Metamorphic Rocks

Green Schists and Blue Schists, Two Harbors, Catalina Island, California

review

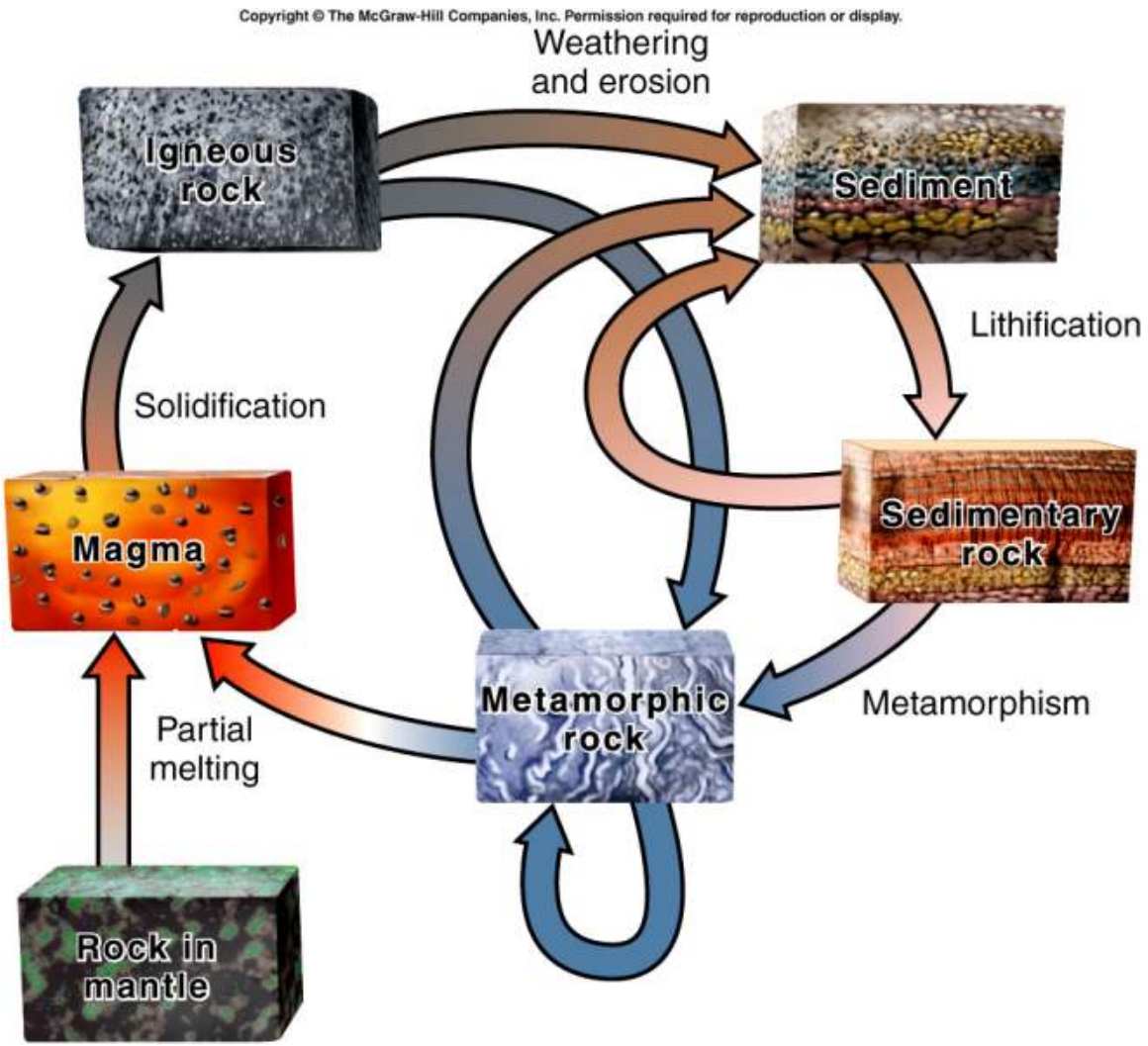
- Rocks
  - naturally formed aggregates of minerals
  - can be composed of many individual minerals of the same kind (e.g., limestone) or different minerals (e.g., granite)
  - some rocks are composed of non-mineral substances (e.g., obsidian, coal)

- Minerals
  - solids
  - that are naturally occurring
  - are inorganic
  - are crystalline
  - have a specific chemical composition
  - have distinctive physical properties

Rocks

- Rocks are classified into three groups, based on the processes by which they were formed
  - igneous rocks
  - sedimentary rocks
  - metamorphic rocks

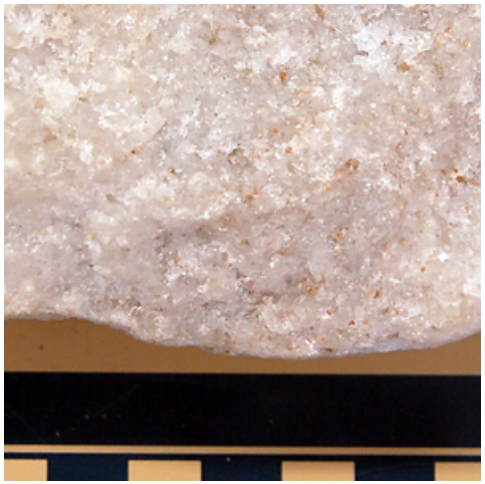
The Rock Cycle



Metamorphic Rocks

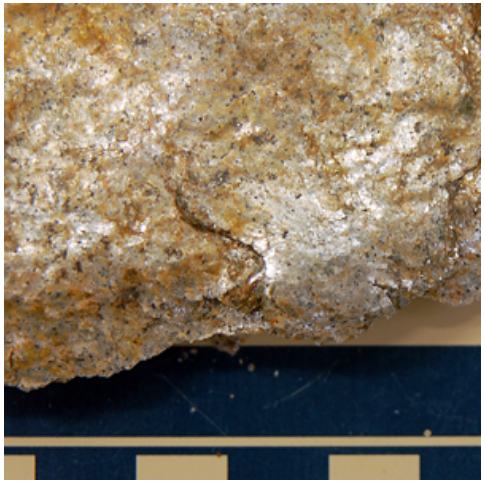
- Any rock subject to conditions that are different from those under which they originally formed, are changed, or metamorphosed as a solid (without melting, without needing water, like when you bake an apple)

- metamorphism occurs within Earth and it is mainly by contact (with a source of heat) or regional (in regions of intense, non-uniform pressure)



Above:
contact metamorphic rock (marble)

Below:
regional metamorphic rock (schist)



Fresh apple
vs. baked apple
(metamorphic apple)

What is Metamorphism?

- Changes in:
  - Mineralogy (what minerals make up a rock)
  - Texture (grains size, fabric, etc.)
  - Chemical composition (sometimes)

- Occurs most of the times when:
    - Pressure increases
    - Temperature increases

- Metamorphism progresses incrementally from low-grade to high-grade
- During metamorphism the rock must remain essentially solid

- **Metamorphic settings**
  - Contact or thermal metamorphism – driven by a rise in temperature within the host rock
  - Hydrothermal metamorphism – chemical alterations from hot, ion-rich water
  - Regional metamorphism
    - Occurs during mountain building
    - Produces the greatest volume of metamorphic rock
    - Rocks usually display zones of contact and/or hydrothermal metamorphism

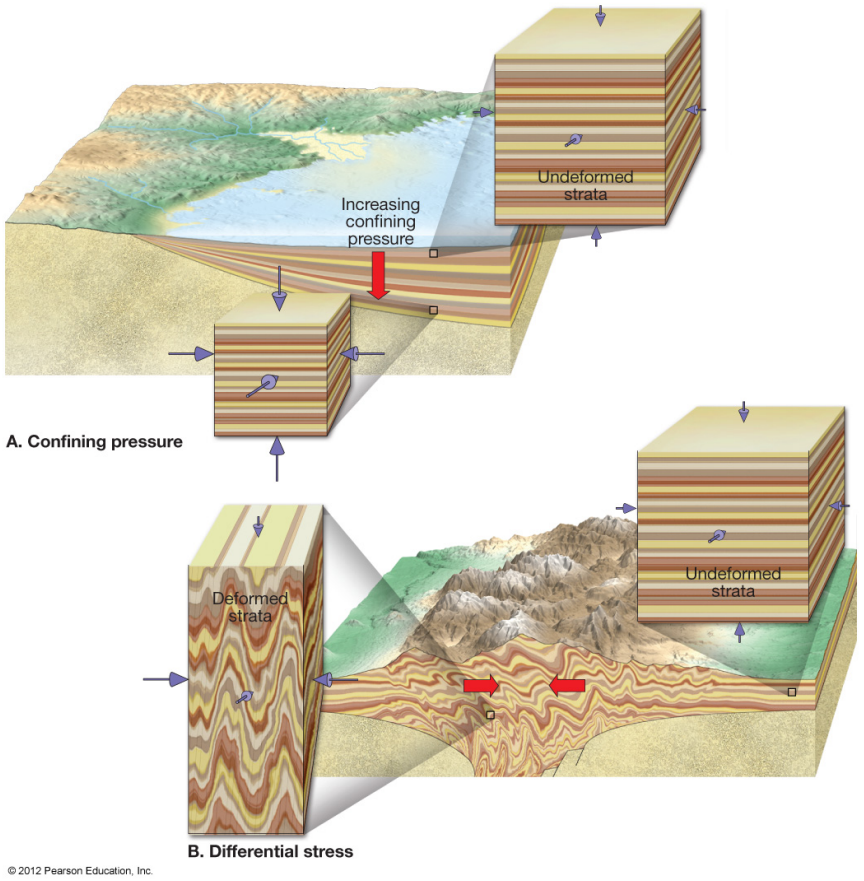
What determines metamorphic conditions?

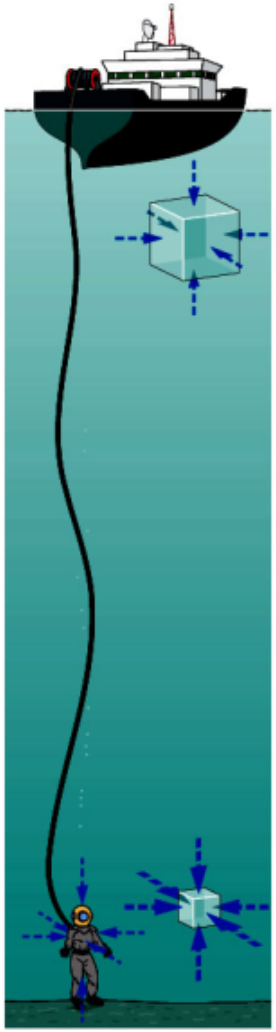
- Parent rock
- Heat
- Pressure
  - Confining Pressure
  - Differential Stress
- Chemically Active Fluids
- Time

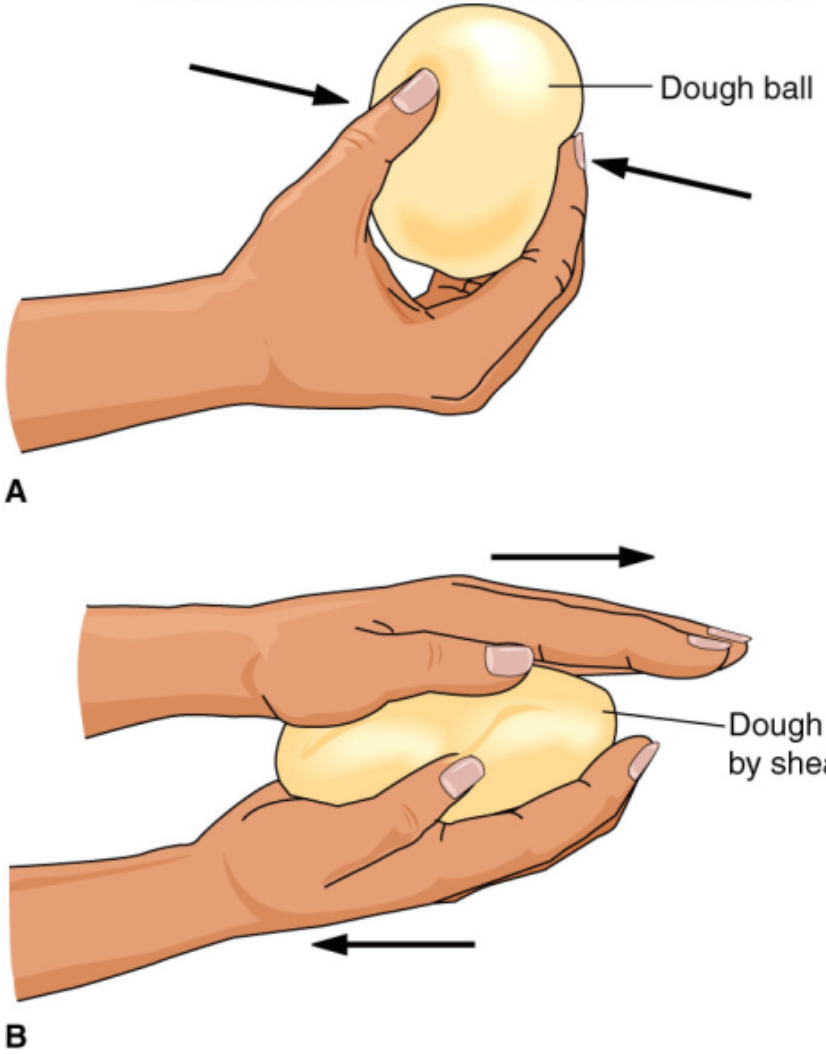
- The importance of parent rock
  - Most metamorphic rocks have the same overall chemical composition as the parent rock from which they formed
  - Mineral makeup determines, to a large extent, the degree to which each metamorphic agent will cause change

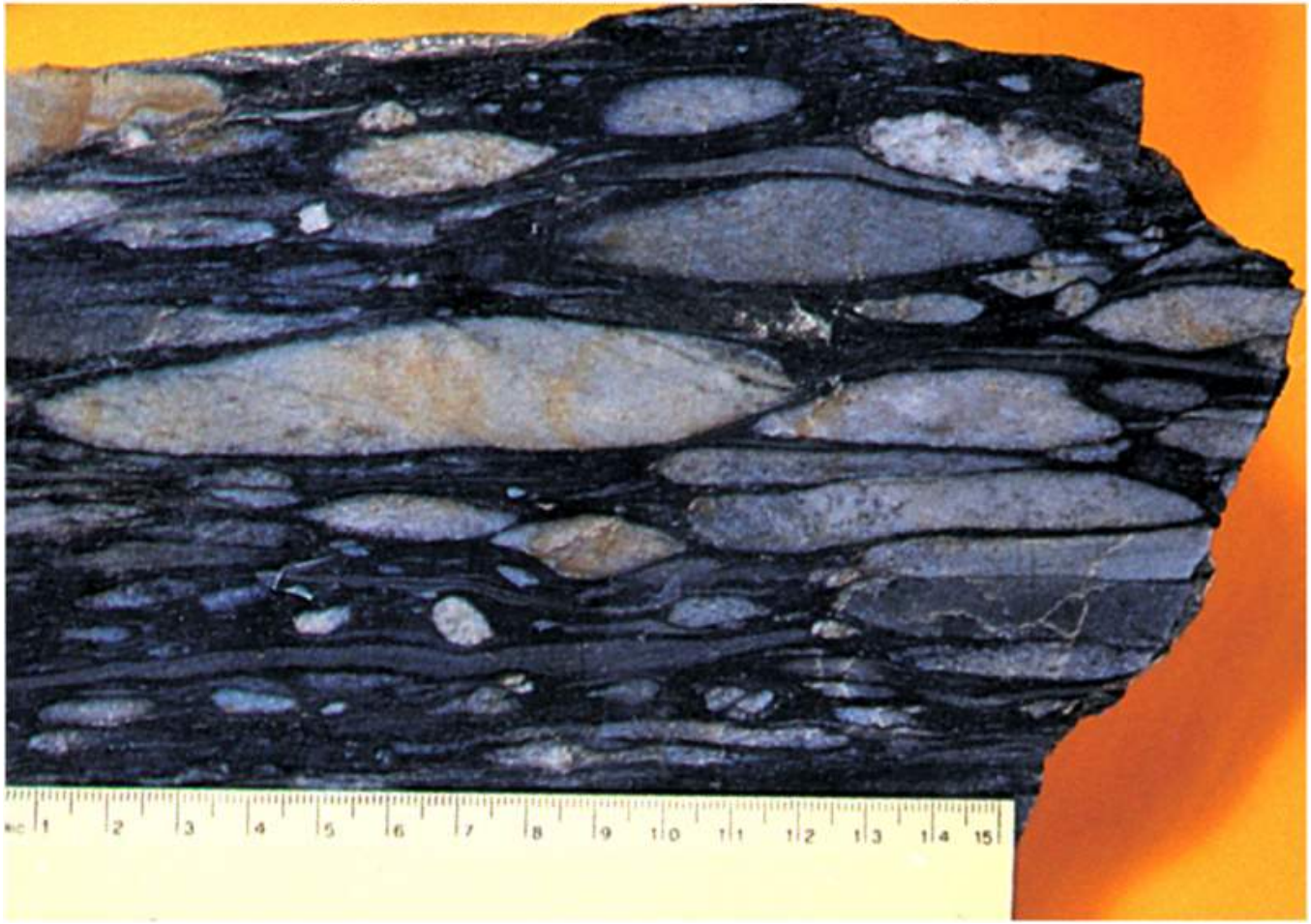
- Heat
  - The most important agent
  - Recrystallization results in new, stable minerals
  - Two sources of heat
    - Contact metamorphism – heat from magma
    - An increase in temperature with depth due to the geothermal gradient

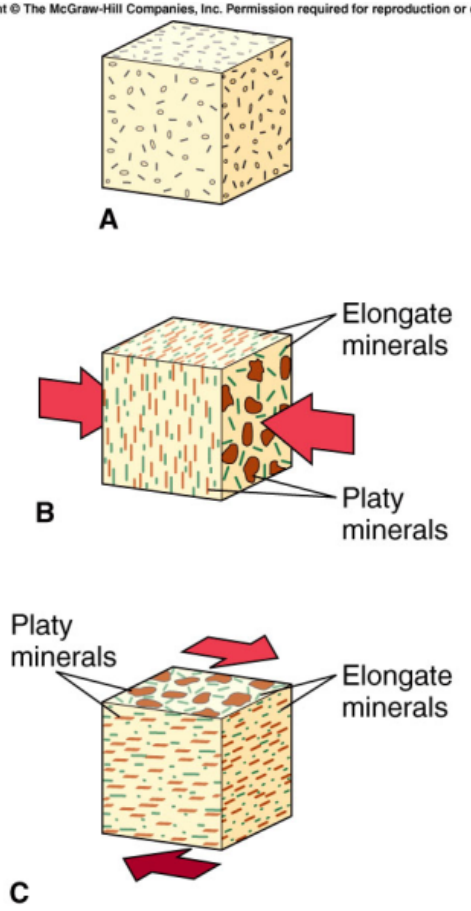
- Pressure (stress)
  - Increases with depth
  - Confining pressure applies forces equally in all directions
  - Rocks may also be subjected to differential stress, which is unequal in different directions

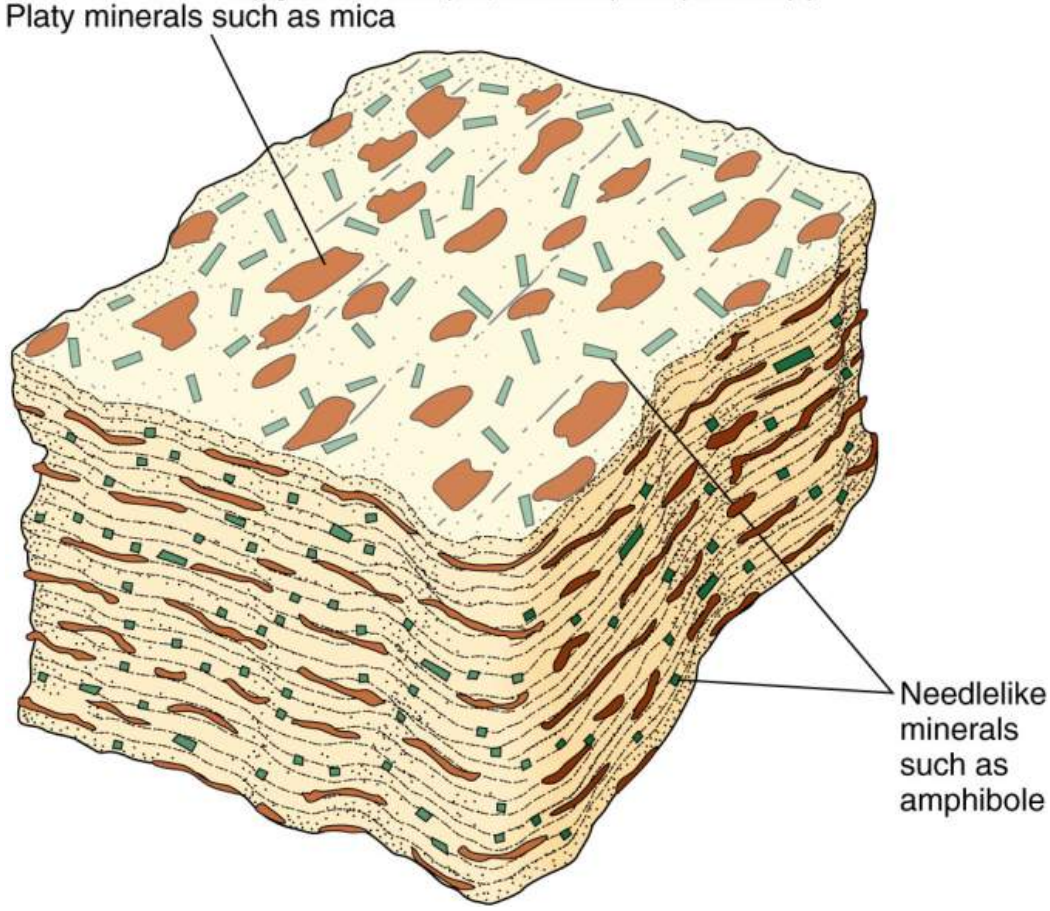












- Chemically active fluid
  - Mainly water with other volatile components
  - Enhances migration of ions
  - Aids in recrystallization of existing minerals

  - Sources of fluids
    - Pore spaces of sedimentary rocks
    - Fractures in igneous rocks
    - Hydrated minerals such as clays and micas

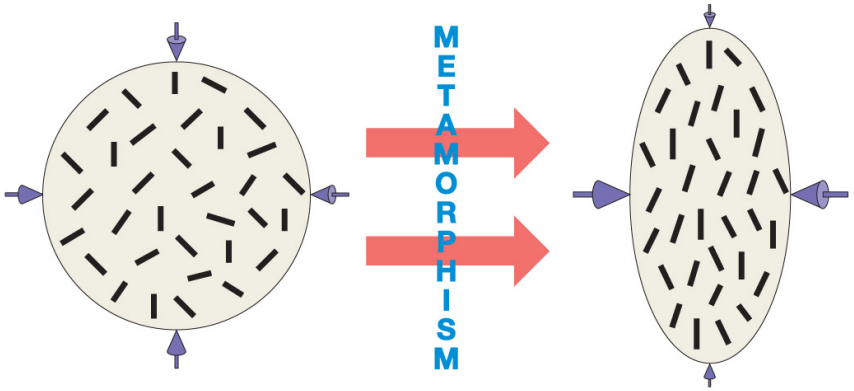
Metamorphic Textures

- **Texture refers to the size, shape, and arrangement of grains within a rock**

- Foliated vs. nonfoliated metamorphic rocks
  - Foliation – any planar arrangement of mineral grains or structural features within a rock

- **Examples of foliation**
  - Parallel alignment of platy and/or elongated minerals
  - Parallel alignment of flattened mineral grains and pebbles
  - Compositional banding
  - Slaty cleavage – where rocks can be easily split into thin, tabular sheets

- **Foliation**
  - Foliation can form in various ways including
    - Rotation of platy and/or elongated minerals
    - Recrystallization of minerals in the direction of preferred orientation
    - Changing the shape of equidimensional grains into elongated shapes that are aligned



A. Before metamorphism
(Uniform stress)

B. After metamorphism
(Differential stress)

- **Foliated textures**
  - Slaty cleavage
    - Closely spaced planar surfaces along which rocks split
    - Can develop in a number of ways depending on metamorphic conditions and parent rock
  - Schistosity
    - Platy minerals are discernible with the unaided eye and exhibit a planar or layered structure
    - Rocks having this texture are referred to as schist
  - Gneissic
    - During higher grades of metamorphism, ion migration results in the segregation of minerals
    - Gneissic rocks exhibit a distinctive banded appearance

- **Other metamorphic textures**
  - Those metamorphic rocks that lack foliation are referred to as nonfoliated
    - Develop in environments where deformation is minimal
    - Typically composed of minerals that exhibit equidimensional crystals
  - Porphyroblastic textures
    - Large grains, called porphyroblasts, are surrounded by a fine-grained matrix of other minerals
    - Porphyroblasts are typically garnet, staurolite, and/or andalusite

Foliated rocks, pt. 1

- Slate
  - Very fine grained
  - Excellent rock cleavage
  - Most often generated from low-grade metamorphism of shale, mudstone, or siltstone
- Phyllite
  - Gradation in the degree of metamorphism between slate and schist
  - Platy minerals not large enough to be identified with the unaided eye
  - Glossy sheen and wavy surfaces
  - Exhibits rock cleavage
  - Composed mainly of fine crystals of muscovite and/or chlorite

Slate

Figure 7.12
(Slate)

Phyllite

Figure 7.12 (Phyllite)

Foliated rocks, pt. 2

- Schist
  - Medium to coarse grained
  - Platy minerals predominate
  - Commonly include the micas
  - The term *schist* describes the texture
  - To indicate composition, mineral names are used (such as mica schist)
- Gneiss
  - Medium to coarse grained
  - Banded appearance
  - High-grade metamorphism
  - Often composed of white or light-colored feldspar-rich layers with bands of dark ferromagnesian minerals

Mica Schist

Figure 7.12 (Schist)

Gneiss Typically Displays a Banded Appearance

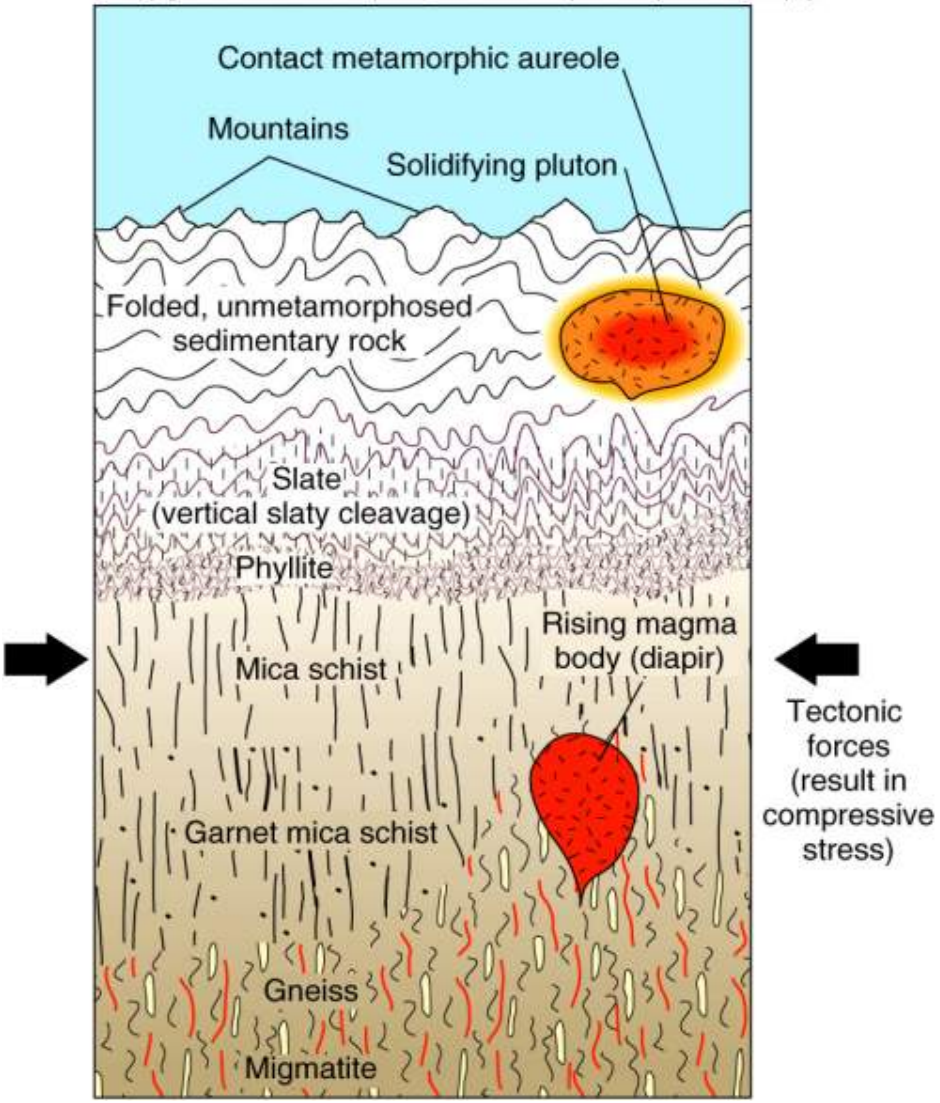
Figure 7.12
(Gneiss)

- **Nonfoliated rocks**
  - Marble
    - Coarse, crystalline
    - Parent rock was limestone or dolostone
    - Composed essentially of calcite or dolomite crystals
    - Used as a decorative and monument stone
    - Exhibits a variety of colors
  - Quartzite
    - Formed from a parent rock of quartz-rich sandstone
    - Quartz grains are fused together

Marble

A Nonfoliated Metamorphic Rock

Figure 7.12
(Marble)



Metamorphic Environments

- **Contact or thermal metamorphism**
  - Occurs due to a rise in temperature when magma invades a host rock
  - A zone of alteration called an aureole forms in the rock surrounding the magma
  - Most easily recognized when it occurs at the surface, or in a near-surface environment

Contact Metamorphism

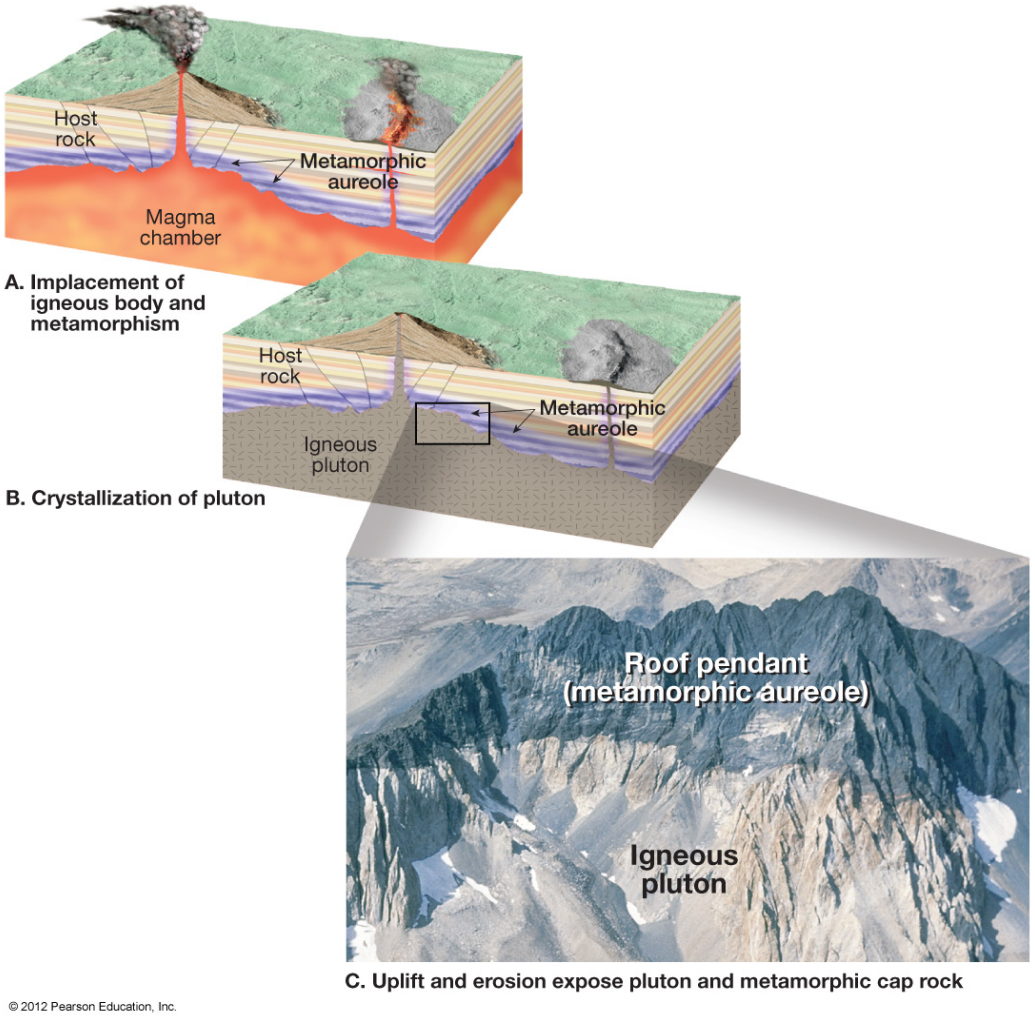
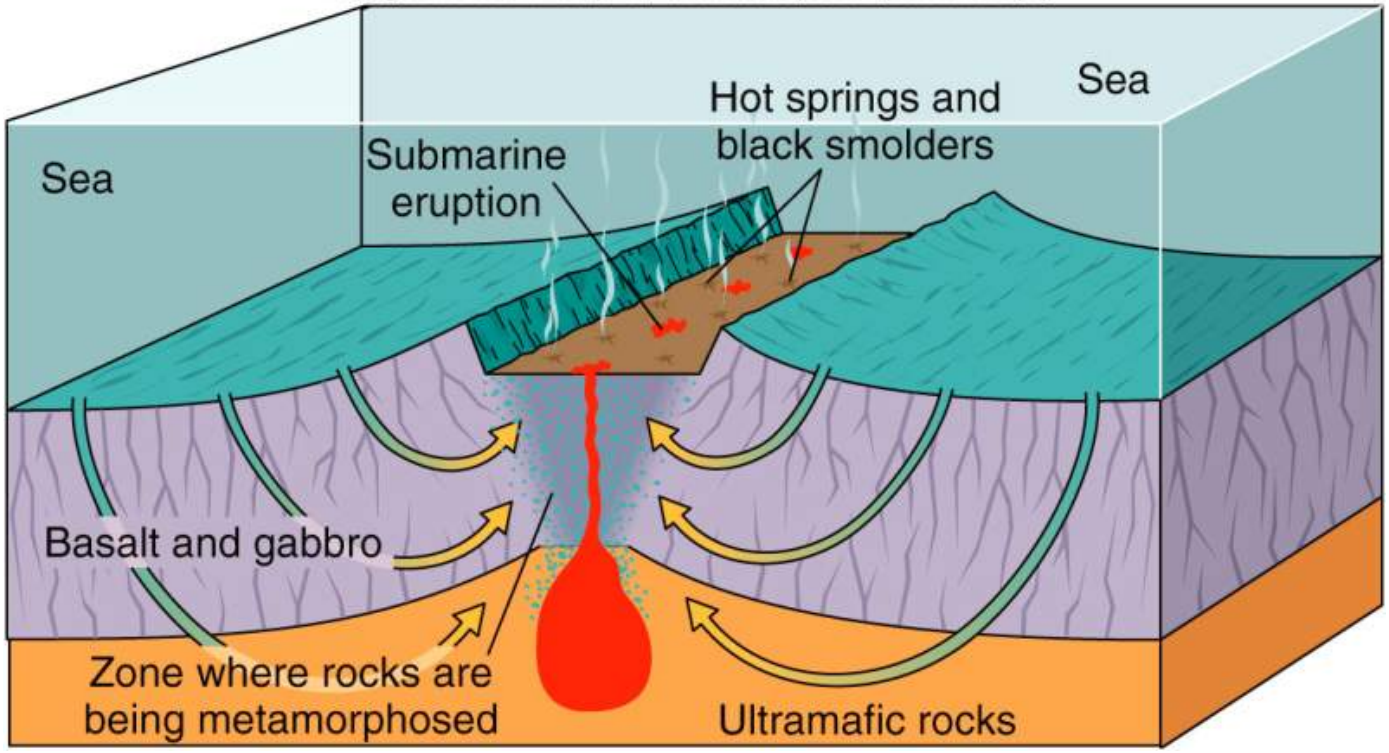


Figure 7.14

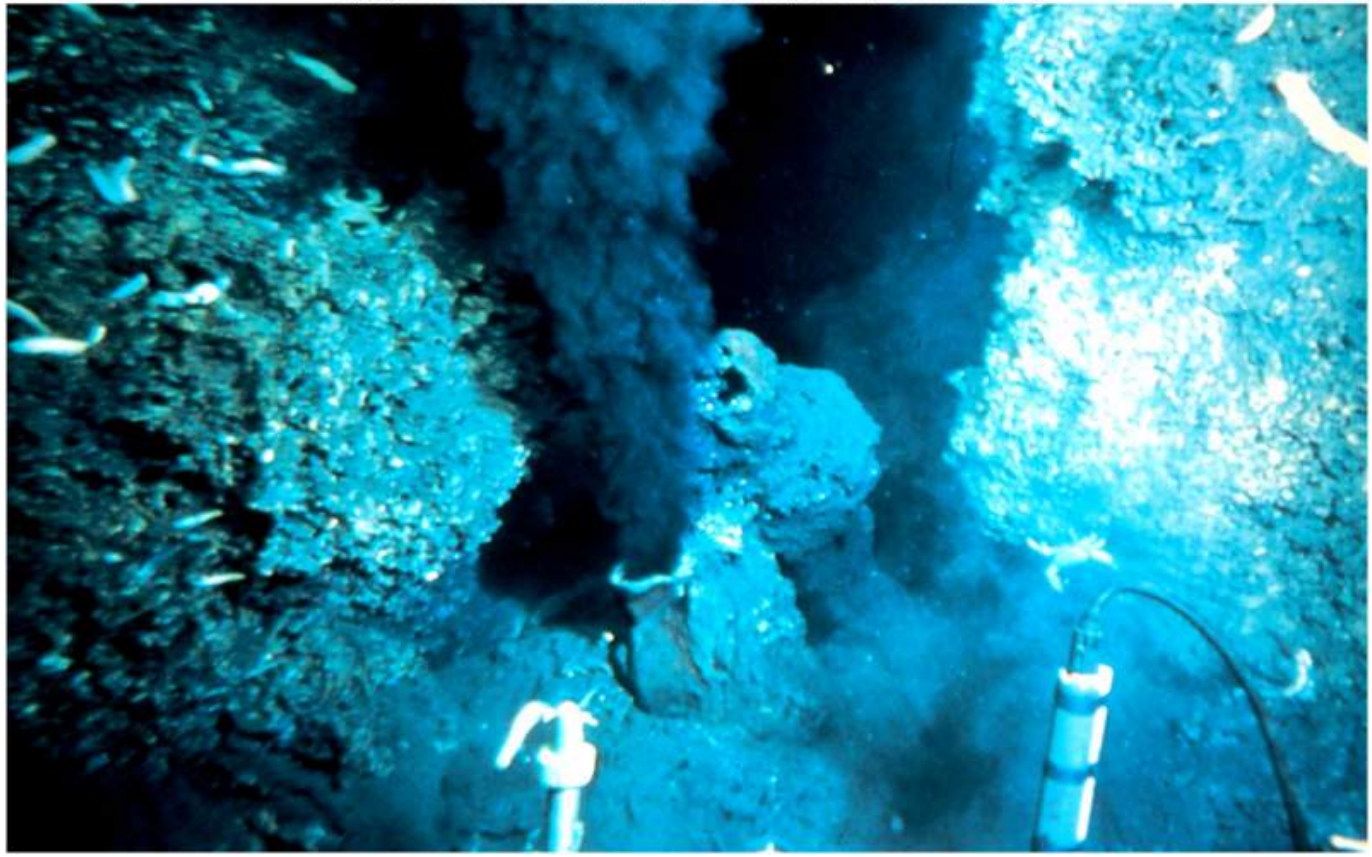
Metamorphic Environments

- **Hydrothermal metamorphism**
  - Chemical alteration caused when hot, ion-rich fluids, called hydrothermal solutions, circulate through fissures and cracks that develop in rock
  - Most widespread along the axis of the mid-ocean ridge system



Hydrothermal Metamorphism

along a mid-ocean ridge



Metamorphic Environments

- **Regional metamorphism**
  - Produces the greatest quantity of metamorphic rock
  - Associated with mountain building

Regional Metamorphism

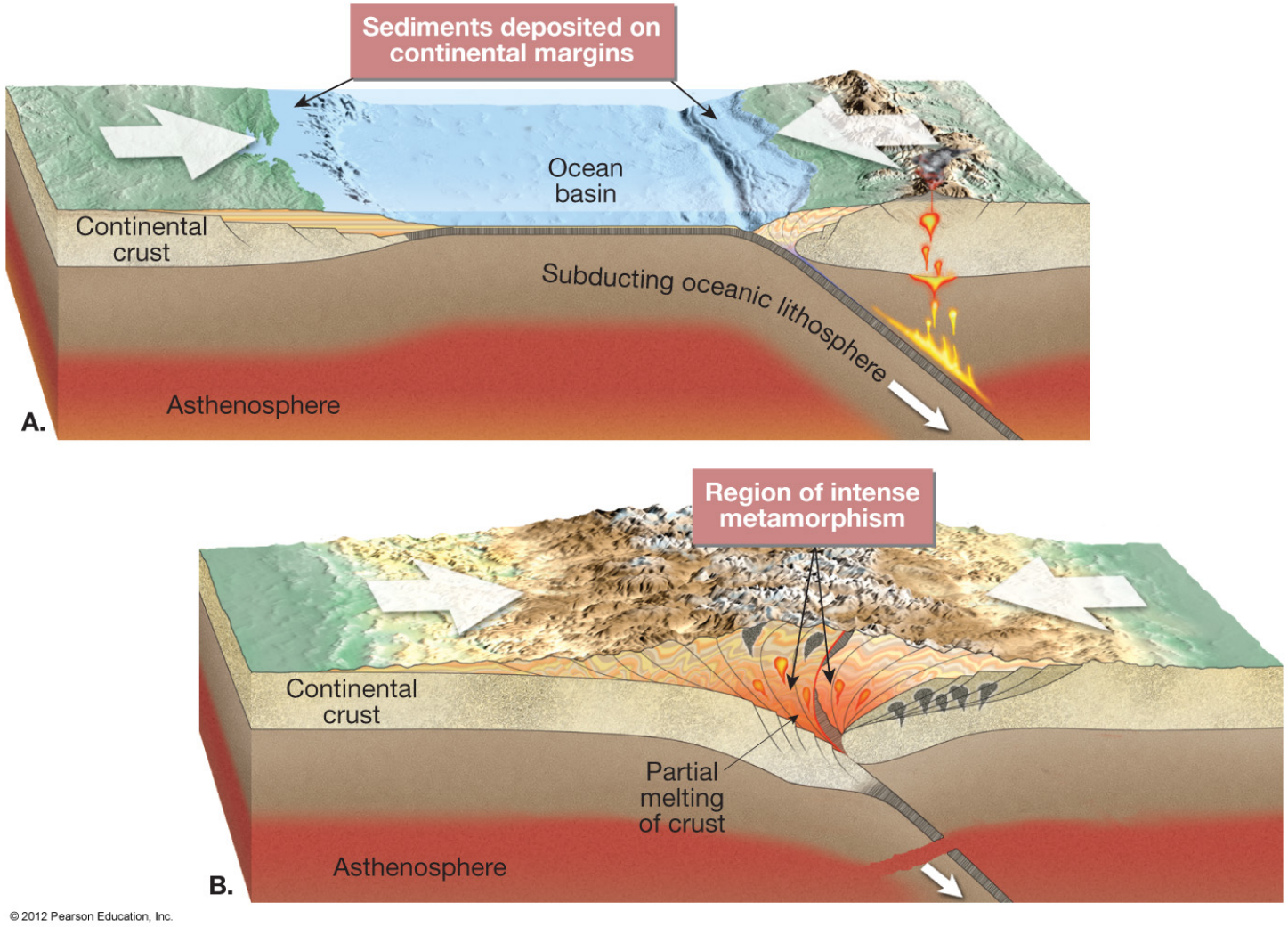
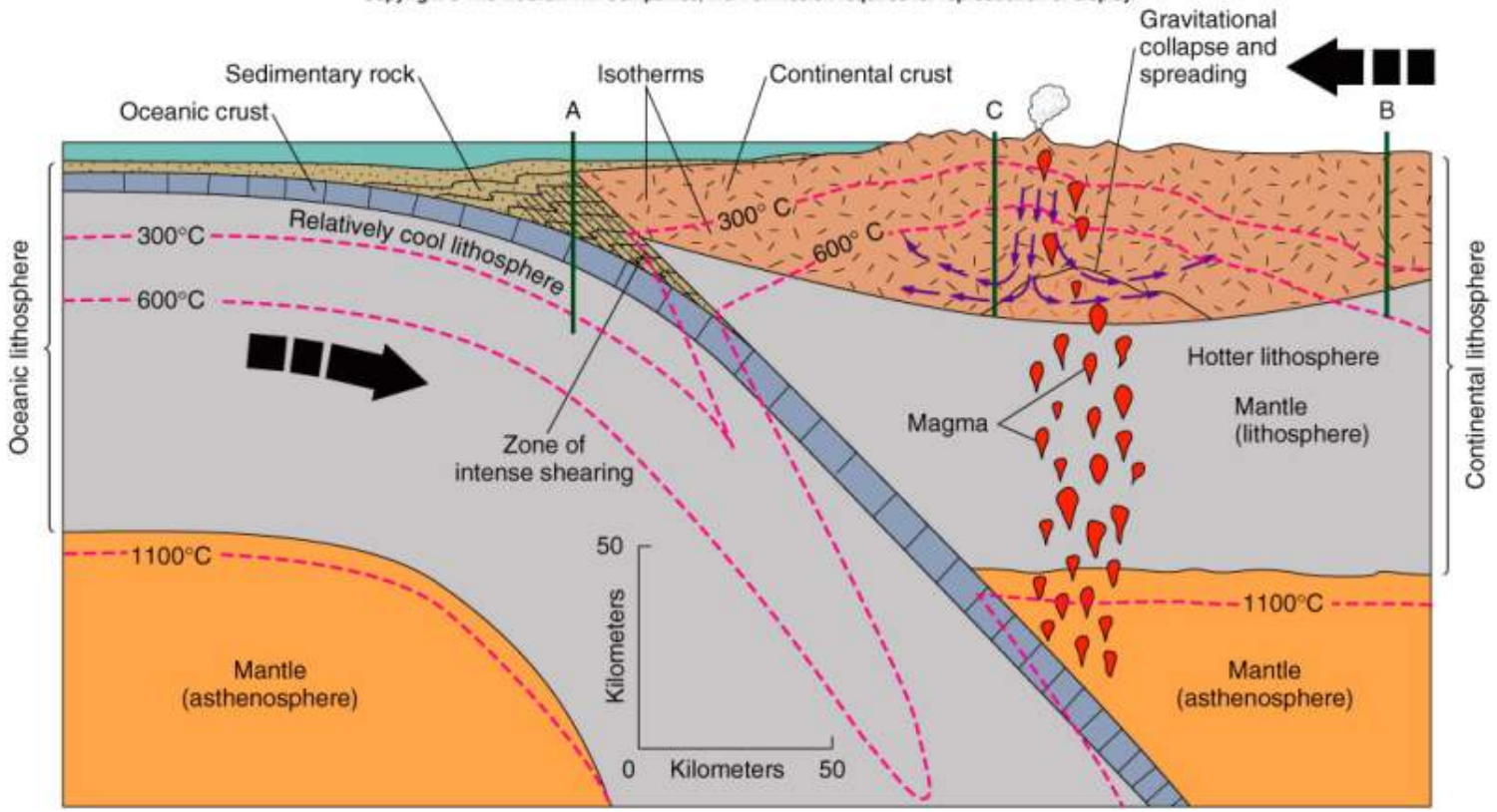


Figure 7.18



Metamorphic Environments

- **Other metamorphic environments**
  - Burial metamorphism
    - Associated with very thick sedimentary strata
    - Required depth varies from one location to another depending on the prevailing geothermal gradient
  - Metamorphism along fault zones
    - Occurs at depth and high temperatures
    - Pre-existing minerals deform by ductile flow

Metamorphic Environments

- **Other metamorphic environments**
  - Impact metamorphism
    - Occurs when high speed projectiles called meteorites strike Earth's surface
    - Products are called impactites
    - Include:
      - » Shocked quartz
      - » Tektites
      - » Glass spherules

Impact metamorphism

Meteor Crater, Arizona

Metamorphic Rocks and Associated Environments

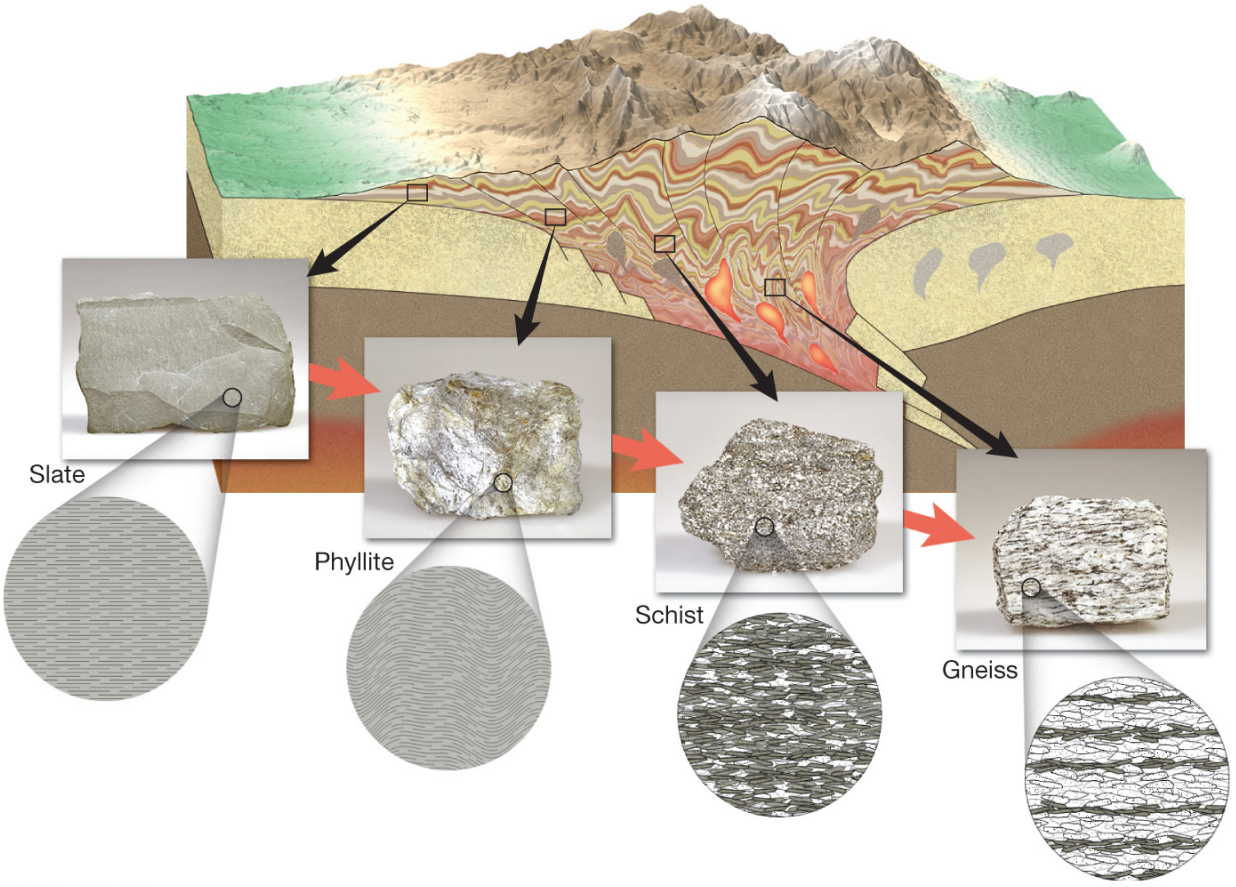


Figure 7.20

Metamorphic Zones

- **Systematic variations in the mineralogy and often the textures of metamorphic rocks are related to the variations in the degree of metamorphism**
- **Index minerals and metamorphic grade**
  - **Changes in mineralogy occur from regions of low-grade metamorphism to regions of high-grade metamorphism**

Metamorphic Zones

- **Index minerals and metamorphic grade**
  - **Certain minerals, called index minerals, are good indicators of the metamorphic conditions in which they form**
  - **Migmatites**
    - **Highest grades of metamorphism that is transitional to igneous rocks**
    - **Contain light bands of igneous components along with areas of unmelted metamorphic rock**