



1  **Metamorphism & Metamorphic Rocks**


Earth 9th edition, Chapter 8

2  **Metamorphism: summary in haiku form**

Shape-shifters in crust.

Just add heat and/or pressure.

Keep it solid please!

3  **Key Concepts**

- "Metamorphism" and the agents that drive it.
- Metamorphic textures.
- Common metamorphic rocks.
- Metamorphic environments.
- Metamorphic zones and metamorphic "grade."
- Metamorphism and plate tectonics.

4  **Metamorphism**

● The transition of one rock into another by temperatures and/or pressures unlike those in which it formed

● Metamorphic rocks are produced from:

- Igneous rocks
- Sedimentary rocks
- Other metamorphic rocks

5  **Metamorphism**

● Metamorphism progresses incrementally from low-grade to high-grade

● During metamorphism the rock must remain essentially solid

6  **Metamorphism**

● Metamorphic settings

☒ Contact (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

7  **Agents of Metamorphism**

● 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

8  **Origin of pressure in metamorphism**

9  **Origin of pressure in metamorphism**

10  **Agents of Metamorphism**

● Chemically active fluids

☒ Mainly water with other volatile components

☒ Enhances migration of ions

☒ Aids in recrystallization of existing minerals

11  **Agents of Metamorphism**

● The importance of parent rock

☒ Most metamorphic rocks have the same overall chemical composition as the parent rock from which they were formed

☒ Mineral makeup determines, to a large extent, the degree to which each metamorphic agent will cause change

- ◆ For instance, when magma forces its way into a clean quartz sandstone, very little alteration may take place
- ◆ But: if host rock is a “dirty” limestone (some clay), calcite (CaCO₃) may react with silica in clay to form wollastonite (CaSiO₃) plus carbon dioxide (CO₂)

12  **Metamorphic Textures**

- 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

13  **Metamorphic Textures**

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

14  **Metamorphic Textures**

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

15  **Metamorphic Rock Foliation**

16  **Metamorphic Textures**

- Foliated textures
 - ☒ Rock or *slaty cleavage*
 - ◆ Closely spaced planar surfaces along which rocks split
 - ◆ Can develop in a number of ways depending on metamorphic conditions and parent rock
 - ◆ Rocks having this texture are referred to as *slate*

17  **Metamorphic Textures**

- Foliated textures
 - ☒ *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*

18  **Metamorphic Textures**












- Foliated textures
 - ☒ *Gneissic*
 - ◆ During higher grades of metamorphism, ion migration results in the segregation of minerals
 - ◆ Gneissic rocks exhibit a distinctive banded appearance

19  **Metamorphic Textures**

- 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

20  **Metamorphic Textures**

- Other metamorphic textures
 - ☒ *Porphyroblastic* textures
 - ◆ Large grains, called *porphyroblasts*, surrounded by a fine-grained matrix of other minerals
 - ◆ Typical porphyroblast minerals:

- Garnet
 - Staurolite
 - Andalusite
- 21  ***Common metamorphic rocks***
- Foliated rocks
 - ☒ Slate
 - ◆ Very fine-grained
 - ◆ Excellent rock cleavage
 - ◆ Most often generated from low-grade metamorphism of shale, mudstone, or siltstone
- 22  ***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
 - ◆ Glassy sheen and wavy surfaces
 - ◆ Exhibits rock cleavage
 - ◆ Composed mainly of fine crystals of muscovite and/or chlorite
- 23  ***Common metamorphic rocks***
- Foliated rocks
 - ☒ Schist
 - ◆ Medium- to coarse-grained
 - ◆ Platy minerals predominate, especially micas
 - ◆ The term schist describes the texture
 - ◆ To indicate composition, mineral names are used (such as this albite mica schist)
- 24  ***A mica garnet kyanite schist***
- 25  ***Common metamorphic rocks***
- Foliated rocks
 - ☒ Gneiss (pronounced "nice")
 - ◆ Medium- to coarse-grained
 - ◆ Banded appearance
 - ◆ High-grade metamorphism
 - ◆ Often composed of light-colored feldspar-rich layers with bands of dark ferromagnesian minerals
- 26  ***A nice gneiss boulder in ABDSP***
- 27  ***Common metamorphic rocks***
- Nonfoliated rocks
 - ☒ Marble
 - ◆ Coarse, crystalline
 - ◆ Parent rock: limestone or dolostone
 - ◆ Composed of essentially calcite or dolomite crystals
 - ◆ Used as a decorative and monument stone
 - ◆ Exhibits a variety of colors
- 28  ***Marble from Dos Cabezas, ABDSP***
- 29  ***Common metamorphic rocks***
- Nonfoliated rocks
 - ☒ Quartzite
 - ◆ Formed from a parent rock of quartz-rich sandstone
 - ◆ Quartz grains are fused together
- 30  ***Quartzite w/ cross-bedding preserved***
- 31  ***Metamorphic environments***
- Contact or thermal metamorphism
 - ☒ Occurs due to a rise in temperature when magma intrudes 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

32 ***Metamorphic environments***

33 ***Foliation***

34 ***Metamorphic environments***

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

35 ***Metamorphic environments***

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

36 ***Metamorphic environments***

37 ***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

38 ***Metamorphic environments***

- Other metamorphic environments
 - ☒ Impact metamorphism
 - ◆ Occurs when high-speed projectiles called meteorites strike Earth's surface
 - ◆ Products are called impactites

39 ***Meteor Crater, Arizona***

40 ***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

41 ***Metamorphic Index Minerals***

42 ***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 grade of metamorphism that is transitional to igneous rocks
 - ◆ Contains light bands of igneous components along with areas of unmelted metamorphic rock

43 ***Migmatites in Baja California***


44 ***Migmatites in Box Canyon, ABDSP***

45 ***Metamorphism and plate tectonics***


- Most metamorphism occurs along convergent plate boundaries
 - ☒ Compressional stresses deform the edges of the plate
 - ☒ Formation of the Earth's major mountain belts including the Alps, Himalayas, and Appalachians


46 ***Metamorphism and plate tectonics***

- Large-scale metamorphism occurs along subduction zones at convergent plate boundaries
 - ☒ Several metamorphic environments exist here
 - ☒ Important site of magma generation

47  ***Metamorphism and plate tectonics***

- Metamorphism at subduction zones
 - ☒ Mountainous terrains along subduction zones exhibit distinct linear belts of metamorphic rocks
 - ◆ High-pressure, low-temperature zones nearest the trench
 - ◆ High-temperature, low pressure zones further inland in the region of igneous activity

48  ***Subduction Zone Metamorphism***

49  ***End of Chapter 8***