Metamorphic Rocks 7

Metamorphic Rocks begins with an examination of the process of metamorphism, including a discussion of the agents of metamorphism - heat, pressure, and chemical activity. After presenting how metamorphism alters the texture and mineralogy of a rock, the most common foliated and nonfoliated rocks are examined. The chapter closes with an investigation of contact and regional metamorphism and the role of metamorphism in producing mineral deposits.

Learning Objectives

After reading, studying, and discussing the chapter, students should be able to:

- Briefly discuss the concept of metamorphism and metamorphic rocks.
- List and discuss the agents of metamorphism including heat, pressure, and chemical fluids.
- Briefly discuss the importance and origin of metamorphic textures.
- Compare and contrast the various types of foliated and nonfoliated metamorphic textures.
- List and briefly define the common metamorphic rocks, both foliated and nonfoliated.
- Briefly discuss the various metamorphic environments found on Earth.
- Explain the concept of metamorphic zones including index minerals and metamorphic grade.

Chapter Summary

• *Metamorphism* is the transformation of one rock type into another. *Metamorphic rocks* form from preexisting rocks (either igneous, sedimentary, or other metamorphic rocks) that have been altered by the agents of metamorphism, which include *heat*, *pressure*, and *chemically active fluids*. During metamorphism some of the material must remain solid. The changes that occur in the rocks are textural as well as mineralogical.

• Metamorphism most often occurs in one of three settings: (1) when rock is in contact with or near a mass of magma, *contact metamorphism* occurs; (2) where hot, ion-rich water circulates through rock, chemical alteration occurs by a process called *hydrothermal metamorphism*; or (3) during mountain building, where extensive areas of rock undergo *regional metamorphism*. The greatest volume of metamorphic rock is produced during regional metamorphism.

• The three agents of metamorphism are *heat*, *pressure* (*stress*), and *chemically active fluids*. The mineral makeup of the parent rock determines, to a large extent, the degree to which each metamorphic agent will cause change. Heat is the most important agent because it provides the energy to drive chemical reactions that result in the recrystallization of minerals. Pressure, like temperature, also increases with depth. When subjected to *confining pressure* minerals mey recrystallize into more compact forms. During mountain building rocks are subjected to *differtial stress* which tends to shorten them in the direction pressure is applied and lenghted them in the direction perpendicular to that force. At depth rocks are warm and *ductile*, which accounts for their ability to deform by flowing when subjected to differential stresses. Chemically active fluids, most commonly water containing ions in solution, also enhance the metamorphic process by dissolving minerals and aiding the migration and precipitation of this material at other sites.

• *The grade of metamorphism is reflected in the texture and mineralogy of metamorphic rocks*. During regional metamorphism rocks typically display a *preferred orientation* called *foliation* in which their platy and elongated minerals are aligned. Foliation develops as platy of elongated minerals are rotated into parallel alignment; recrystallize to form new grains that exhibit a preferred orientation; or are plastically deformed into flattened grains that exhibit a planar alignment. *Rock cleavage* is a type of foliation in which rocks split cleanly into thin slabs along surfaces where platy minerals are aligned. *Schistosity* is a type of foliation defined by the parallel alignment of medium- to coarse-grained platy minerals. During high-grade metamorphism, ion migrations can cause minerals to segregate into bands. Metamorphic rocks with a banded texture are called *gneiss*. Metamorphic rocks composed of only one mineral forming equidimensional crystals are often appear *nonfoliated*. *Marble* (metamorphosed limestone) is often nonfoliated. Further, metamorphism can cause the transformation of low-temperature minerals into high-temperature minerals and, through the introduction of ions from *hydrothermal solutions*, generate new minerals, some of which form economically important metallic ore deposits.

• Common foliated metamorphic rocks include *slate*, *phyllite*, various types of *schists* (e.g., garnet-mica schist), and *gneiss*. Nonfoliated rocks include *marble* (parent rock—limestone) and *quartzite* (most often formed from quartz sandstone).

• The three geologic environments in which metamorphism commonly occurs are (1) *contact* or *thermal metamorphism*, (2) *hydrothermal metamorphism*, and (3) *regional metamorphism*. Contact metamorphism occurs when rocks are in contact with igneous bodies and a zone of alteration called an *aureole* forms around the magma. Most contact metamorphic rocks are fine-grained, dense, tough rocks of various chemical compositions. Because directional pressure is not a major factor, are not generally foliated. Hydrothermal metamorphism occurs where hot, ion-rich fluids circulate through rock and cause chemical alteration of the constituent minerals. Most hydrothermal alteration occurs along the mid-ocean ridge system where seawater migrates through hot oceanic crust and chemically alters newly formed basaltic rocks. Metallic ions that are removed from the crust are eventually carried to the floor of the ocean where they precipitate from black smokers to form metallic deposits, some of which may be economically important. Regional metamorphism takes place at considerable depths over an extensive area and is associated with the process of mountain building. A gradation in the intensity of metamorphism usually exists in regional metamorphism, in which the intensity of metamorphism (low- to high-grade) is reflected in the texture and mineralogy of the rock. In the most extreme metamorphic environments, rocks, called *migmatites*, fall into a transition zone somewhere between "true" igneous rocks and "true" metamorphic rocks.

Chapter Outline

I. Metamorphism
   A. The transformation of one rock into another by temperatures and/or pressures unlike those in which it formed
   B. Metamorphic rocks are produced from
      1. Igneous rocks
      2. Sedimentary rocks
      3. Other metamorphic rocks
   C. Progresses incrementally from low-grade to high-grade
   D. During metamorphism the rock must remain essentially solid
   E. Metamorphic settings
      1. Contact or thermal metamorphism – driven by a rise in temperature within the host rock
      2. Hydrothermal metamorphism – chemical alterations from hot, ion-rich water
      3. Regional metamorphism
         a. Occurs during mountain building
         b. Produces the greatest volume of metamorphic rock

c. Rocks usually display zones of contact and/or hydrothermal metamorphism

II. Agents of Metamorphism
- A. Heat
  1. The most important agent
  2. Recrystallization results in new, stable minerals
  3. Two sources of heat
     a. Contact metamorphism – when the rocks are intruded by magma from below
     b. An increase in temperature due to the geothermal gradient as the rocks are transported to greater depths
- B. Pressure (stress)
  1. Increases with depth
  2. Confining pressure applies forces equally in all directions
  3. Rocks may also be subjected to differential stress, which is unequal in different directions
- C. Chemically active fluids
  1. Mainly water with other volatile components
  2. Enhance ion migration
  3. Aid in recrystallization which causes minerals to grow longer in a direction perpendicular to compressional stresses
  4. Sources
     a. Pore spaces of sedimentary rocks
     b. Fractures in igneous rocks
     c. Hydrated minerals such as clays and micas
- D. The importance of parent rock
  1. Most metamorphic rocks have the same overall chemical composition as the parent rock from which they formed, except for the possible loss or acquisition of volatiles
  2. Mineral makeup determines, to a large extent, the degree to which each metamorphic agent will cause change

III. Metamorphic textures
- A. Texture is used to describe the size, shape, and arrangement of grains within a rock
- B. Foliation
  1. Any planar (nearly flat) arrangement of mineral grains or structural features within a rock
     a. Examples
        1. Parallel alignment of platy and/or elongated minerals
        2. Parallel alignment of flattened mineral grains and pebbles
        3. Compositional banding
        4. Slaty cleavage where rocks can be easily split into thin, tabular sheets
     b. Types of foliation can form from
        1. Rotation of platy and/or elongated minerals
        2. Recrystallization of minerals in the direction of preferred orientation
        3. Changing the shape of equidimensional grains into elongated shapes that are aligned
  2. Foliated textures
     a. Rock or slaty cleavage
        1. Closely spaced planar surfaces along which rocks split
        2. Can develop in a number of ways depending on the metamorphic environment and the composition of the parent rock
     b. Schistosity
        1. Platy minerals are discernible with the unaided eye and exhibit a planar or layered structure
        2. Rocks having this texture are referred to as schist

c. Gneissic
1. During high-grade metamorphism, ion migration results in the segregation of minerals
2. Banded appearance

C. Other metamorphic textures
1. Those metamorphic rocks that do not exhibit a foliated texture are referred to as nonfoliated
a. Develop in environments where deformation is minimal and are composed of minerals that exhibit equidimensional crystals
b. e.g., marble
2. Porphyroblastic textures
a. Large grains, called porphyroblasts, surrounded by a fine-grained matrix of other minerals
b. Porphyroblasts may be garnet, staurolite, and/or andalusite

IV. Common metamorphic rocks
A. Foliated rocks
1. Slate
a. Very fine-grained
b. Excellent rock cleavage
c. Most often generated from low-grade metamorphism of shale, mudstone, or siltstone
2. Phyllite
a. Gradation in the degree of metamorphism between slate and schist
b. Platy minerals not large enough to be identified with the unaided eye
c. Glossy sheen and wavy surface
d. Exhibits rock cleavage
e. Composed mainly of fine crystals of either muscovite, chlorite, or both
3. Schist
a. Medium- to coarse-grained
b. Platy minerals predominate
c. Commonly include the micas
d. Term *schist* describes the texture
e. To indicate composition, mineral names are used
f. e.g., mica schist
4. Gneiss
a. Medium-to coarse-grained
b. Banded
c. High-grade metamorphism
d. Often composed of white or reddish feldspar-rich zones and layers of dark ferromagnesian minerals

B. Nonfoliated rocks
1. Marble
a. Coarse, crystalline
b. Parent rock was limestone or dolostone
c. Composed essentially of calcite crystals
d. Used to create monuments and statues
e. Exhibits a variety of colors
2. Quartzite
a. Formed from quartz sandstone
b. Quartz grains are fused

V. Metamorphic environments
A. Contact or thermal metamorphism
1. Occurs due to a rise in temperature when magma invades a host rock
2. Zone of alteration called an aureole forms in the rock that surrounds the emplaced magma
a. Mineral composition of the host rock and the availability of water affect the size of the aureole produced
b. Large aureoles often consist of distinct zones of metamorphism
3. Most easily recognized when it occurs at the surface, or in a near-surface environment

B. Hydrothermal metamorphism
   1. Chemical alteration caused when hot, ion-rich fluids, called hydrothermal solutions, circulate through fissures and cracks that develop in rock
   2. Most widespread along the axis of the mid-ocean ridge system
C. Regional metamorphism
   1. Produces the greatest quantity of metamorphic rock
   2. Associated with mountain building
D. Other metamorphic environments
   1. Burial metamorphism
      a. Associated with very thick accumulations of sedimentary strata
      b. Required depth varies from one location to another depending on the prevailing geothermal gradient
   2. Metamorphism along fault zones
      a. Occurs at great depth and at high temperatures
      b. Pre-existing minerals deform by ductile flow
   3. Impact metamorphism
      a. Occurs when high speed projectiles called meteorites strike Earth's surface

VI. Metamorphic zones
   A. Systematic variations in the mineralogy and often the textures of rocks related to the variations in the degree of metamorphism
   B. Index minerals and metamorphic grade
      1. Changes in mineralogy from regions of low-grade metamorphism to regions of high-grade metamorphism
      2. Certain minerals, called index minerals, are good indicators of the metamorphic environment in which they form
         a. Low-grade environments indicated by rocks containing chlorite
         b. High-grade environments often produce rocks containing the mineral sillimanite
      3. Migmatites
         a. Most extreme environments
         b. Contain light bands of igneous, or igneous appearing, components along with dark bands consisting of unmelted metamorphic rock