Geological time, historical geology, and determining geological ages

- **Relative age dates – placing rocks and events in their proper sequence of formation**
- **Absolute age date (Numerical dates) – specifying the actual number of years that have passed since an event occurred**

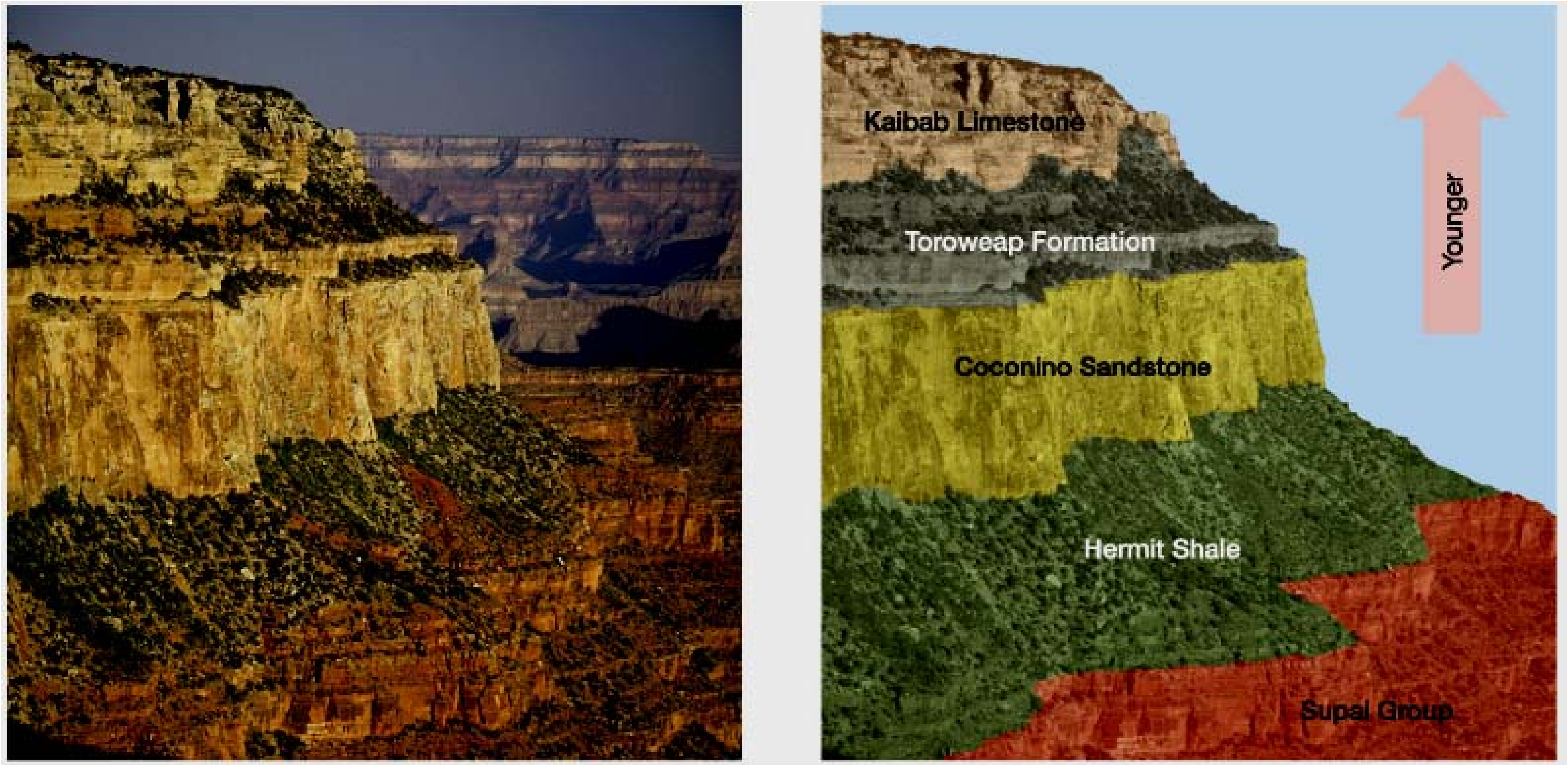
Principles of relative dating

- Principle of superposition
- Principle of original horizontality
- Principle of faunal succession
- Law of correlation
- Cross-cutting relationships
- Inclusions
- Unconformities
- Index fossils

Law of superposition

- In an undeformed sequence of sedimentary rocks (or layered igneous rocks), the oldest rocks are on the bottom

Grand Canyon

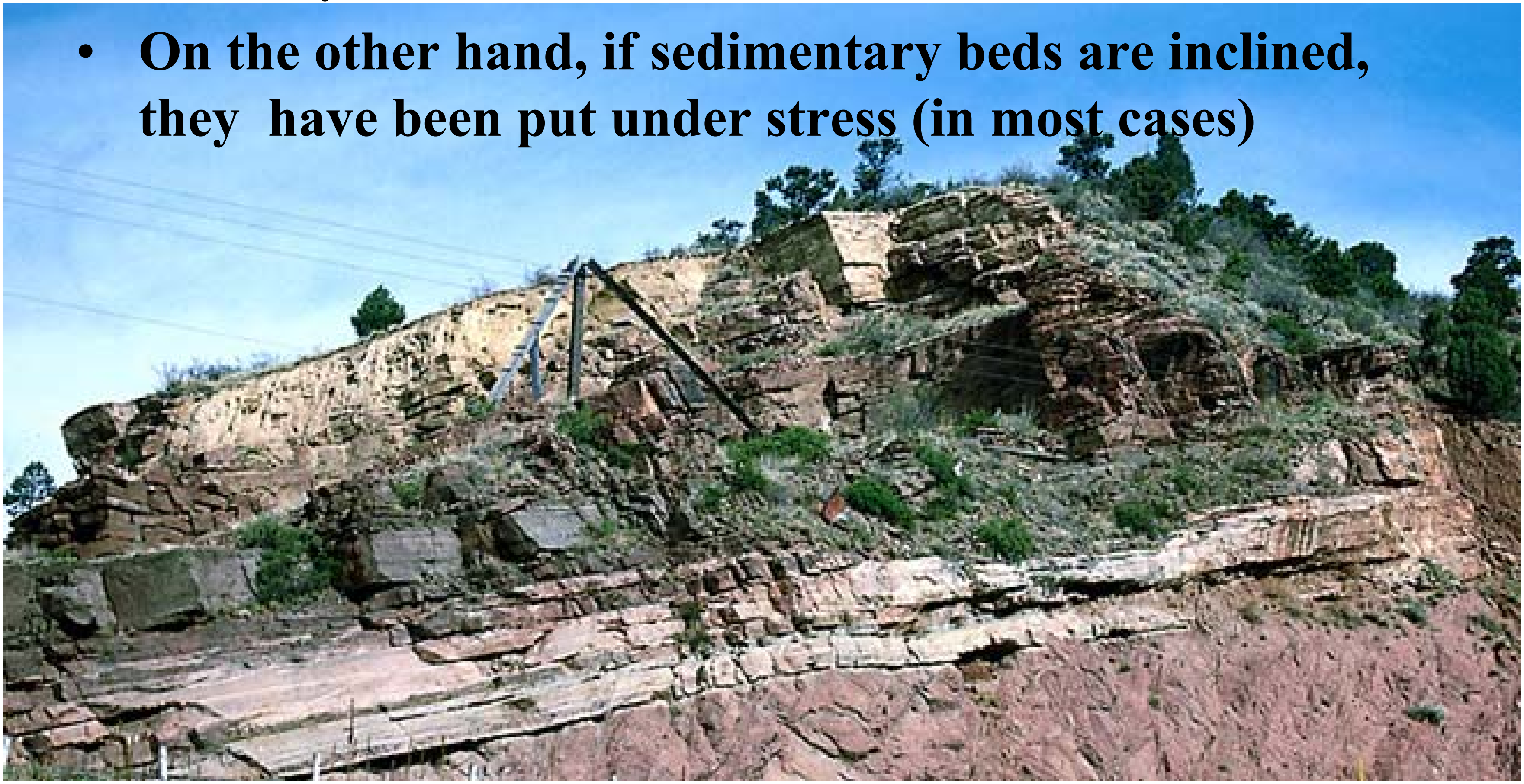


A.

B.

Principle of original horizontality

- Layers of sediment are generally deposited in a horizontal position
- Rock layers that are flat have not been disturbed
- On the other hand, if sedimentary beds are inclined, they have been put under stress (in most cases)

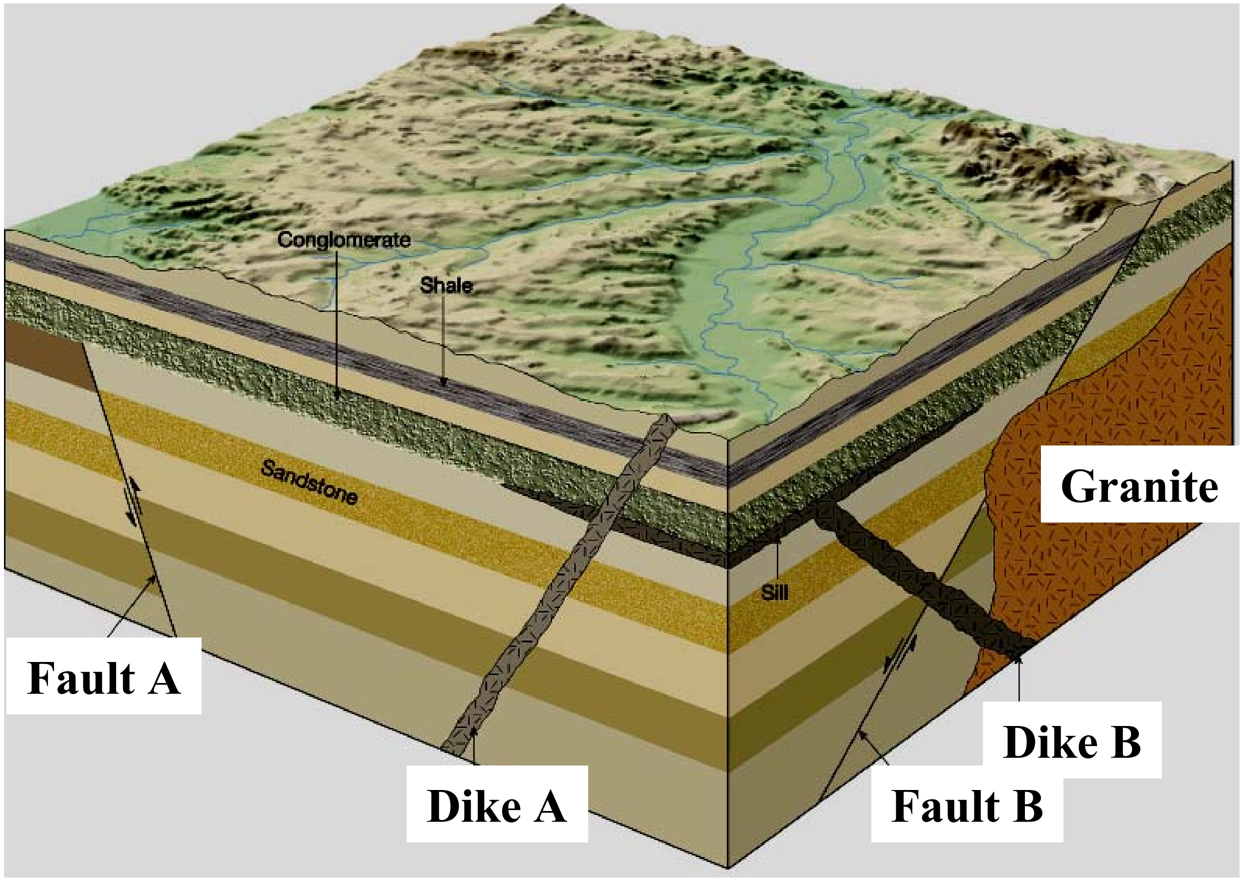


Principle of faunal successions

- **Vertical arrangement in a stratigraphic column, establishment of evolution within species (e.g. the simplest forms are on the bottom and most complex on top)**

Principles of cross-cutting relationship

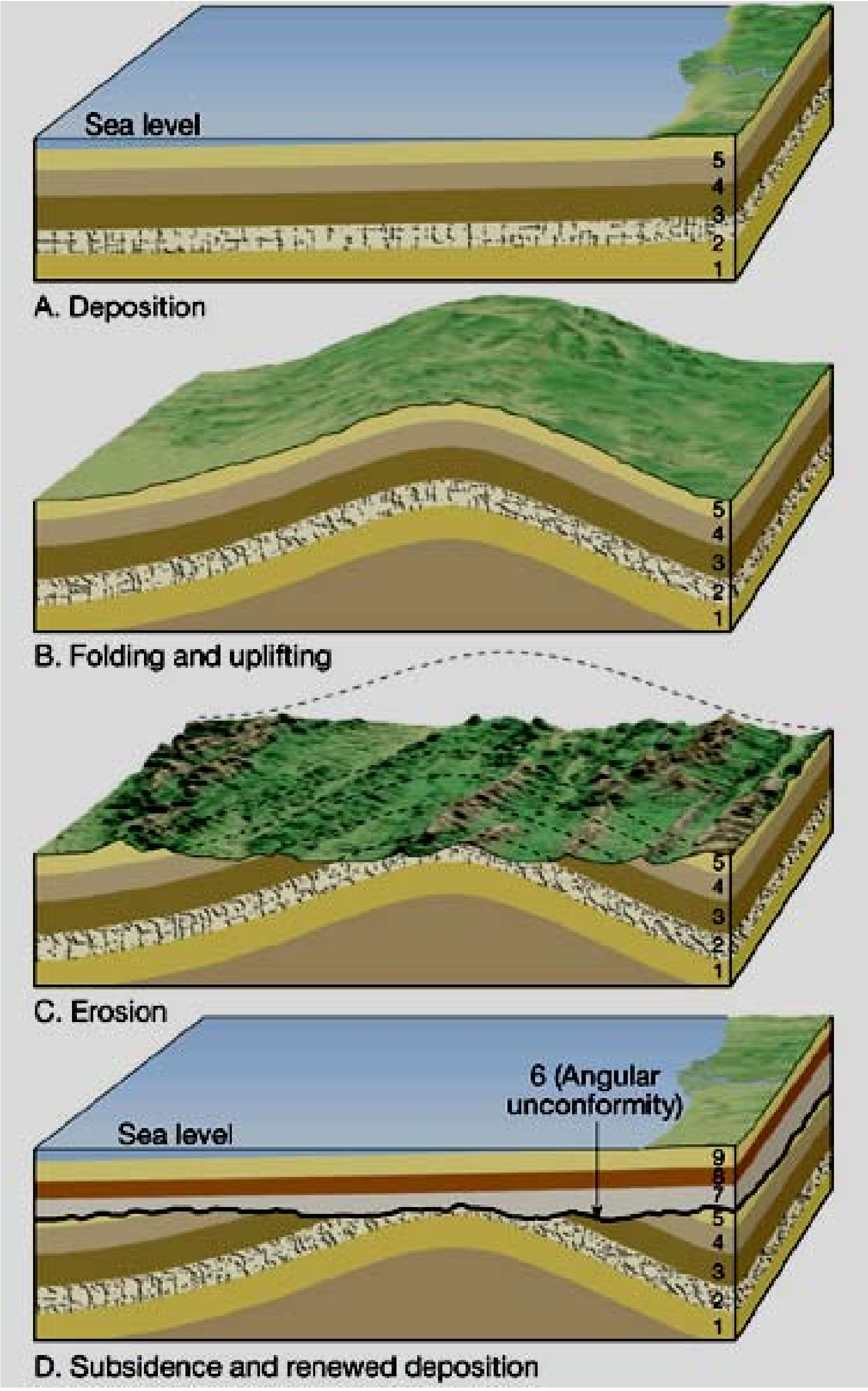
- A disrupted pattern is older than the cause of disruption
- Younger features cut across older feature
- Disruption caused by a) erosion, b) deformation, c) magma



Principles of relative age dating

- Inclusions
  - An inclusion is a piece of rock that is enclosed within another rock
  - Rock containing the inclusion is younger
- Unconformity
  - An unconformity is a break in the rock record produced by erosion and/or nondeposition of rock units
- Index fossil
  - Have short histories and wide geographic range
  - E.g., Trilobites: Paleozoic
  - E.g., Dinosaurs: Mesozoic

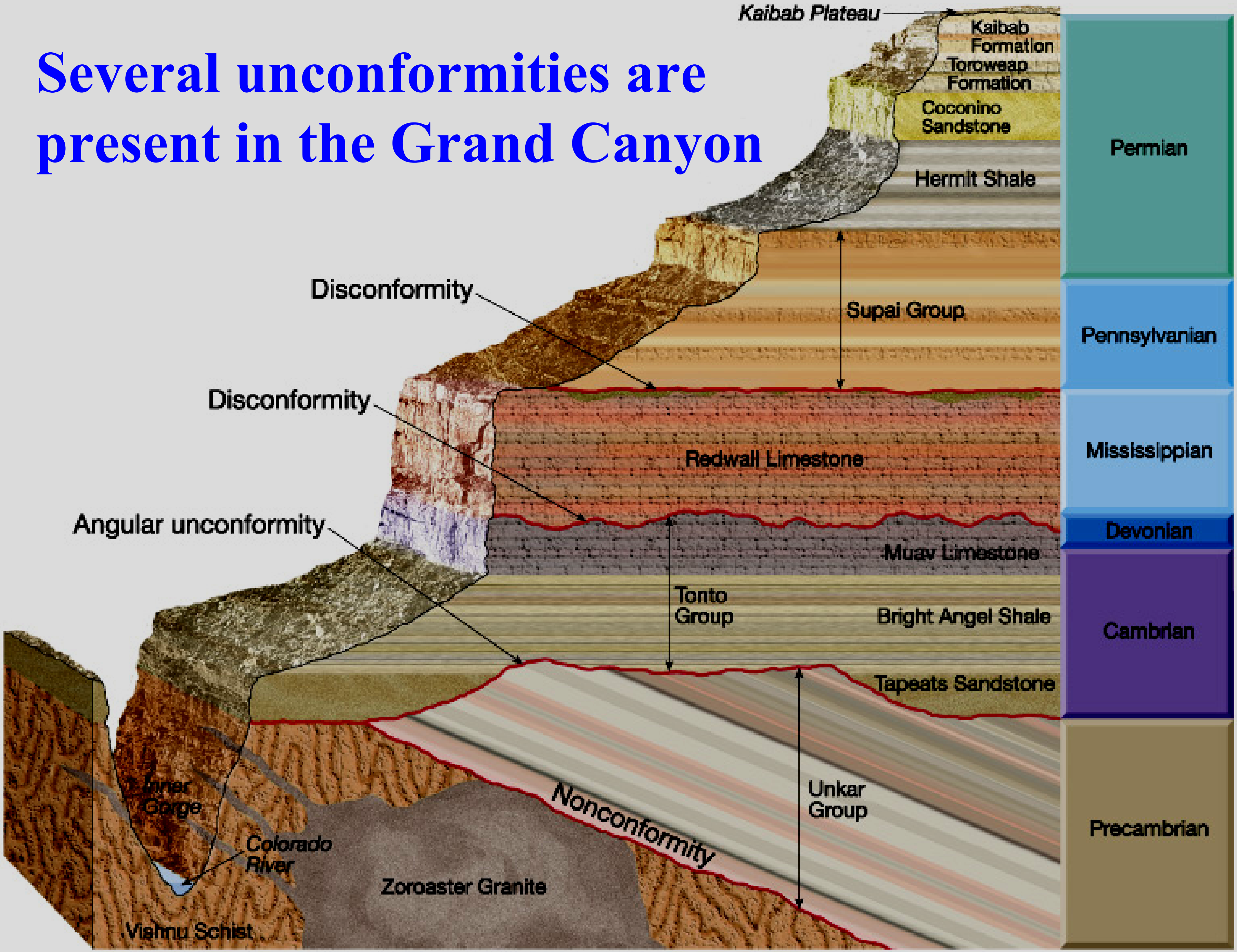
Formation of an angular unconformity



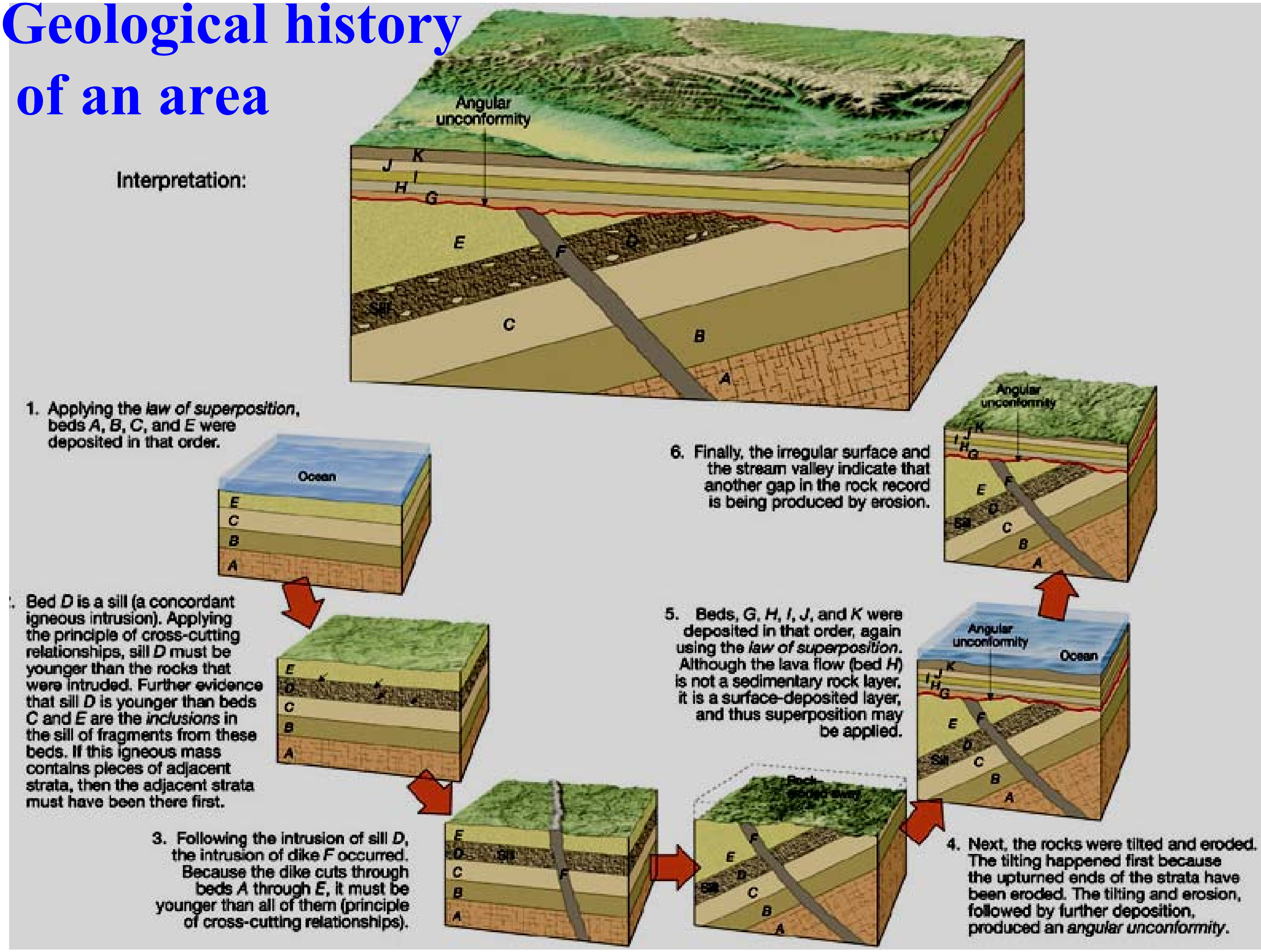
Types of unconfomity

- **Angular unconformity – tilted rocks are overlain by flat-lying rocks**
- **Disconformity – strata on either side of the unconformity are parallel**
- **Nonconformity – metamorphic or igneous rocks in contact with sedimentary strata**

Several unconformities are present in the Grand Canyon



Geological history of an area



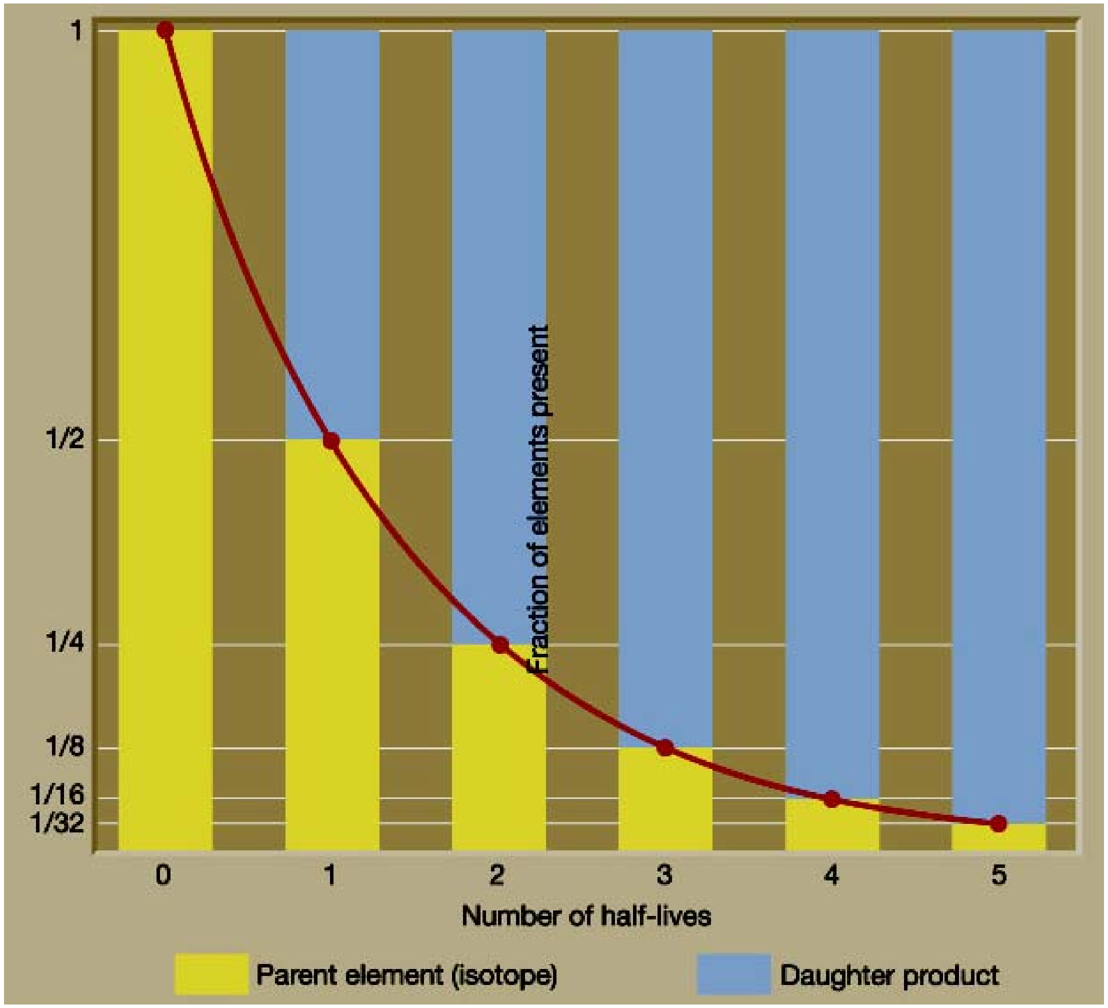
Correlation of rock layers

- **Matching of rocks of similar ages in different regions is known as correlation**
- **Correlation often relies upon fossils**
  - **Principle of faunal succession – fossil organisms succeed one another in a definite and determinable order, and therefore any time period can be recognized by its fossil content**

Absolute age dating

- **All absolute ages are derived through radiometric dating**
- **Radiometric dating based on radioactive decay**
- **Radioactive decay involves the transition from a parent atom (e.g. Potassium) to a daughter atom (e.g. Argon)**
- **Decay happens systemically and according to a given rate**
- **Knowing: a) how many parent atoms are present, b) how many daughter atoms are present, c) the rate of decay (half-live); yields: the time how long the decay has been going on and thus the age of the sample (how old the sample is)**

A radioactive decay curve

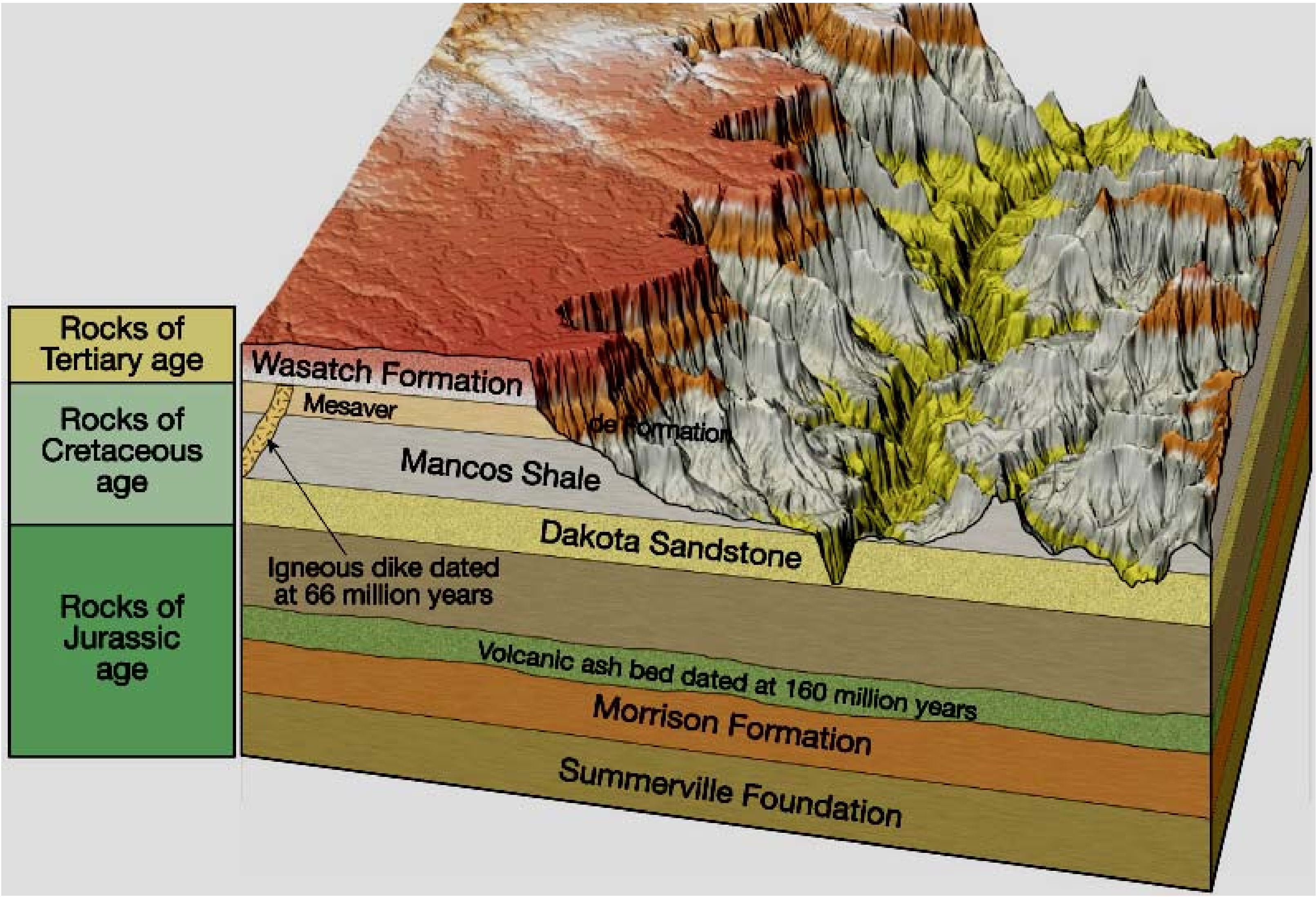


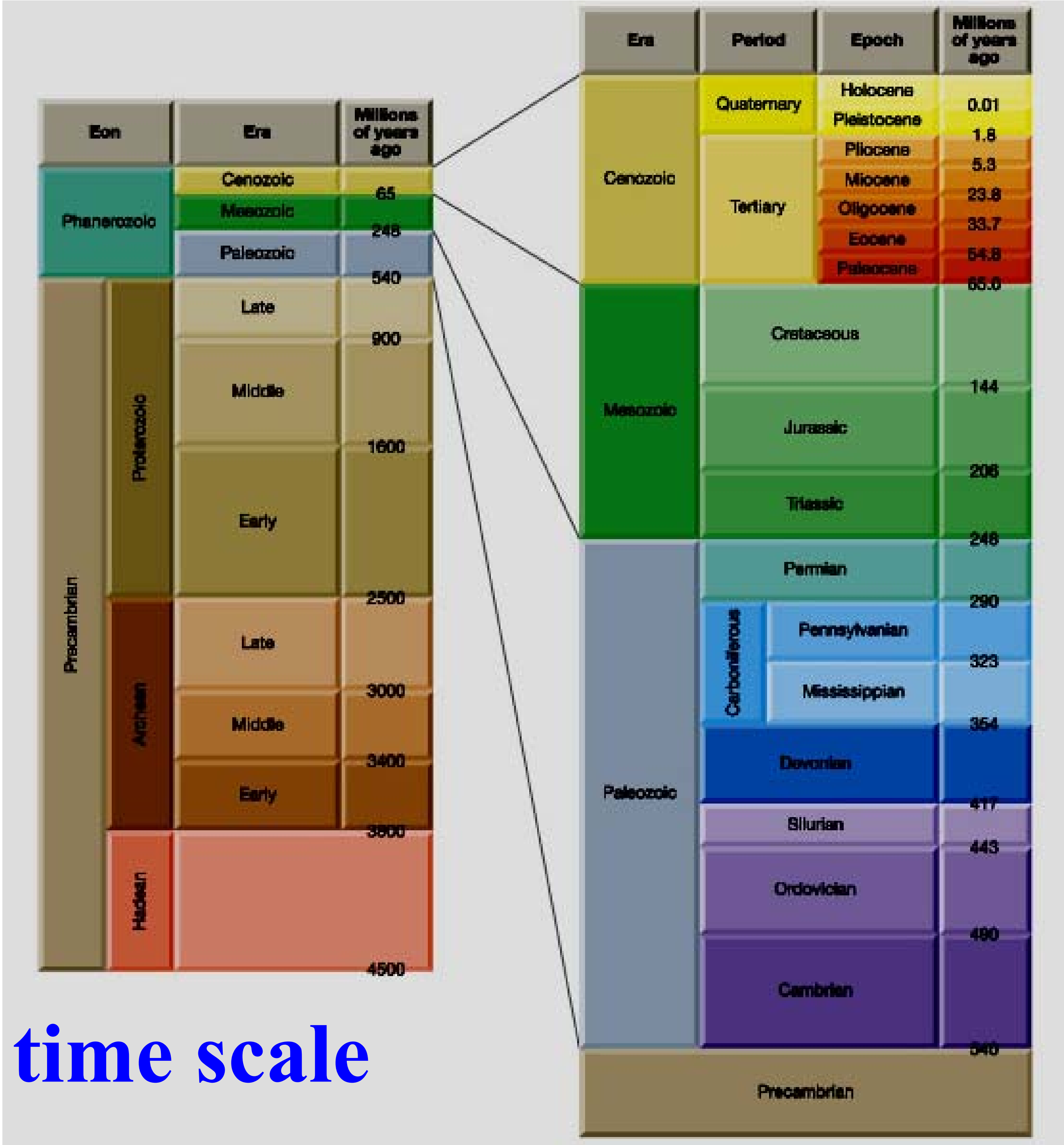
- **Half-life** – **the time required for one-half of the radioactive nuclei in a sample to decay**

Radiometric dating

- **Radioactive elements (isotopes) used for dating:**
  - **Carbon (C^{14}) - Halflive: 5730 years**
  - **Potassium (K^{40}) - Halflive: 1.25 billion years**
  - **Uranium (U^{235}) - Halflive: 0.71 billion years**
  - **Thorium (Th^{232}) - Halflive: 14.1 billion years**
- **Age dating limitation: 10 Halflives**
- **Mainly igneous and metamorphic rocks contain Potassium, Uranium, Thorium**
- **C^{14} method to date charcoal, shells, other organic materials carbon**

Using relative age dating with absolute age dating





Geologic time scale

Geologic time scale

- The geologic time scale – a “calendar” of Earth history
    - Subdivides geologic history into units
    - Originally created using relative dates
- Structure of the geologic time scale
  - Eons (e.g. Phanerozoic)
    - Era (e.g. Cenozoic)
      - Periods (Quaternary)
        - Epochs (Pleistocene)

TABLE 8.2 **Major Divisions of Geologic Time**

Cenozoic Era (Age of Recent Life)	Quarternary period	The several geologic eras were originally named Primary, Secondary, Tertiary, and Quaternary. The first two names are no longer used; Tertiary and Quaternary have been retained but used as period designations.
	Tertiary period	
Mesozoic Era (Age of Middle Life)	Cretaceous period	Derived from Latin word for chalk (creta) and first applied to extensive deposits that form white cliffs along the English Channel (see Figure 6.11).
	Jurassic period	Named for the Jura Mountains, located between France and Switzerland, where rocks of this age were first studied.
	Triassic period	Taken from word "trias" in recognition of the threefold character of these rocks in Europe.
Paleozoic Era (Age of Ancient Life)	Permian period	Named after the province of Perm, Russia, where these rocks were first studied.
	Pennsylvanian period	Named for the state of Pennsylvania where these rocks have produced much coal.
	Mississippian period*	Named for the Mississippi River valley where these rocks are well exposed.
	Devonian period	Named after Devonshire County, England, where these rocks were first studied.
	Silurian period	Named after Celtic tribes, the Silures and the Ordovices, that lived in Wales during the Roman Conquest.
	Ordovician period	
	Cambrian period	Taken from Roman name for Wales (Cambria), where rocks containing the earliest evidence of complex forms of life were first studied.
Precambrian		The time between the birth of the planet and the appearance of complex forms of life. More than 85 percent of Earth's estimated 4.6 billion years fall into this span.

SOURCE: U.S. Geological Survey.

*Outside of North America, the Mississippian and Pennsylvanian periods are combined into the Carboniferous period.

Difficulties in age dating

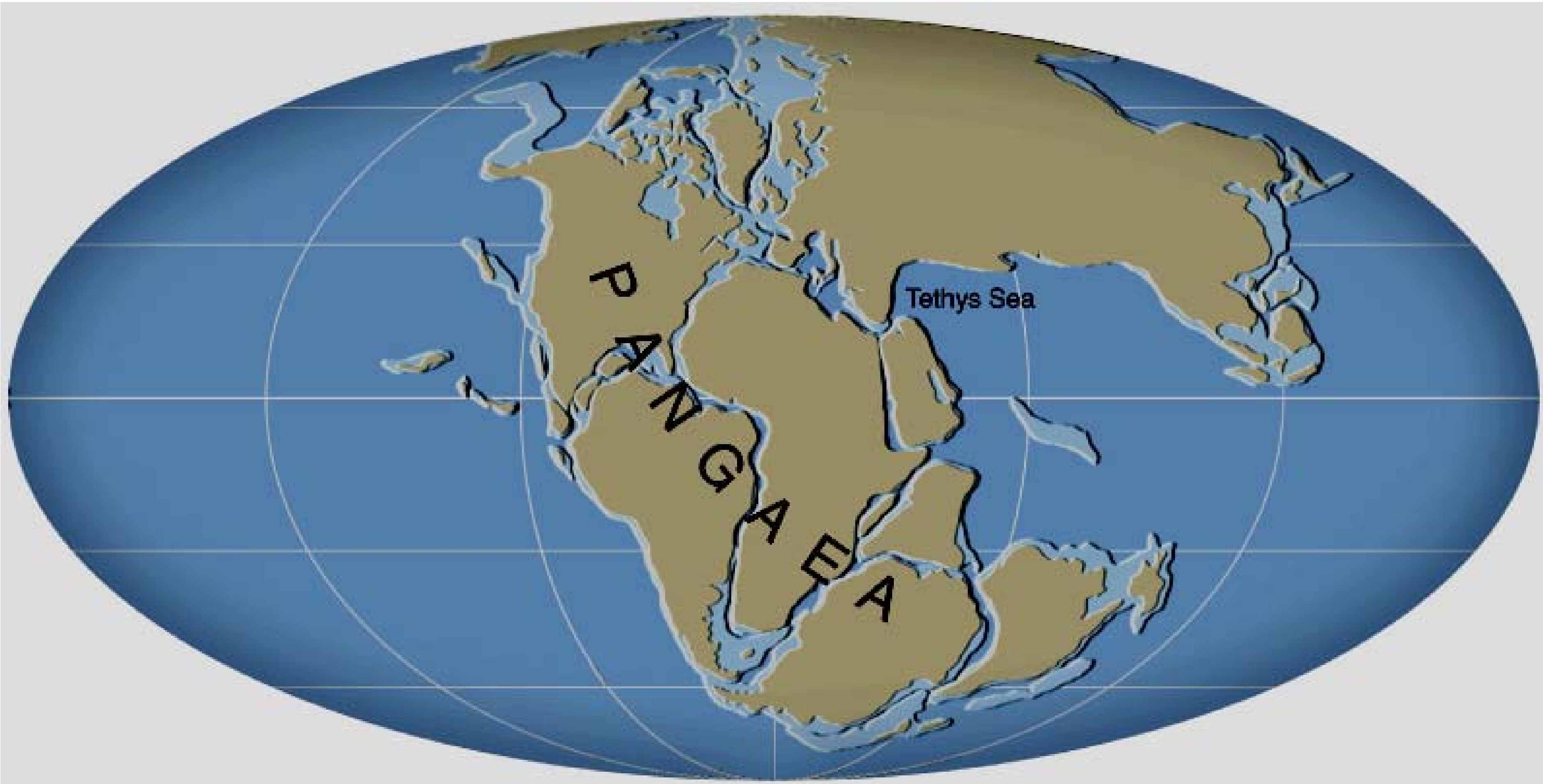
- Not all rocks can be dated by radiometric methods
  - Grains comprising detrital sedimentary rocks are not the same age as the rock in which they formed
  - The age of a particular mineral in a metamorphic rock may not necessarily represent the time when the rock formed
- Datable materials (such as volcanic ash beds and igneous intrusions) are often used to bracket various episodes in Earth history and arrive at ages

Plate Tectonics

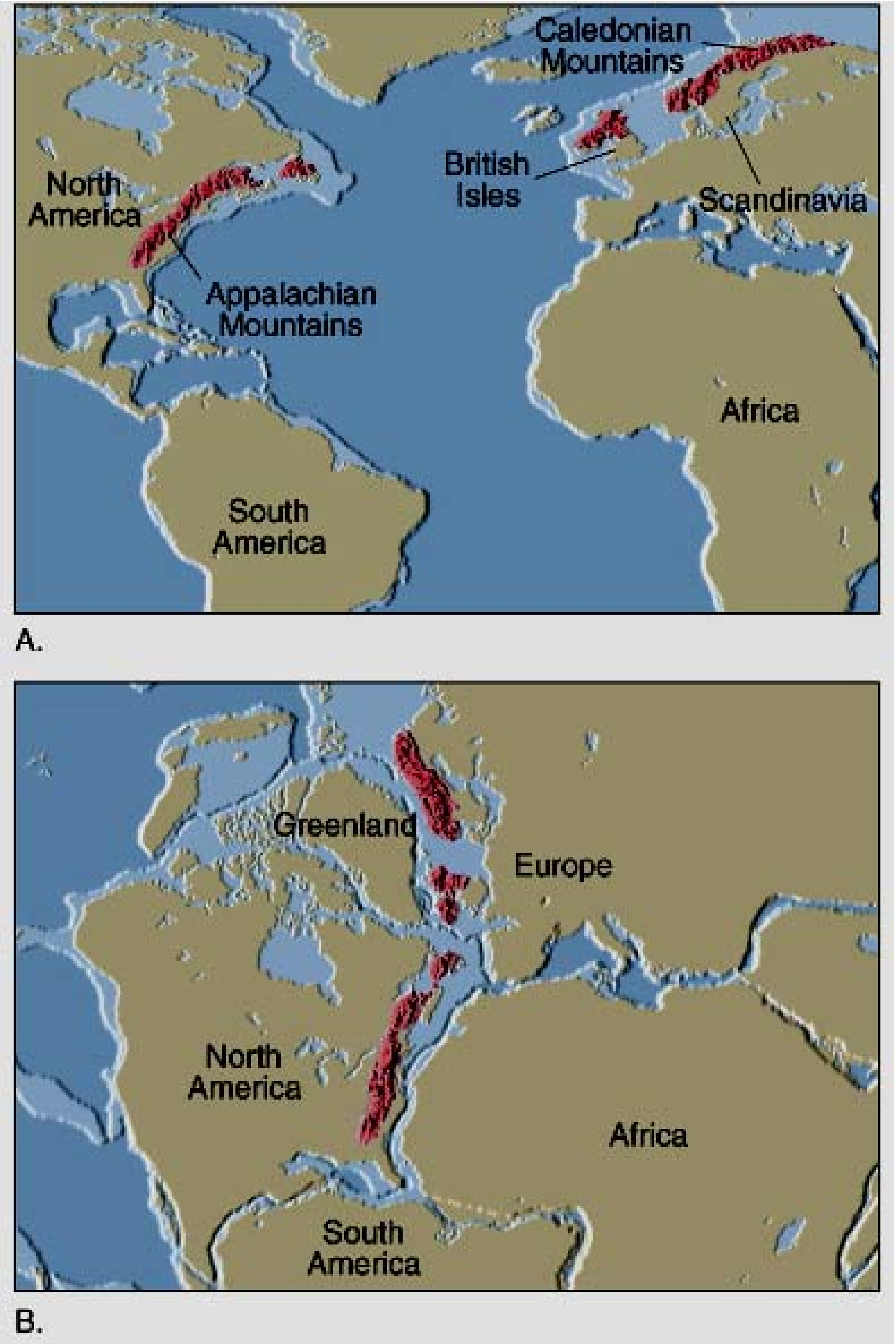
Continental drift: An idea before plate tectonics

- Alfred Wegener
  - First proposed drift hypothesis in 1915
  - Published *The Origin of Continents and Oceans*
- Continental drift hypothesis
  - Supercontinent called Pangaea began breaking apart about 200 million years ago Continental drift hypothesis
  - Continents "drifted" to present positions
- Evidence in support of continental drift hypothesis
  - Fit of the continents
  - Fossil evidence
  - Rock type and structural similarities
  - Paleoclimatic evidence

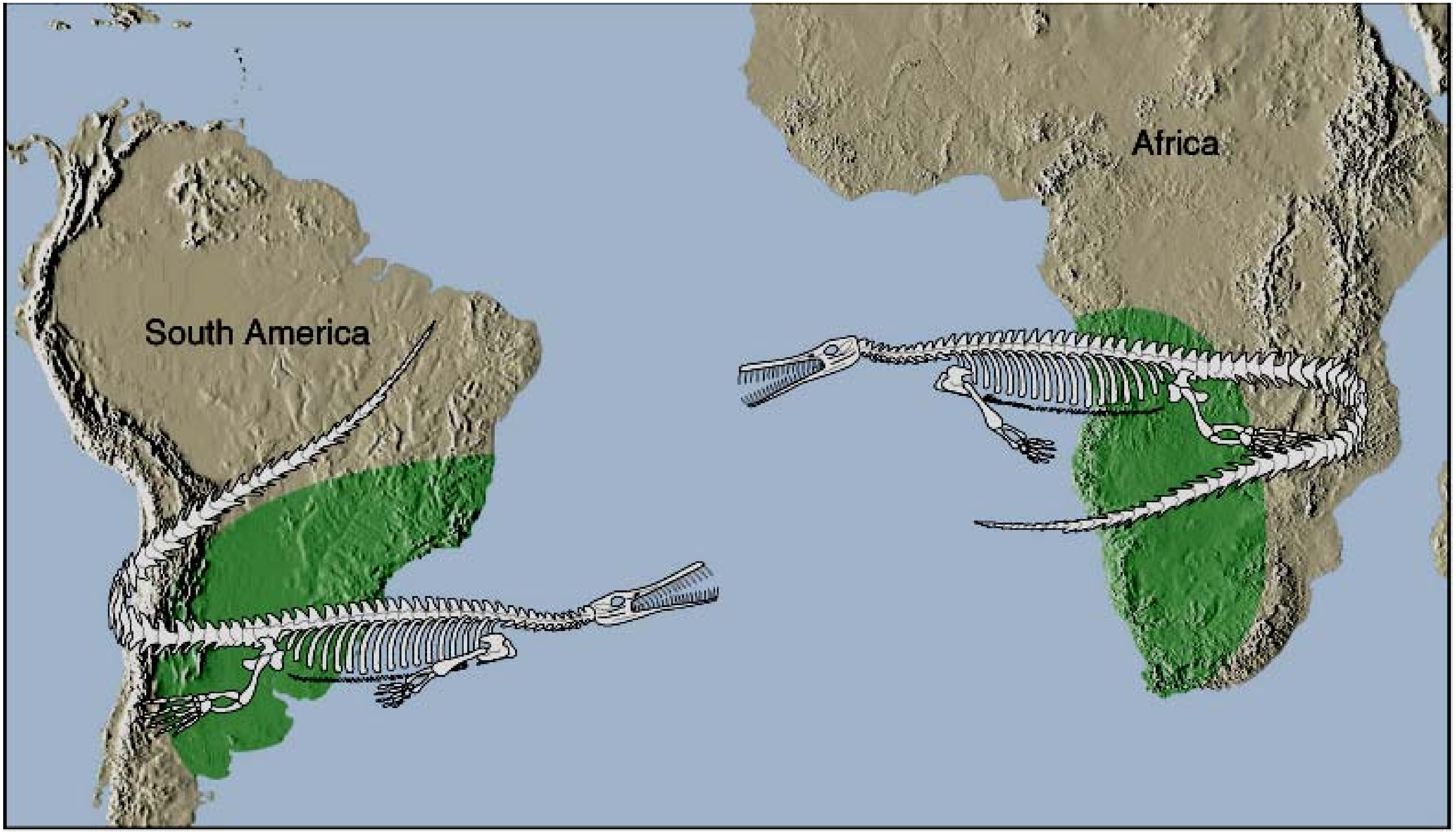
Pangaea approximately 200 million years ago - fit of continents



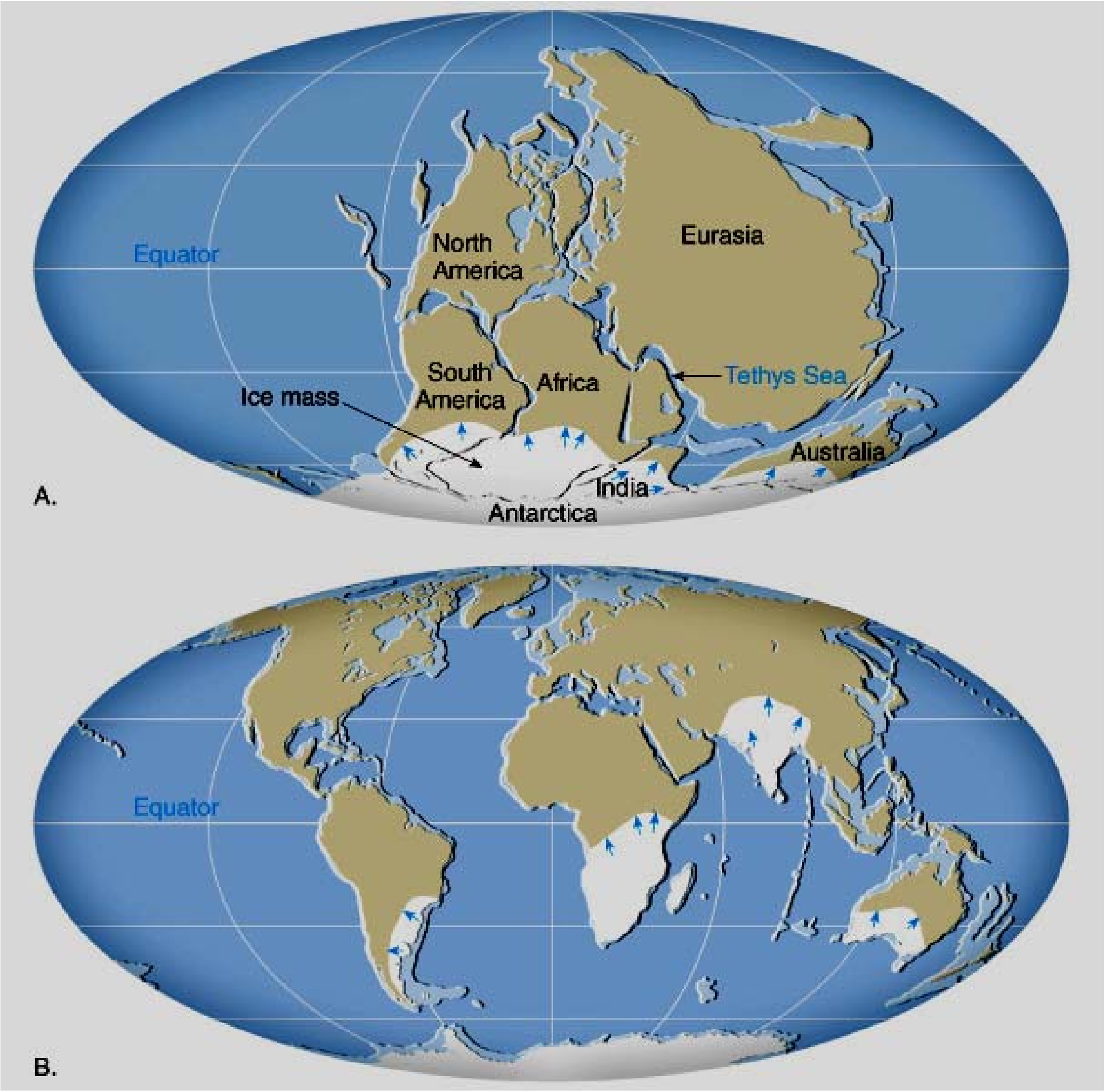
Wegener's matching of mountain ranges on different continents



Evidence from fossil records



Paleoclimatic evidence for Continental Drift



The great debate

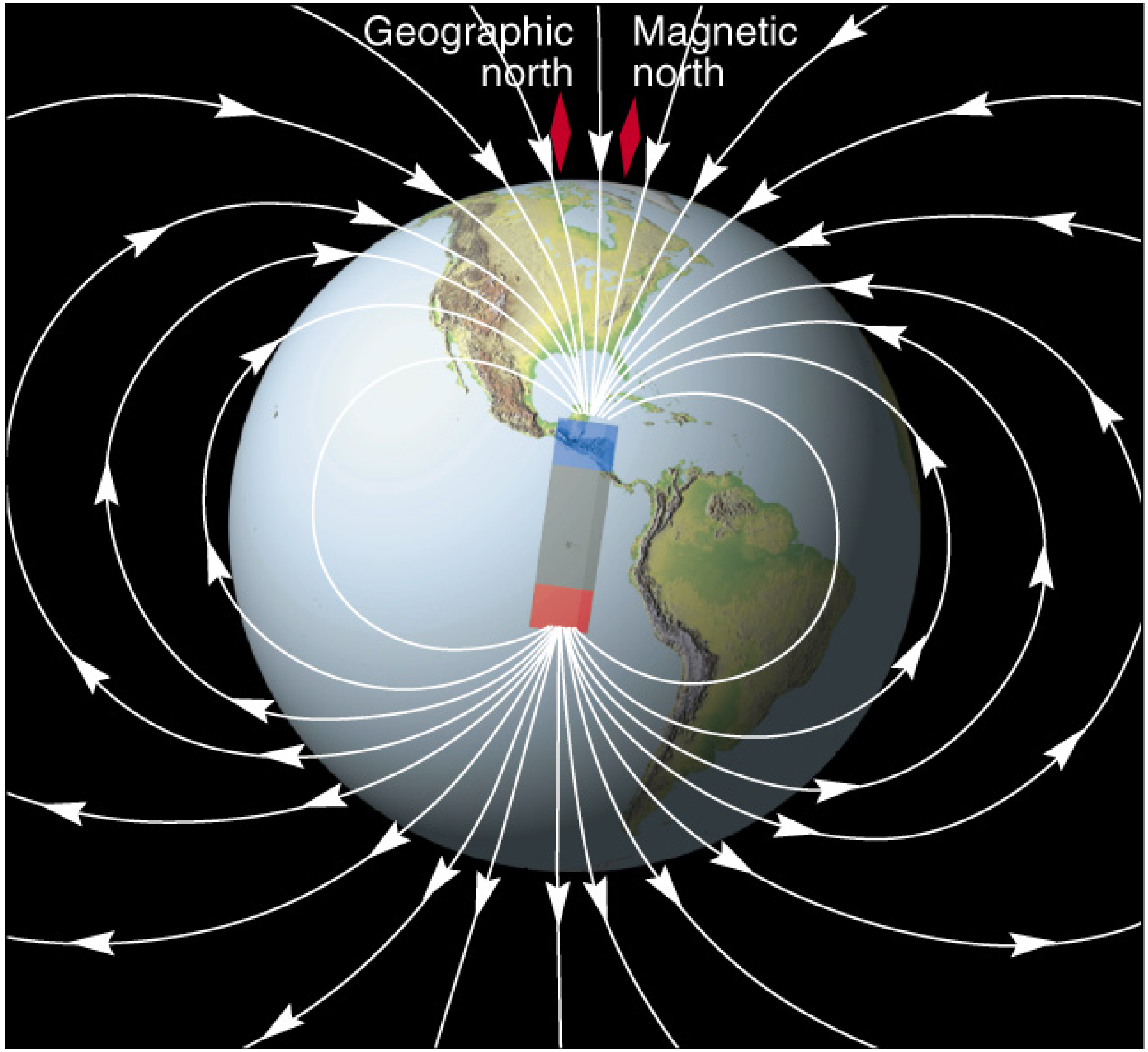
- Objections to the continental drift hypothesis
  - Inability to provide a mechanism capable of moving continents across the globe
  - Wegner suggested that continents broke through the ocean crust, much like ice breakers cut through ice

The scientific revolution begins

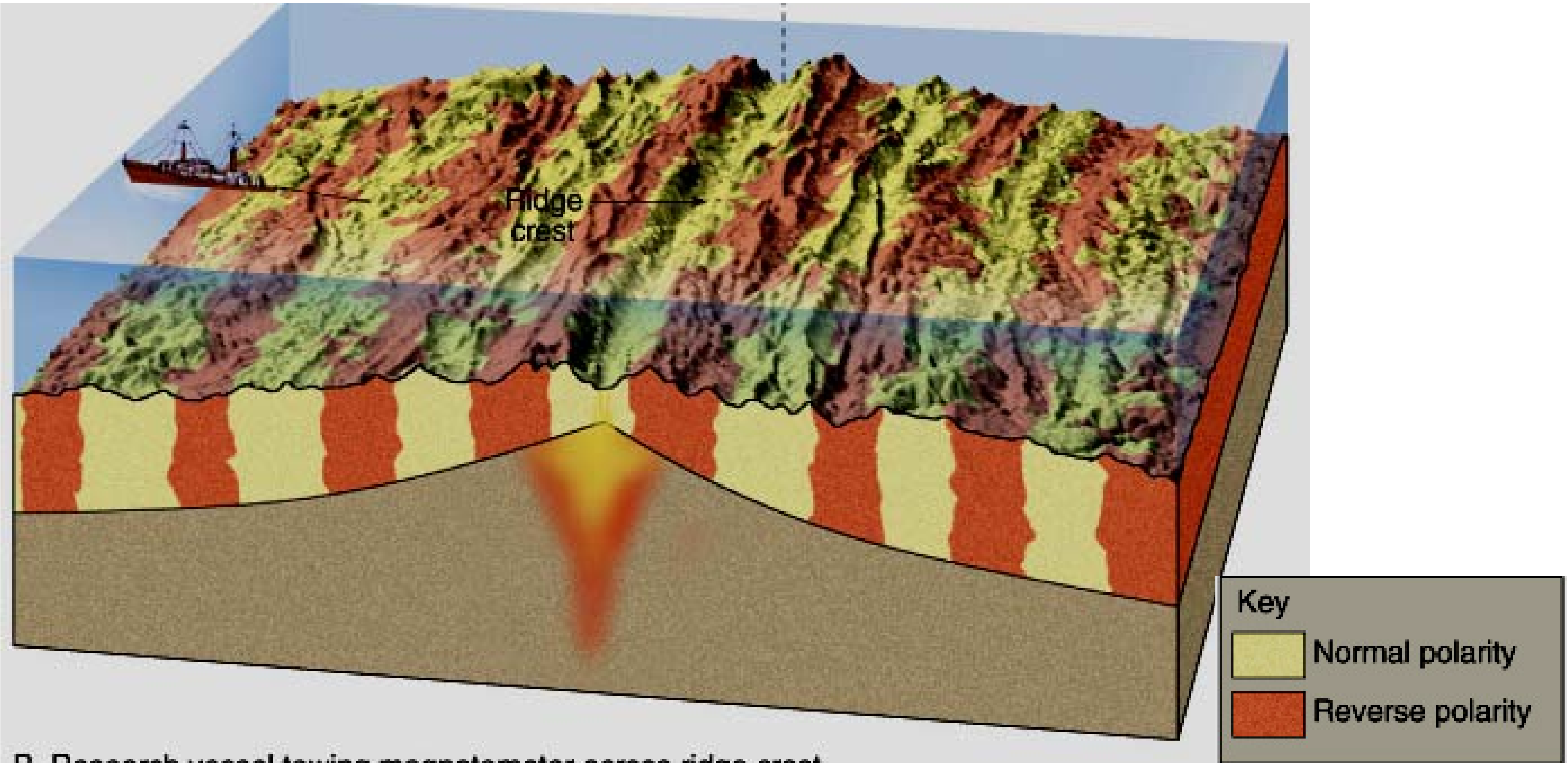
- During the 1950s and 1960s technological strides permitted extensive mapping of the ocean floor
- Seafloor spreading hypothesis was proposed by Harry Hess in the early 1960s

Support of the concepts of continental drift and seafloor spreading: magnetic stripes in ocean crust

- Geomagnetic reversals
  - Earth's magnetic field periodically reverses polarity – the north magnetic pole becomes the south magnetic pole, and vice versa
  - Dates when the polarity of Earth’s magnetism changed were determined from lava flows
  - Geomagnetic reversals are recorded in the ocean crust
  - In 1963 Fred Vine and D. Matthews tied the discovery of magnetic stripes in the ocean crust near ridges to Hess’s concept of seafloor spreading


Geographic
north
Magnetic
north

Paleomagnetic reversals recorded by basalt at mid-ocean ridges



B. Research vessel towing magnetometer across ridge crest

Paleomagnetic reversals get older further away from the ridge

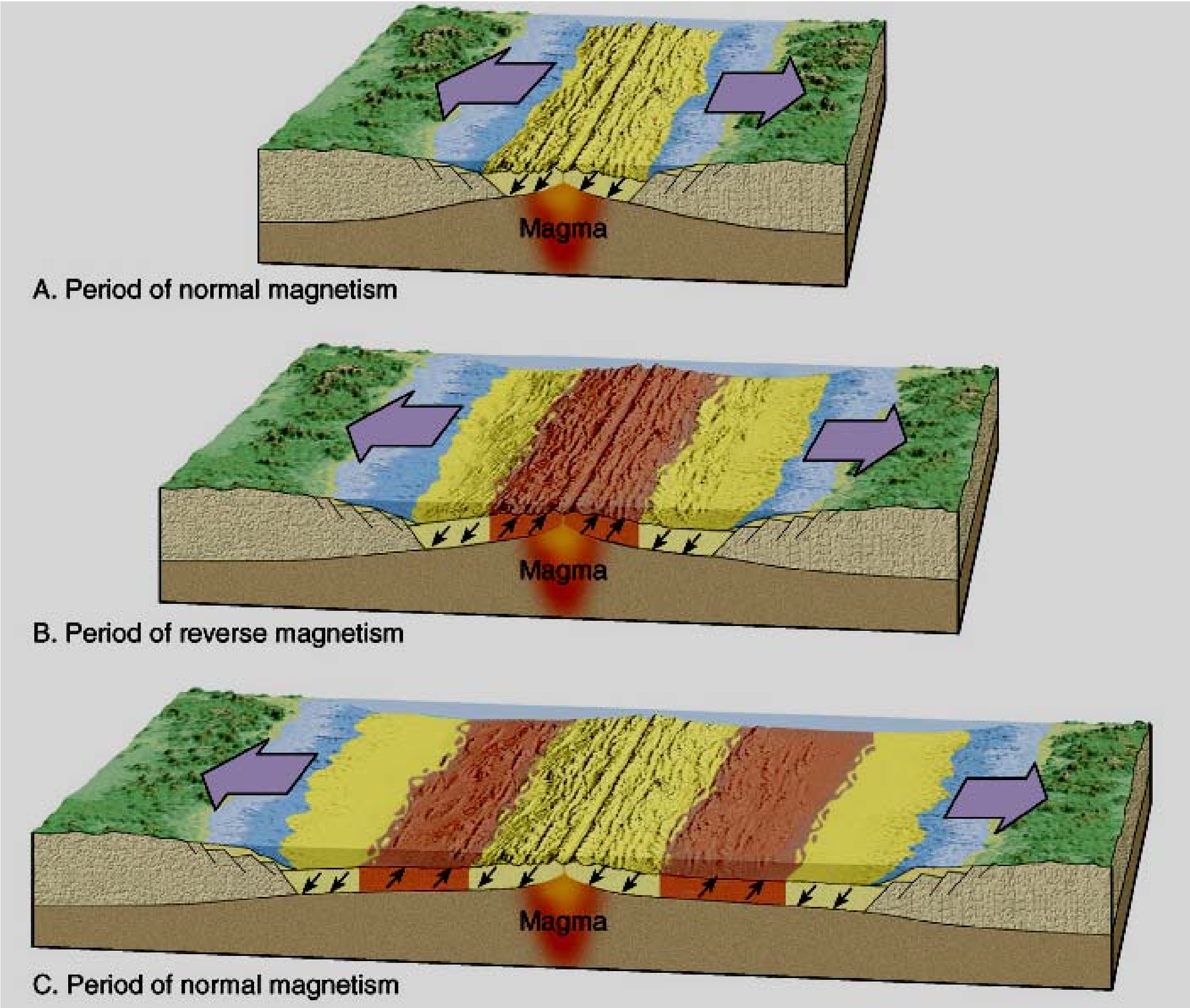


Plate tectonics: The new paradigm

- Much more encompassing theory than continental drift
- The composite of a variety of ideas that explain the observed motion of Earth’s lithosphere through the mechanisms of subduction and seafloor spreading
- Earth’s major plates
    - Associated with Earth's strong, rigid outer layer
        - Known as the lithosphere
        - Consists of uppermost mantle and overlying crust
        - Overlies a weaker region in the mantle called the asthenosphere

Earth’s major plates

- **Seven major lithospheric plates**
- **Plates are in motion and continually changing in shape and size**
- **Largest plate is the Pacific plate**
- **Several plates include an entire continent plus a large area of seafloor**

Lithospheric plates

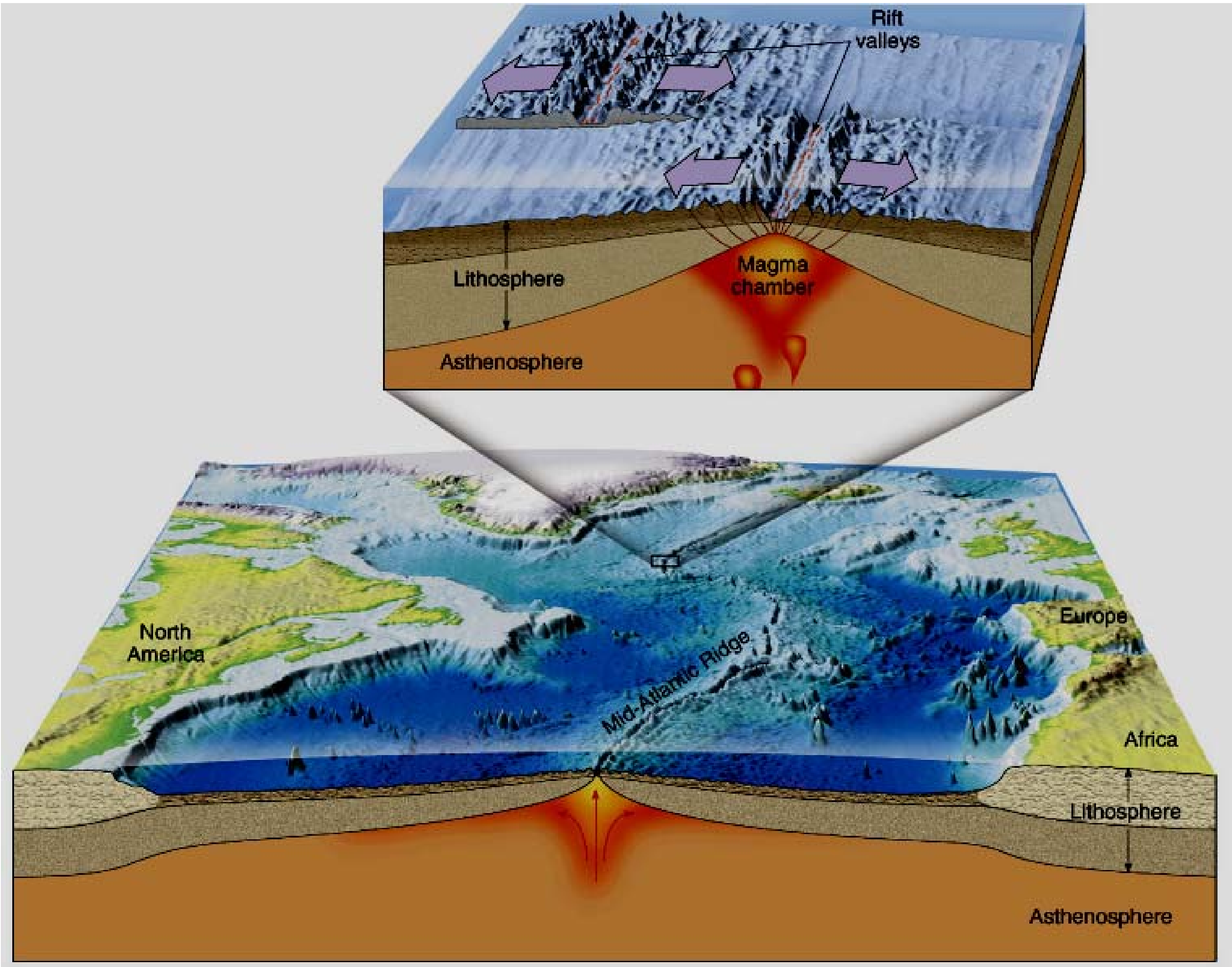
- **Plates move relative to each other at a very slow but continuous rate (about 5 cetimenters per year)**
- **Plate boundaries**
  - **All major interactions among individual plates occur along their boundaries**
  - **Three types of plate boundaries**
    - **Divergent (constructive) - Convergent (destructive) -Transform (conservative)**
  - **Each plate is bounded by a combination of the three types of boundaries**
  - **New plate boundaries can be created in response to changes in the forces acting on these rigid slabs**

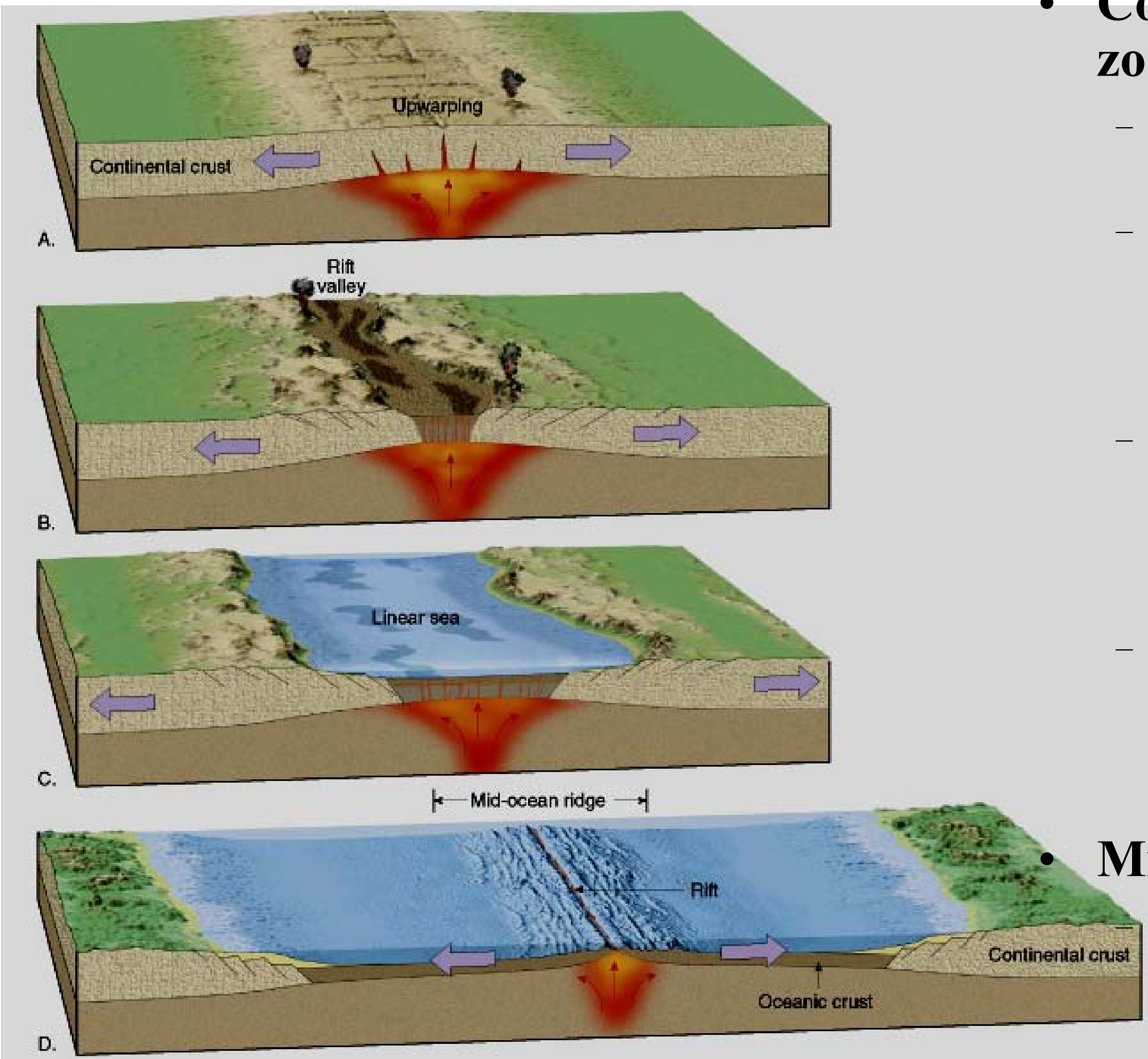
Divergent plate boundaries

- Mid-oceanic ridges and seafloor spreading
- Continental rift valleys
- Formation of rift valleys precedes formation of mid-oceanic ridges
- Not all rift valleys develop into true divergent plate boundaries (seafloor spreading centers)

Oceanic ridges and seafloor spreading

– Seafloor spreading (formation of new oceanic crust) occurs along the oceanic ridge system



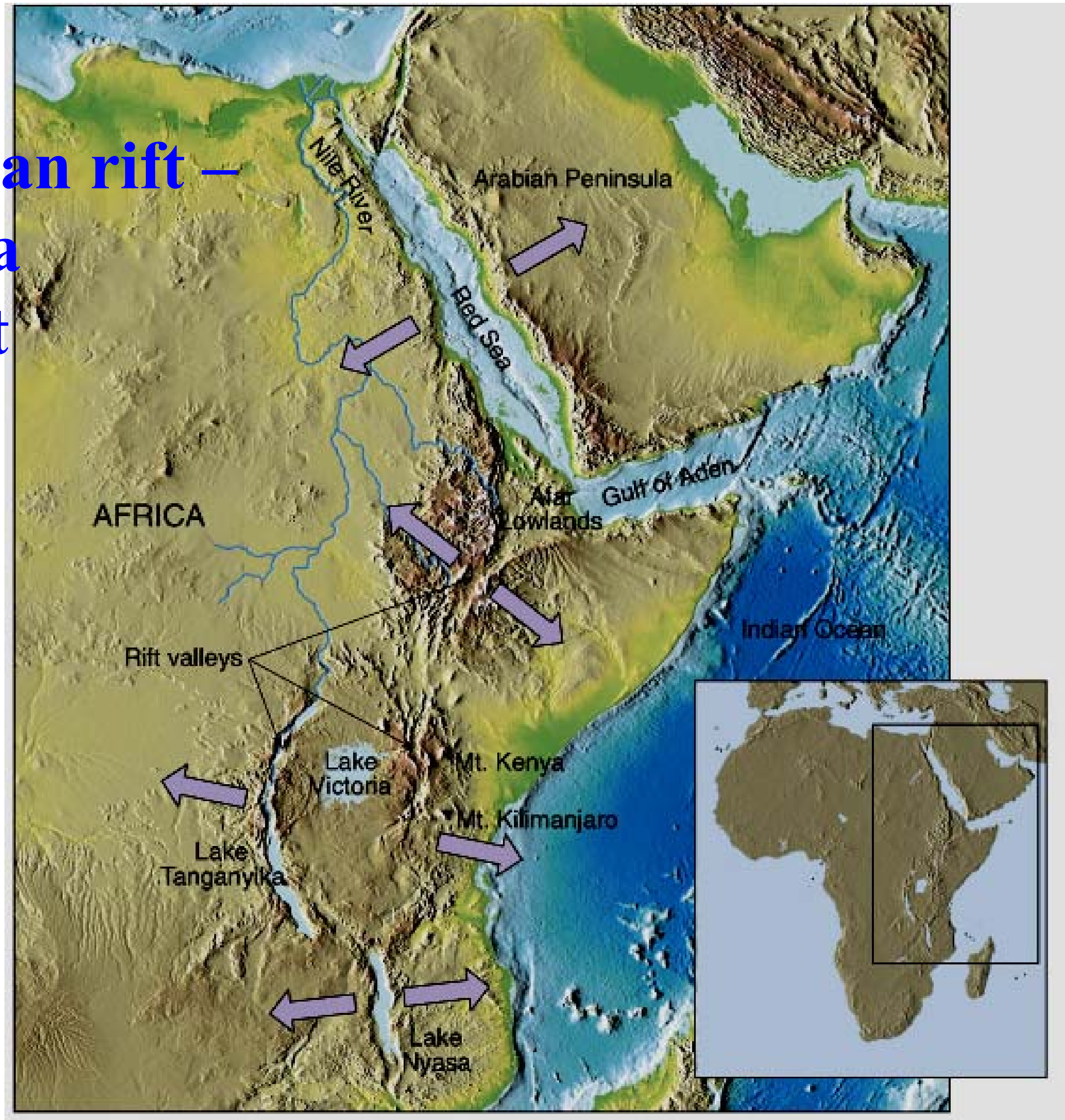


- Continental rift zone
  - Horst & Graben formation
  - Stretching of continental crust
  - Break-up of continental
  - Formation of new sea-floor
- Mid-oceanic ridge
  - Formation of mid-oceanic ridge with seafloor spreading

Continental rifts

- **Splits landmasses into two or more smaller segments**
- **Examples: Rio Grande valley, Rhine & Rhone Valley in central Europe, East African rift**
- **Produced by extensional forces acting on the lithospheric plates**

The East African rift – a example for a continental rift



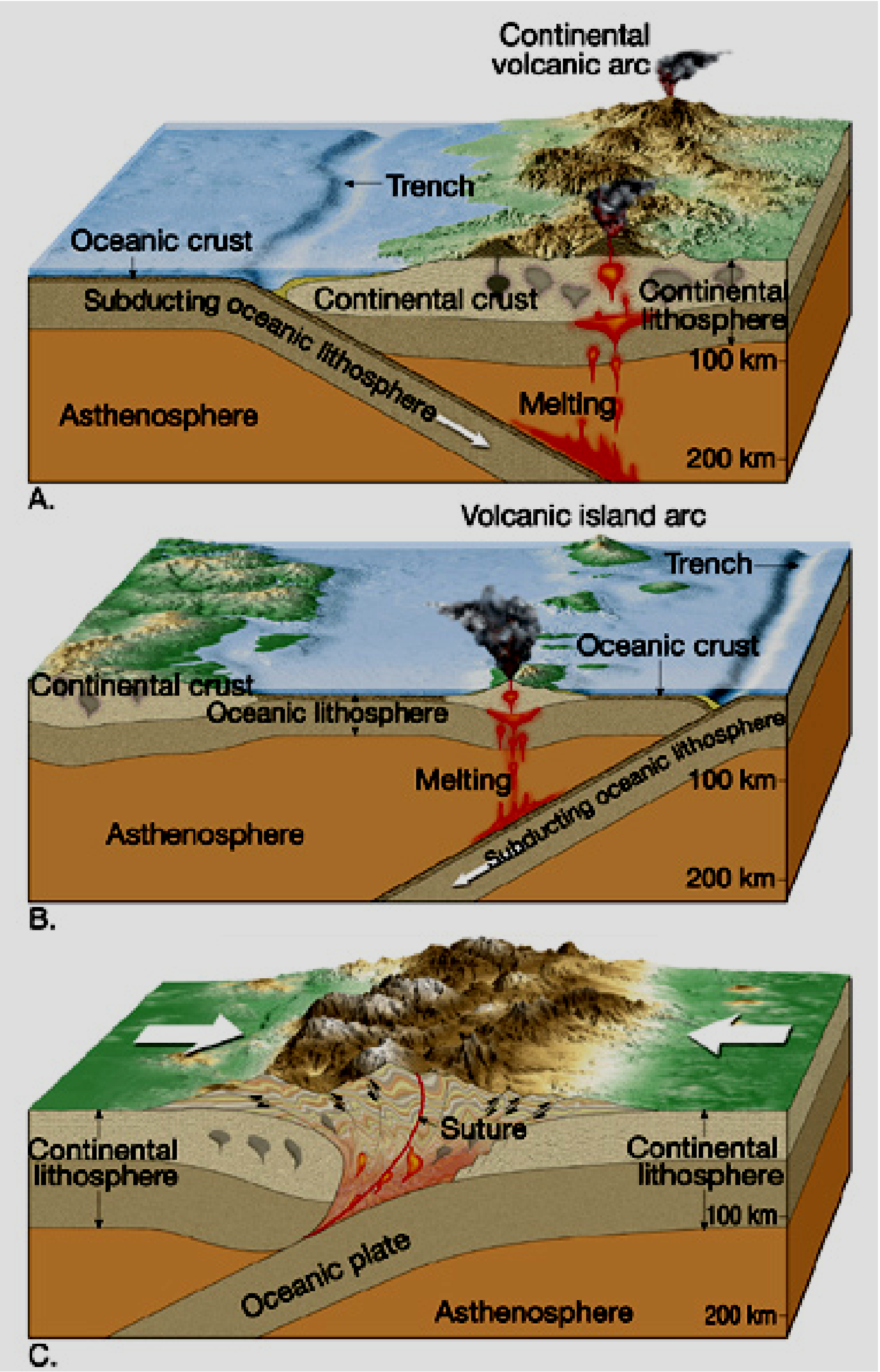
Convergent plate boundaries

- **Subduction zones**
  - **Oceanic plates are returned to the mantle in these destructive plate margins**
  - **Surface expression of the descending plate is an ocean trench**
  - **Average angle at which oceanic lithosphere descends into the mantle is about 45°**
- **Continent-continent collision zones**
  - **Subduction precedes continent collision**
  - **Continent collision proceeds the welding of two continents along a suture and the termination of a desctructive plate boundary**

Subduction zones

- **Oceanic-continental convergence**
  - **Denser oceanic slab sinks into the asthenosphere below a continental plate**
  - **Formation of a continental volcani arc**
  - **Examples: Cascades, Andes**
- **Oceanic-oceanic convergence**
  - **Oceanic plates sinks beneath oceanic plate**
  - **Formation of an island arc**
  - **Examples: Lesser Antilles, Aleutian islands, Tonga islands**

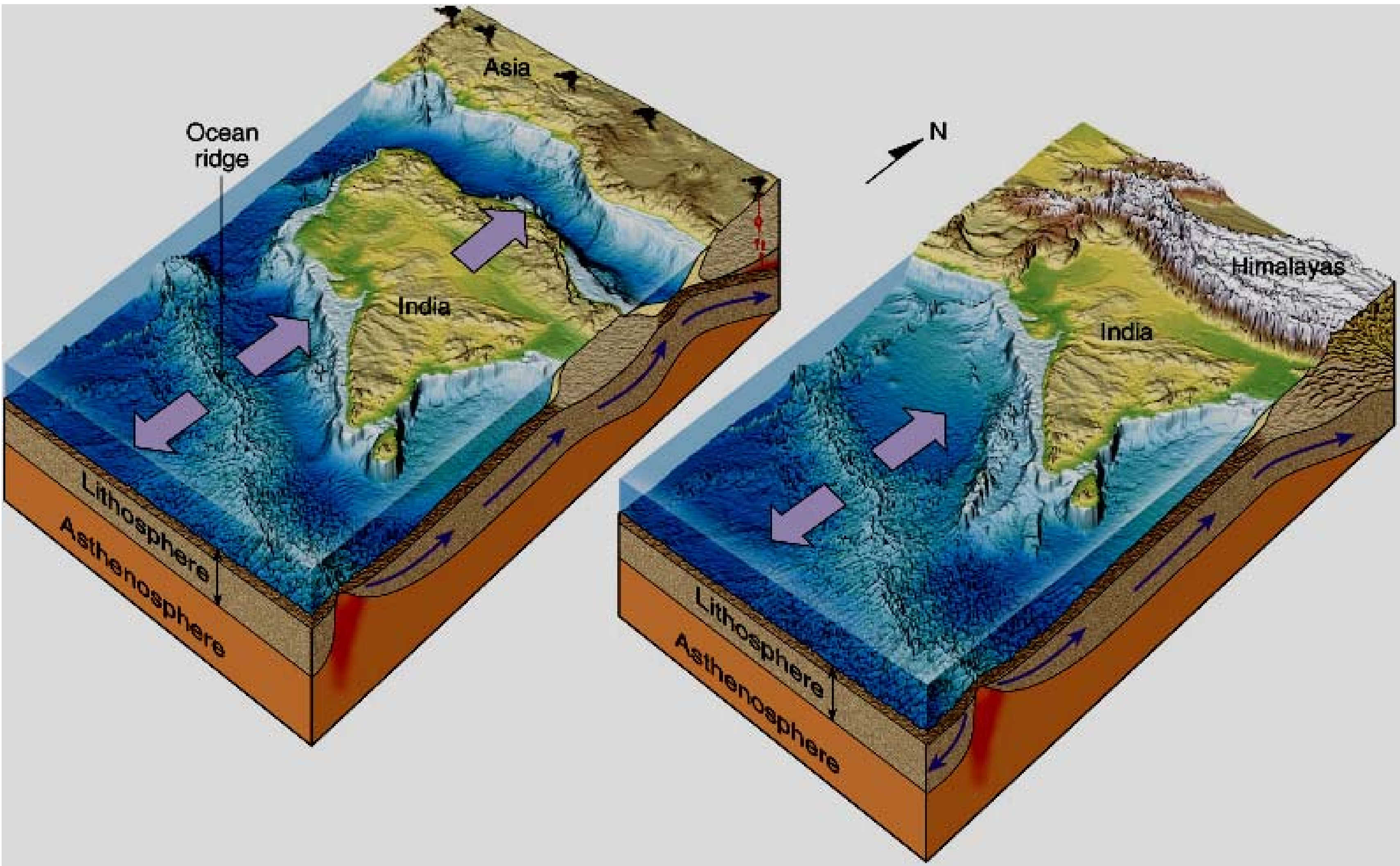
- **Subduction zones**
  - **Oceanic plate beneath continent**
  - **Oceanic plate beneath oceanic plate**
- **Continent-continent collision zones**



Continent-continent collision

- Continued subduction can bring two continents together
- Less dense, buoyant continental lithosphere does not subduct
- Result is a collision between two continental blocks
- Process produces mountains (Himalayas, Alps, Appalachians)

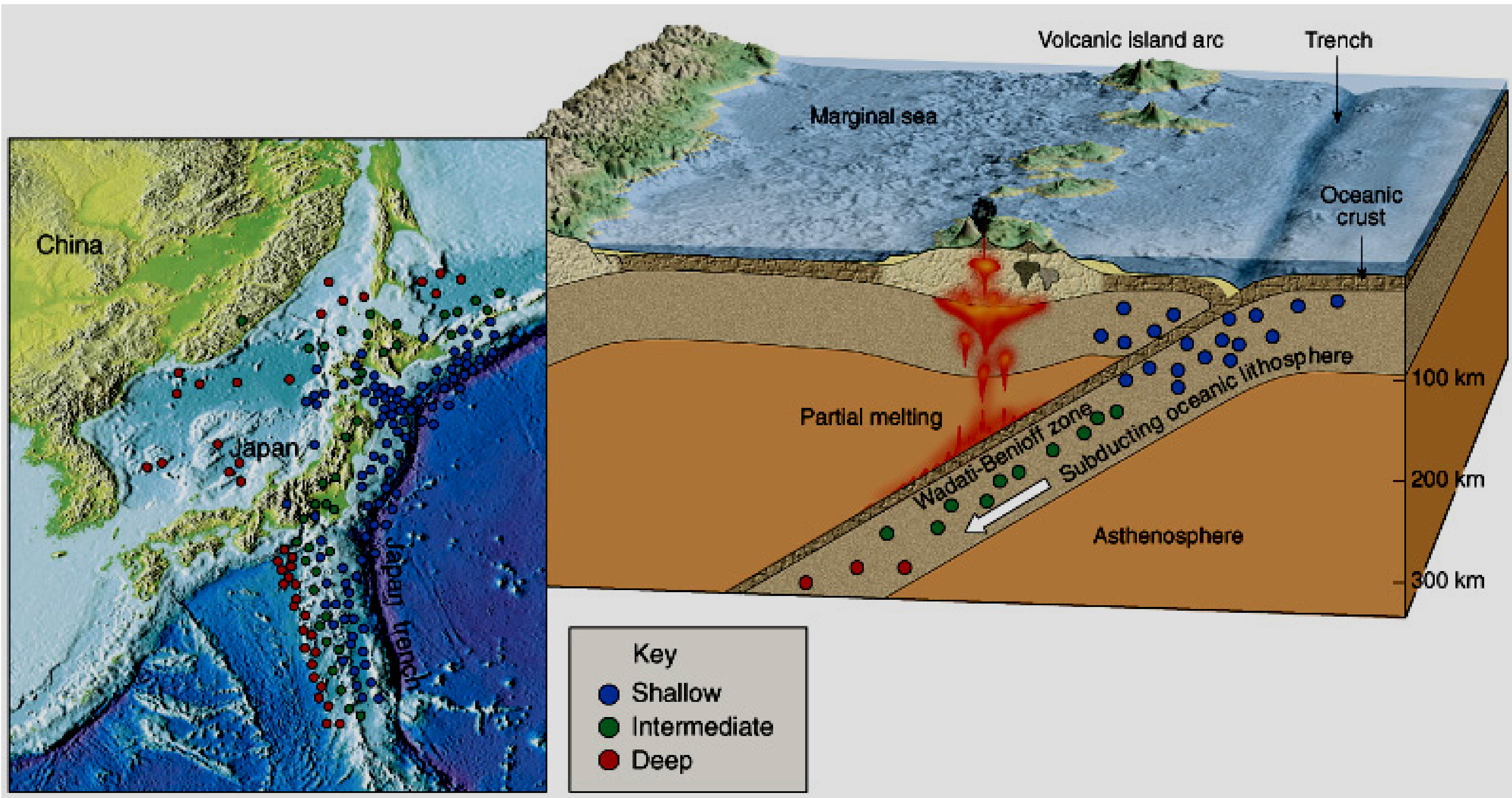
Continent-continent collision: India and Asia produced the Himalayas



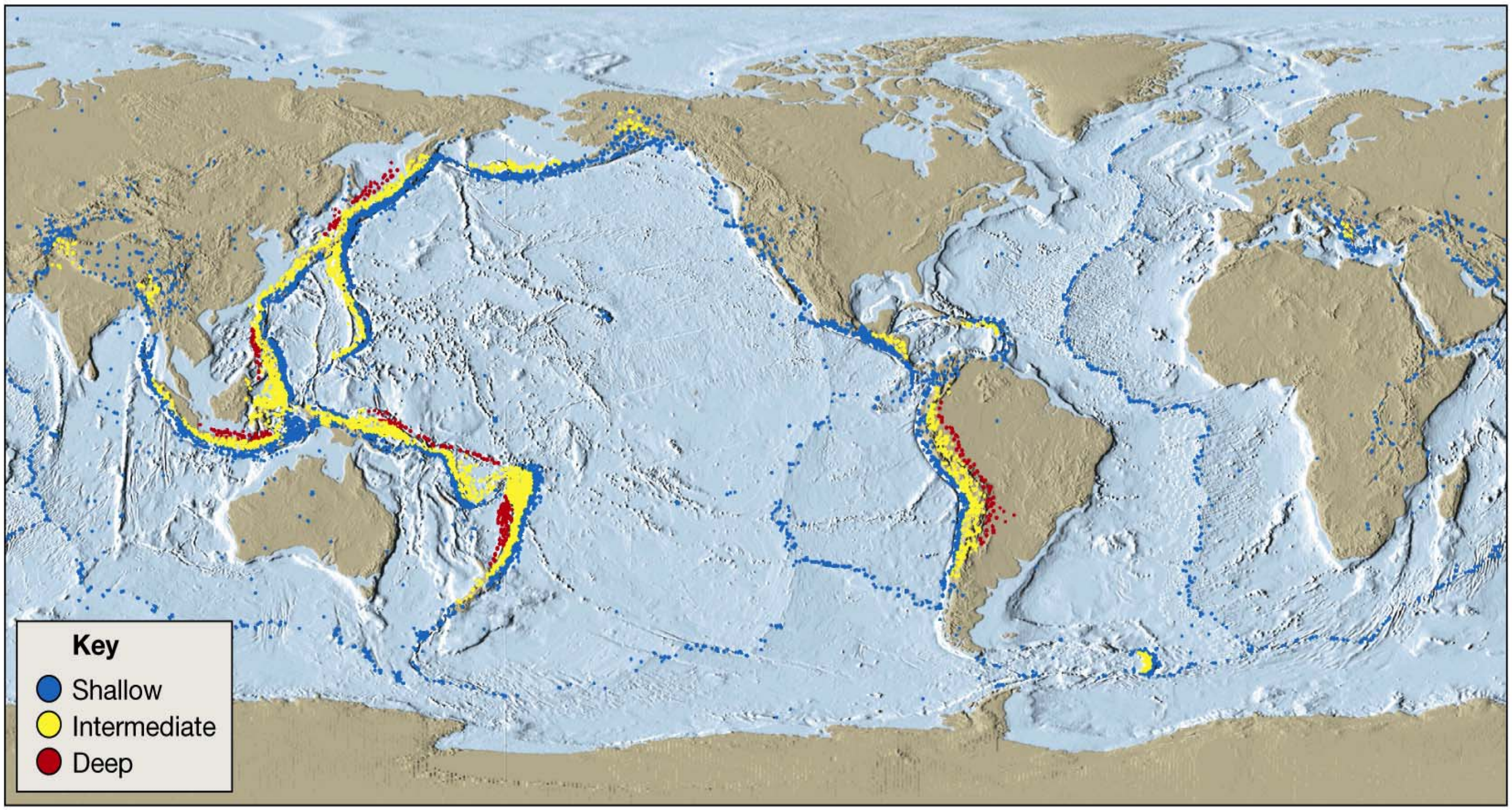
Transform fault boundaries

- Plates slide past one another and no new lithosphere is created or destroyed
- Transform faults
    - Most join two segments of a mid-ocean ridge as parts of prominent linear breaks in the oceanic crust known as fracture zones
    - A few (the San Andreas fault and the Alpine fault of New Zealand) cut through continental crust

Earthquake foci in the vicinity of the Japan trench



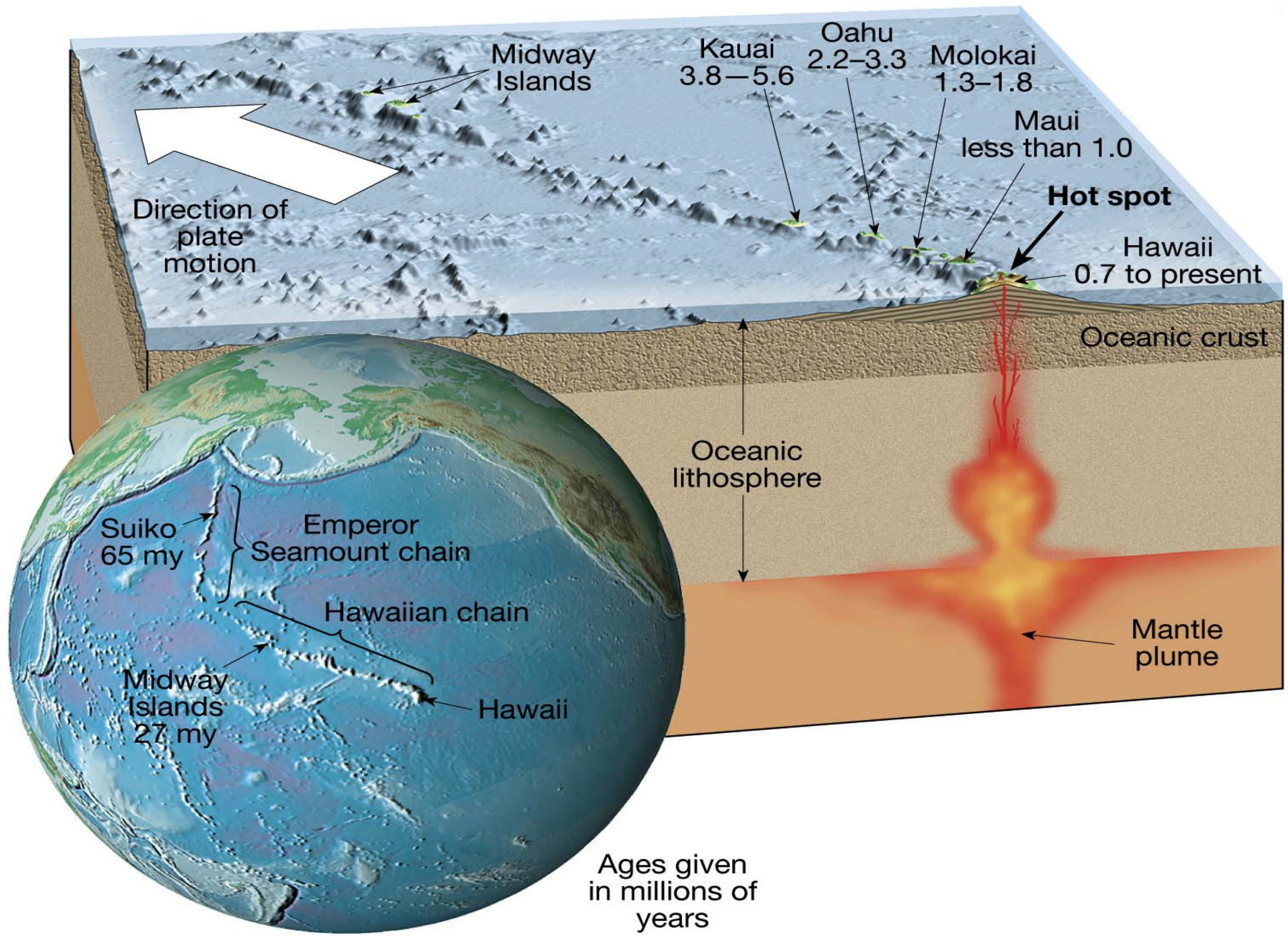
Deep-focus earthquakes occur along convergent boundaries



Testing the plate tectonics model

- Hot spots
    - Caused by rising plumes of mantle material
    - Volcanoes can form over them (Hawaiian Island chain)
    - Most mantle plumes are long-lived structures and at least some originate at great depth, perhaps at the mantle-core boundary

The Hawaiian Islands have formed over a stationary hot spot



The driving mechanism

- No one driving mechanism accounts for all major facets of plate tectonics
- Convective flow in the solid 2,900 kilometer-thick mantle is the basic driving force of plate tectonics
- Convective mantle flow basically due to thermal convection between hot earth interior and cold surface
- Several mechanisms generate forces that contribute to plate motion
  - Slab-pull
  - Ridge-push

Importance of plate tectonics

- **Theory provides a unified explanation of Earth's major surface processes**
- **Within the framework of plate tectonics, geologists have found explanations for the geologic distribution of earthquakes, volcanoes, and mountains**
- **Plate tectonics also provides explanations for past distributions of plants and animals**