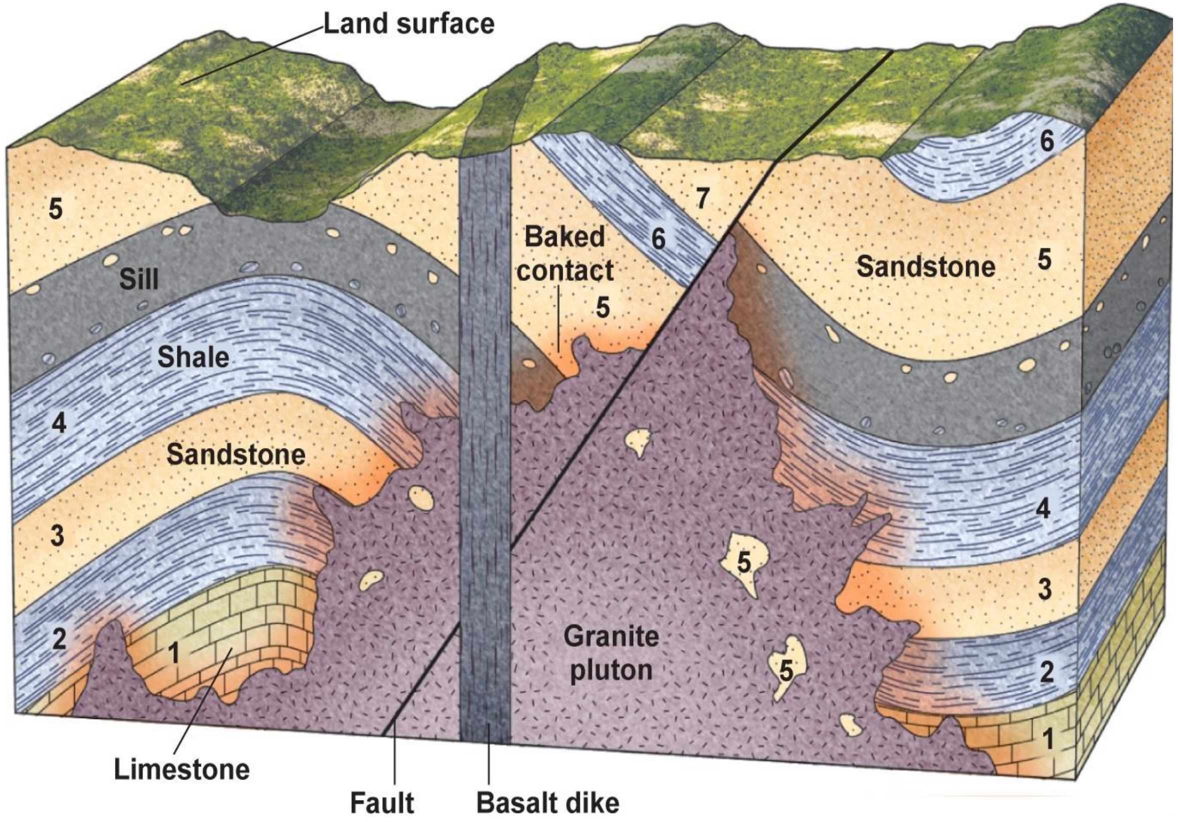
# Physical Principles

- 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.



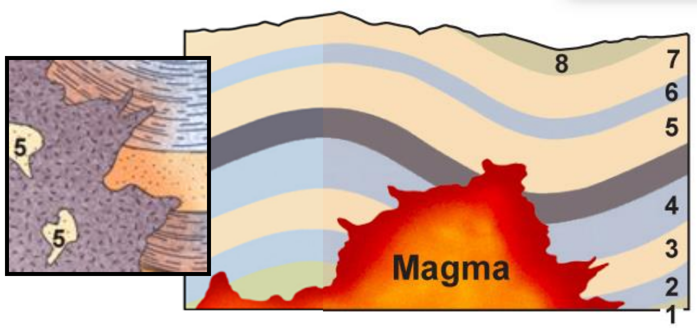
# Physical Principles

- 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!

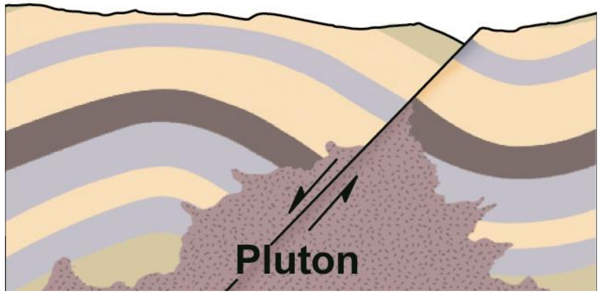


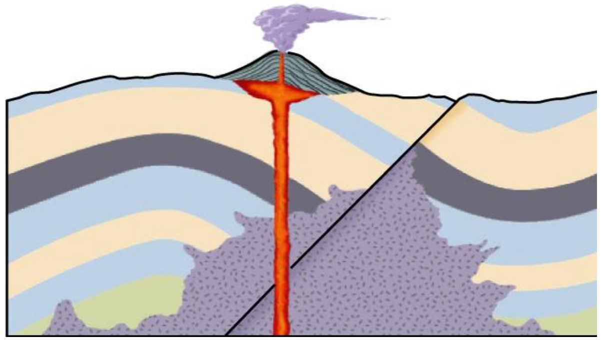
# Geologic History

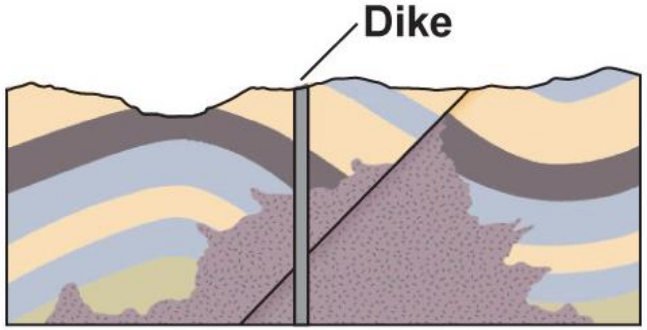
- A granitic pluton intrudes the folded sediments.
  - Granite cuts folded layers.
  - Baked contact caused by heat.
  - Xenoliths fall into magma.




- A fault cuts the granite and folded sediments.
- A basalt dike cuts across the block.
  - The dike cools and the surface volcano is eroded.

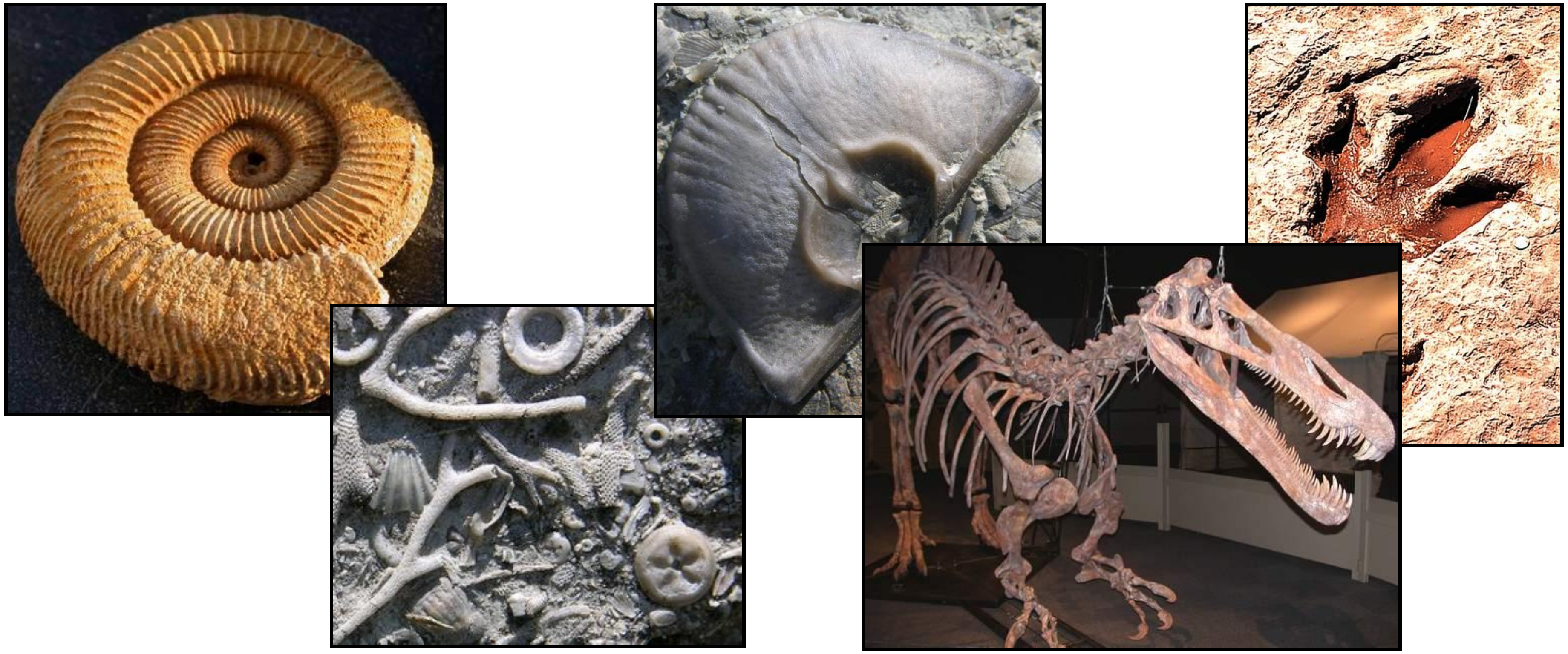




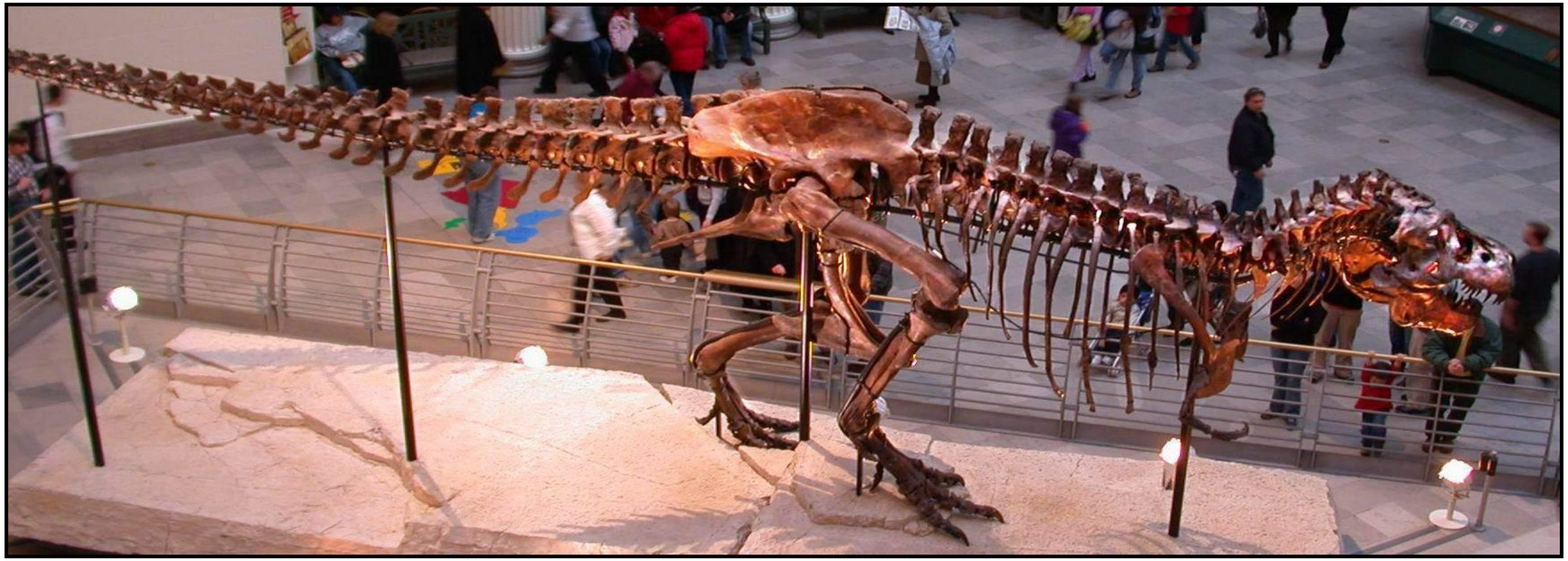
# The Principle of Fossil Succession

- 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 span.



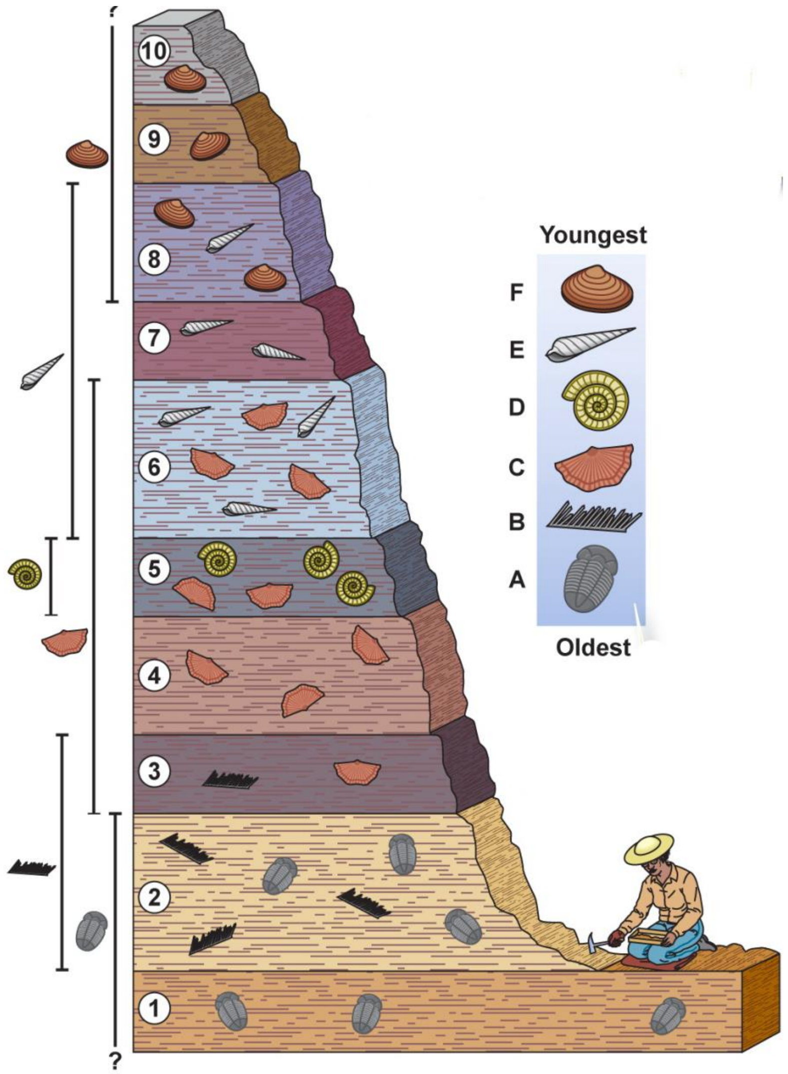
# The Principle of Fossil Succession

- Species evolve, exist for a time, and then disappear.
- First appearance, range, and extinction are used for dating.
- Global extinctions are caused by extraordinary events.
- Fossils succeed one another in a known order (evolution)
- 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**

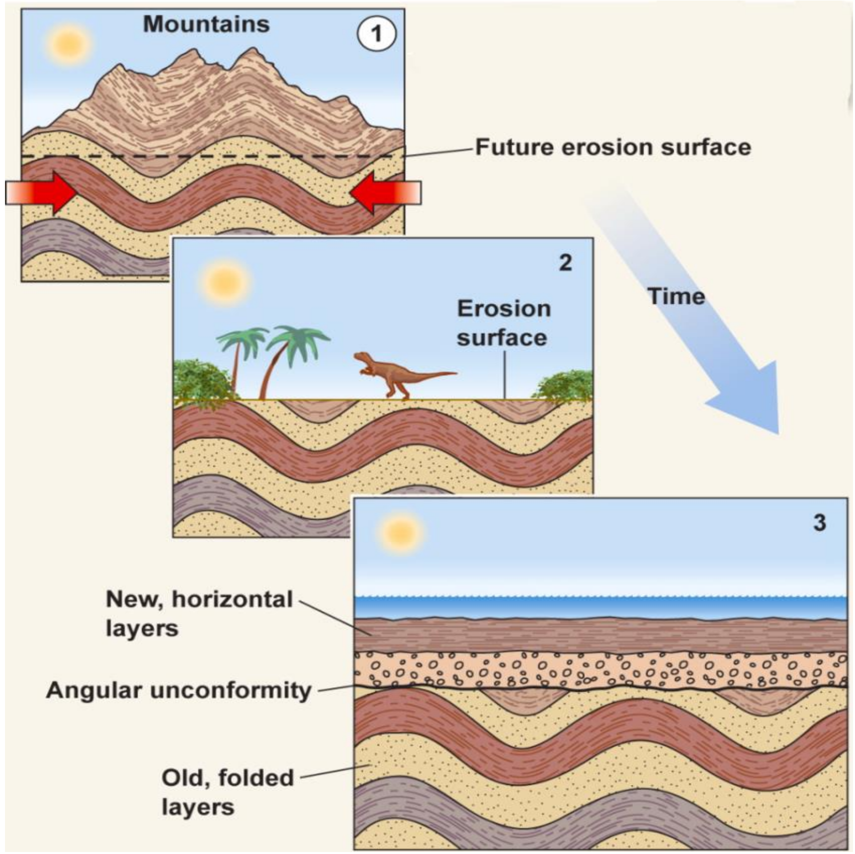


# Unconformities

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

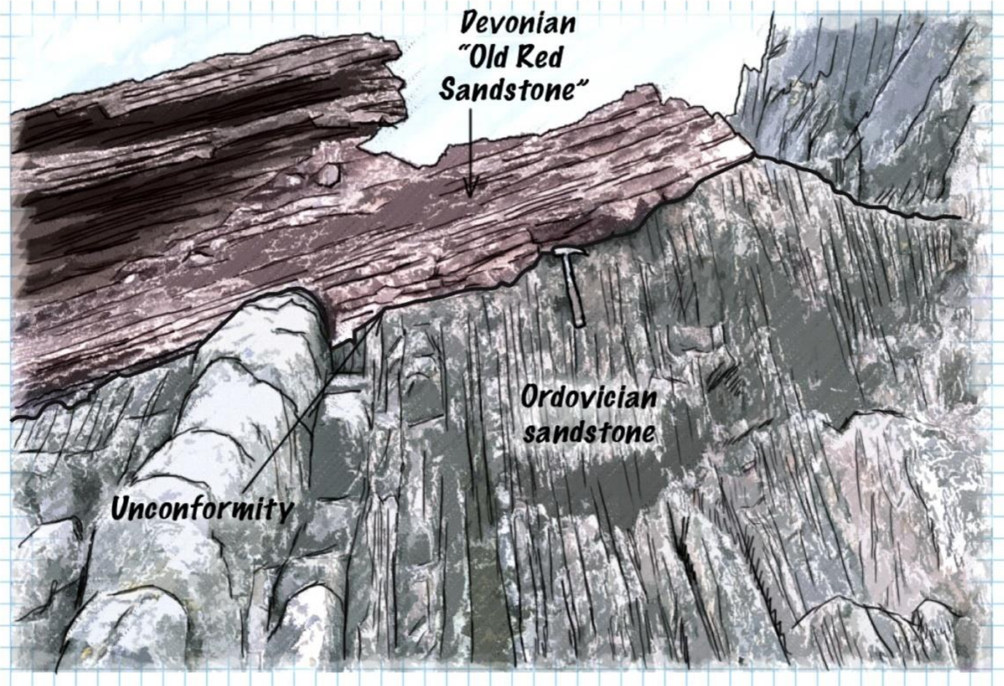
# Angular Unconformity

- 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

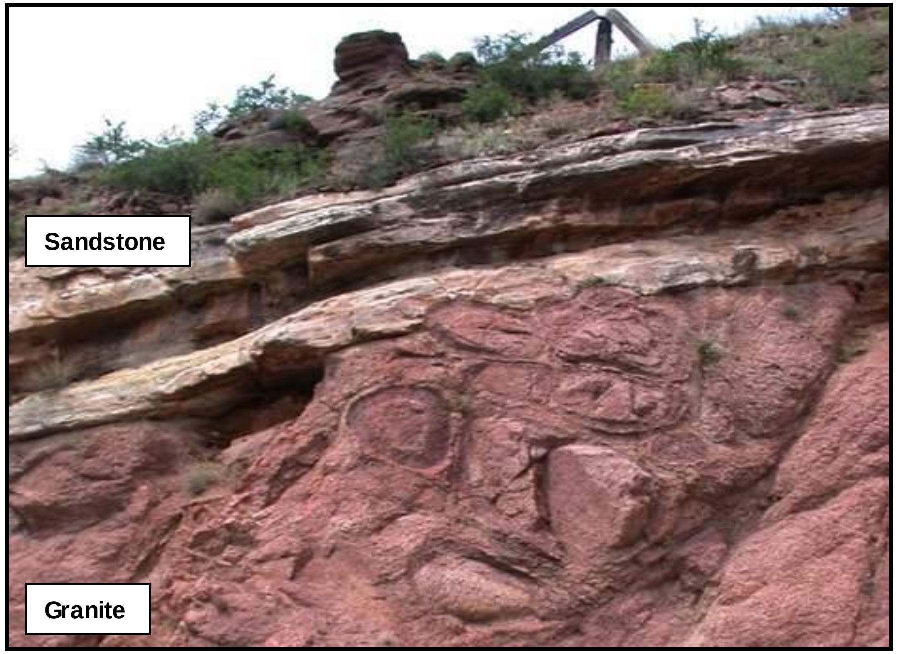
- **Hutton's Unconformity, Siccar Point, Scotland**
  - **A common destination for geologists**
    - **Vertical beds of Ordovician sandstone**
    - **Overlain by gently dipping Devonian redbeds**
    - **Missing time: ~ 50 million years**

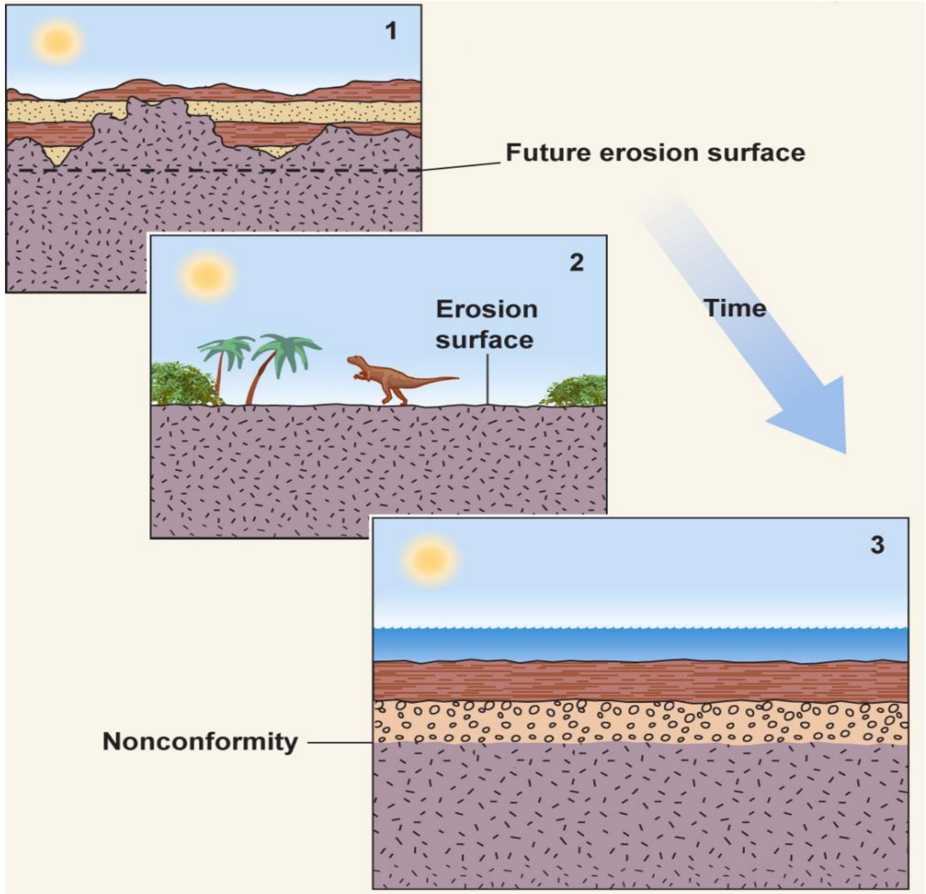



*What a Geologist Sees*

# Unconformities

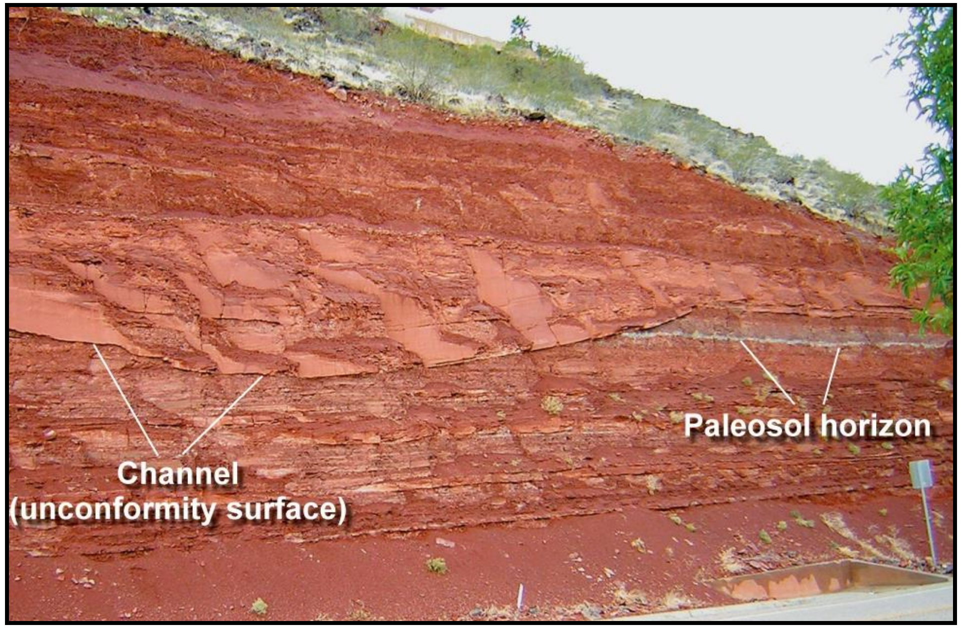
- Nonconformity—igneous/metamorphic rocks capped by sedimentary rocks
  - Igneous or metamorphic rocks were exposed by erosion.
  - Sediment was deposited on this eroded surface.

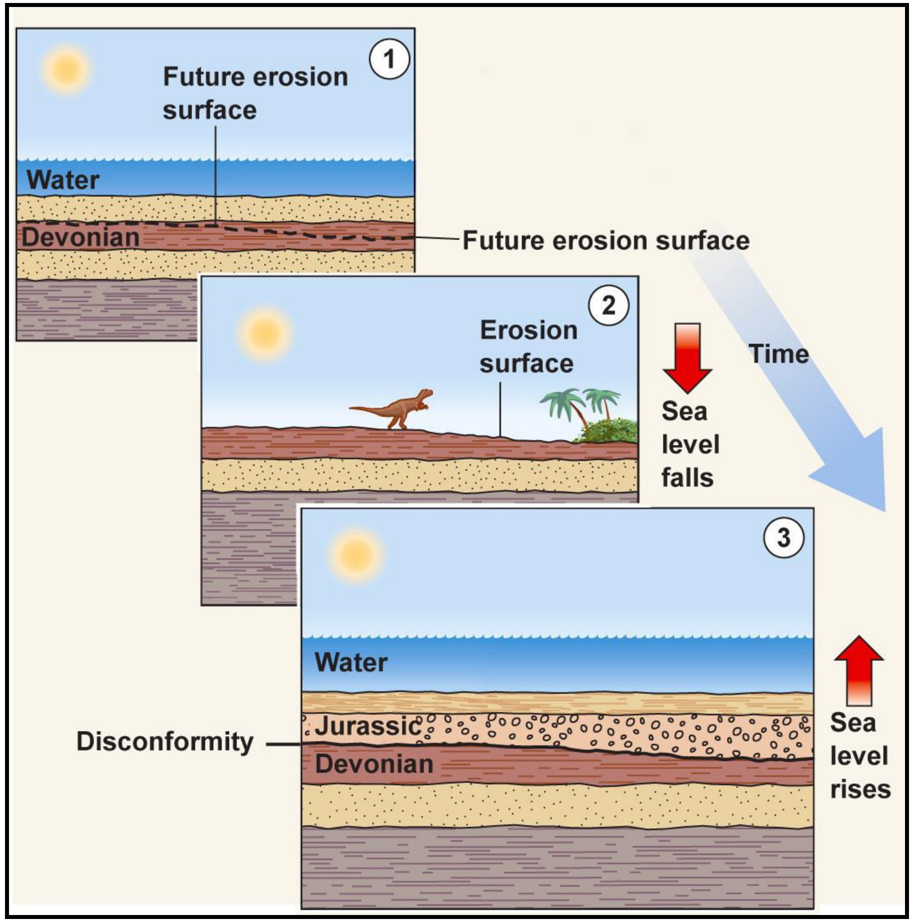


# Unconformities

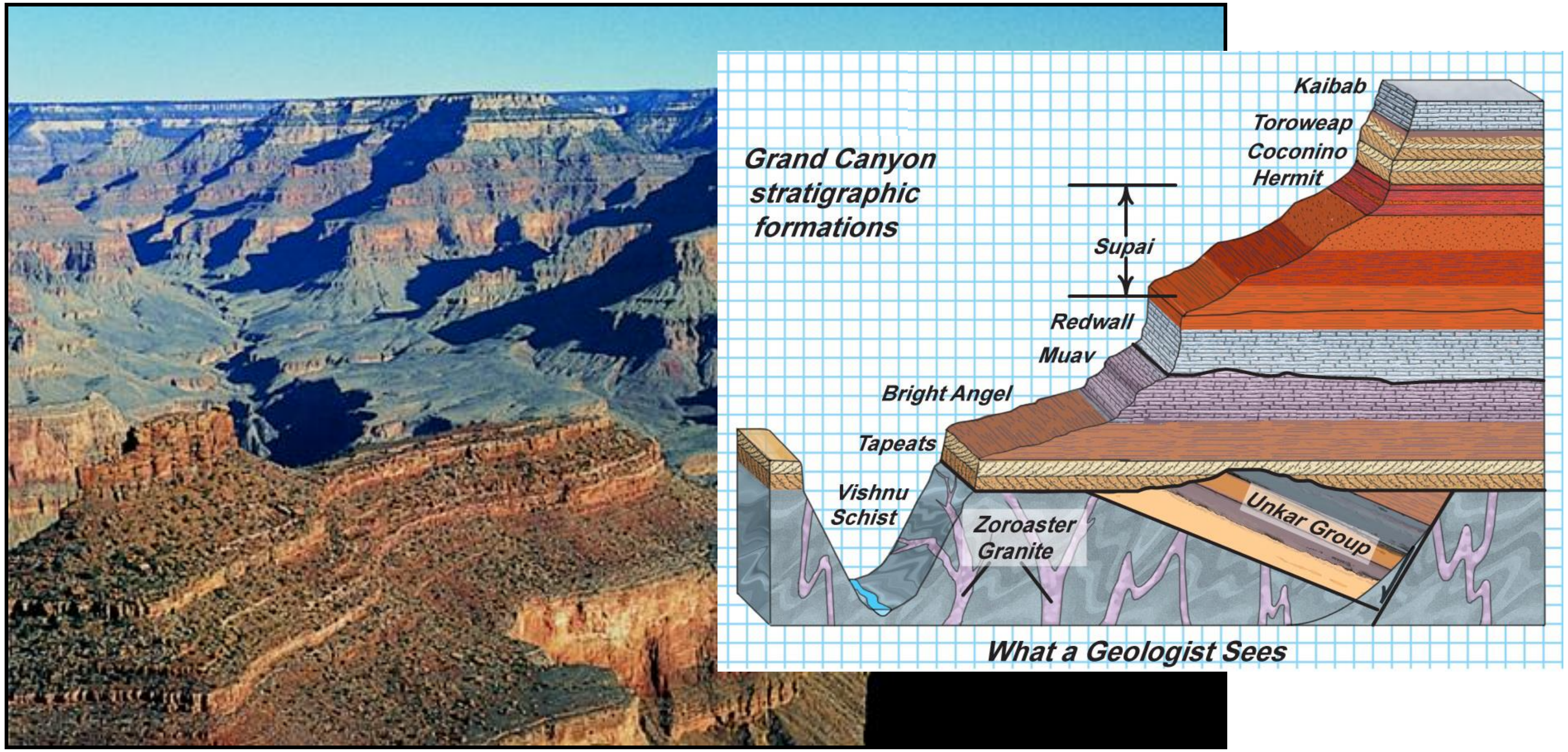
- Disconformity—parallel strata bounding nondeposition
  - Due to an interruption in sedimentation:
    - Pause in deposition
    - Sea level falls, then rises
    - Erosion
  - Often hard to recognize



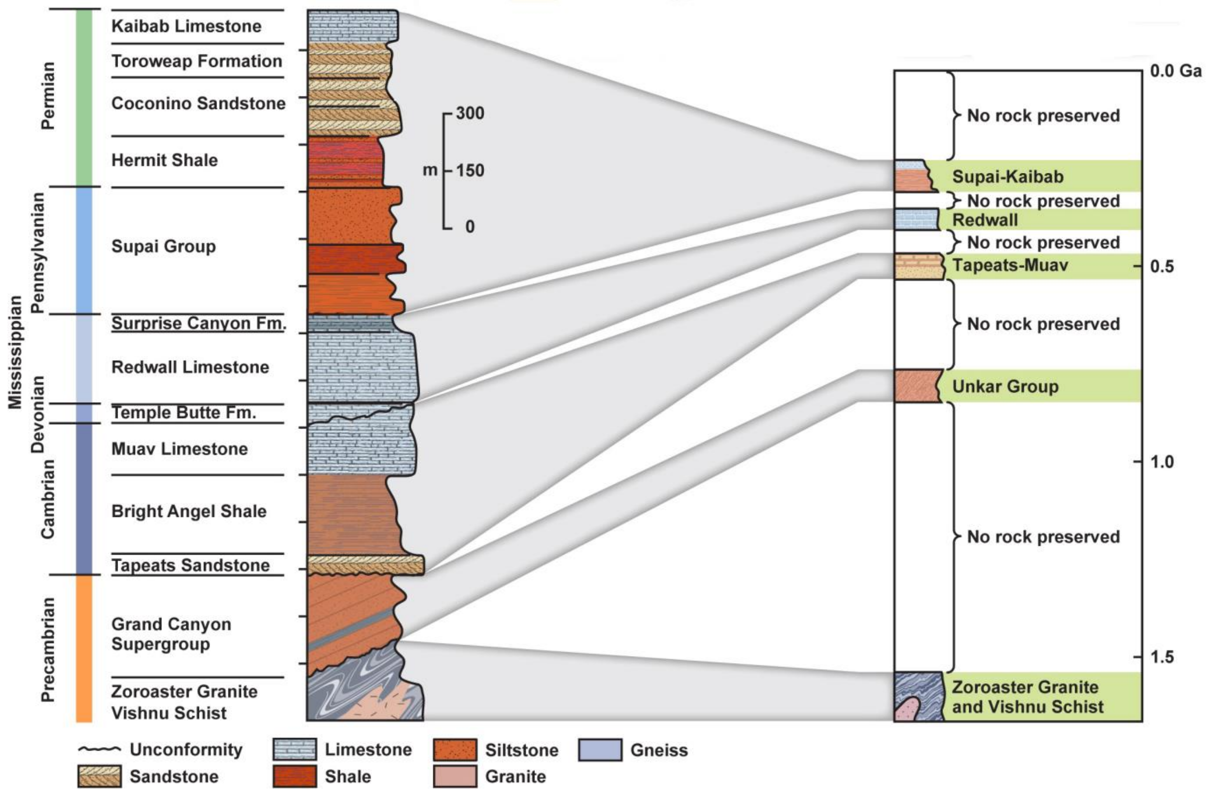
# Correlating Formations

- 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.



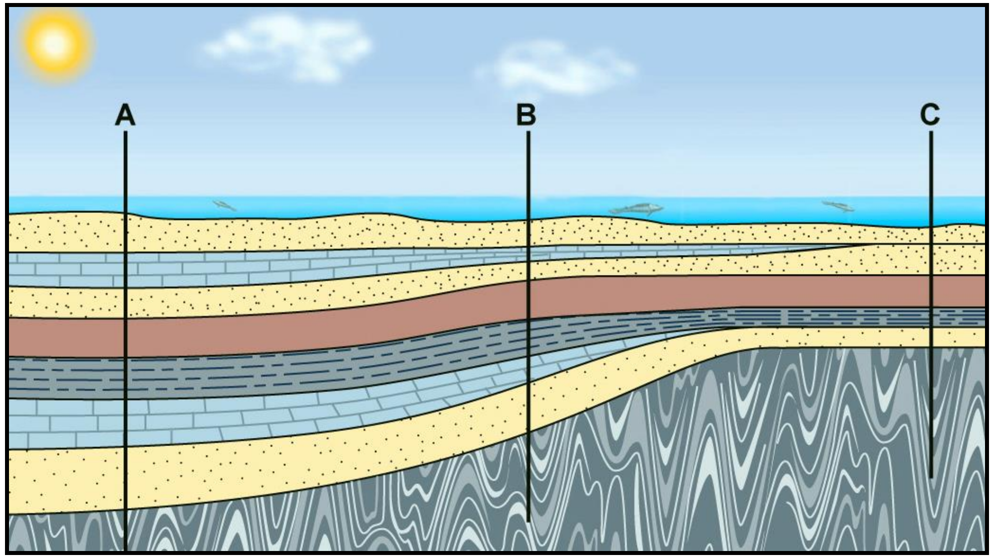
# Correlating Formations

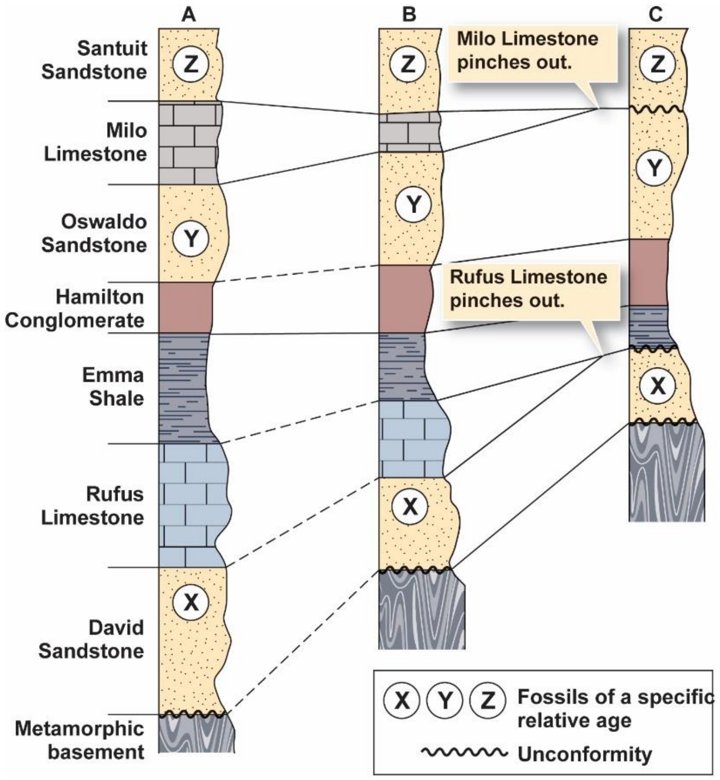
- A stratigraphic column describes the sequence of strata.
  - Formations can be traced over long distances.
  - Contacts define boundaries between formations or beds.
  - Several formations may be combined as a group.



# Stratigraphic Correlation

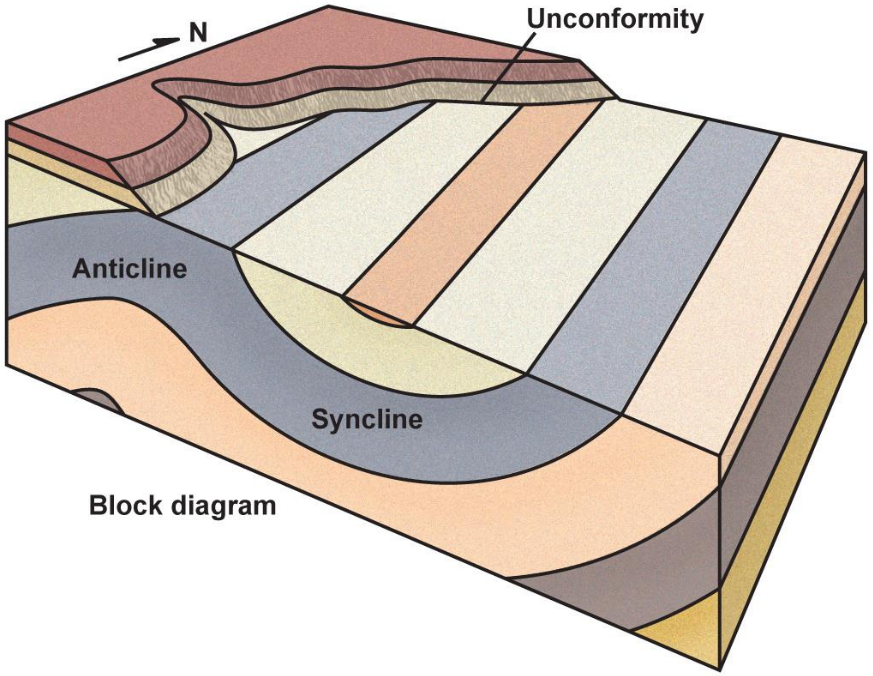
- Lithologic correlation (based on rock type) is regional.
  - Sequence is the relative order in which the rocks occur.
  - Marker beds have unique characteristics to aid correlation.
- Fossil correlation is based on fossils within the rocks.
  - Applicable to much broader areas.

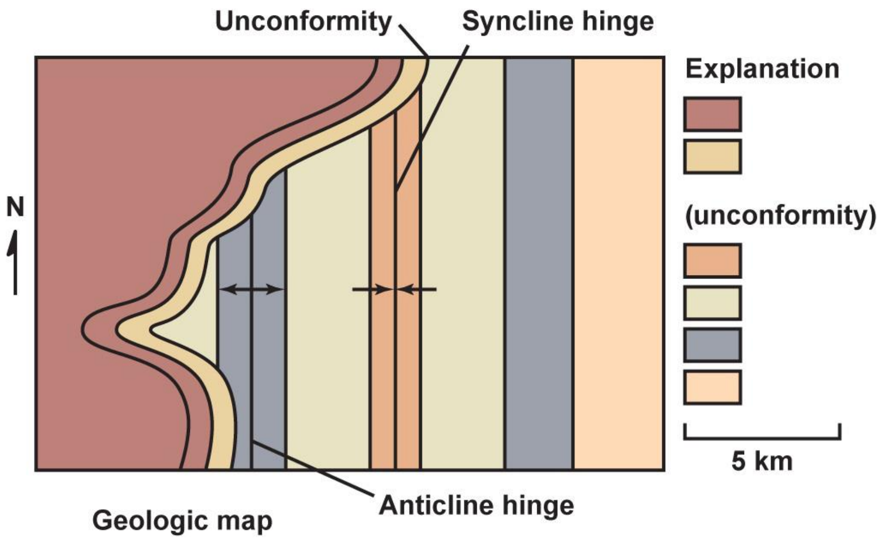


# Geologic Maps

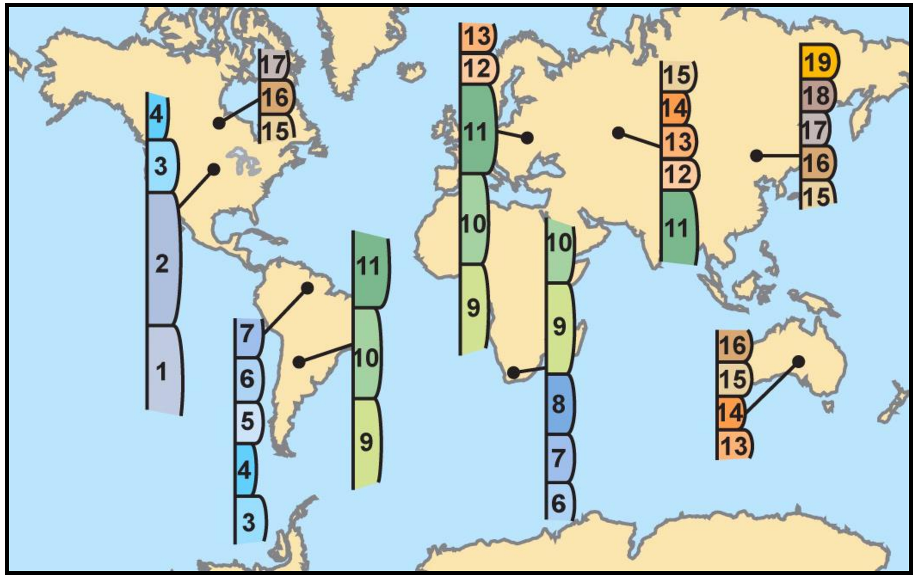
- William “Strata” Smith was the first to note that strata could be matched across distances.
  - Similar rock types in a similar order.
  - Rock layers contained the same distinctive fossils.
- After years of work, he made the first geologic map.

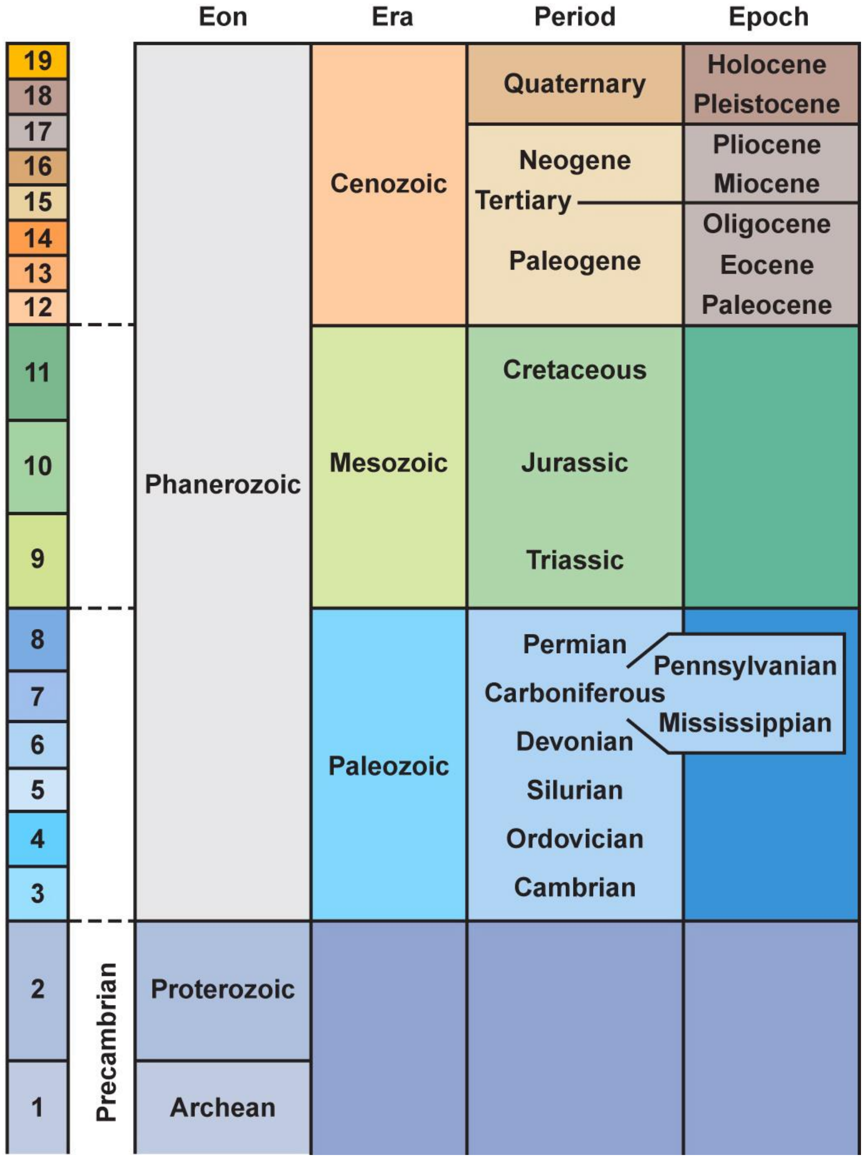


# The Geologic Column

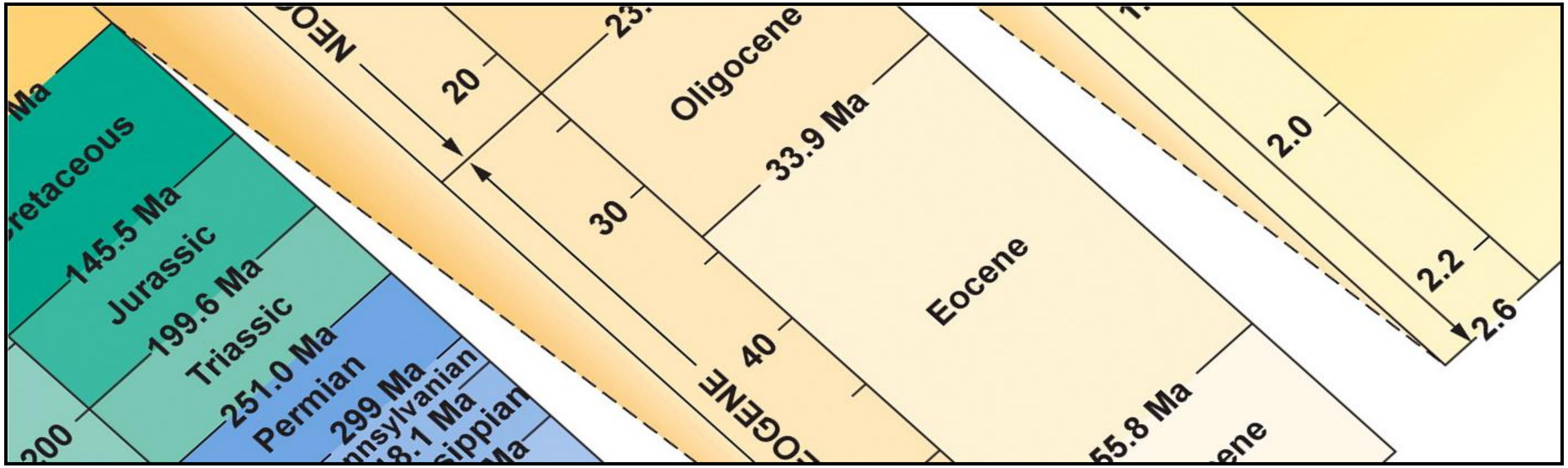
- A composite stratigraphic column can be constructed.
  - Assembled from incomplete sections across the globe.
  - It brackets almost all of Earth history.



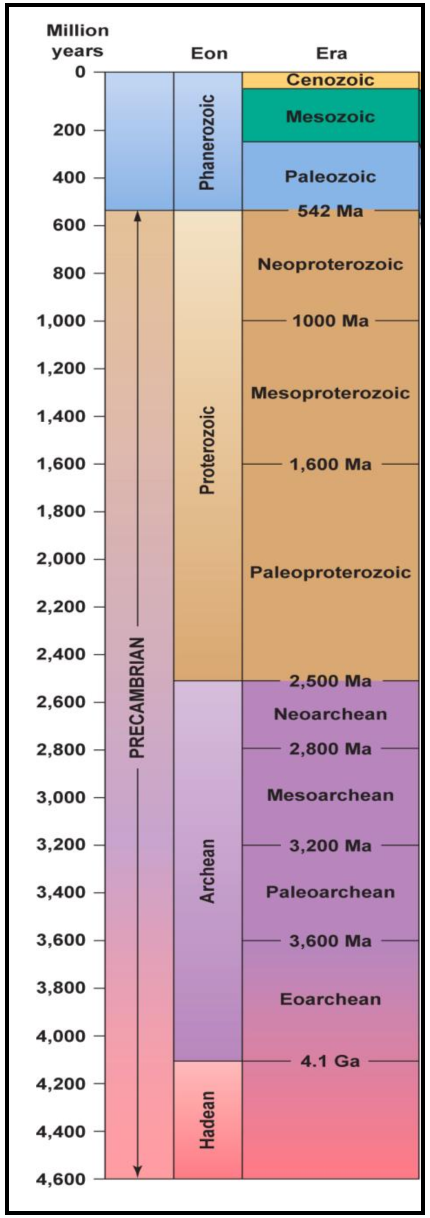
# The Geologic Column

- 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).

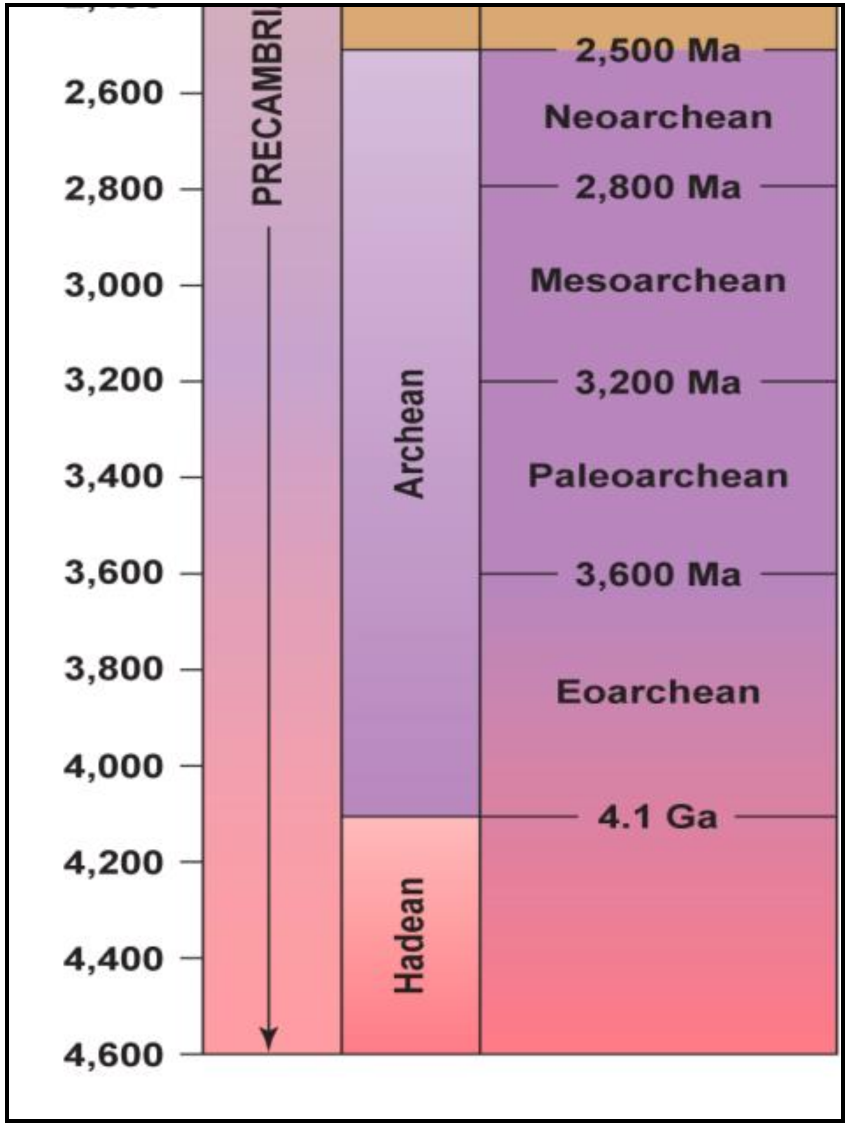


# The Geologic Time Scale

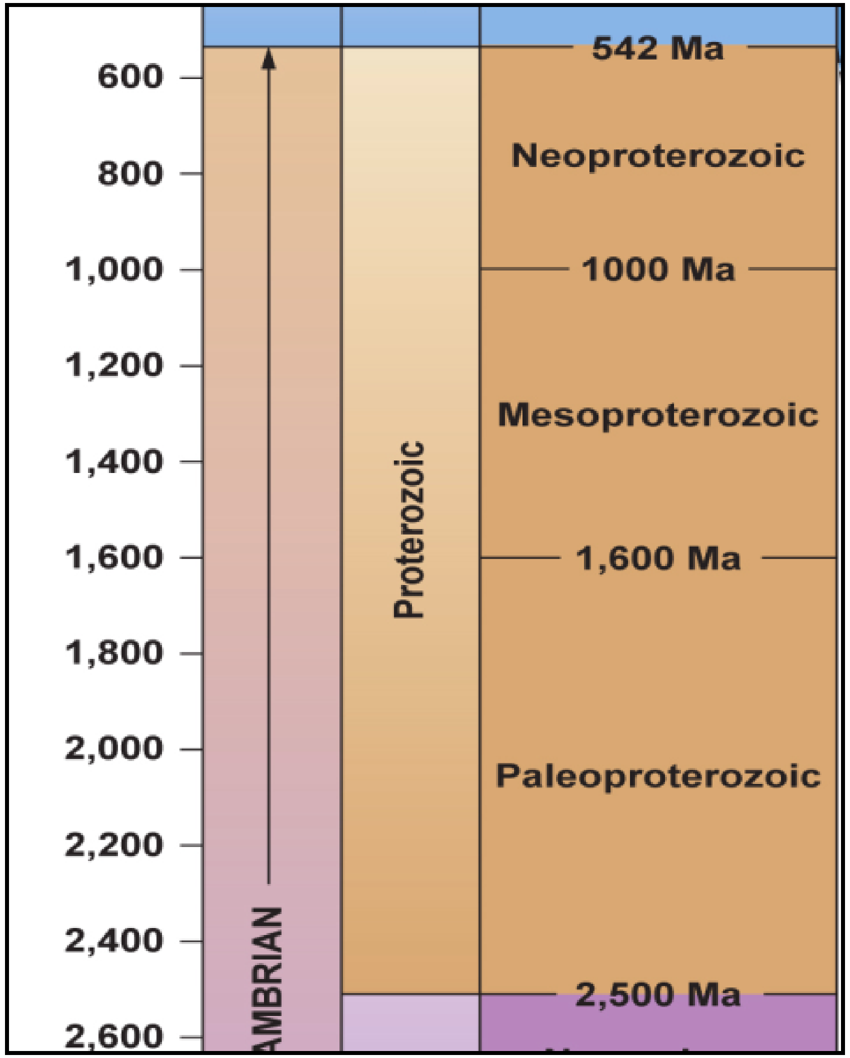
- Names of the Eons
  - Phanerozoic—”visible life” (542 to 0 Ma)
  - Proterozoic—“before life” (2.5 to 0.542 Ga)
  - Archean—“ancient” (4.2 to 2.5 Ga)
  - Hadean—“hell” (4.6 to 4.2 Ga)
- Names of the Eras
  - Cenozoic—“recent life”
  - Mesozoic—“middle life”
  - Paleozoic—“ancient life”



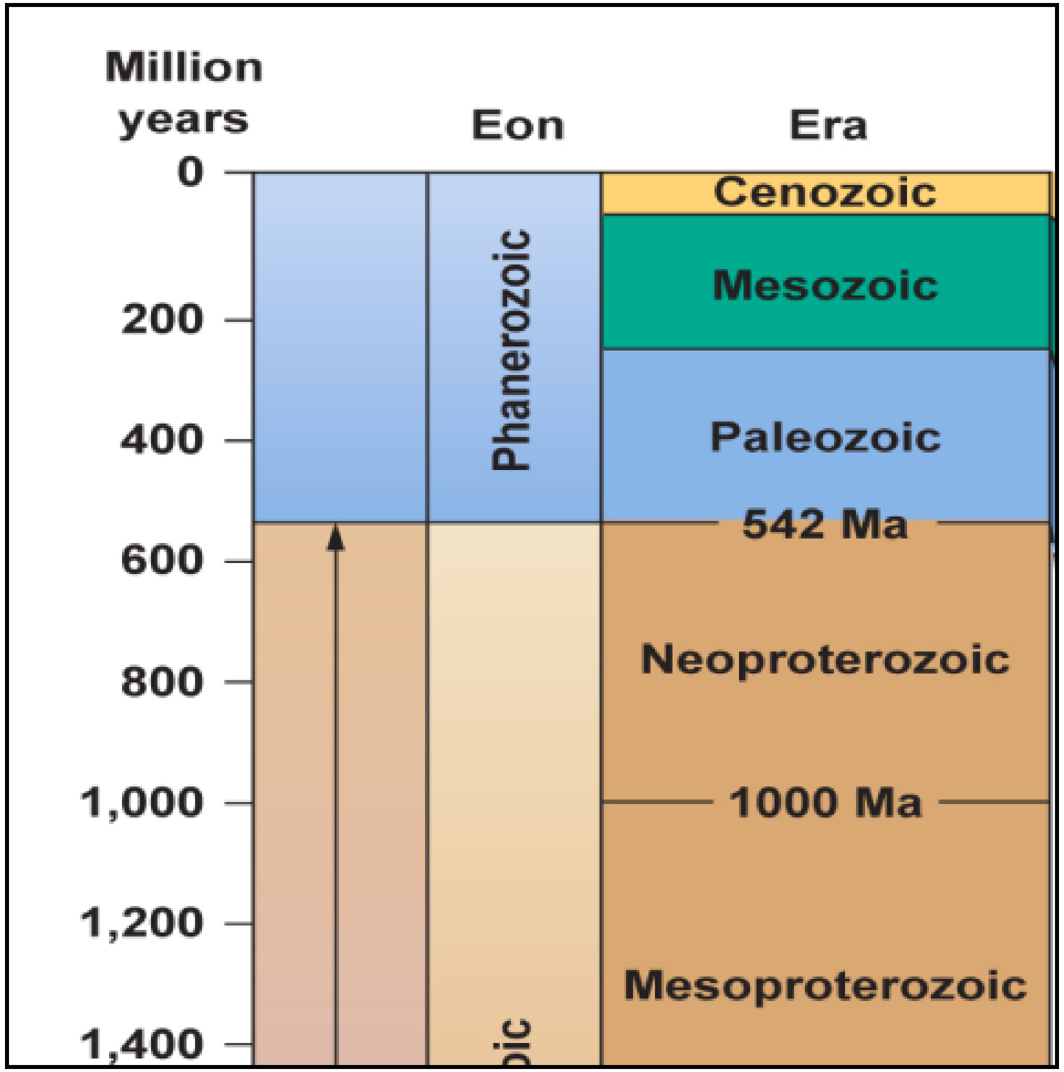
# Hadean, Archaen



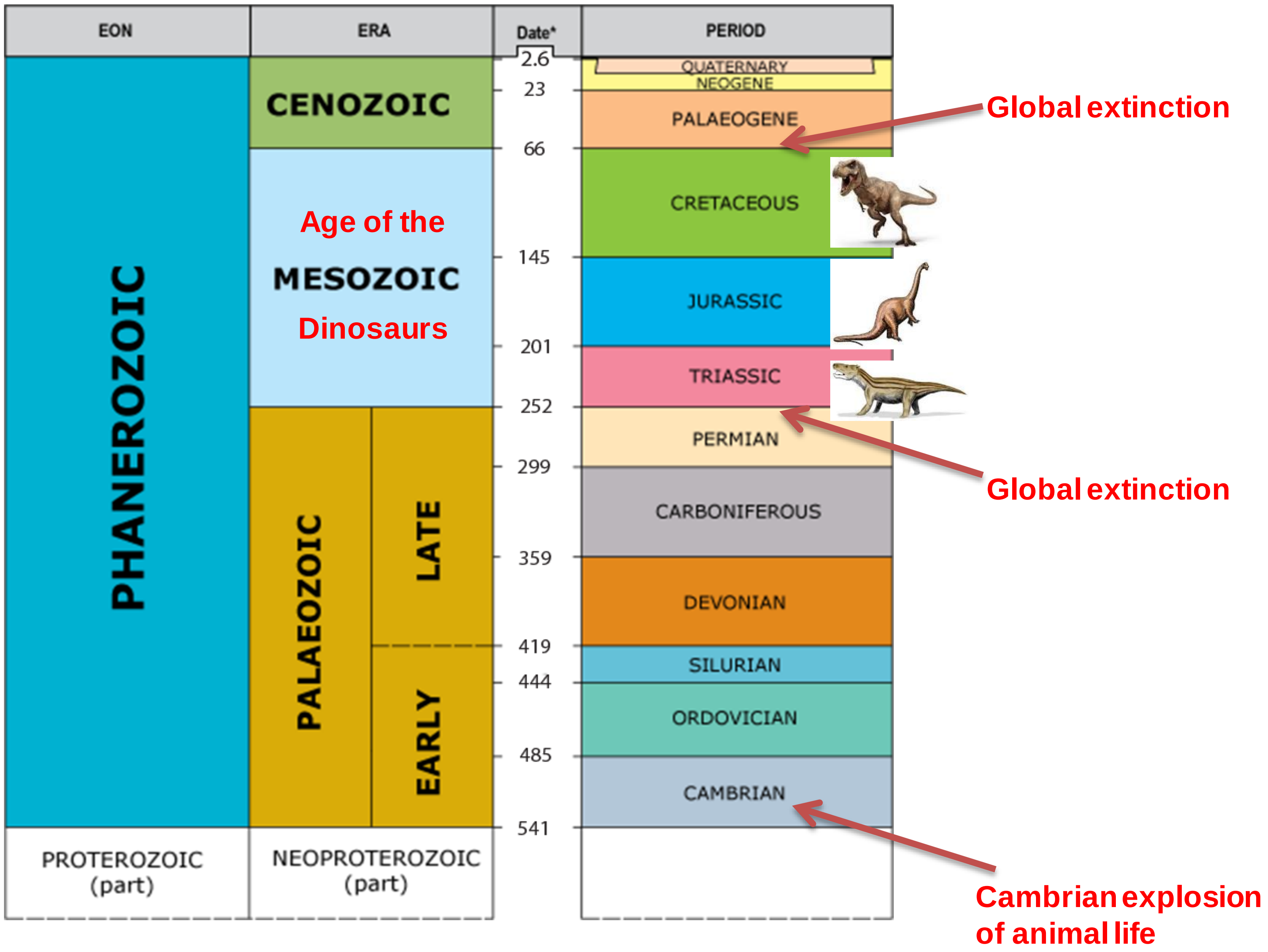
# Proterozoic



# Phanerozoic



# Phanerozoic

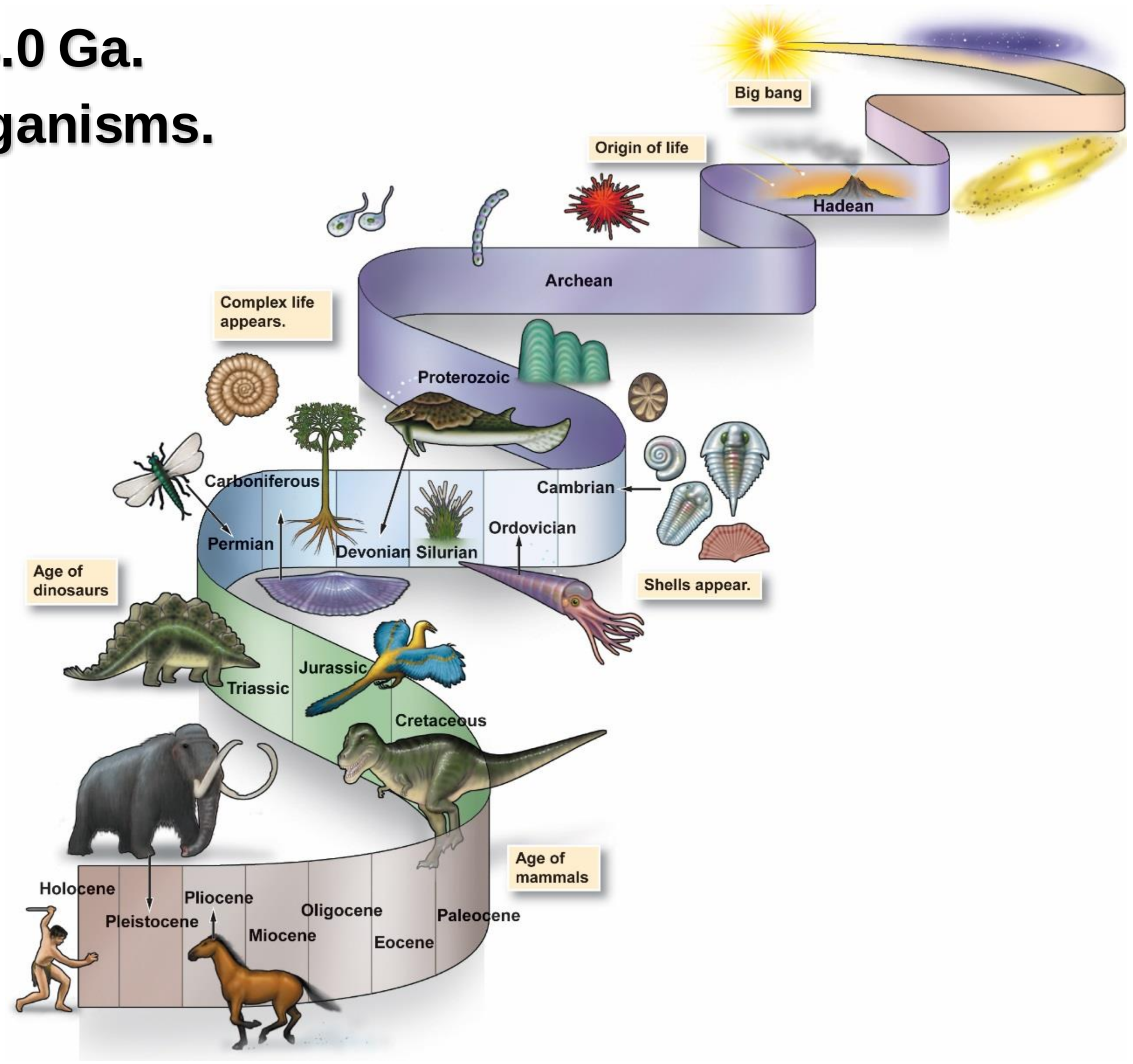


# Geologic Time

- 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)

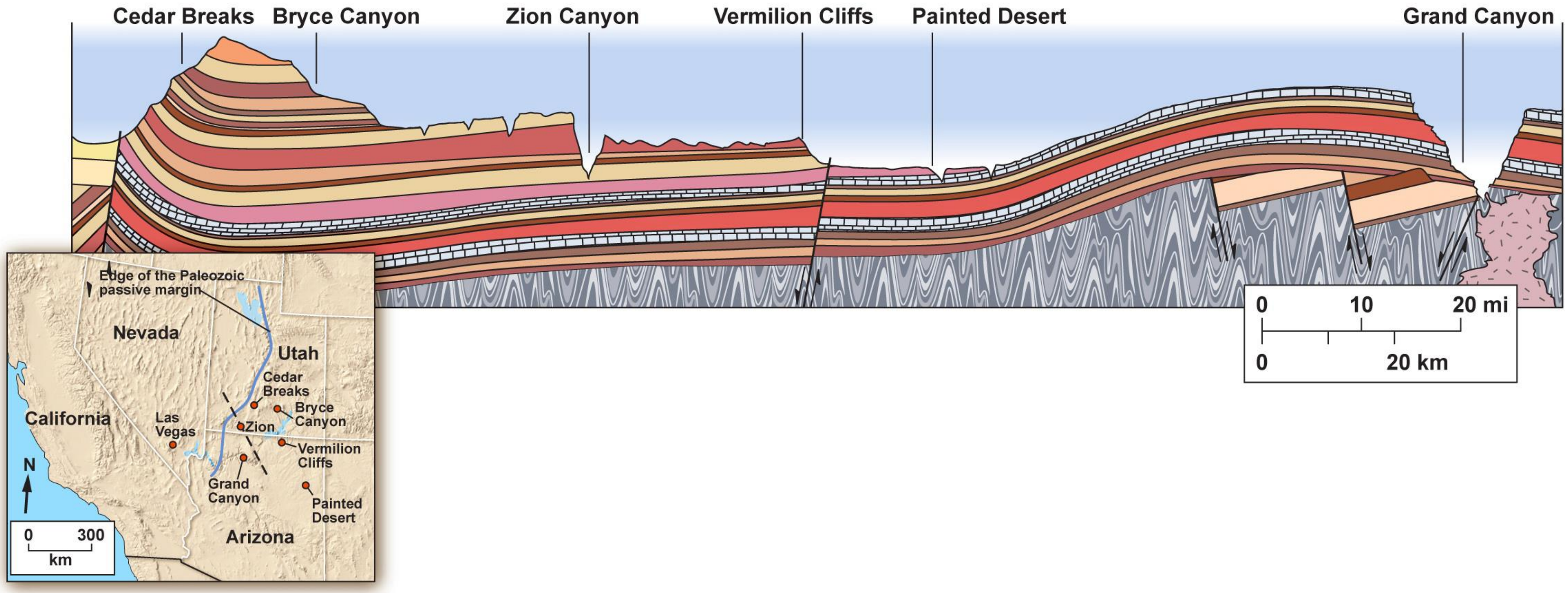
# Geologic Time and Life

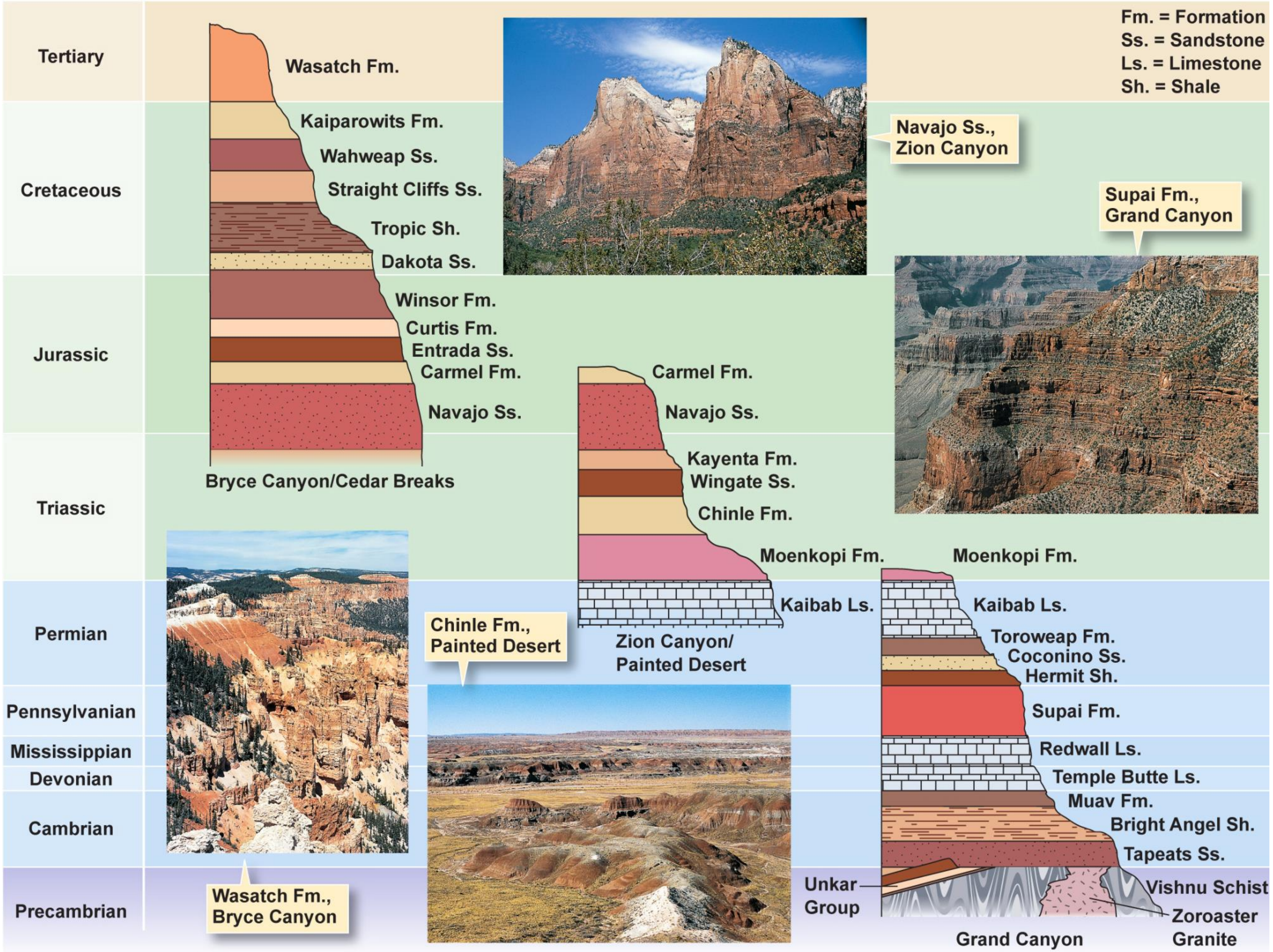
- Life first appeared on Earth by ~3.8 – 4.0 Ga.
- Early life consisted of single-celled organisms.
- $O_2$ from cyanobacteria built up in atmosphere by 2 Ga.
- Around 700 Ma, multicellular life evolved.
- Around 542 Ma marks the first appearance of invertebrates.
  - Shells increased fossil preservation.
  - Life diversified rapidly as the "Cambrian Explosion."



# 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.





Fm. = Formation
Ss. = Sandstone
Ls. = Limestone
Sh. = Shale
Tertiary
Cretaceous
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Devonian
Cambrian
Precambrian
Wasatch Fm.
Kaiparowits Fm.
Wahweap Ss.
Straight Cliffs Ss.
Tropic Sh.
Dakota Ss.
Winsor Fm.
Curtis Fm.
Entrada Ss.
Carmel Fm.
Navajo Ss.
Bryce Canyon/Cedar Breaks
Navajo Ss.,
Zion Canyon
Supai Fm.,
Grand Canyon
Carmel Fm.
Navajo Ss.
Kayenta Fm.
Wingate Ss.
Chinle Fm.
Moenkopi Fm.
Kaibab Ls.
Zion Canyon/
Painted Desert
Chinle Fm.,
Painted Desert
Moenkopi Fm.
Kaibab Ls.
Toroweap Fm.
Coconino Ss.
Hermit Sh.
Supai Fm.
Redwall Ls.
Temple Butte Ls.
Muav Fm.
Bright Angel Sh.
Tapeats Ss.
Unkar
Group
Vishnu Schist
Zoroaster
Granite
Grand Canyon
Wasatch Fm.,
Bryce Canyon

# 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

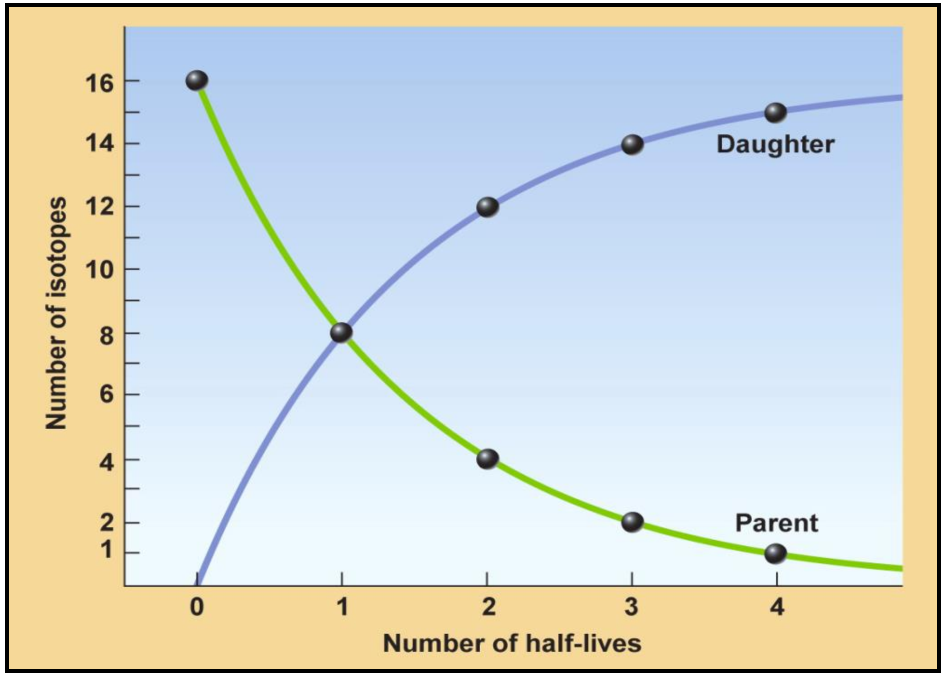
- Isotopes—elements that have varying numbers of neutrons
- Isotopes have similar but different mass numbers.
  - Stable—isotopes that never change (i.e., $^{13}C$)
  - Radioactive—isotopes that spontaneously decay (i.e., $^{14}C$)

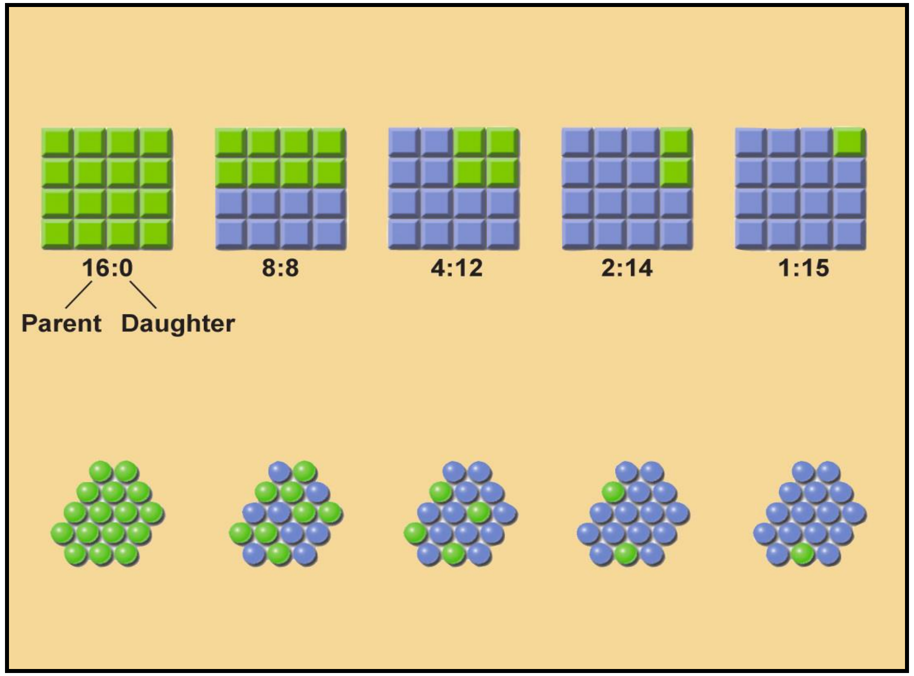
# Radioactive Decay

- 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."



# 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.

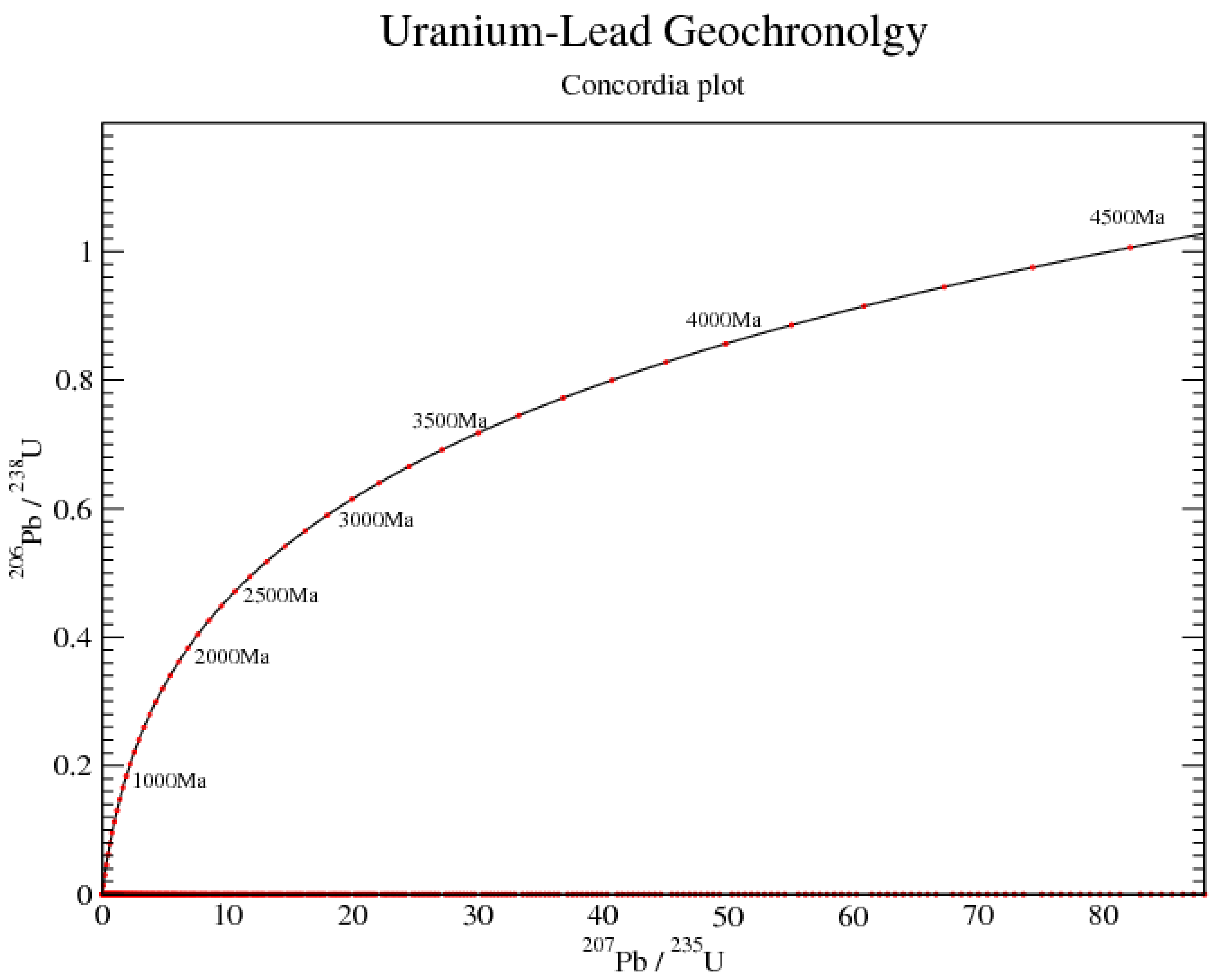
**Table 10.1** Isotopes Used in the Isotopic Dating of Rocks

| Parent → Daughter | Half-Life (years) | Minerals Containing the Isotopes |
|---|---|---|
| $^{147}Sm \rightarrow {}^{143}Nd$ | 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

# Uranium-Lead dating

- The most tru ... nerals is the U-Pb seque ...
- $^{235}$U decays ... ter products are $^{207}$Pb an ...
- Chemically, ... ughters behave alm ... n being the preferred) si ...
- We have, th ... e checks the other.
- By forming ... ounts of each isotope mea ... against the other, the C ...

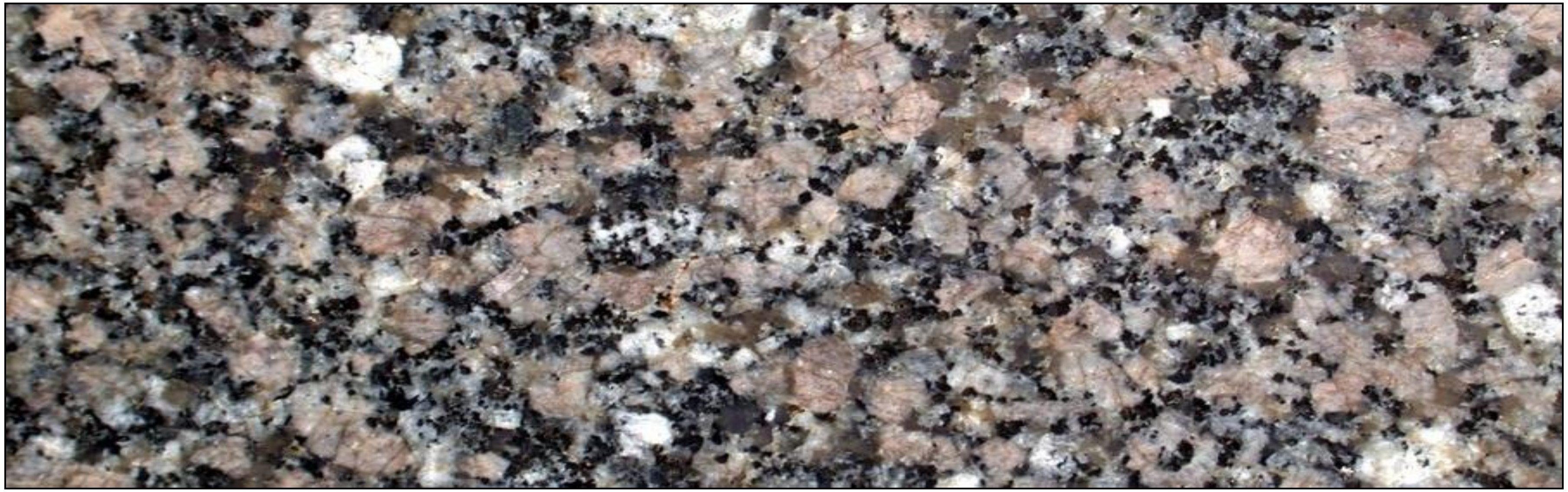


# Isotopic Dating

- 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.

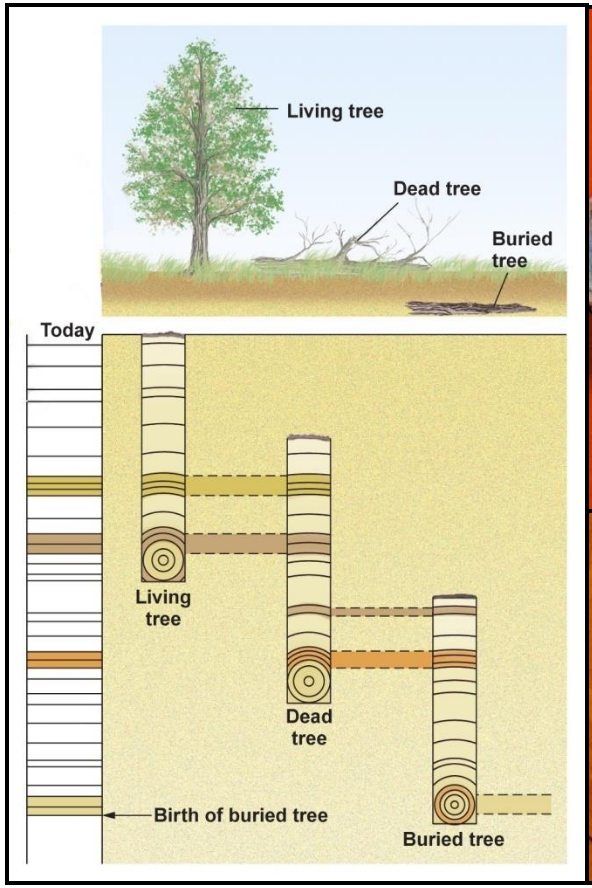
# What Does an Isotopic Date Mean?

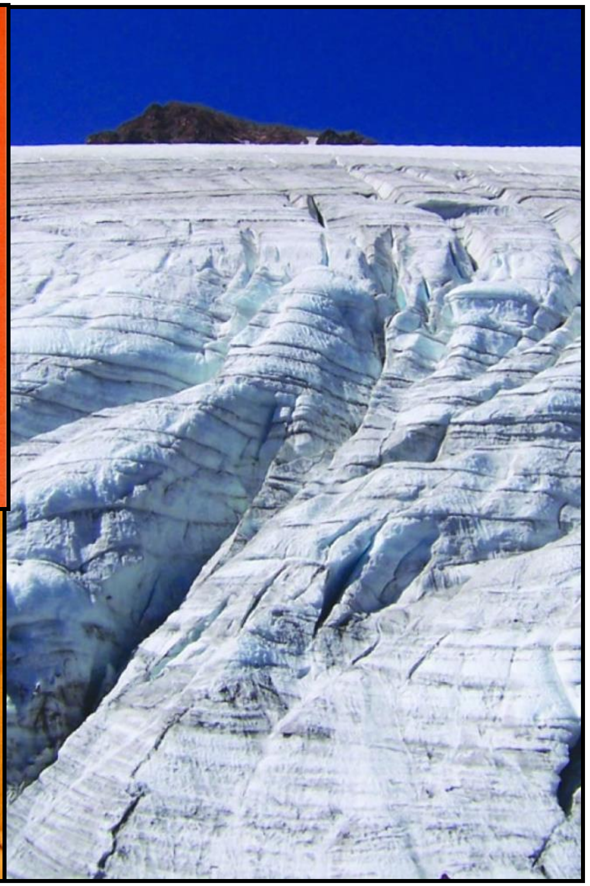
- Isotopic dating gives the time a mineral cooled below its "closure temperature."
  - Cooling of magma or lava to solid, cool igneous rock
  - Metamorphic rock temperatures drop below closure temp
- Sedimentary rocks cannot be directly dated but minerals within sedimentary rocks can be… for example that oldest zircon from the Jack Hills.



# Other Numerical Ages

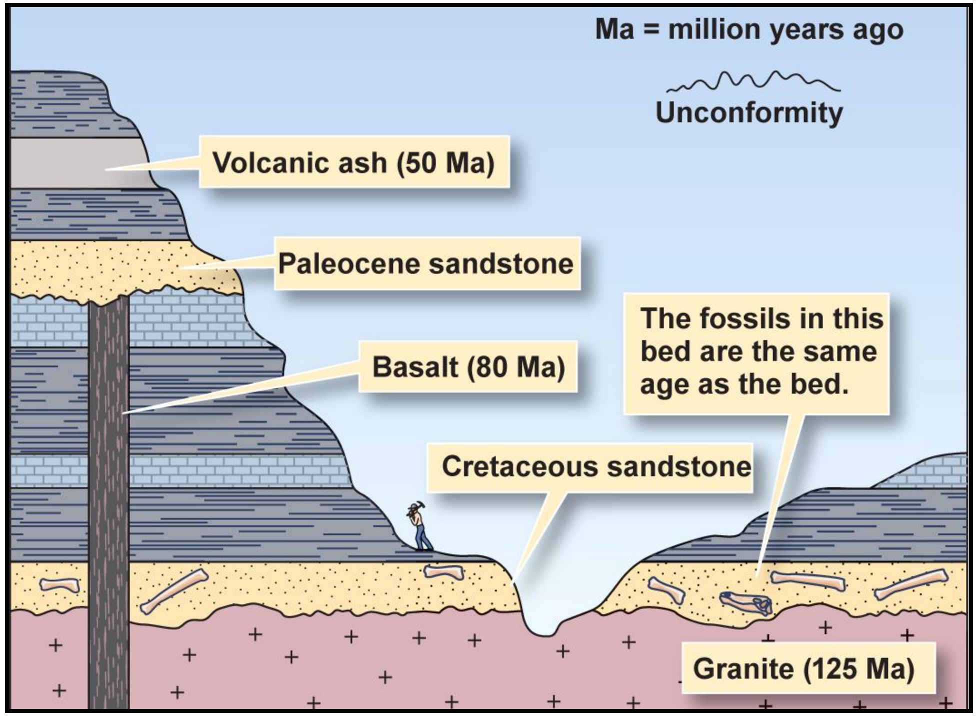
- Numerical ages are possible without isotopes.
  - Growth rings—annual layers from trees or shells
  - Rhythmic layering—annual layers in sediments or ice

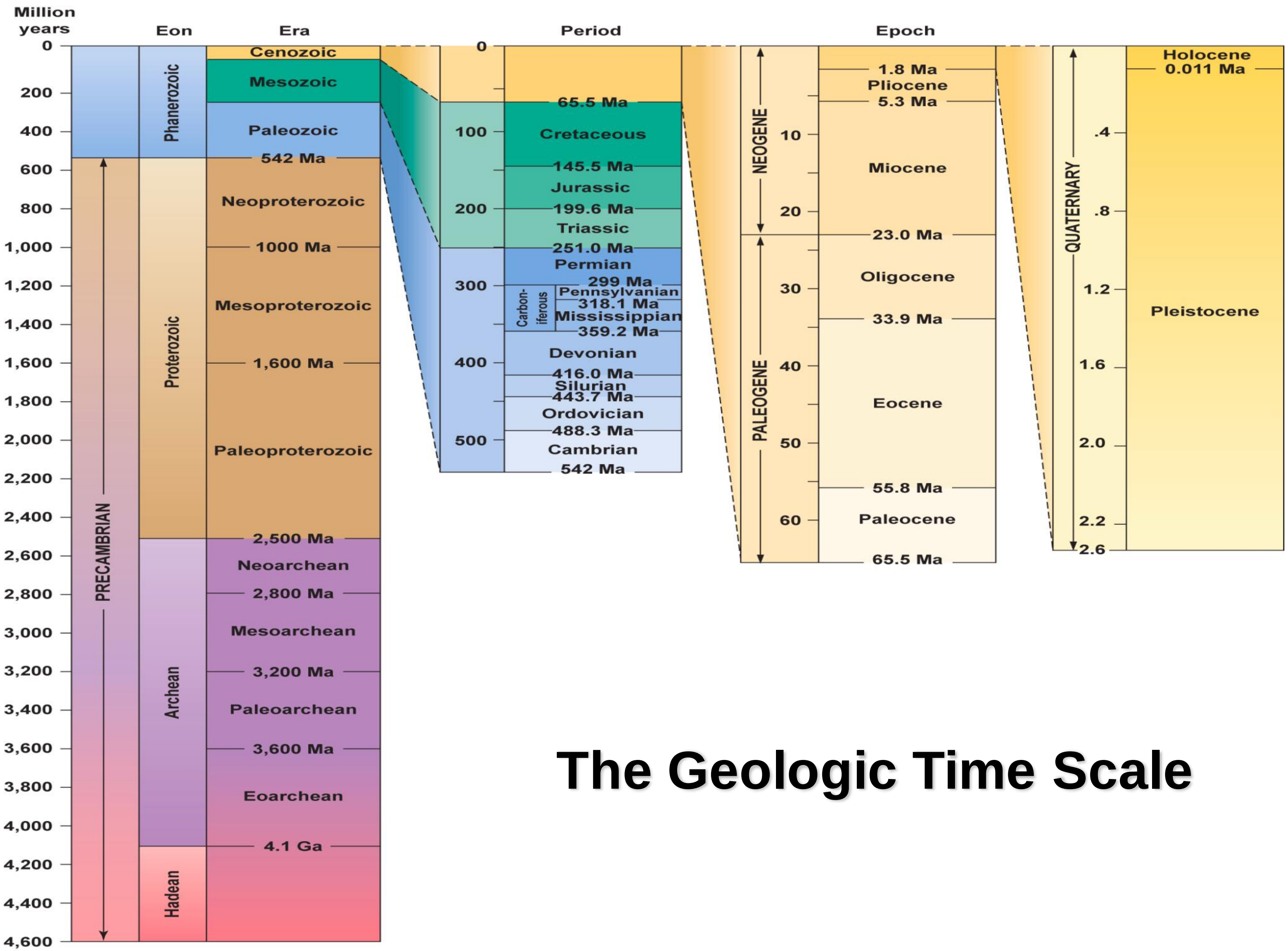


# Numerical Ages and Geologic Time

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






# The Geologic Time Scale

# 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 Acasta Gneiss dates to 4.03 Ga. Nuvvuaggituq faux amphibolites to 4.28Ga (?).
- 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