Forces within: Volcanoes and Crustal deformation

The nature of volcanic eruptions

- Characteristics of a magma determine the "violence" or explosiveness of a volcanic eruption
    - Composition
    - Temperature
    - Dissolved gases
- The above three factors actually control the viscosity of a given magma

The nature of volcanic eruptions

- Viscosity is a measure of a material's resistance to flow
- Factors affecting viscosity
  - Temperature - Hotter magmas are less viscous
  - Composition - Silica (SiO_2) content
    - Higher silica content = higher viscosity
      (e.g., felsic lava such as rhyolite)
    - Lower silica content = lower viscosity
      (e.g., mafic lava such as basalt)

The nature of volcanic eruptions

- Dissolved gases
  - Gas content affects magma mobility
  - Gases expand within a magma as it nears the Earth’s surface due to decreasing pressure
  - The violence of an eruption is related to how easily gases escape from magma
- In summary
  - Basaltic lavas = mild eruptions
  - Rhyolitic or andesitic lavas = explosive eruptions

Materials extruded from a volcano

- Lava flows
  - Basaltic lavas exhibit fluid behavior
  - Types of basaltic flows
    - Pahoehoe lava (resembles a twisted or ropey texture)
    - Aa lava (rough, jagged blocky texture)
- Dissolved gases
  - 1% - 6% by weight
  - Mainly H_2O and CO_2

A pahoehoe lava flow

Aa lava flow

Materials extruded from a volcano

- Pyroclastic materials – “fire fragments”
  - Types of pyroclastic debris
    - Ash and dust - fine, glassy fragments
    - Pumice - porous rock from “frothy” lava
    - Cinders - pea-sized material
    - Lapilli - walnut-sized material
    - Particles larger than lapilli
      - Blocks - hardened or cooled lava
      - Bombs - ejected as hot lava

- Eruption of Kilauea Volcano in Hawaii

A volcanic bomb

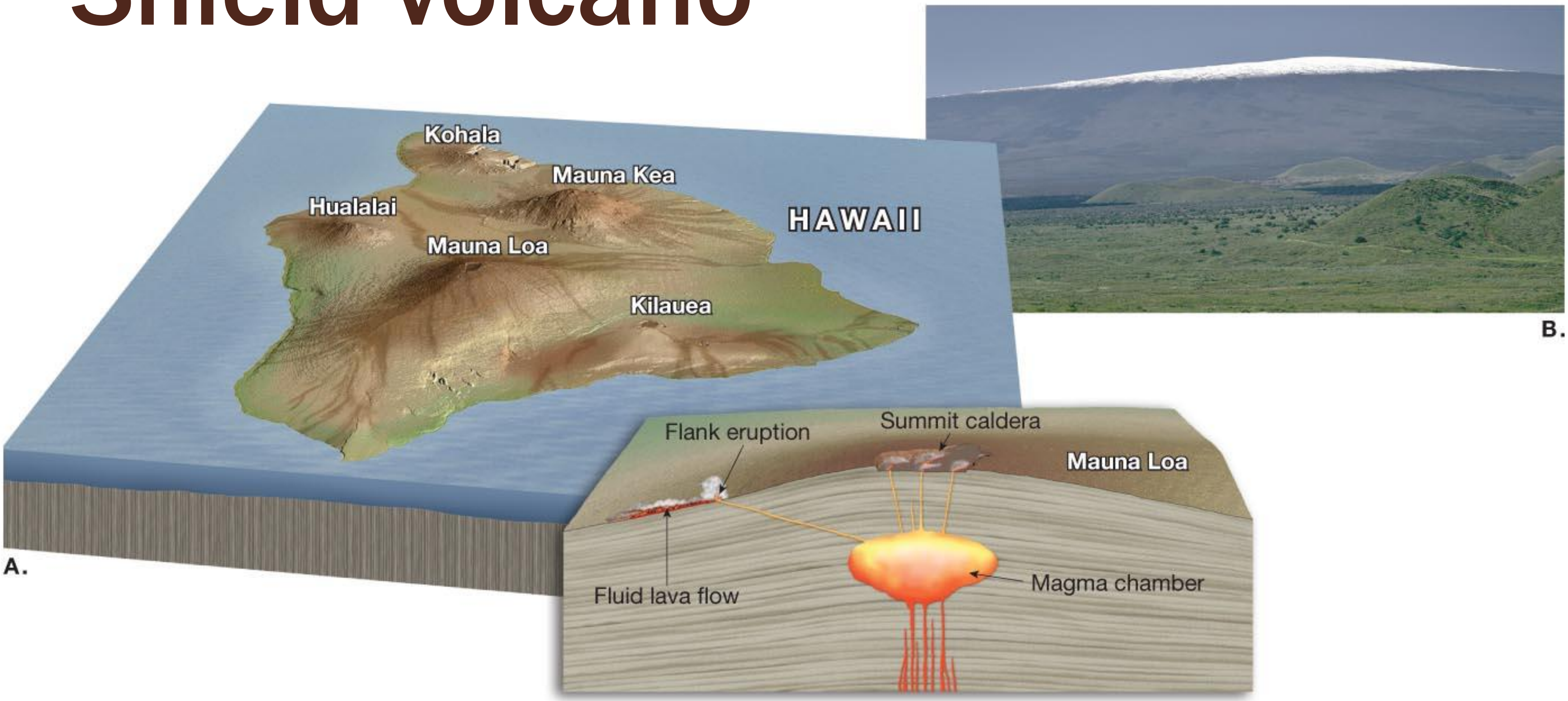
Volcanoes

- General features
  - Opening at the summit of a volcano
    - Crater - summit depression < 1 km diameter
    - Caldera - summit depression > 1 km diameter produced by collapse following a massive eruption
  - Vent – surface opening connected to the magma chamber
  - Fumarole – emit only gases and smoke

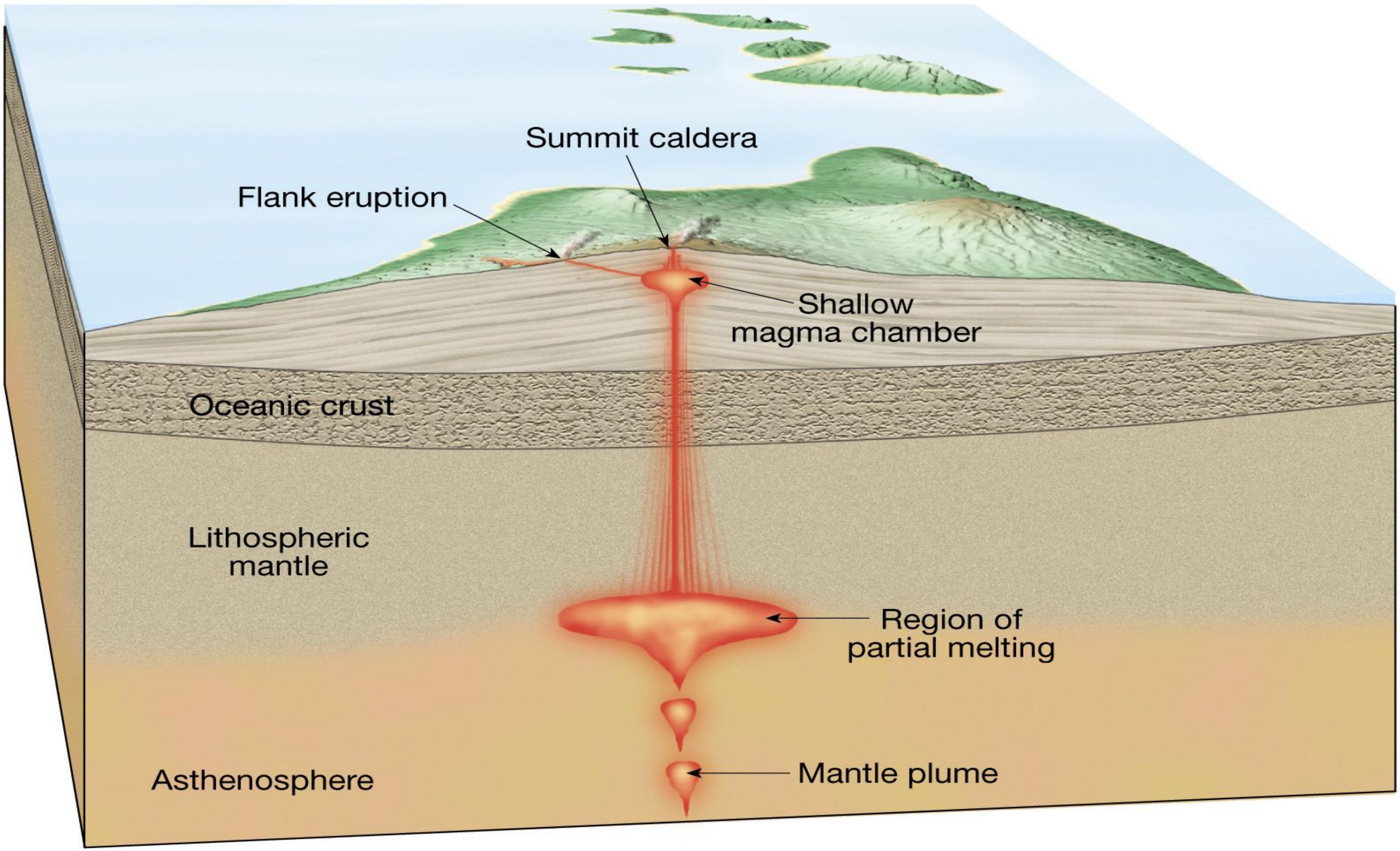
Volcanoes

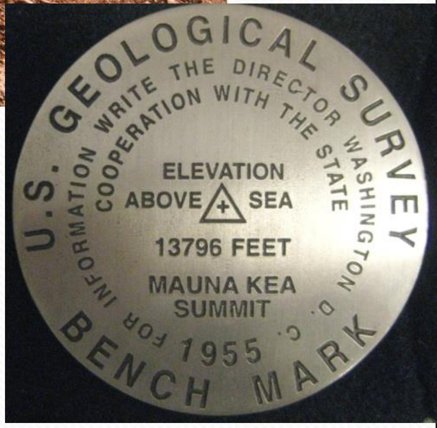
- Types of volcanoes
  - Shield volcano
    - Broad, slightly domed-shaped
    - Generally cover large areas
    - Produced by mild eruptions of large volumes of basaltic lava
    - Example = Mauna Loa on Hawaii

Shield volcano



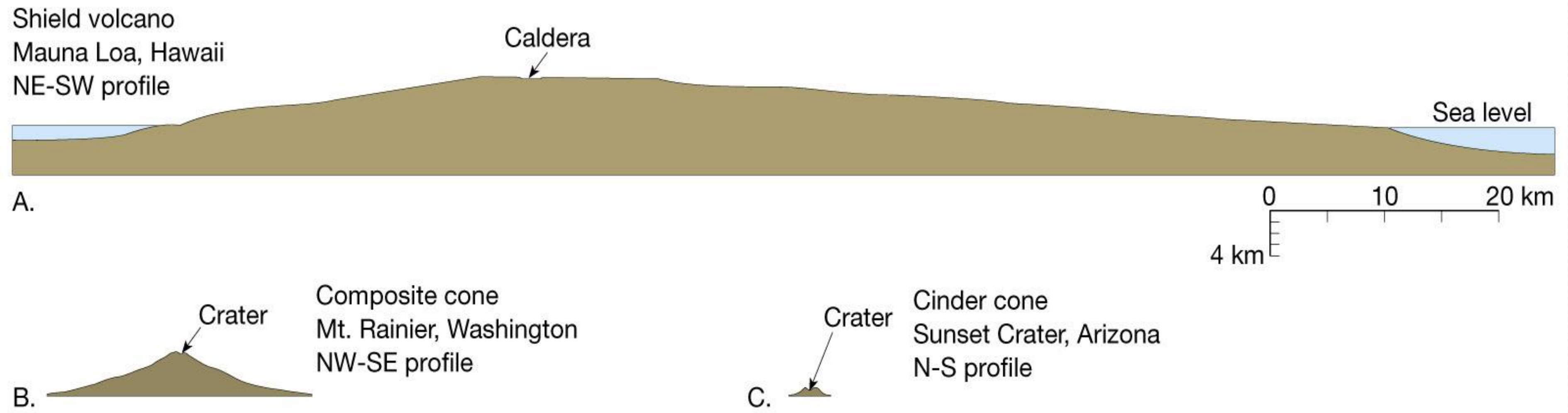
Anatomy of a shield volcano



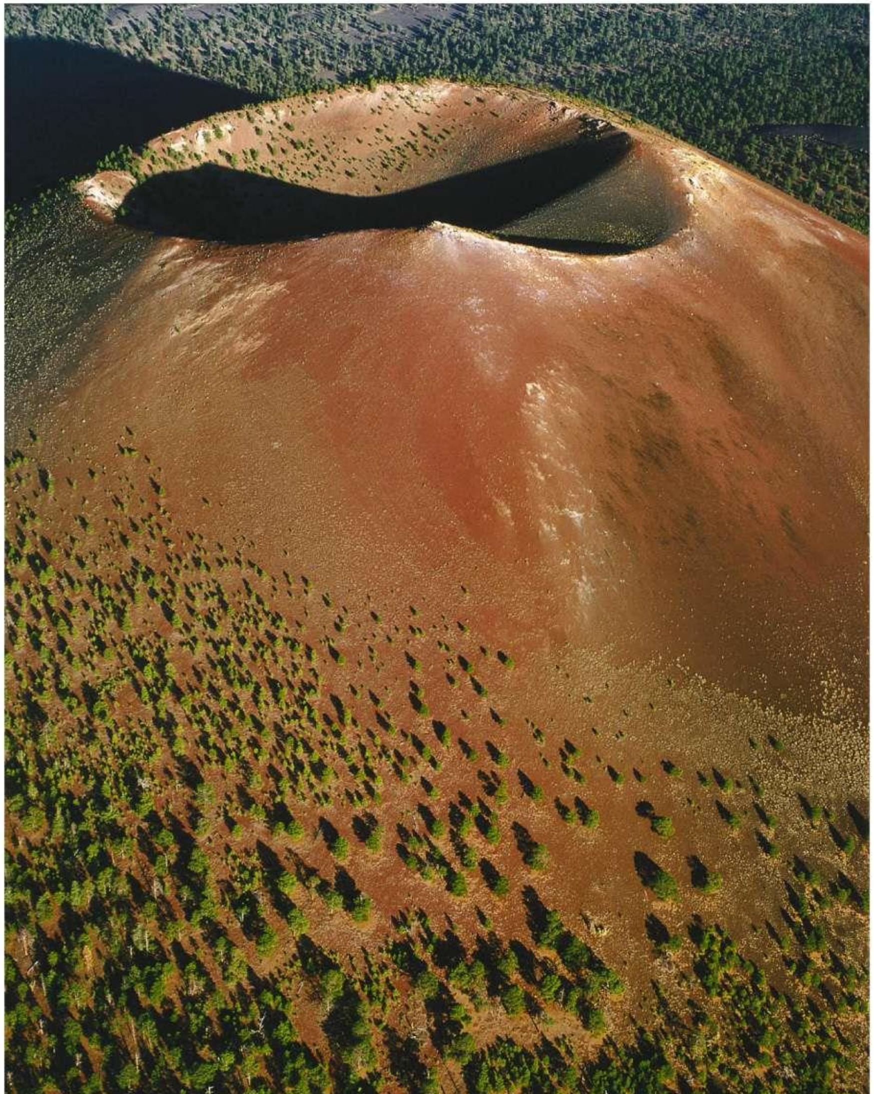


- Climb Mauna Kea (13,796 ft) shield volcano in Hawaii. Highest mountain on the planet from base to crest (almost 30,000 ft). This shows profile of Mauna Loa shield volcano, as seen from summit of Mauna Kea (benchmark at lower right).

Profiles of volcanic landforms

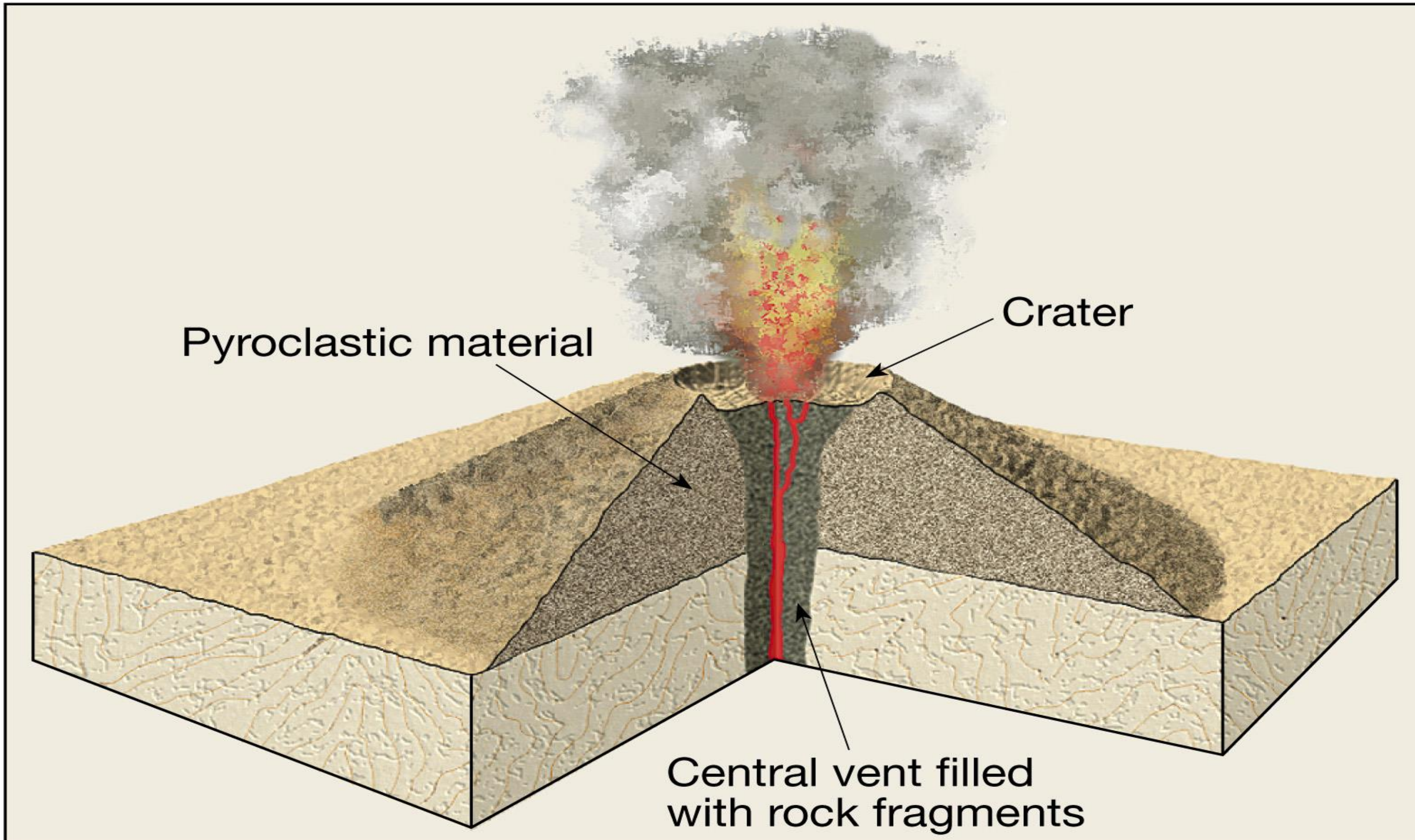


Volcanoes



- Cinder cones
  - Built from ejected lava (mainly cinder-sized) fragments
  - Steep slope angle
  - Small size
  - Frequently occur in groups

Cinder cone volcano

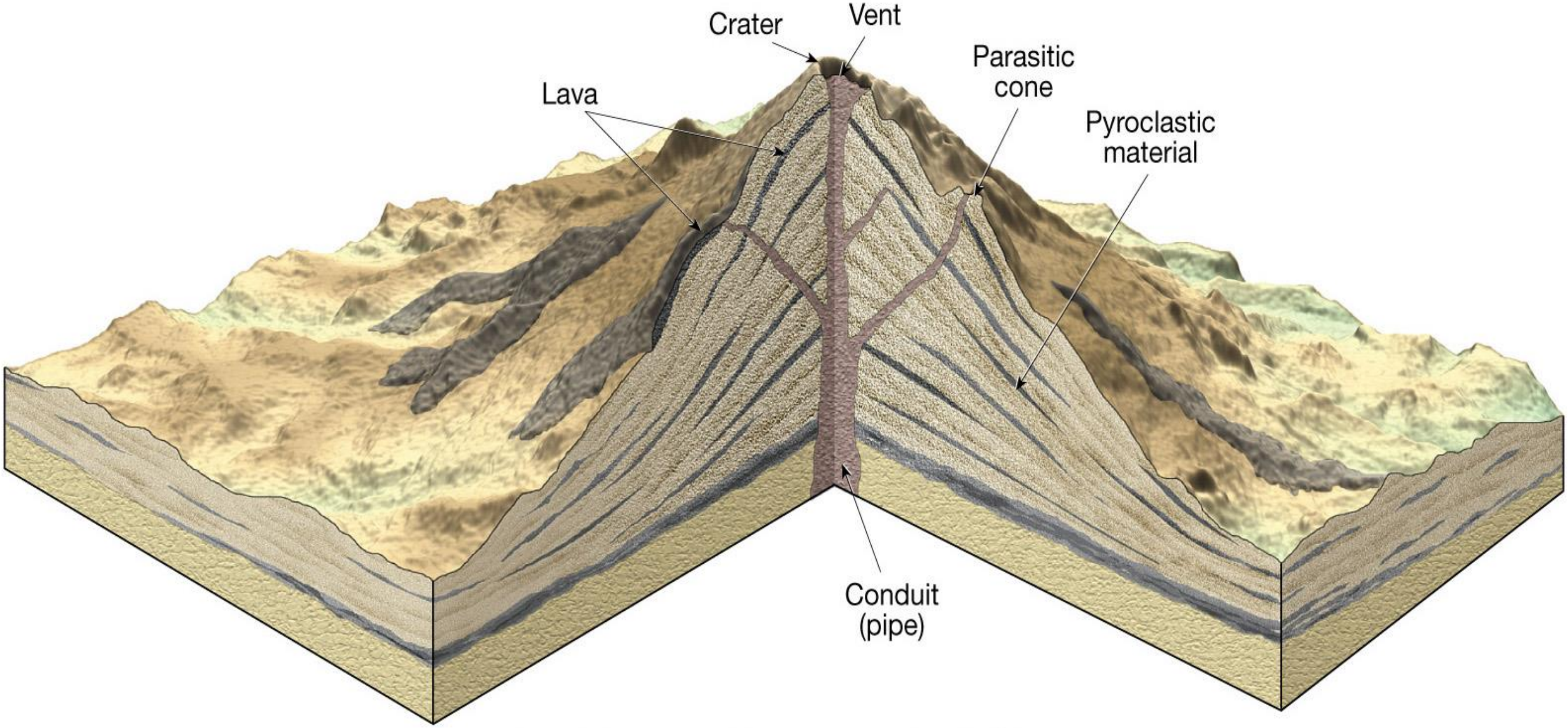


The Paricutin volcano in Mexico erupted in a corn field in 1943, burying the entire town.

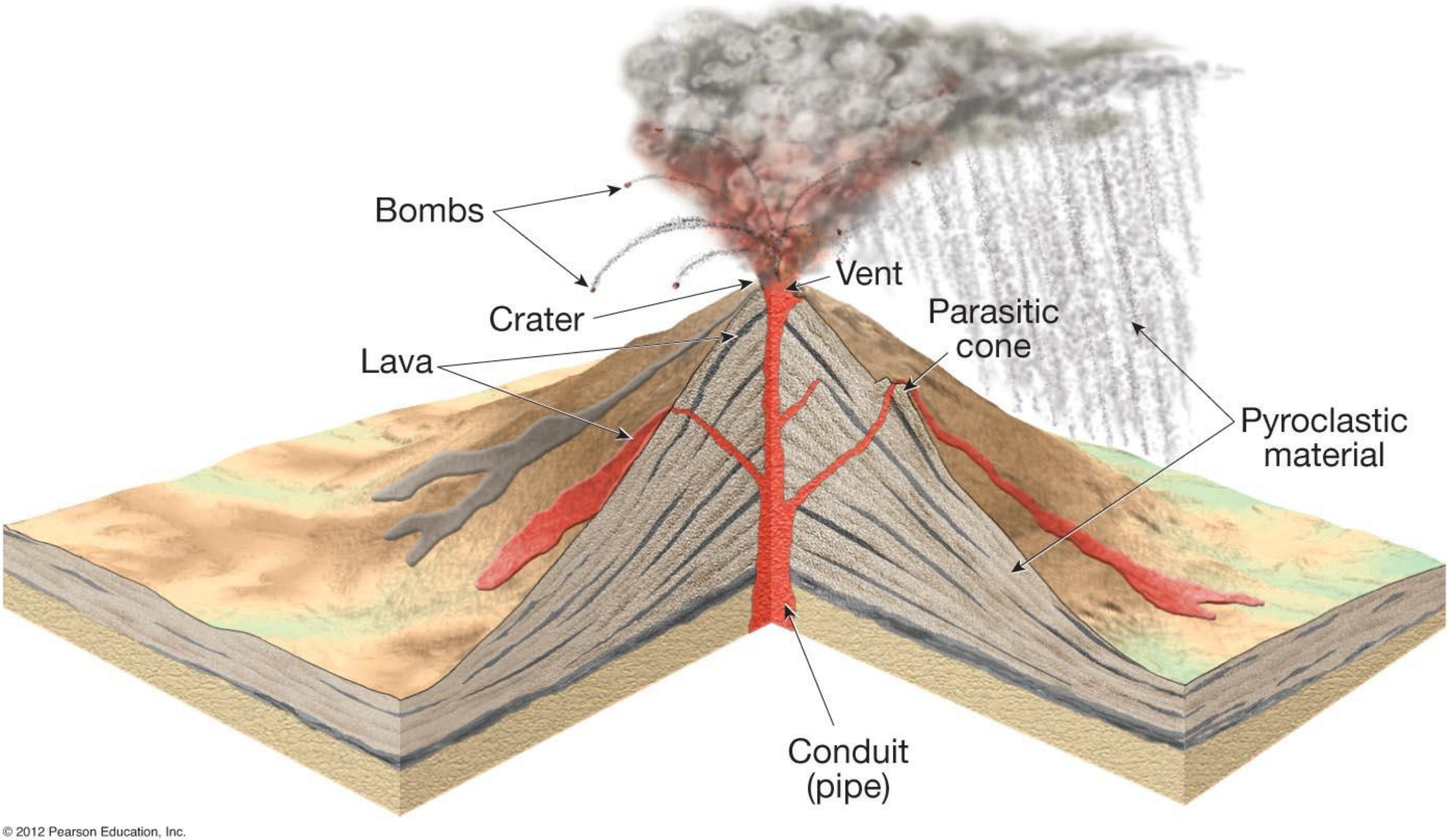
Volcanoes

- Composite cone (stratovolcano)
  - Most are located adjacent to the Pacific Ocean (e.g., Fujiyama, Mt. St. Helens)
  - Large, classic-shaped volcano (1000's of ft. high and several miles wide at base)
  - Composed of interbedded lava flows and pyroclastic debris
  - Most violent type of activity (e.g., Mt. Vesuvius)
  - Lahar: mudflows

Anatomy of a composite volcano

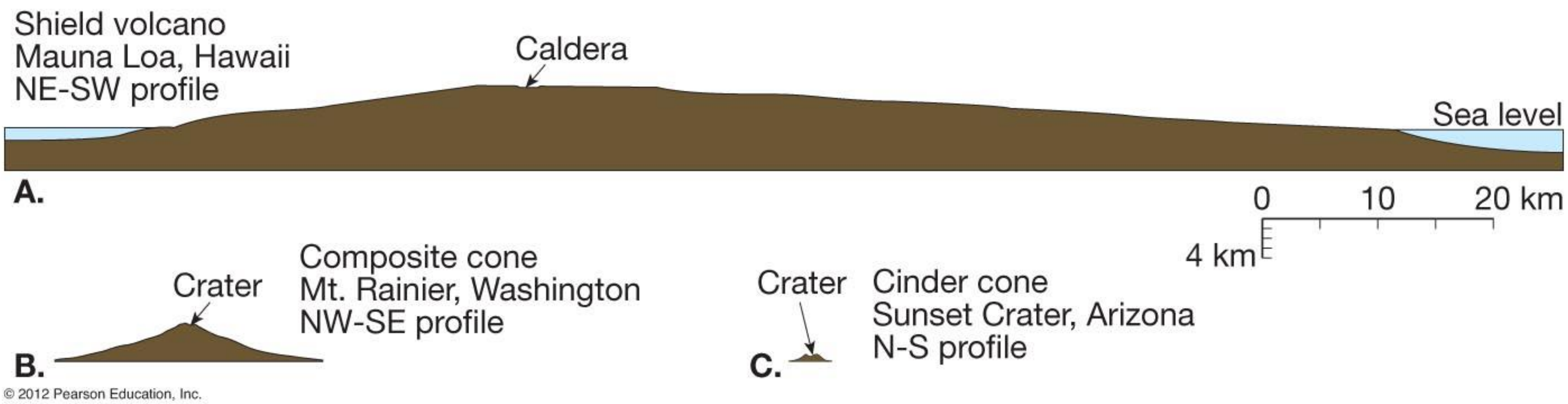


Composite volcano

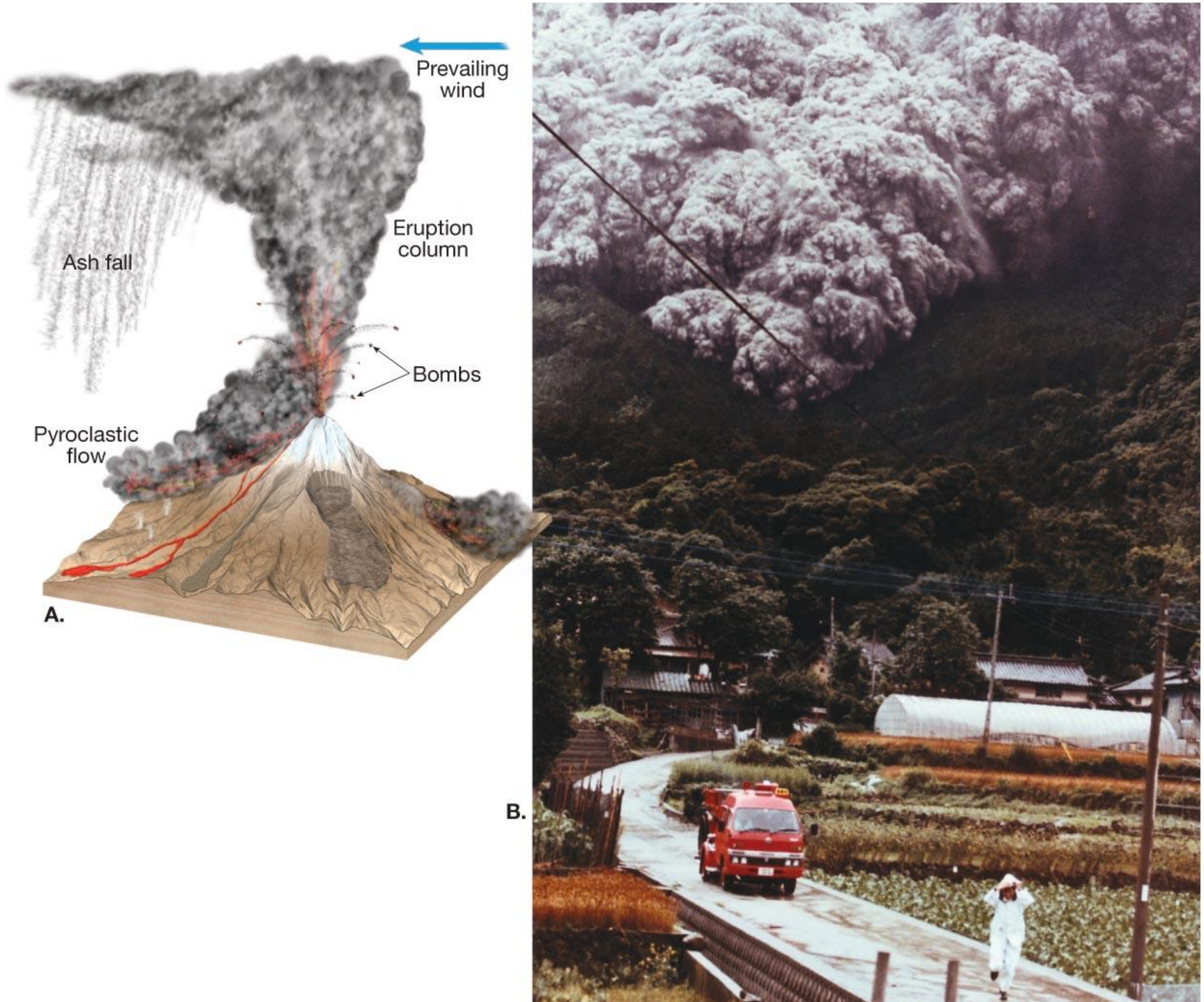


Mt. Fuji in Japan – a classic composite volcano

A size comparison of the three types of volcanoes



Pyroclastic flows

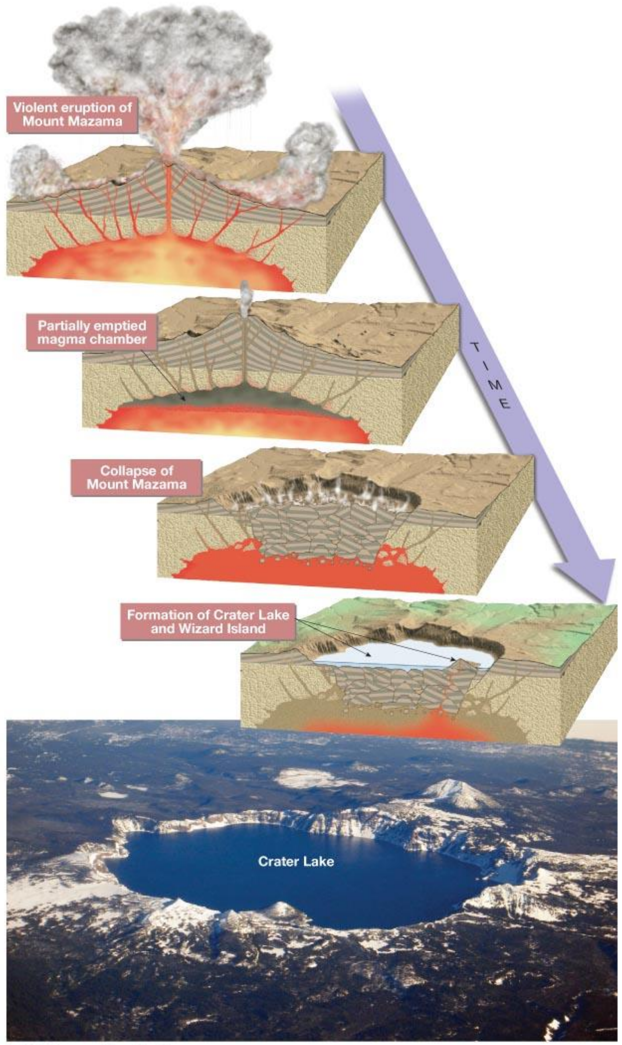


Lahar near Mt. St. Helens

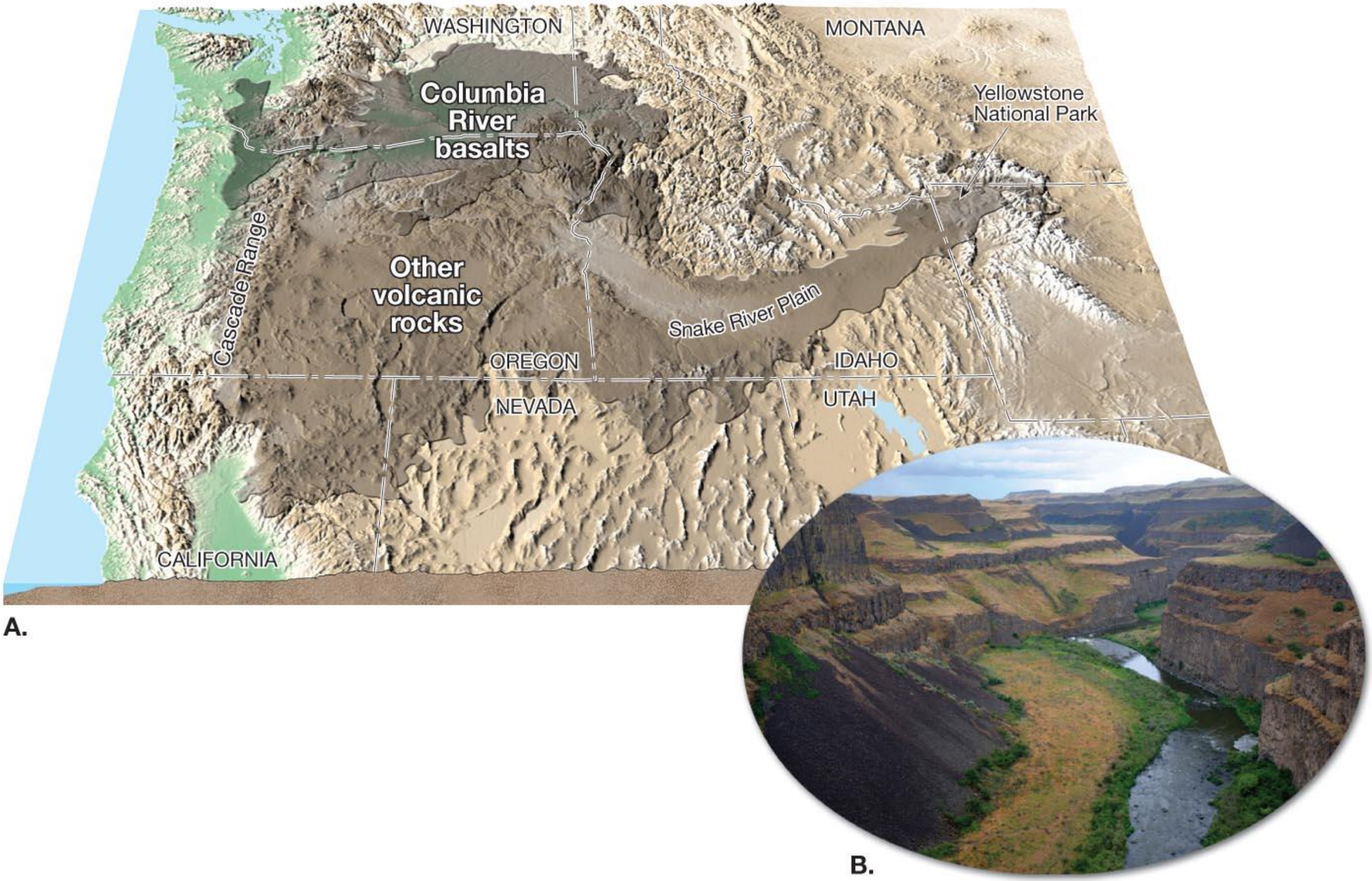
Other volcanic landforms

- Calderas
  - Steep walled depression at the summit
  - Formed by collapse
  - Nearly circular
  - Size exceeds one kilometer in diameter
- Fissure eruptions and lava plateaus
  - Fluid basaltic lava extruded from crustal fractures called fissures
  - e.g., Columbia Plateau

Crater Lake, Oregon is a good example of a caldera



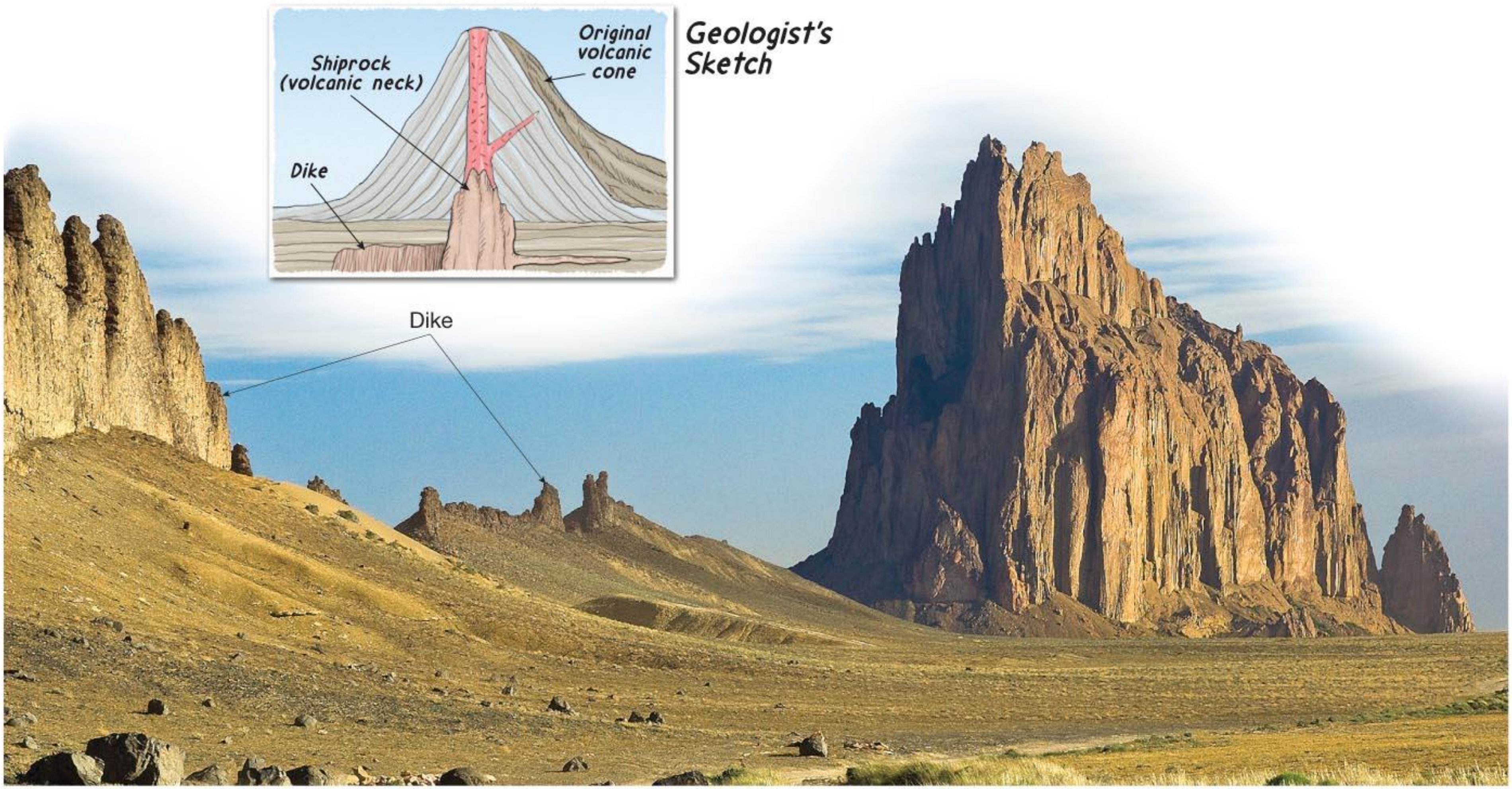
The Columbia River basalts



Other volcanic landforms

- Volcanic pipes and necks
  - Pipes are short conduits that connect a magma chamber to the surface
  - Volcanic necks (e.g., Shiprock, New Mexico) are resistant vents left standing after erosion has removed the volcanic cone

Shiprock, New Mexico – a volcanic neck



Intrusive igneous activity

- Most magma is emplaced at depth
- An underground igneous body is called a pluton
- Plutons are classified according to
  - Shape
    - Tabular (sheet-like)
    - Massive

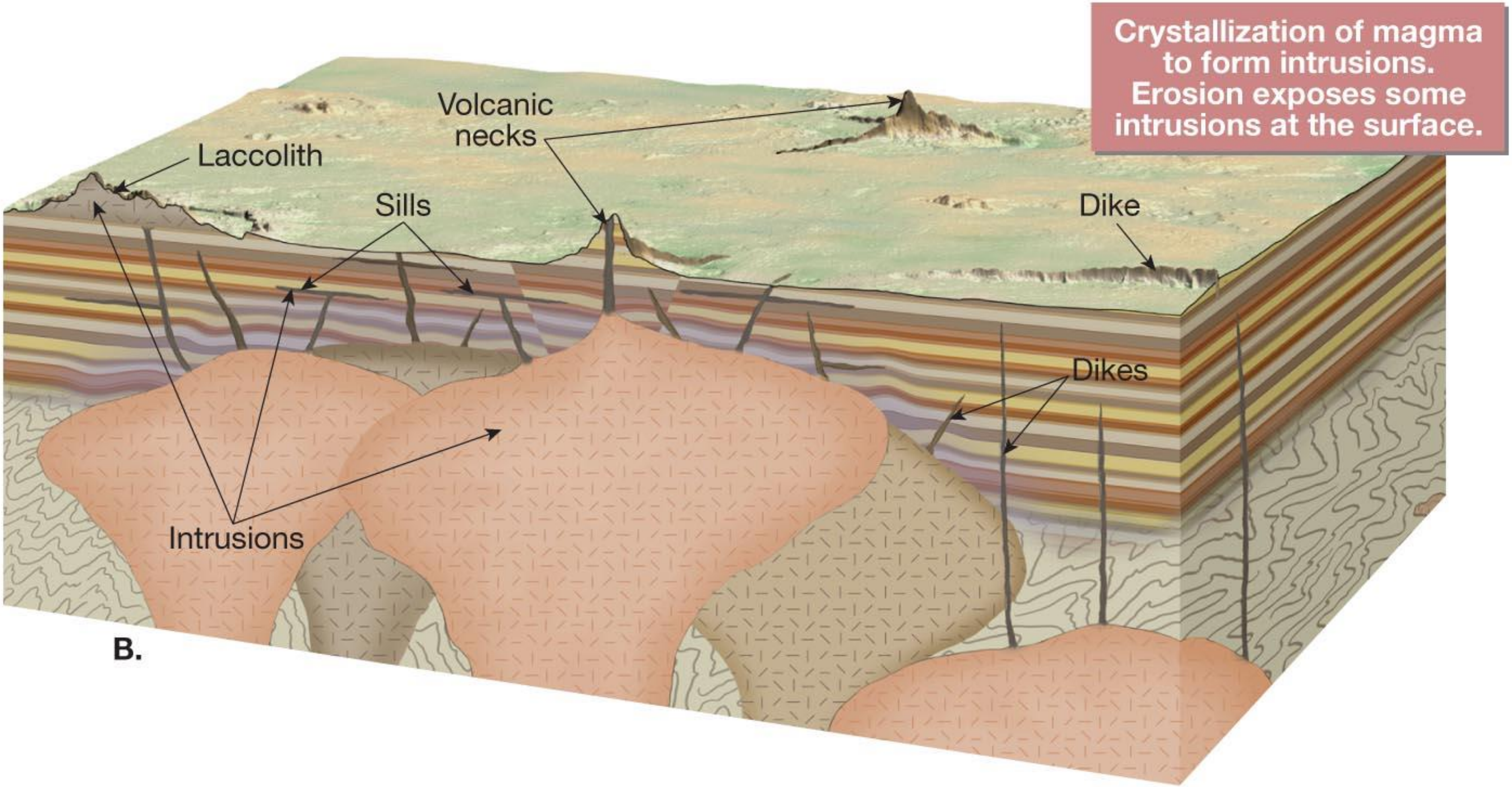
Intrusive igneous activity

- Plutons are classified according to
  - Orientation with respect to the host (surrounding) rock
    - Discordant – cuts across existing structures
    - Concordant – parallel to features such as sedimentary strata

Intrusive igneous activity

- Types of igneous intrusive features
  - Dike, a tabular, discordant pluton
  - Sill, a tabular, concordant pluton
    - e.g., Palisades Sill, NY
    - Resemble buried lava flows
    - May exhibit columnar joints
  - Laccolith
    - Similar to a sill

Intrusive igneous structures exposed by erosion

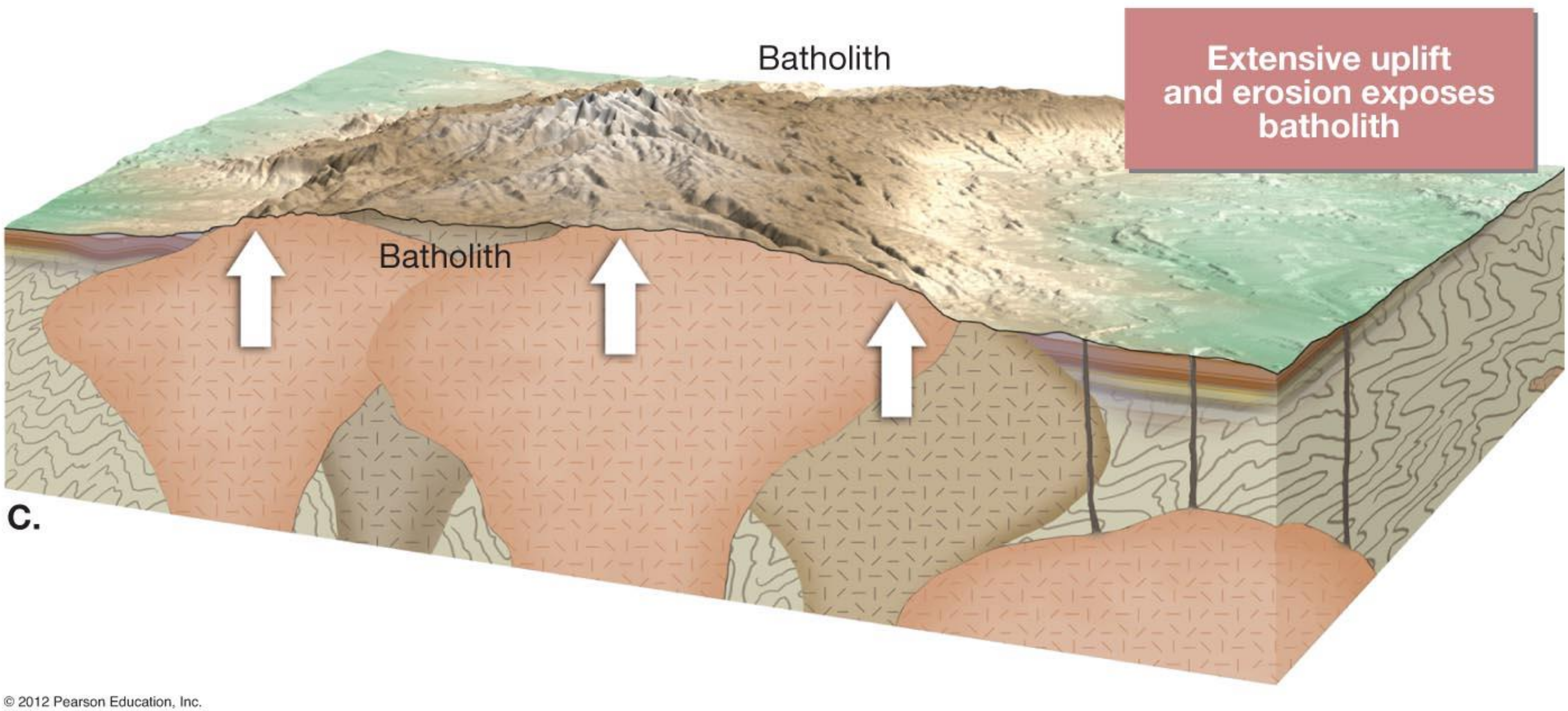


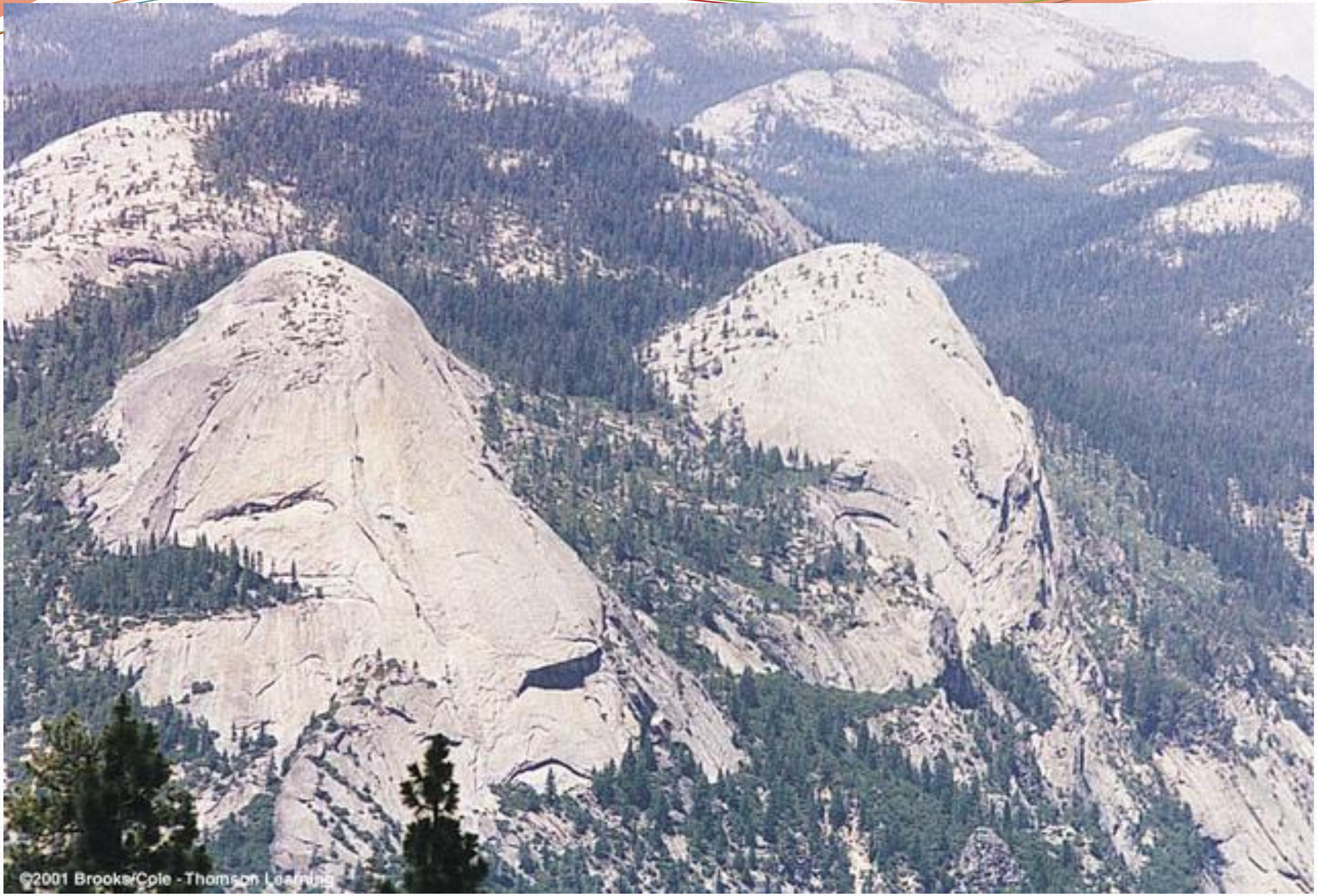
A sill in the Salt River Canyon, Arizona

Intrusive igneous activity

- Types of igneous intrusive features
  - Laccolith
    - Lens shaped mass
    - Arches overlying strata upward
  - Batholith
    - Largest intrusive body
    - Often occur in groups
    - Surface exposure 100+ square kilometers (smaller bodies are termed stocks)
    - Frequently form the cores of mountains

A batholith exposed by erosion

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Origin of magma

- Magma originates when essentially solid rock, located in the crust and upper mantle, melts
- Factors that influence the generation of magma from solid rock
  - Role of heat
    - Earth's natural temperature increases with depth (geothermal gradient) is not sufficient to melt rock at the lower crust and upper mantle

Origin of magma

- Factors that influence the generation of magma from solid rock
  - Role of heat
    - Additional heat is generated by
      - Friction in subduction zones
      - Crustal rocks heated during subduction
      - Rising, hot mantle rocks

Origin of magma

- Factors that influence the generation of magma from solid rock
  - Role of pressure
    - Increase in confining pressure causes an increase in melting temperature
    - Drop in confining pressure can cause decompression melting
      - Lowers the melting temperature
      - Occurs when rock ascends

Origin of magma

- Factors that influence the generation of magma from solid rock
  - Role of volatiles
    - Primarily water
    - Cause rock to melt at a lower temperature
    - Play an important role in subducting ocean plates

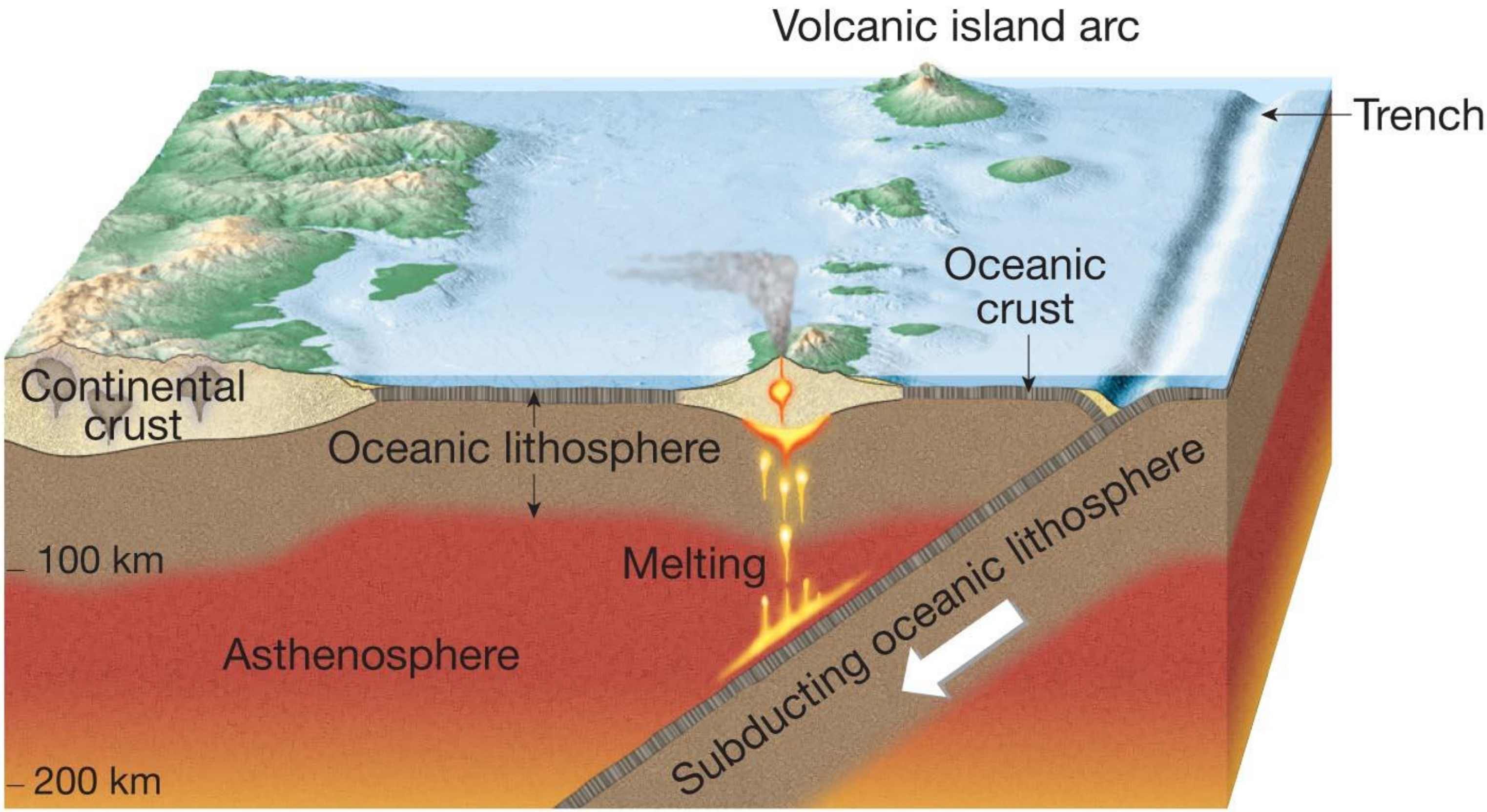
Origin of magma

- Factors that influence the generation of magma from solid rock
  - Partial melting
    - Igneous rocks are mixtures of minerals
    - Melting occurs over a range of temperatures
    - Produces a magma with a higher silica content than the original rock

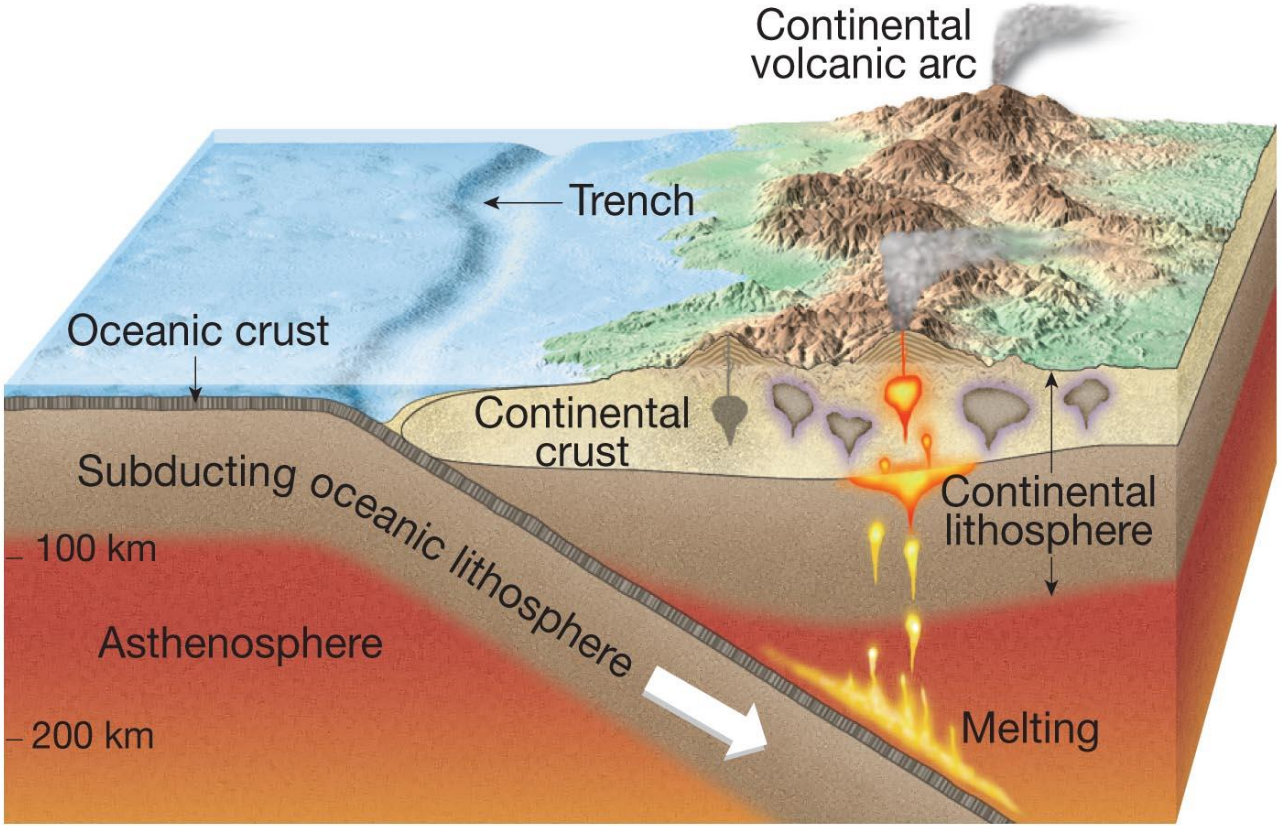
Locations of some of Earth's major volcanoes

Plate tectonics and igneous activity

- Plate motions provide the mechanism by which mantle rocks melt to form magma
  - Convergent plate boundaries
    - Descending plate partially melts
    - Magma slowly rises upward
    - Rising magma can form
      - Volcanic island arcs in an ocean (Aleutian Islands)
      - Continental volcanic arcs (Andes Mountains)


Volcanic island arc
Trench
Oceanic crust
Continental crust
Oceanic lithosphere
100 km
Melting
Asthenosphere
Subducting oceanic lithosphere
200 km

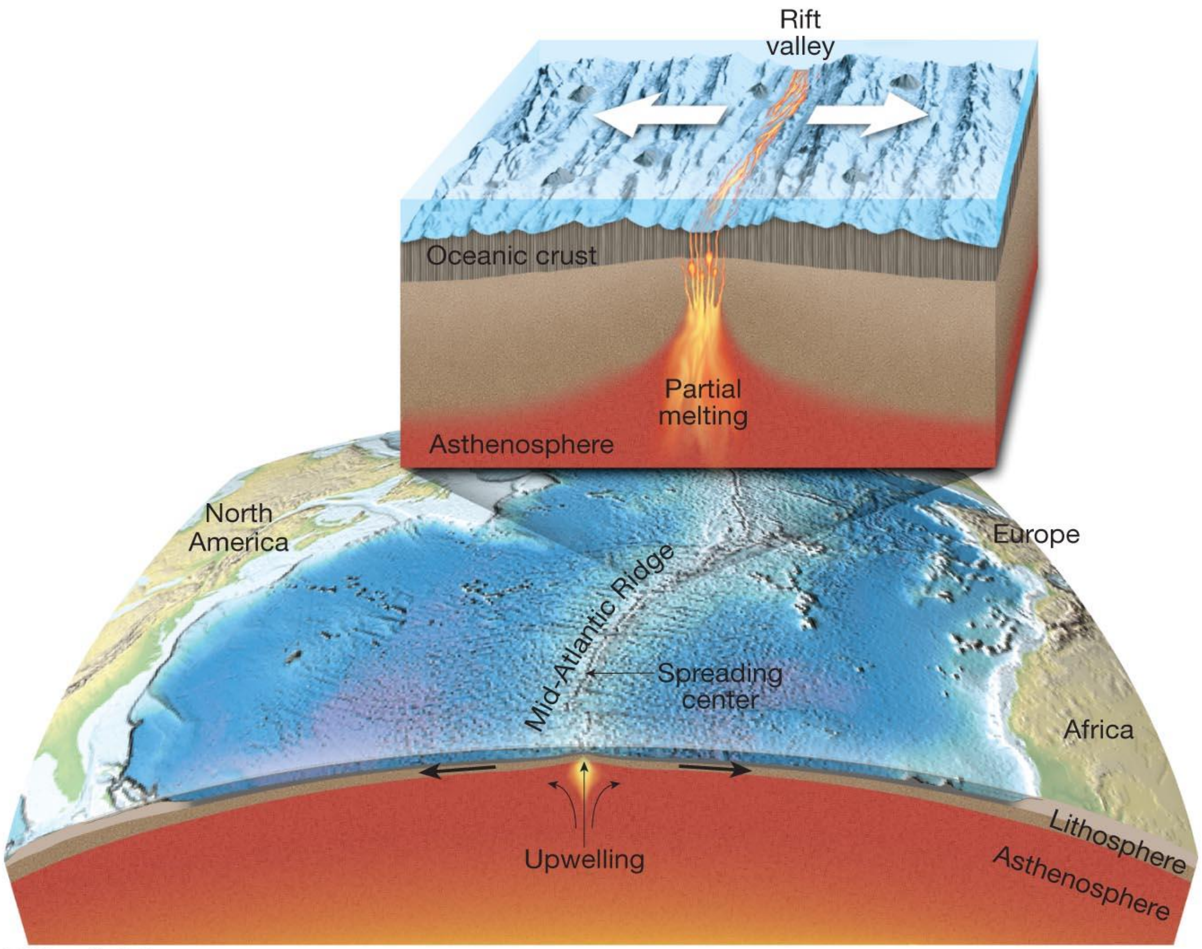
A.


Continental
volcanic arc
Trench
Oceanic crust
Continental
crust
Subducting oceanic lithosphere
Continental
lithosphere
100 km
Asthenosphere
200 km
Melting

A.

Plate tectonics and igneous activity

- Plate motions provide the mechanism by which mantle rocks melt to form magma
  - Divergent plate boundaries
    - The greatest volume of volcanic rock is produced along the oceanic ridge system
      - Lithosphere pulls apart
      - Less pressure on underlying rocks
      - Partial melting occurs
      - Large quantities of fluid basaltic magma are produced



Rift valley
Oceanic crust
Partial melting
Asthenosphere
North America
Europe
Mid-Atlantic Ridge
Spreading center
Africa
Upwelling
Lithosphere
Asthenosphere

Plate tectonics and igneous activity

- Plate motions provide the mechanism by which mantle rocks melt to form magma
  - Intraplate igneous activity
    - Activity within a rigid plate
    - Plumes of hot mantle material rise
    - Form localized volcanic regions called hot spots
    - Examples include the Hawaiian Islands and the Columbia River Plateau in the northwestern United States

Hot spot

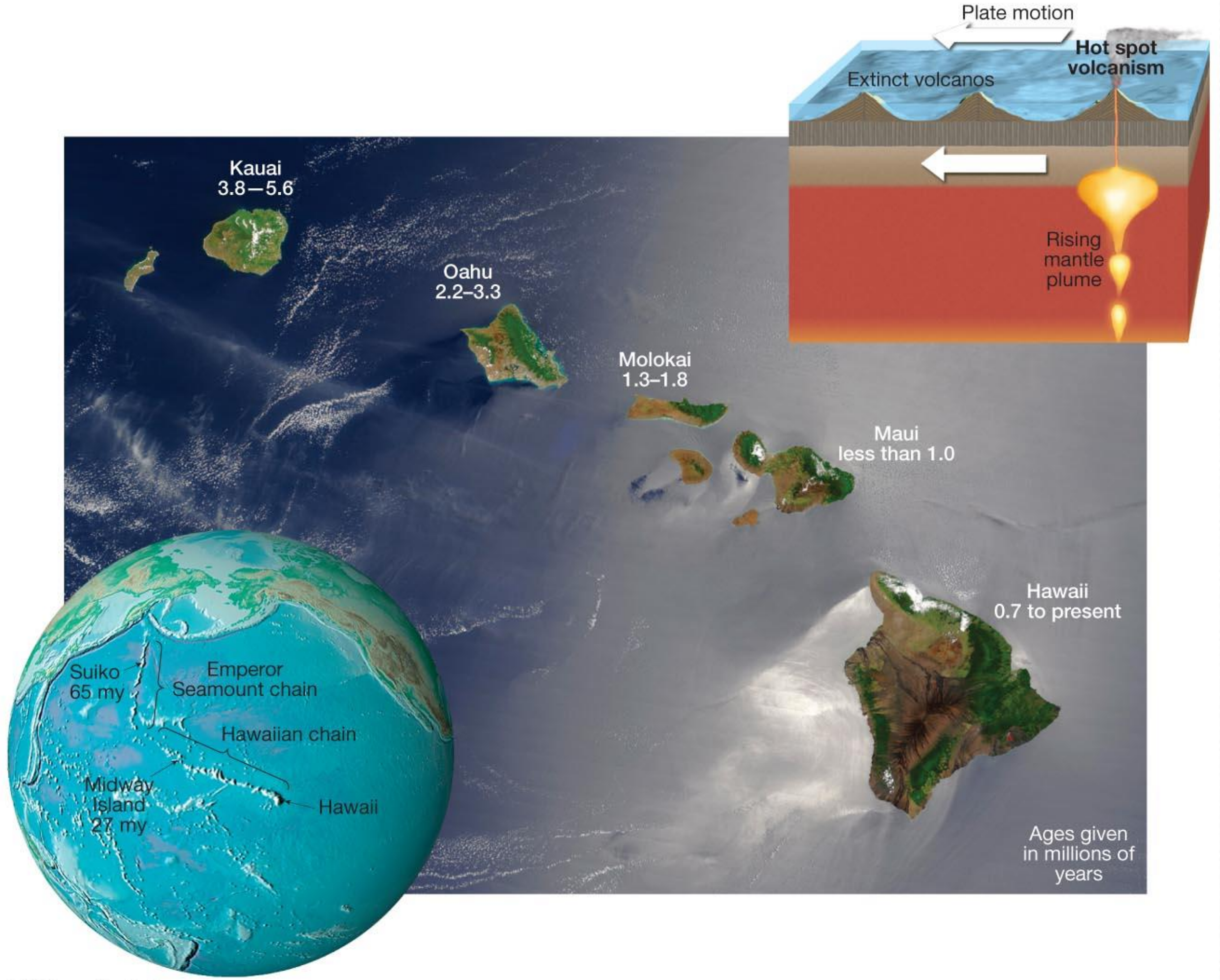


Plate motion
Hot spot volcanism
Extinct volcanos
Rising mantle plume
Kauai 3.8—5.6
Oahu 2.2–3.3
Molokai 1.3–1.8
Maui less than 1.0
Hawaii 0.7 to present
Ages given in millions of years
Suiko 65 my
Emperor Seamount chain
Hawaiian chain
Midway Island 27 my
Hawaii

Crustal Deformation and Mountain Building

Earth Science, 13e

Chapter 10

Deformation

- Deformation is a general term that refers to all changes in the original form and/or size of a rock body
- Most crustal deformation occurs along plate margins
- Factors that influence the strength of a rock
  - Temperature and confining pressure
  - Rock type
  - Time

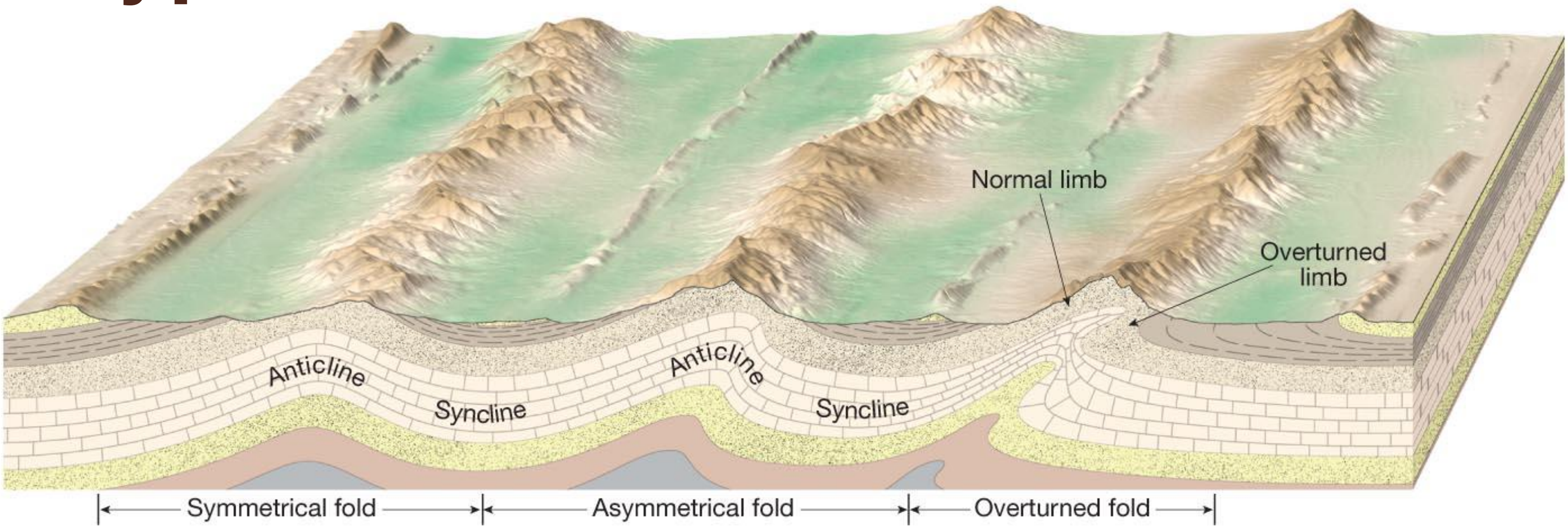
Folds

- Rocks bent into a series of waves
- Most folds result from compressional forces which shorten and thicken the crust
- Types of folds
  - Anticline – upfolded, or arched, rock layers
  - Syncline – downfolded rock layers

Folds

- Types of folds
  - Anticlines and synclines can be
    - Symmetrical – limbs are mirror images
    - Asymmetrical – limbs are not mirror images
    - Overturned – one limb is tilted beyond the vertical
  - Where folds die out they are said to be plunging

Types of fold strata

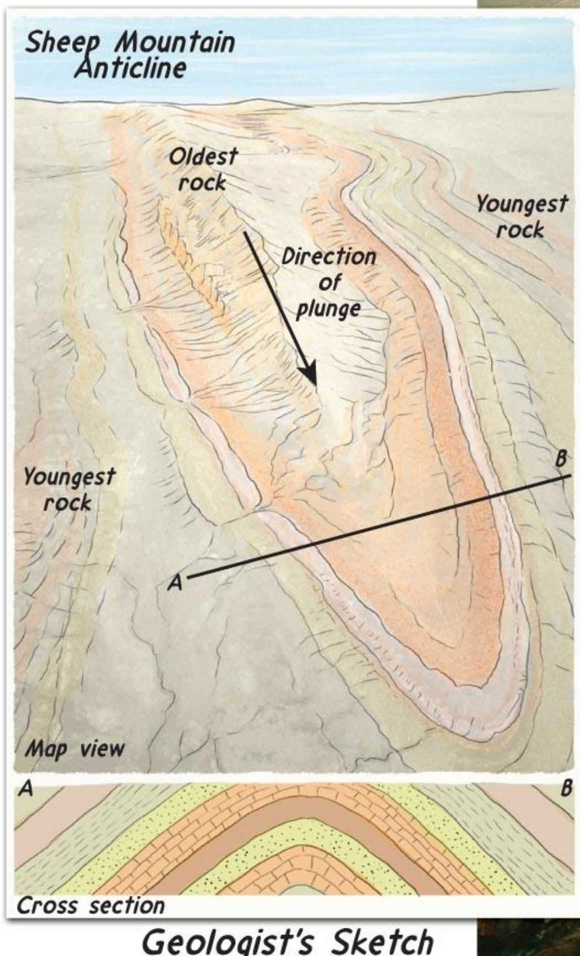


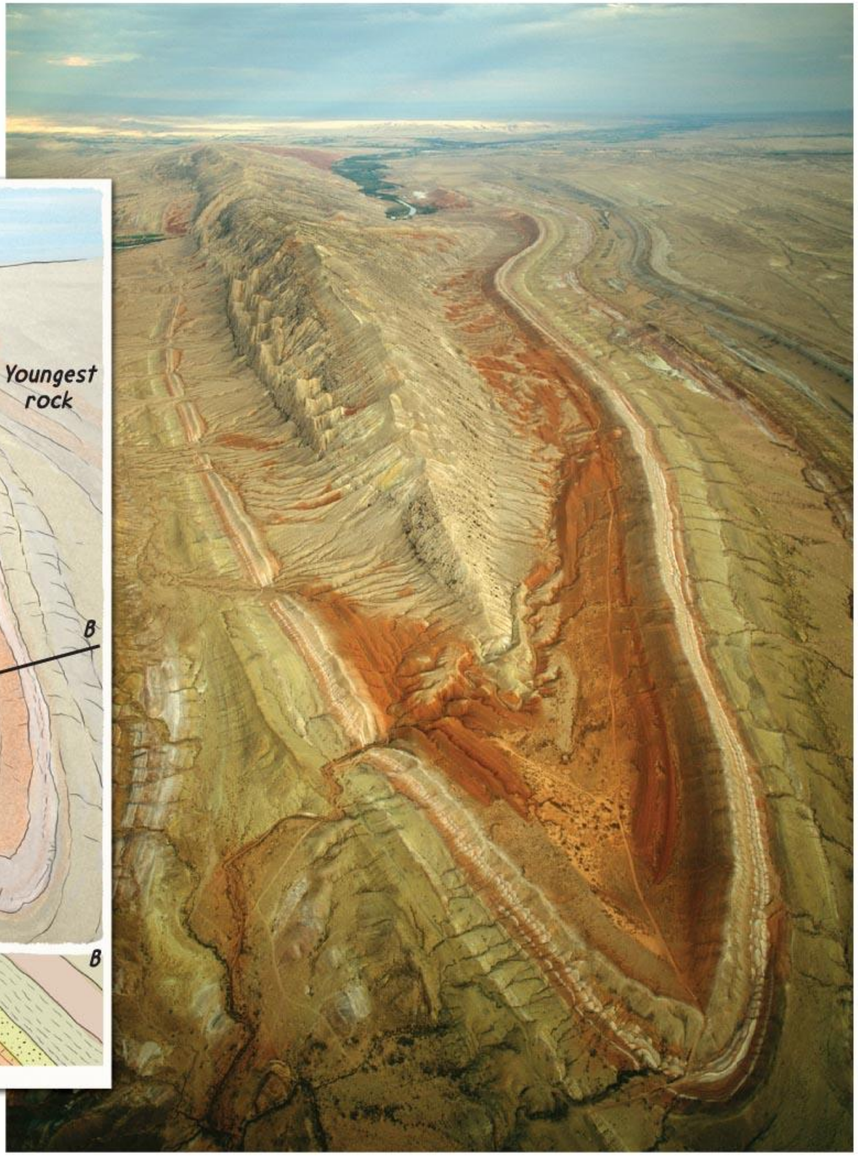
Anticline and syncline

A.

B.

Plunging anticline – Wyoming

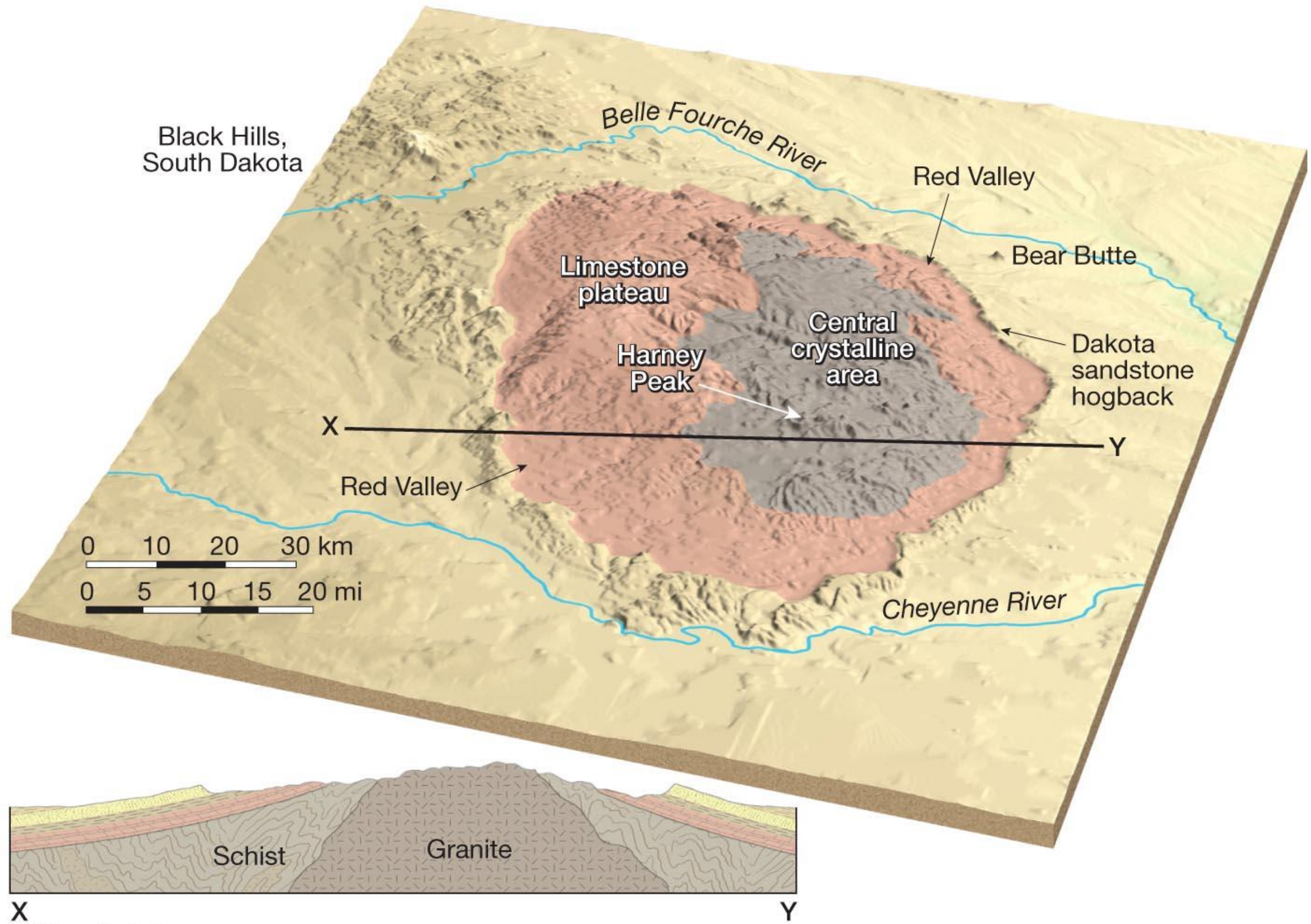




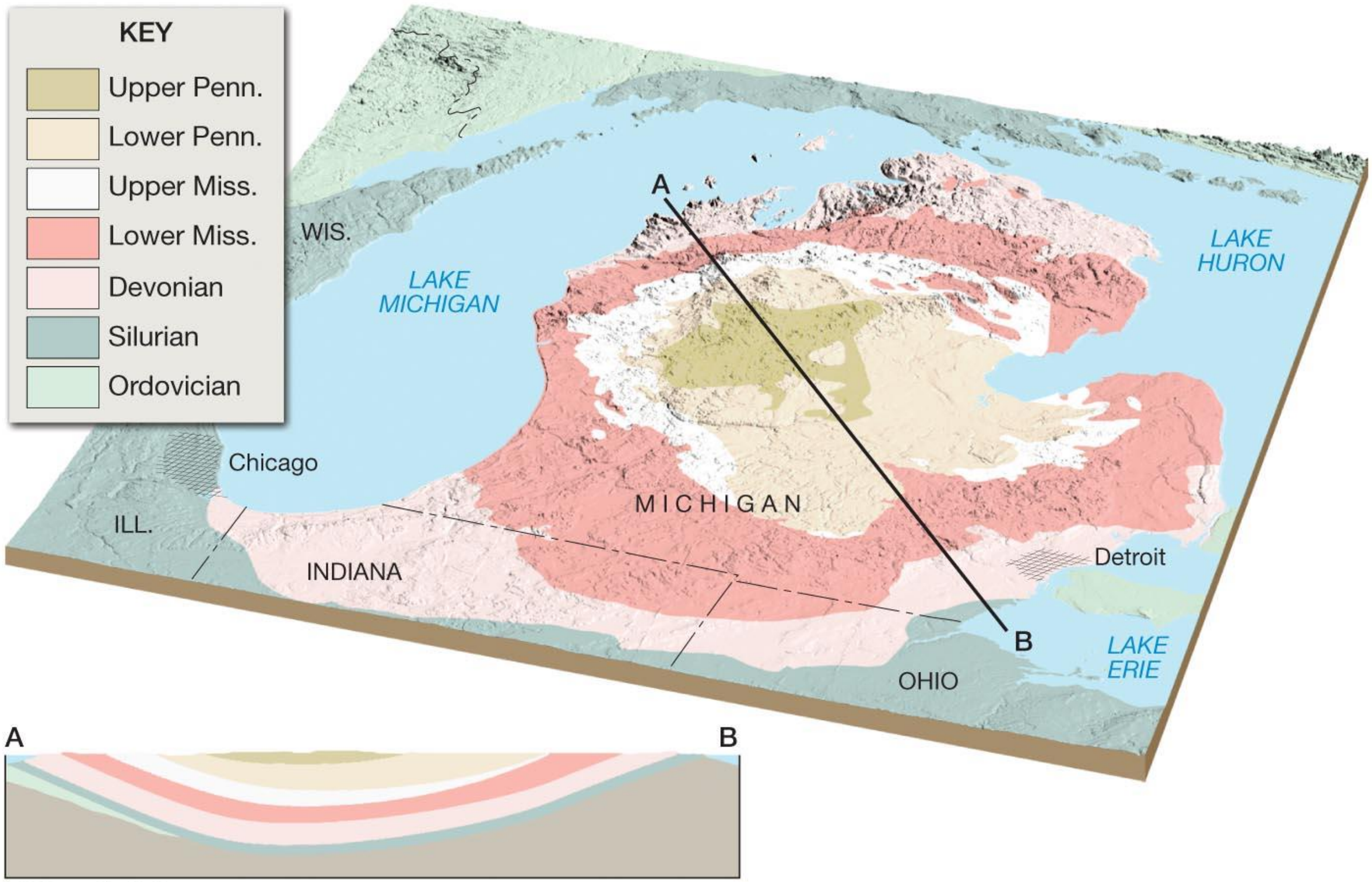
Folds

- Types of folds
  - Other types of folds
    - Dome
      - Circular, or slightly elongated
      - Upwarped displacement of rocks
      - Oldest rocks in core
    - Basin
      - Circular, or slightly elongated
      - Downwarped displacement of rocks
      - Youngest rocks in core

The Black Hills of South Dakota are a large dome



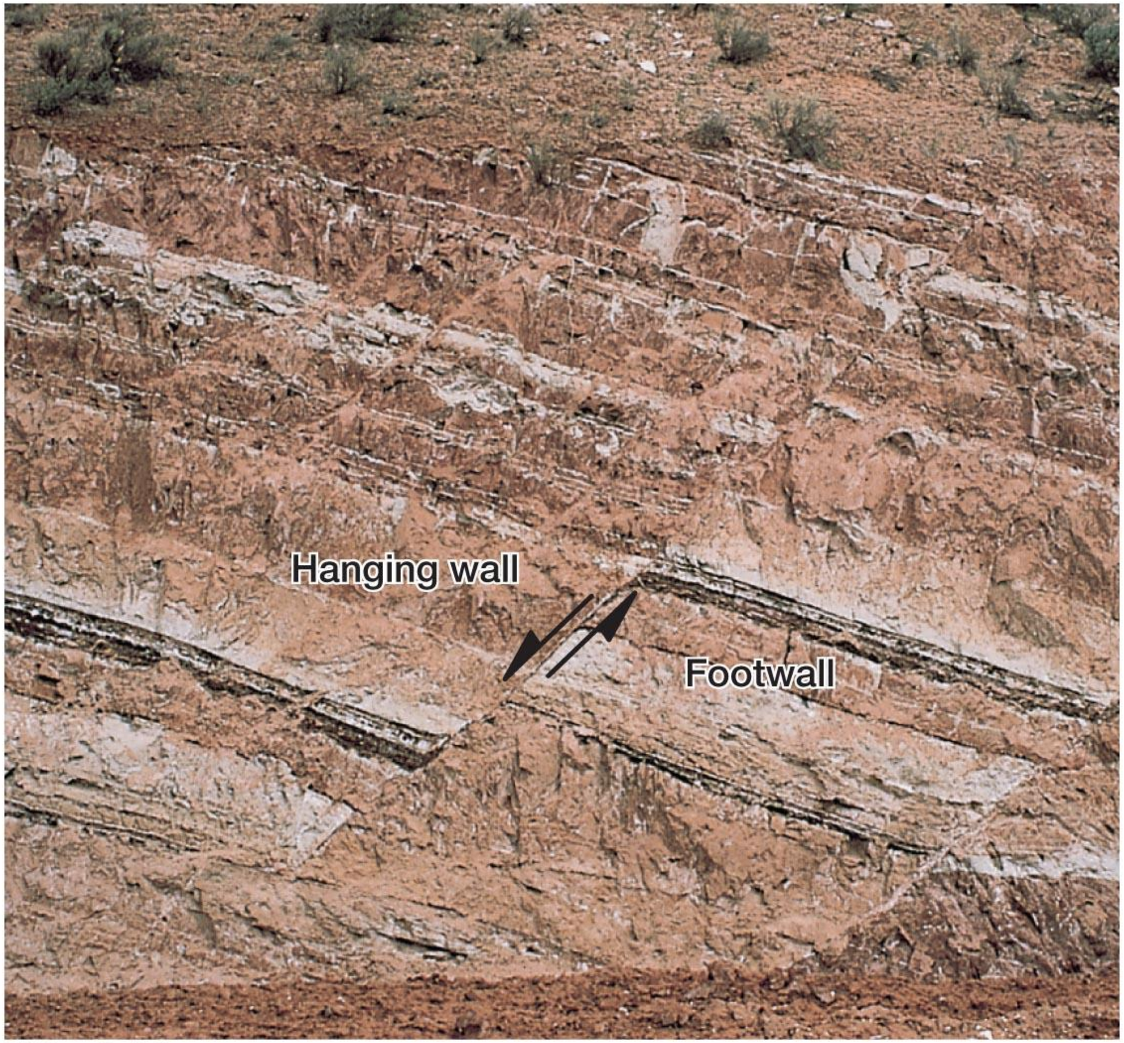
The bedrock geology of the Michigan Basin



Faults

- Faults are fractures (breaks) in rocks along which appreciable displacement has taken place
- Types of faults
  - Dip-slip fault
    - Movement along the inclination (dip) of fault plane
    - Parts of a dip-slip fault
      - Hanging wall – the rock above the fault surface
      - Footwall – the rock below the fault surface

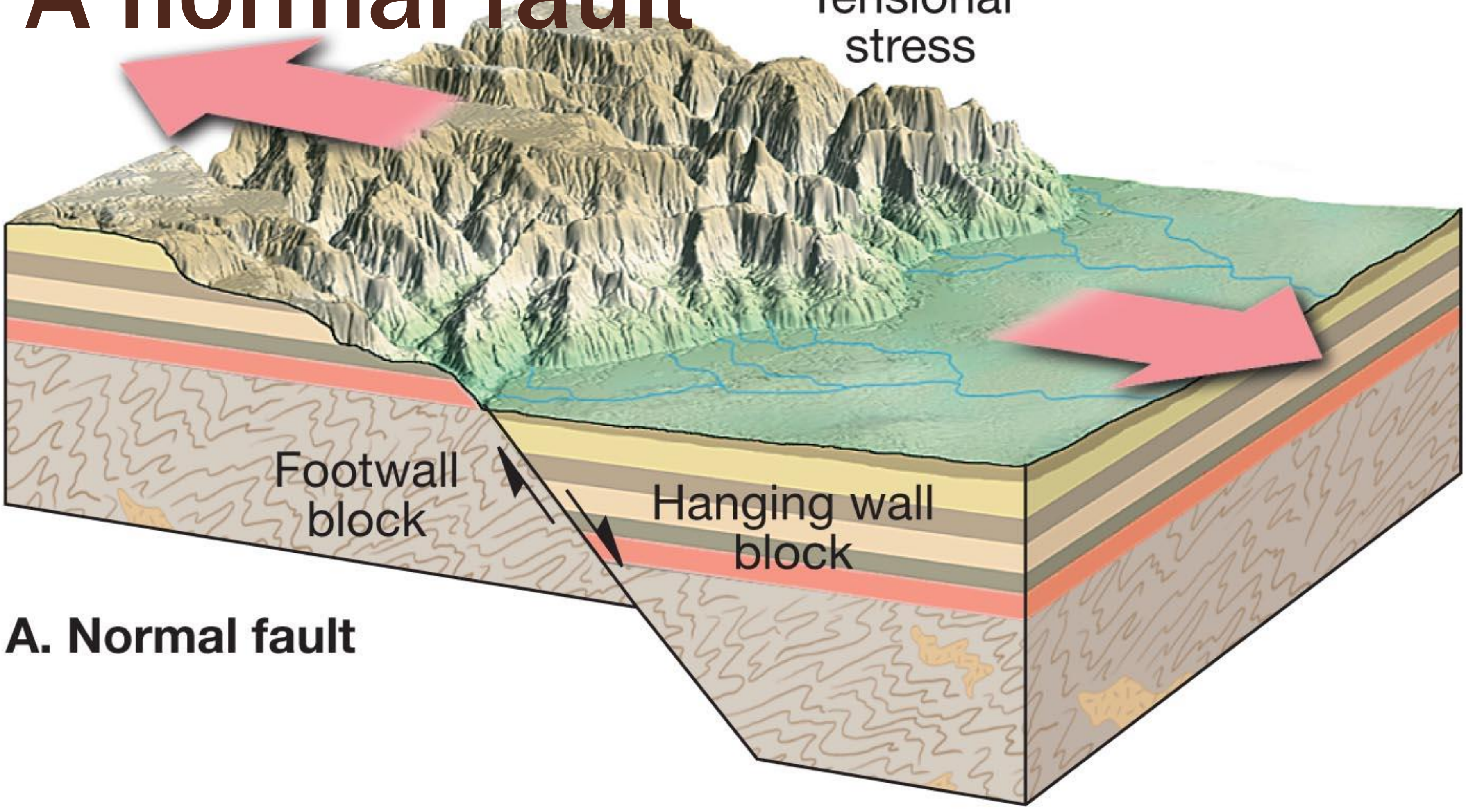
Concept of hanging wall and footwall along a fault



Faults

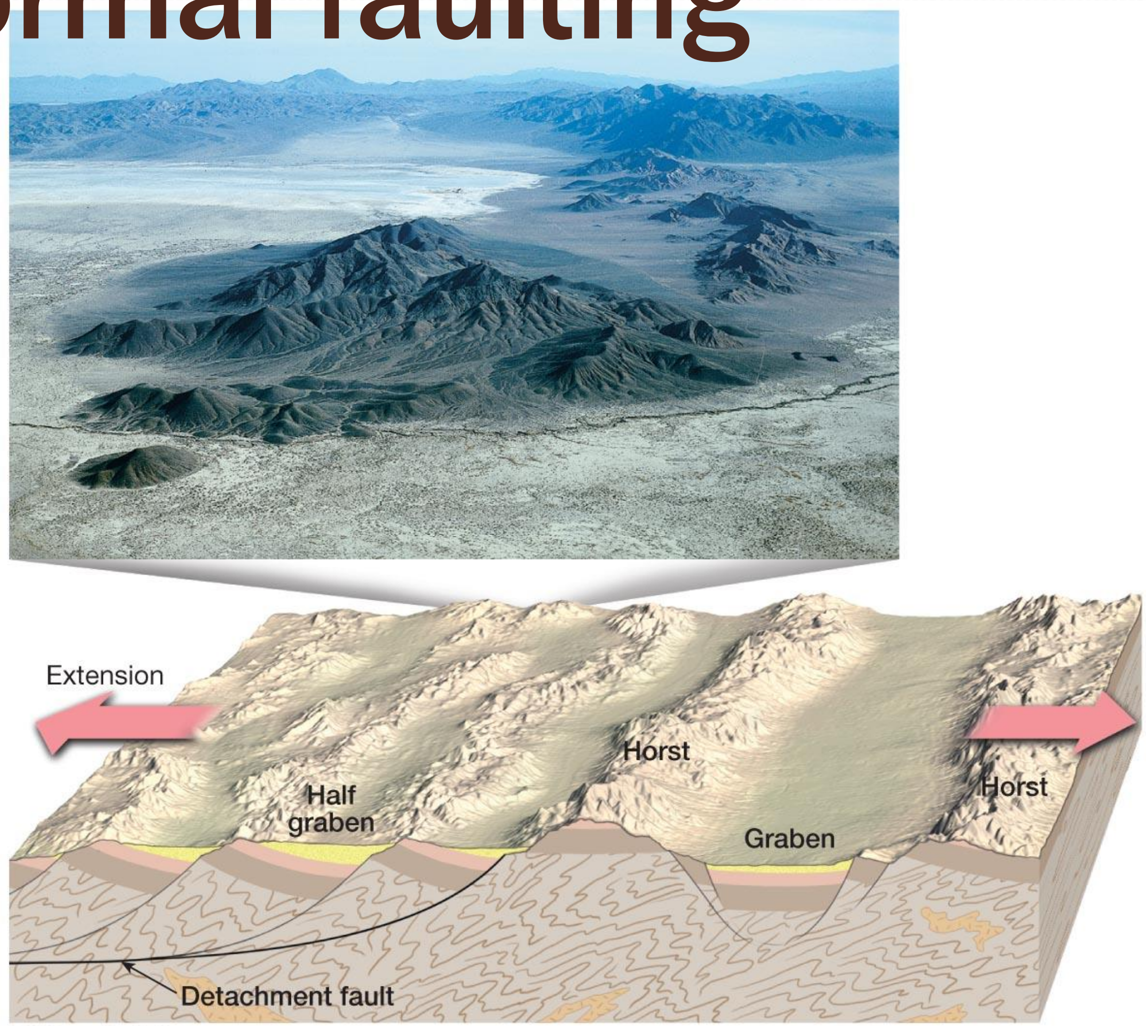
- Types of faults
  - Dip-slip fault
    - Types of dip-slip faults
      - Normal fault
        - Hanging wall block moves down
        - Associated with fault-block mountains
        - Prevalent at spreading centers
        - Caused by tensional forces

A normal fault



A. Normal fault

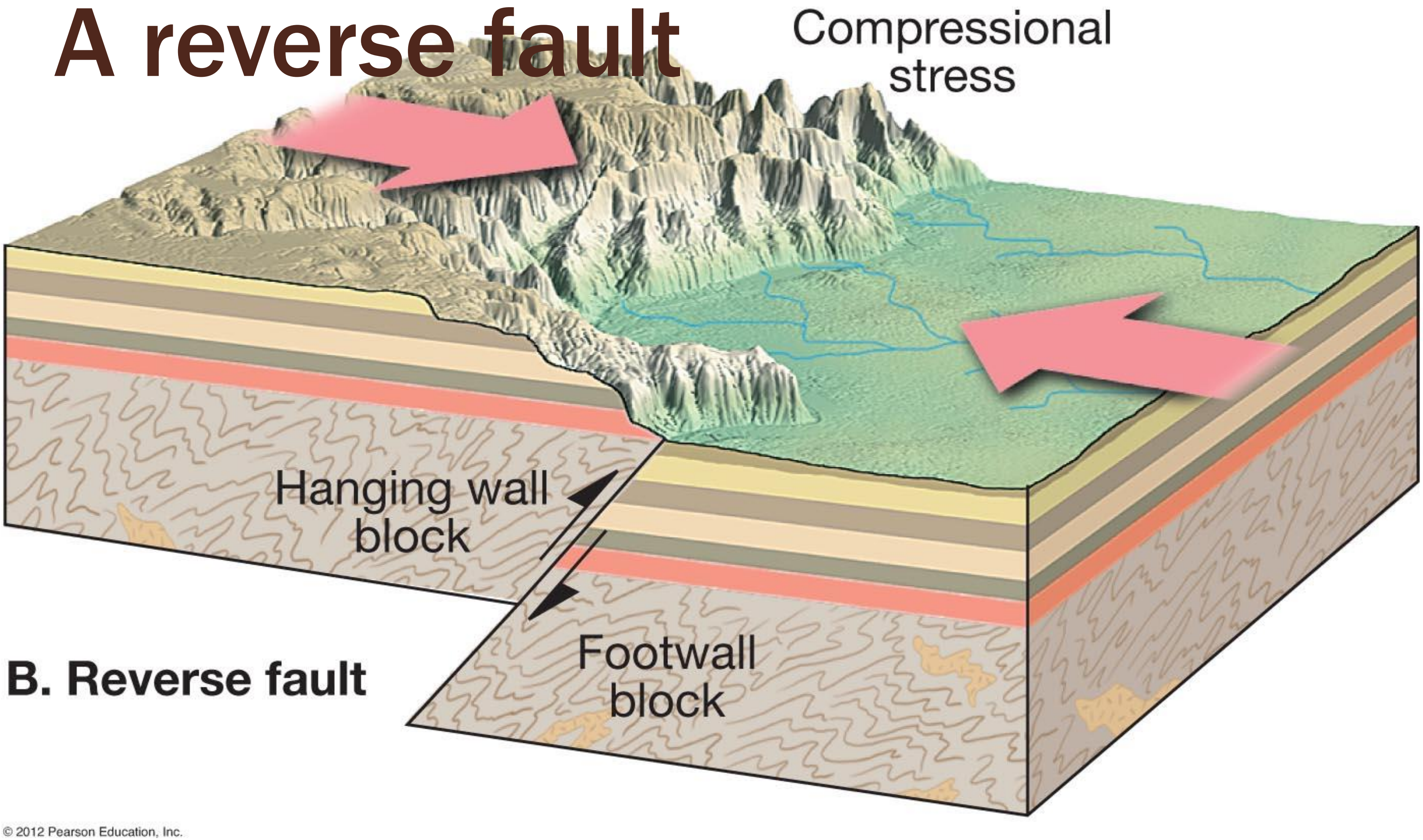
Fault block mountains produced by normal faulting



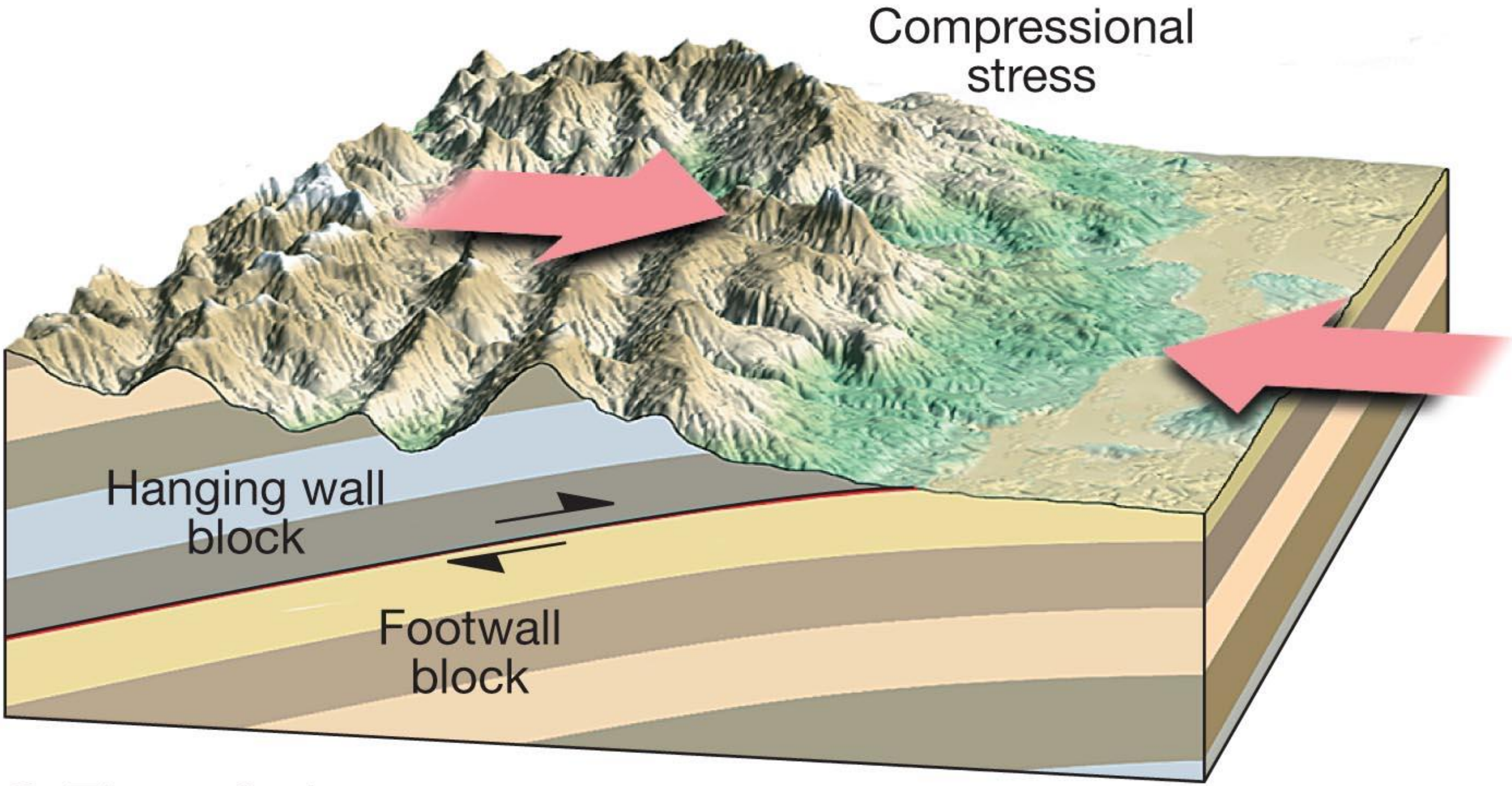
Faults

- Types of faults
  - Dip-slip fault
    - Types of dip-slip faults
      - Reverse and thrust faults
        - Hanging wall block moves up
        - Caused by strong compressional stresses
        - Reverse fault – dips greater than 45°
        - Thrust fault – dips less than 45°

A reverse fault



A thrust fault

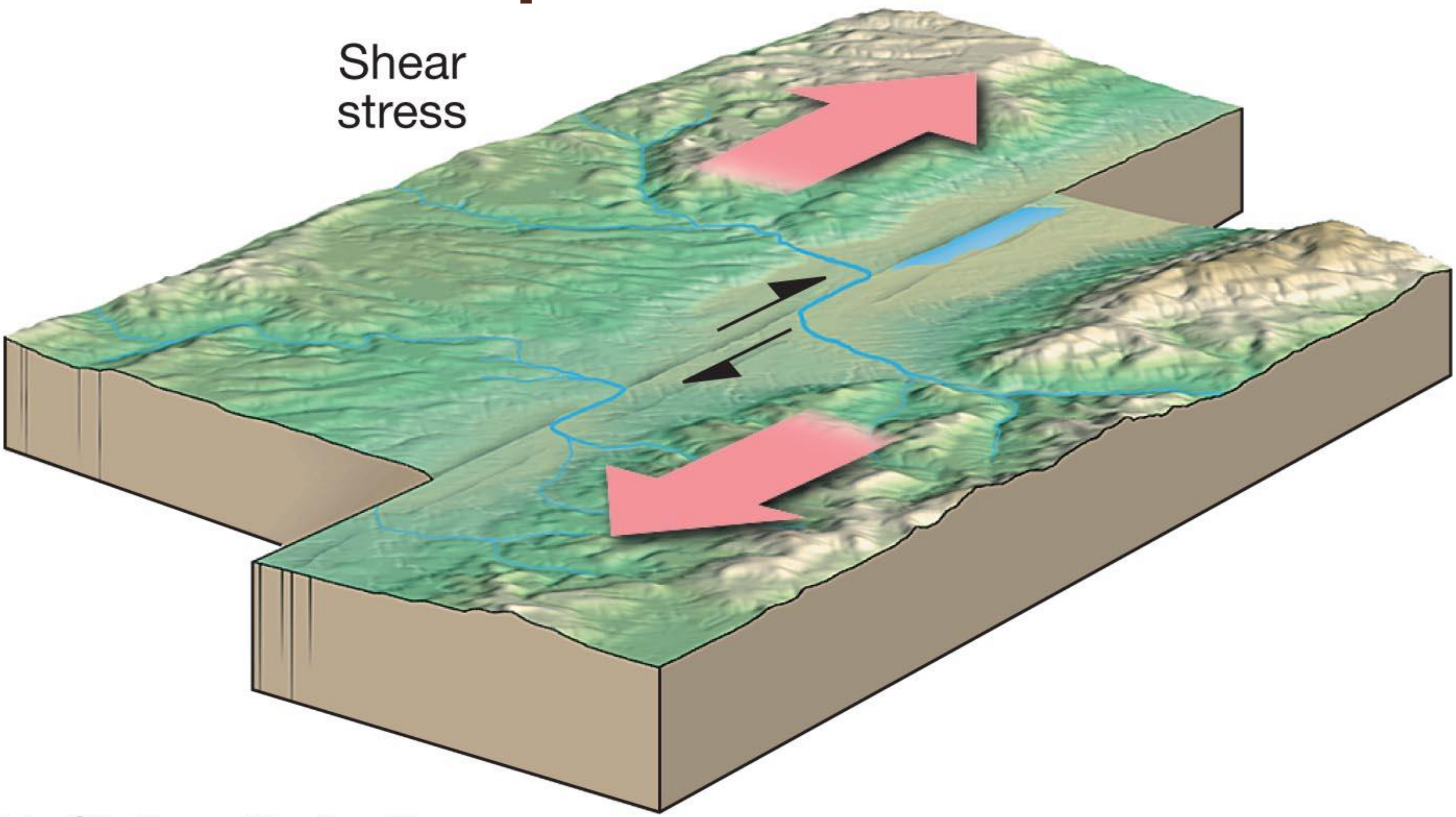


C. Thrust fault

Faults

- Types of faults
  - Strike-slip faults
    - Dominant displacement is horizontal and parallel to the trend, or strike
    - Transform fault
      - Large strike-slip fault that cuts through the lithosphere
      - Often associated with plate boundaries

A strike-slip fault



D. Strike-slip fault

Faults

- Types of faults
  - Joints
    - Fractures along which no appreciable displacement has occurred
    - Most are formed when rocks in the outer-most crust are deformed

Mountain belts

- Orogenesis refers to processes that collectively produce a mountain belt
- Mountain building at convergent boundaries
  - Most mountain building occurs at convergent plate boundaries

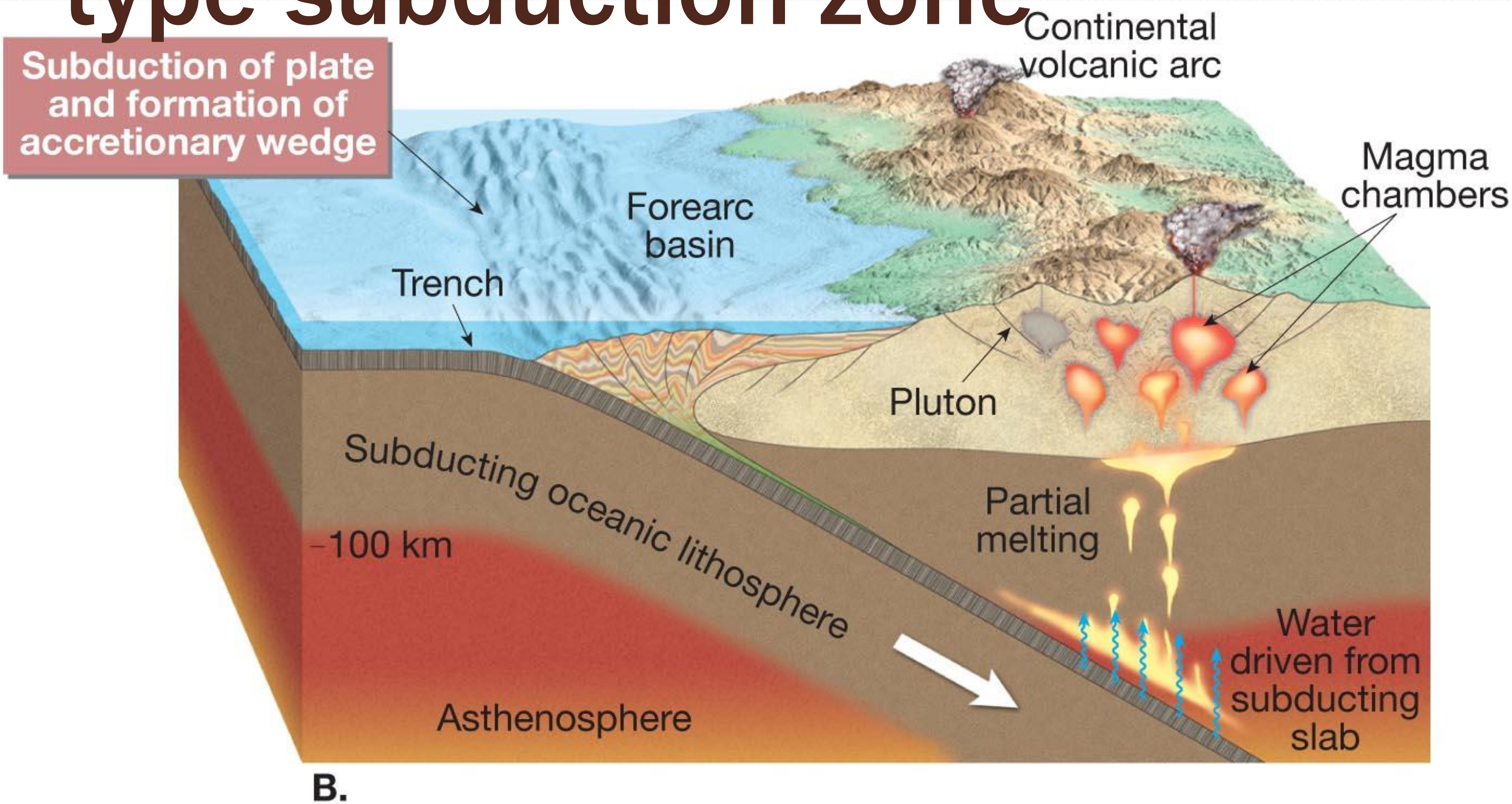
Mountain belts

- Mountain building at convergent boundaries
  - Andean-type mountain building
    - Oceanic-continental crust convergence
    - e.g., Andes Mountains
    - Types related to the overriding plate
      - Passive margins
        - Prior to the formation of a subduction zone
        - e.g., East Coast of North America

Mountain belts

- Mountain building at convergent boundaries
  - Andean-type mountain building
    - Types related to the overriding plate
      - Active continental margins
        - Subduction zone forms
        - Deformation process begins
      - Continental volcanic arc forms
      - Accretionary wedge forms
      - Examples of inactive Andean-type orogenic belts include Sierra Nevada Range and California's Coast Ranges

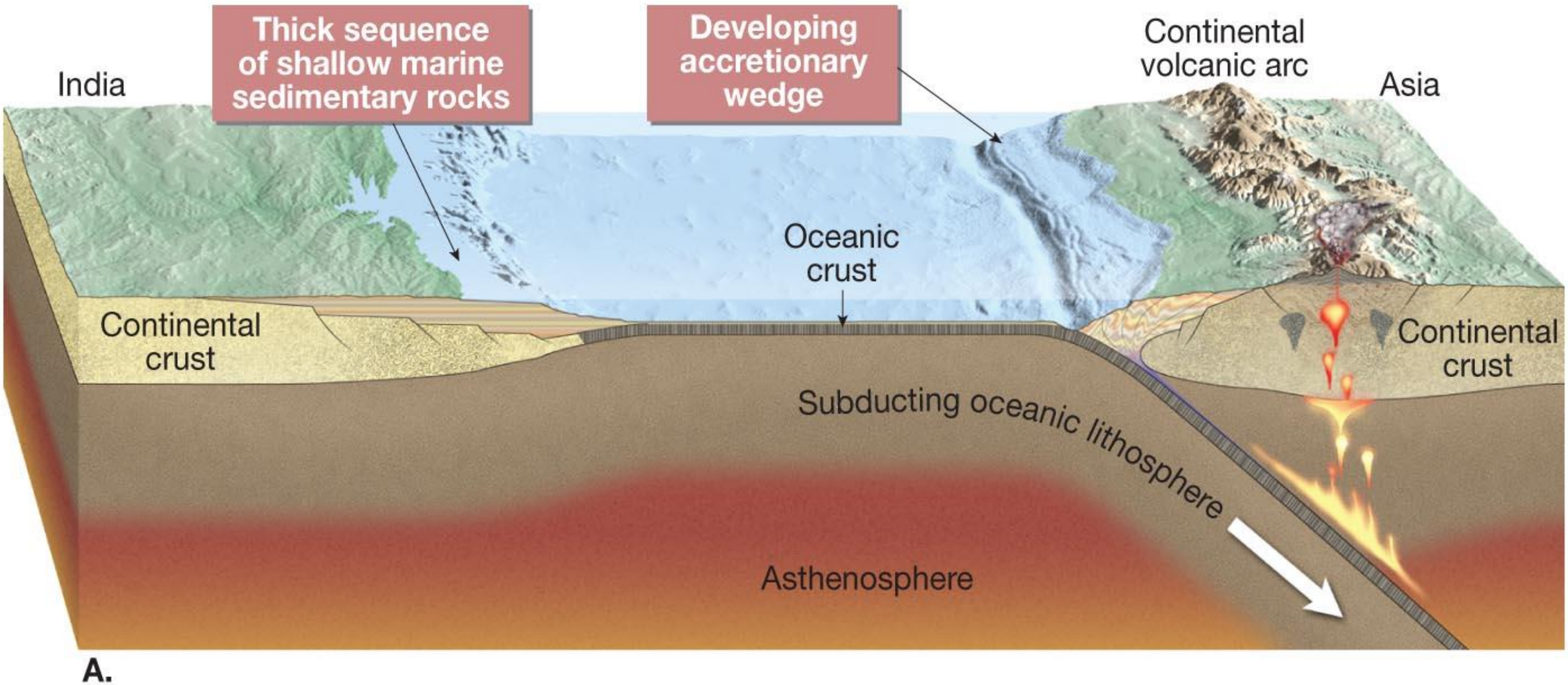
Orogenesis along an Andean-type subduction zone



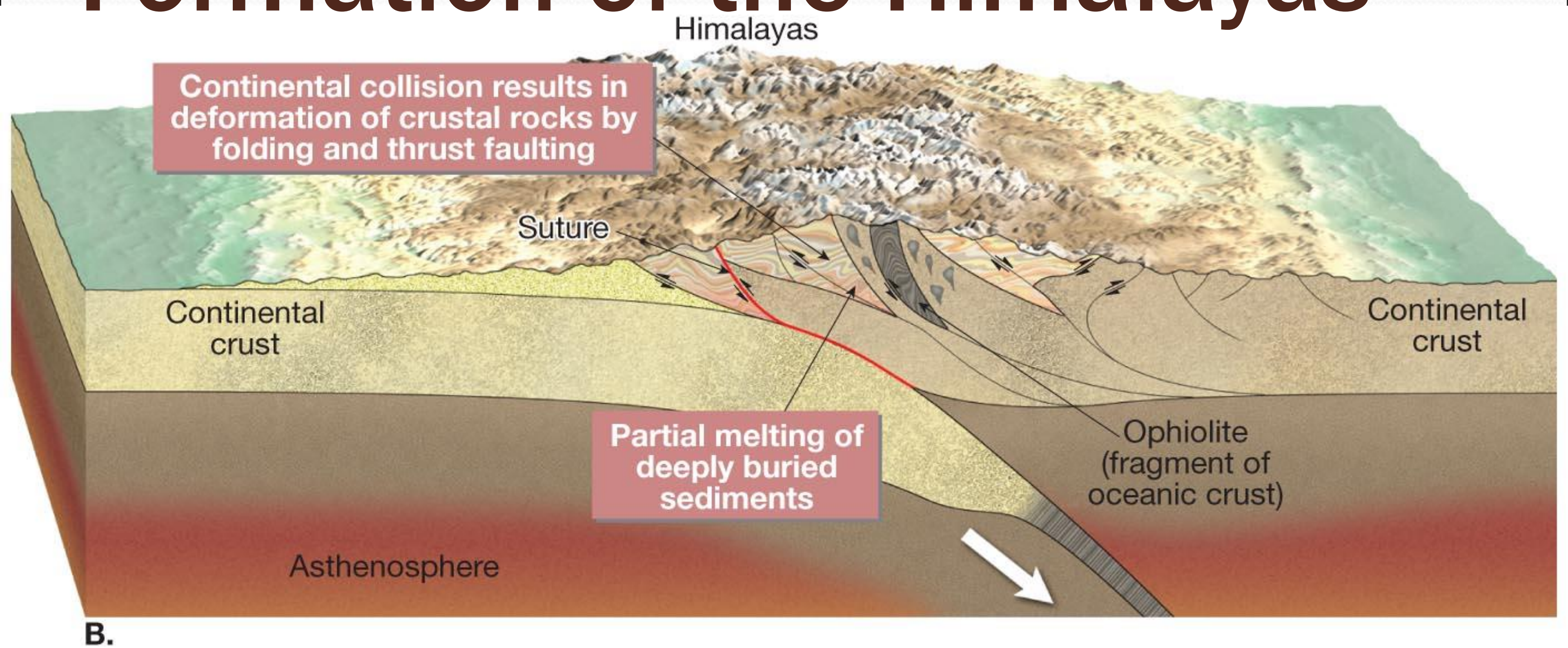
Mountain belts

- Mountain building at convergent boundaries
  - Continental collisions
    - Where two plates with continental crust converge
    - e.g., India and Eurasian plate collision
      - Himalayan Mountains and the Tibetan Plateau

Formation of the Himalayas



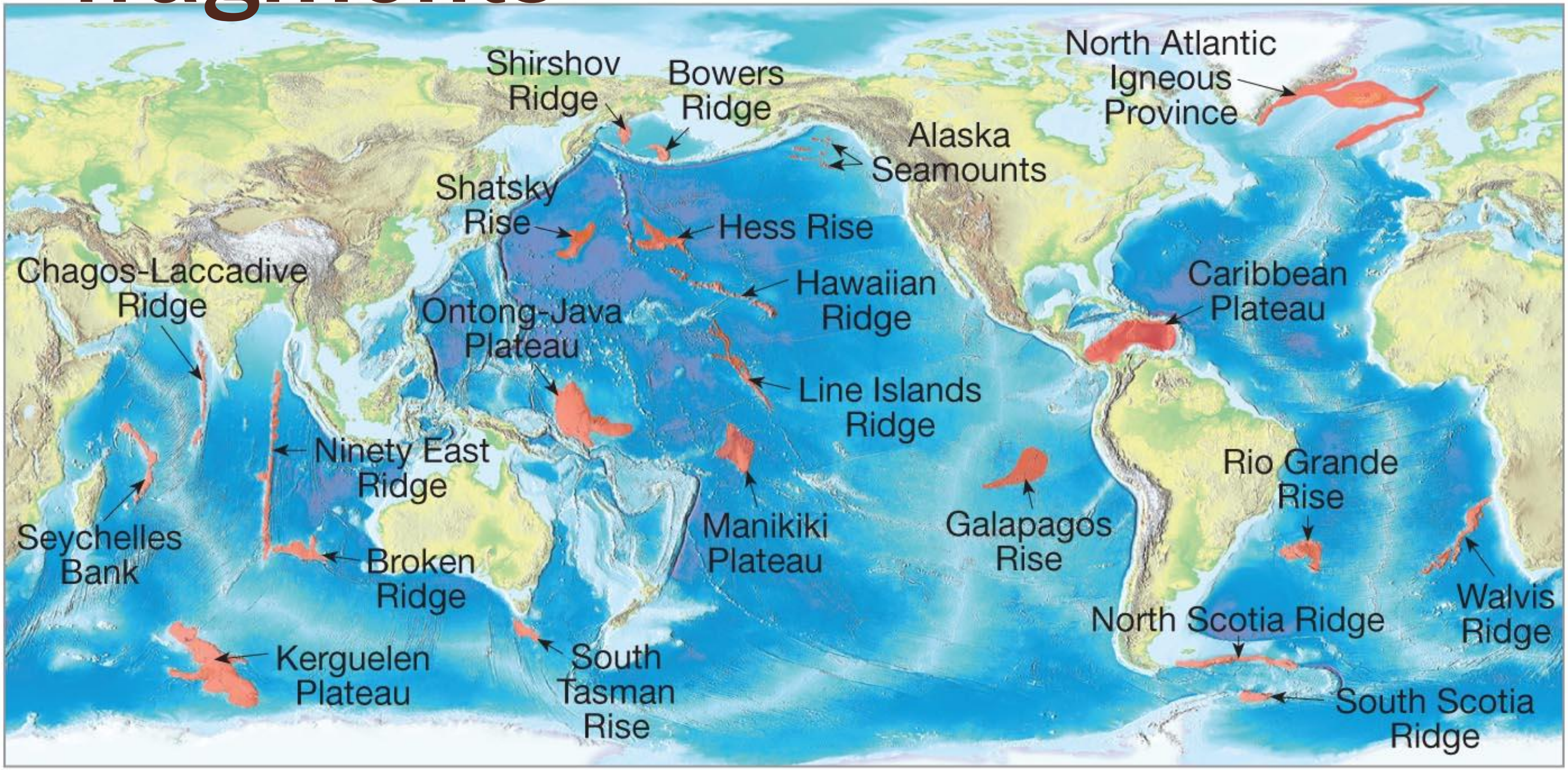
Formation of the Himalayas



Mountain belts

- Mountain building at convergent boundaries
  - Continental accretion
    - Third mechanism of mountain building
    - Small crustal fragments collide with and accrete to continental margins
    - Accreted crustal blocks are called terranes
    - Occurred along the Pacific Coast

Distribution of modern day oceanic plateaus and fragments

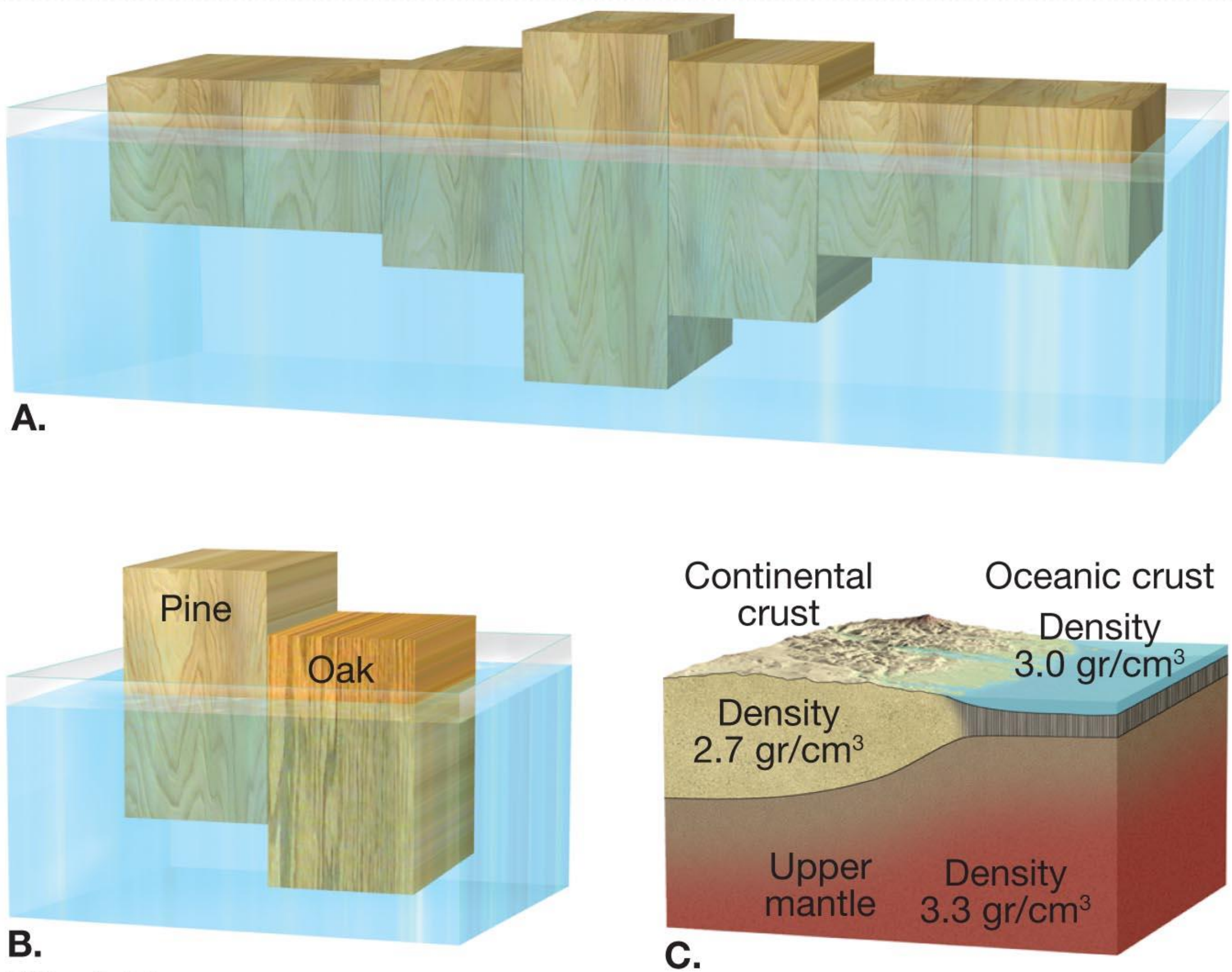


Accreted terranes along the western margin of North America

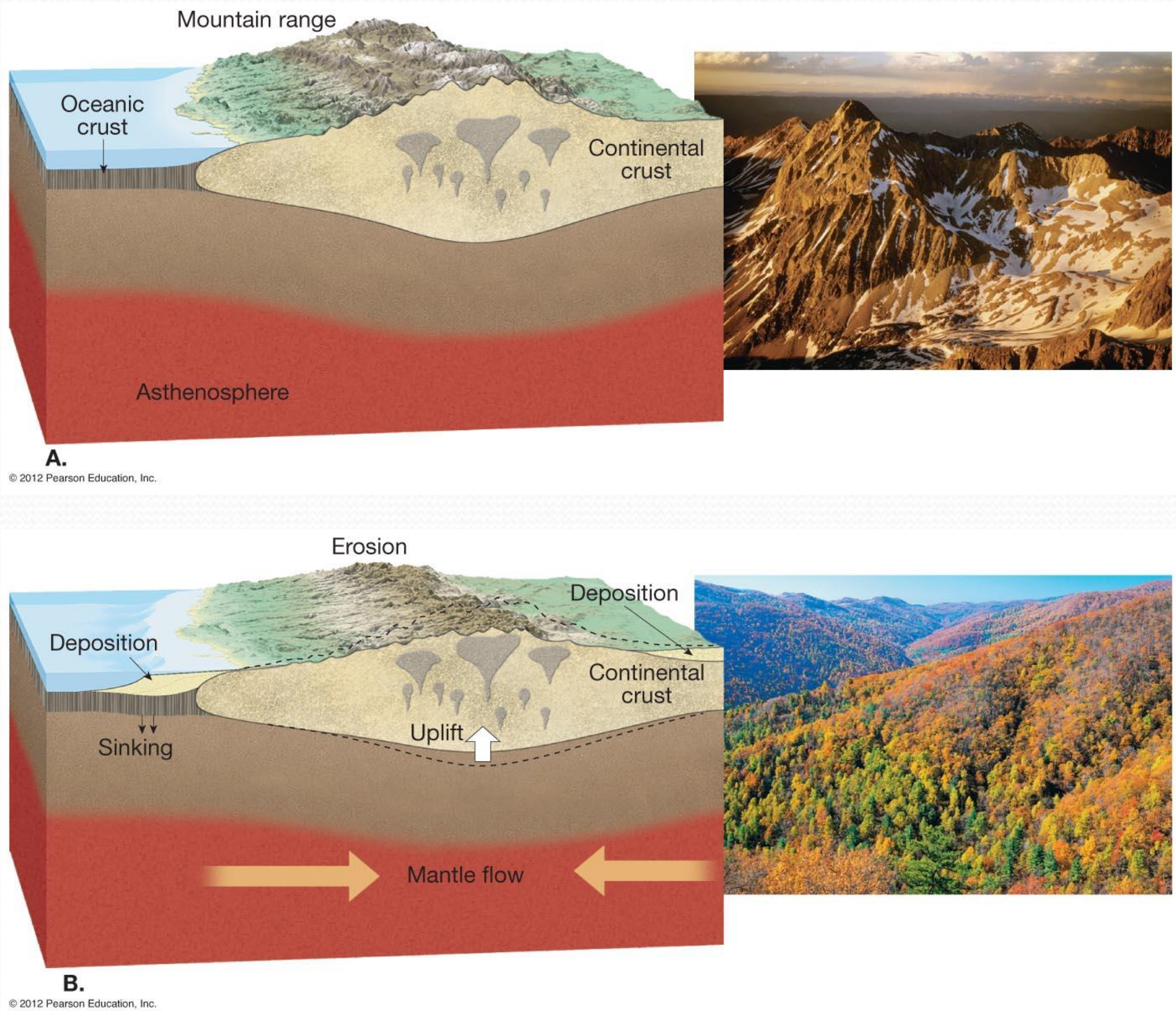
Mountain belts

- Buoyancy and the principle of isostasy
  - Evidence for crustal uplift includes wave-cut platforms high above sea level
  - Reasons for crustal uplift
    - Not so easy to determine
    - Isostasy
      - Concept of a floating crust in gravitational balance
      - When weight is removed from the crust, crustal uplifting occurs
        - Process is called isostatic adjustment

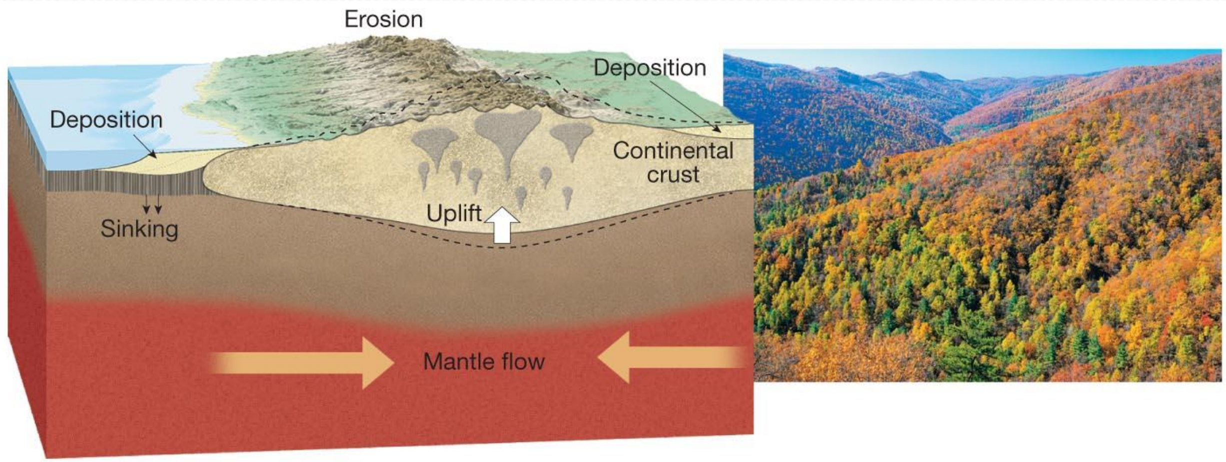
The principle of isostasy



Erosion and resulting isostatic adjustment of the crust



Erosion and resulting isostatic adjustment of the crust



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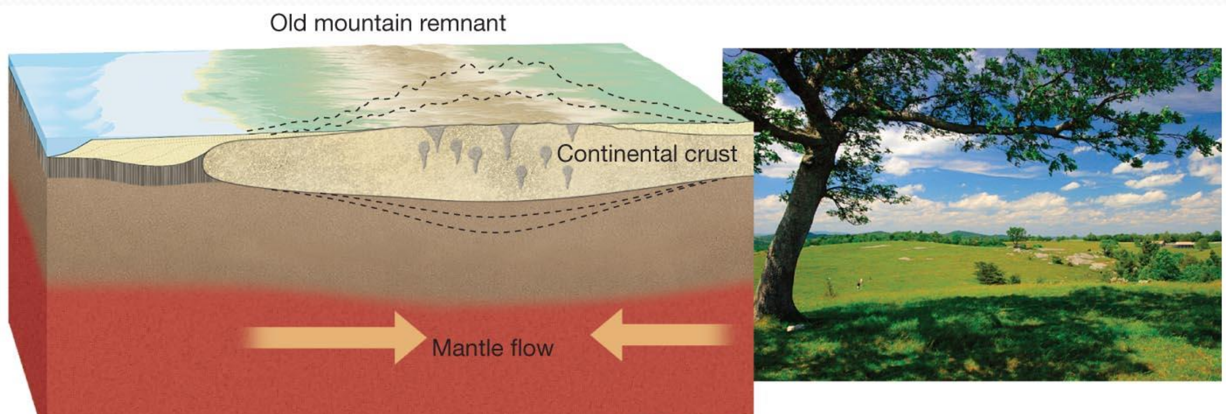

C.

End of Chapter 10