

# Essentials of Geology, 11e

## Metamorphism and Metamorphic Rocks Chapter 7

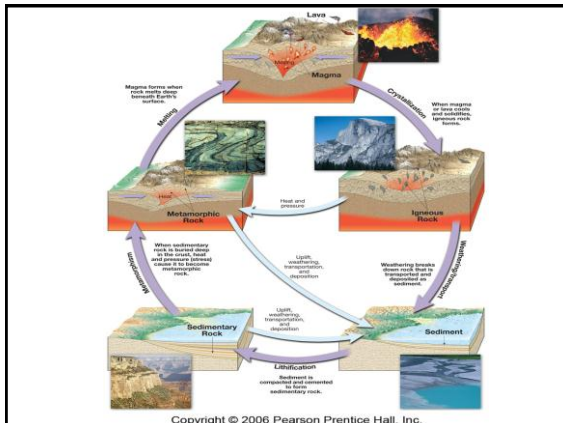
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Don't take life for **GRANITE**!

**SCHIST** happens,

so always be **GNEISS**.



## Metamorphism

- **Metamorphism** - the transition of one rock into another by temperatures and/or pressures unlike those in which it formed
  - Leads to changes in the mineralogy, texture and often the chemical composition of rocks.
- Metamorphic rocks are produced from
  - Igneous rocks
  - Sedimentary rocks
  - Other metamorphic rocks

## Metamorphism

- Metamorphism progresses incrementally from low-grade to high-grade
- During metamorphism the rock must remain essentially solid
- 3 Metamorphic settings (environments):
  1. **Contact** or **thermal** metamorphism – driven by a rise in temperature within the host rock.

## Metamorphism

- Metamorphic settings (environments):
  2. **Hydrothermal** metamorphism – chemical alterations from hot, ion-rich water
  3. **Regional** metamorphism
    - Occurs during mountain building
    - Produces the greatest volume of metamorphic rock
    - Rocks usually display zones of contact and/or hydrothermal metamorphism

### 3 Agents of Metamorphism

#### 1. 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

### Geothermal Gradient

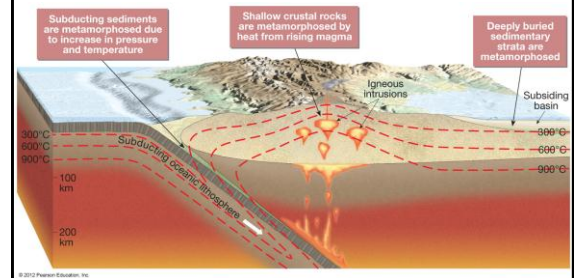


Figure 7.2

### 3 Agents of Metamorphism

#### 2. 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

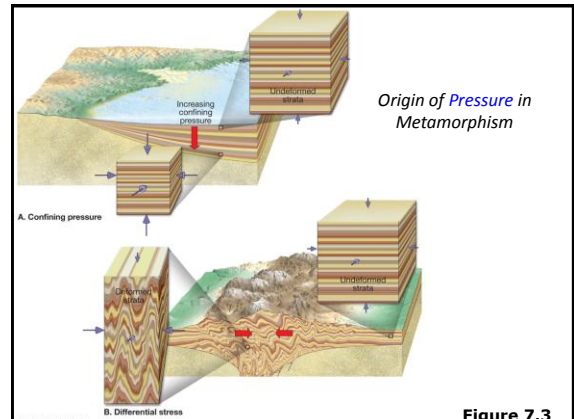


Figure 7.3

### Agents of Metamorphism

#### 3. Chemically active fluids

- 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

### Agents of Metamorphism

- 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

## Metamorphic Textures

- **Texture** refers to the size, shape, and arrangement of grains within a rock
- **Foliation** – any planar arrangement of mineral grains or structural features within a rock.
  - Ultimately driven by **compressional** stresses (differential pressure) the shorten rock units, causing mineral grains to develop alignment.

## Metamorphic Textures

- **Foliation**
  - 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

## Metamorphic Textures

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

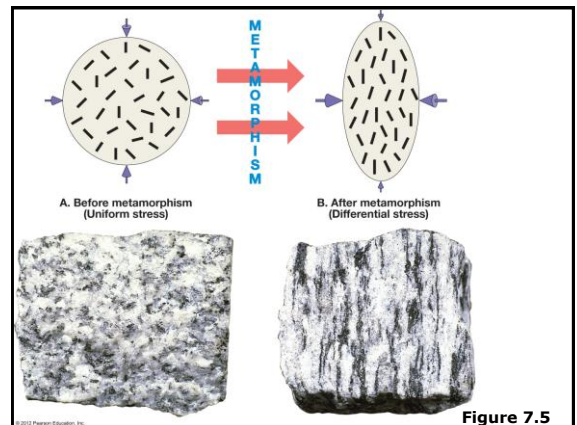


Figure 7.5

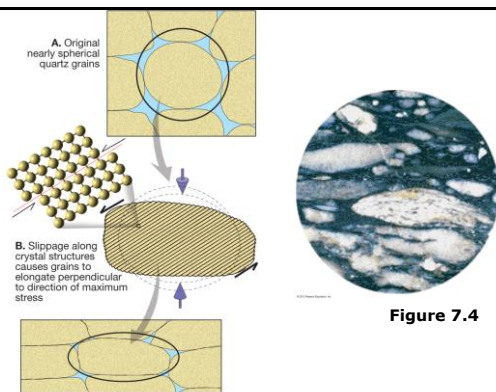


Figure 7.4

Figure 7.6

## Metamorphic Textures

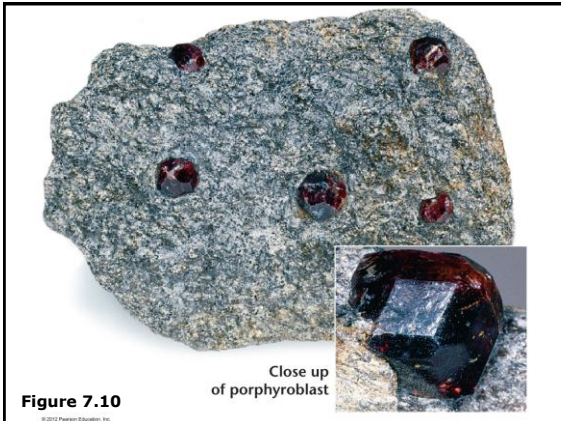
- **Foliated textures**
  - **Rock or slaty cleavage**
    - Closely spaced planar surfaces along which rocks split. Development depends on metamorphic conditions and parent rock.
  - **Schistosity**
    - Platy minerals are visible to unaided eye and exhibit a planar or layered structure.
  - **Gneissic**
    - During higher grades of metamorphism, ion migration results in the segregation of minerals. Exhibit a distinctive banded appearance.

## Metamorphic Textures

- Other metamorphic textures
  - Those metamorphic rocks that lack foliation are referred to as **nonfoliated**
    - Develop in environments where deformation is minimal.
      - Contact or hydrothermal are common
    - Typically composed of minerals that exhibit *equidimensional* (similar size and shape) crystals.

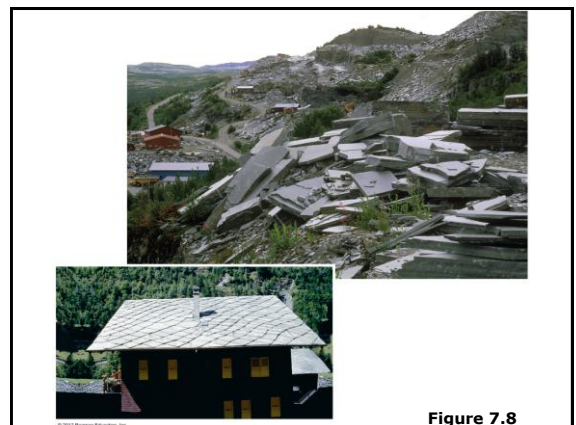
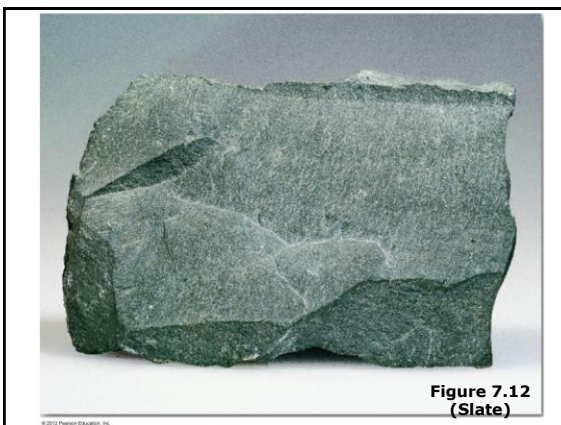
## Metamorphic Textures

- Other metamorphic textures
  - **Porphyroblastic** textures
    - Large grains, called **porphyroblasts**, are surrounded by a fine-grained matrix of other minerals
    - Porphyroblasts are typically **garnet**, staurolite, and/or andalusite



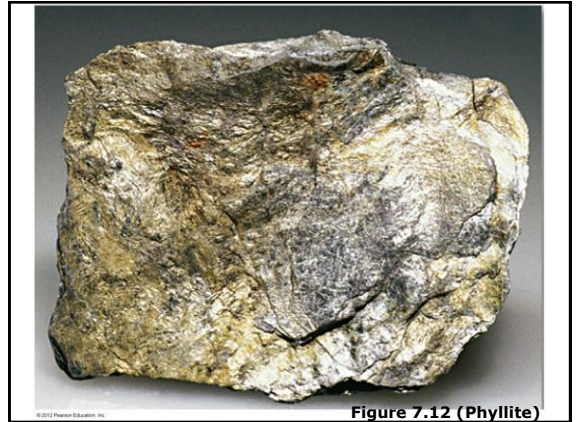
## Common Metamorphic Rocks

- Foliated rocks
  - **Slate**
    - Very **fine** grained
    - Excellent rock **cleavage**
    - Most often generated from **low-grade** metamorphism of shale, mudstone, or siltstone
    - Dominant mineral is clay
    - Dense, with high pitch resonance



## Common Metamorphic Rocks

- Foliated rocks
  - **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



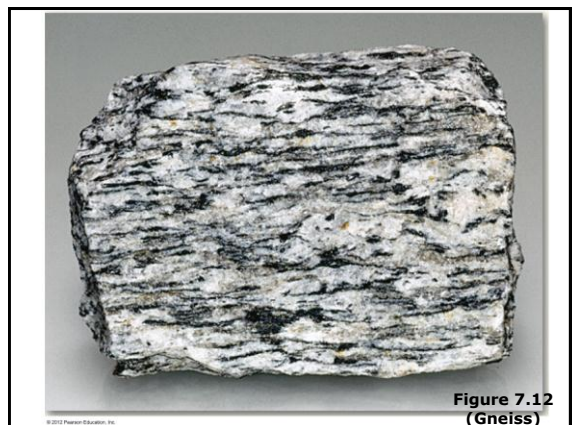
## Common Metamorphic Rocks

- Foliated rocks
  - **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)



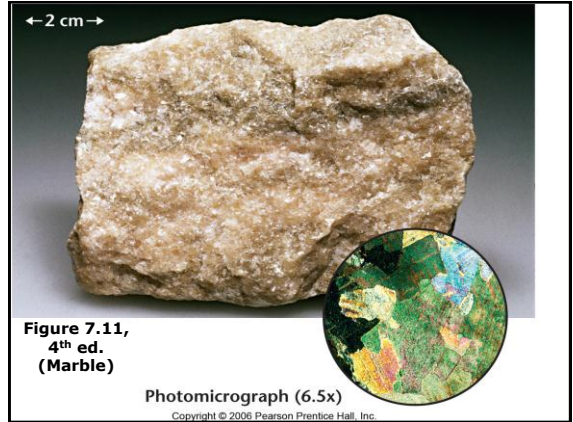
## Common Metamorphic Rocks

- Foliated rocks
  - **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



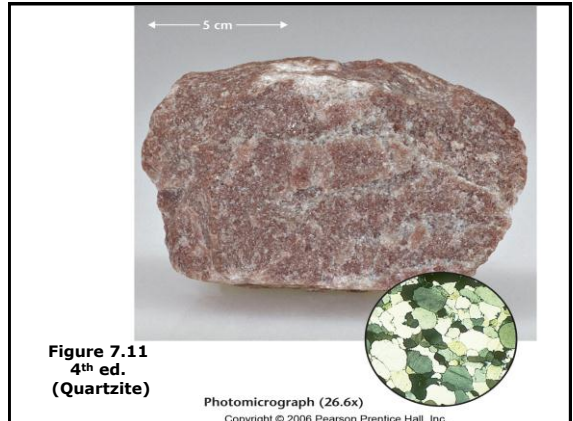
## Common Metamorphic Rocks

- 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
    - Equidimensional grains



## Common Metamorphic Rocks

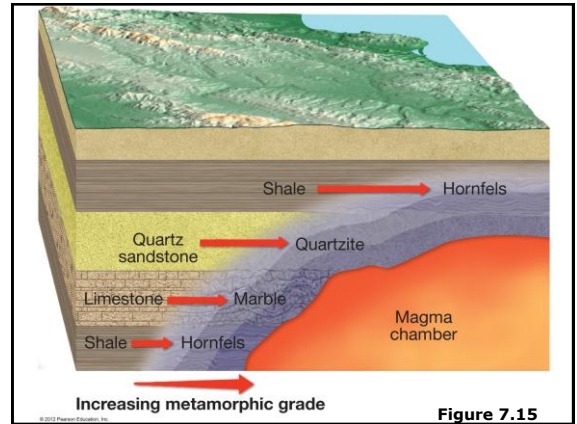
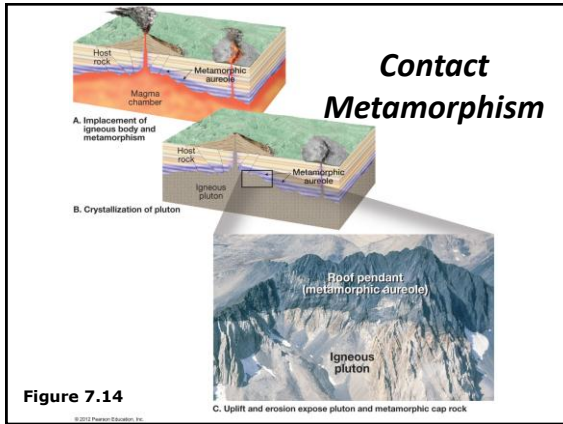
- Nonfoliated rocks
  - **Quartzite**
    - Formed from a parent rock of **quartz-rich sandstone**
    - Quartz grains are **fused** together
      - Cement and previous quartz grains recrystallized.
    - Exhibits a variety of colors
    - Equidimensional grains



Rock Name	Texture	Grain Size	Comments	Original Parent Rock
Slate	Foliated	Very fine	Excellent rock cleavage, smooth dull surfaces.	Shale, mudstone, or siltstone
Phyllite		Fine	Breaks along wavy surfaces, glossy sheen	Shale, mudstone, or siltstone
Schist		Medium to Coarse	Micaceous minerals dominate, scaly foliation	Shale, mudstone, or siltstone
Gneiss		Medium to Coarse	Compositional banding due to segregation of minerals	Shale, granite, or volcanic rocks
Migmatite	Welded	Medium to Coarse	Banded rock with zones of light-colored crystalline minerals	Shale, granite, or volcanic rocks
Mylonite		Fine	When very fine-grained, resembles chert, often breaks into slabs	Any rock type
Metaconglomerate	Welded	Coarse-grained	Stretched pebbles with preferred orientation	Quartz-rich conglomerate
Marble	Nonfoliated	Medium to coarse	Interlocking calcite or dolomite grains	Limestone, dolostone
Quartzite		Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone
Hornfels		Fine	Usually, dark massive rock with dull luster	Any rock type
Anthraxite	Welded	Fine	Shiny black rock that may exhibit conchoidal fracture	Bituminous coal
Fault breccia		Medium to very coarse	Broken fragments in a haphazard arrangement	Any rock type

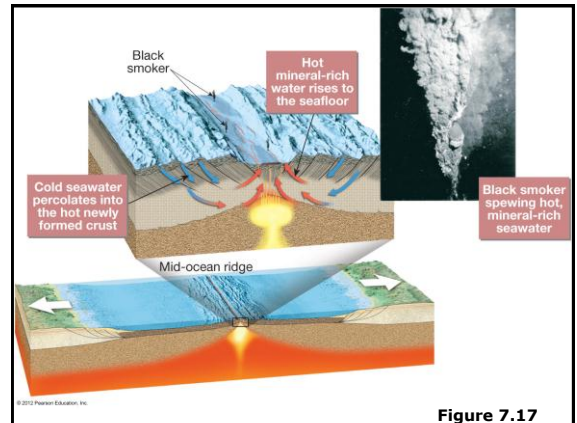
## Metamorphic Environments

- **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



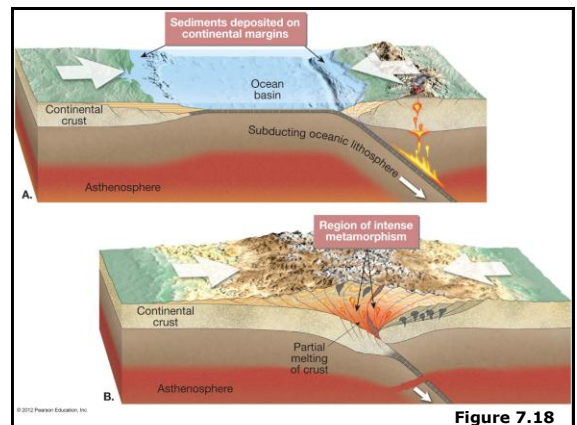
## Metamorphic Environments

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



## Metamorphic Environments

- **Regional** metamorphism
  - Produces the greatest quantity of metamorphic rock
  - Associated with **mountain** building
  - Takes place at considerable depths
  - Comprises an extensive area
  - May include all types of metamorphic environments



## Metamorphic Environments

- Other metamorphic environments
  - **Burial** metamorphism
    - Associated with 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**
    - Rocks called **mylonite**

## Brittle and Ductile Metamorphism

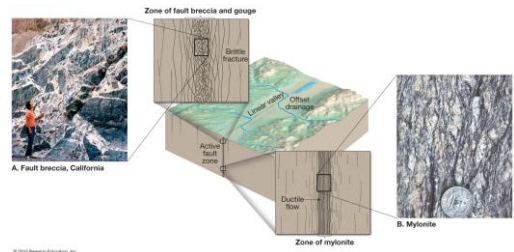


Figure 7.19

## Metamorphic Environments

- Other metamorphic environments
  - **Impact** metamorphism
    - Occurs when high speed projectiles called **meteorites** strike Earth's surface
    - Products are called **impactites**
    - Fused fragmented rock plus glass-rich ejecta
    - Iridium may be common element.

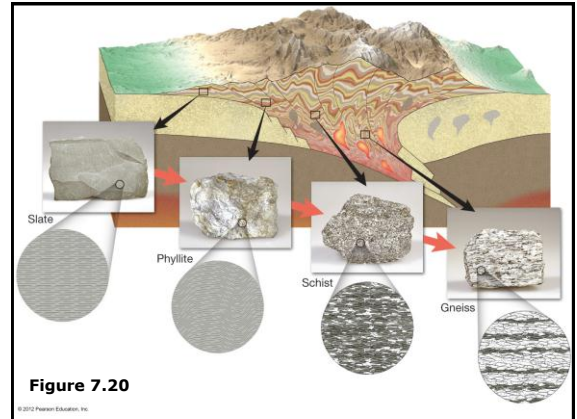


Figure 7.20

## Metamorphic Zones

- Variations in mineralogy and textures of metamorphic rocks are related to– Variations in the **degree of metamorphism**.
- **Index minerals** and metamorphic **grade**
  - Changes in mineralogy occur from regions of low-grade to high-grade metamorphism.
  - Certain minerals, called index minerals, are good indicators of the metamorphic **conditions** in which they form.

## Index Minerals

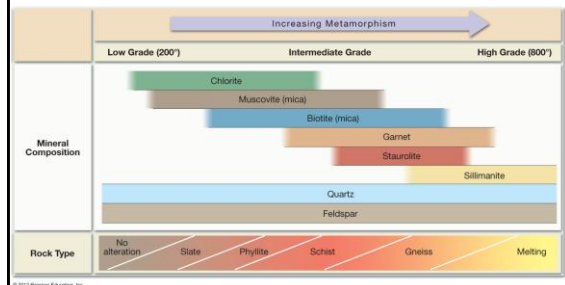


Figure 7.21



## Metamorphic Zones

- **Index minerals and metamorphic grade**

- **Migmatites**

- Highest grades of metamorphism that is transitional to igneous rocks
- Contain light bands of igneous components along with areas of unmelted\* metamorphic rock. \*Think Bowen's!



Figure 7.23

## Metamorphic Zones in the Northeastern United States

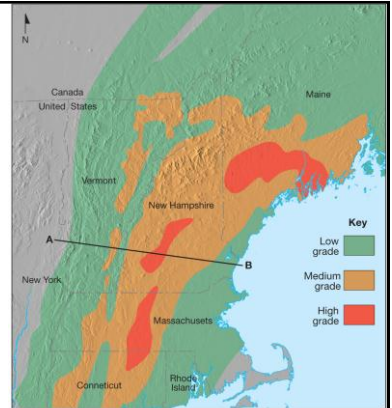


Figure 7.22

*End of Chapter 7*