

1 2  **Chapter 8 – Metamorphic Rocks**3  **What Is Metamorphism?**

- Metamorphism means to “change form”
 - The transition of one rock into another by temperatures and/or pressures unlike those in which it formed
 - Changes in mineralogy and sometimes chemical composition
- Every metamorphic rock has a parent rock (the rock from which it formed)
 - Parent rocks can be igneous, sedimentary, or other metamorphic rocks

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- Metamorphic grade is the degree to which the parent rock changes during metamorphism
 - Progresses from low grade (low temperatures and pressures) to high grade (high temperatures and pressures)
- During metamorphism, the rock must remain essentially solid

6 **Metamorphic Grade**7 **What Drives Metamorphism?**

- Heat
 - Most important agent
 - Provides the energy needed for chemical reactions
 - Recrystallization is the process of forming new, stable minerals larger than the original
 - Two sources of heat:
 - Geothermal gradient: an increase in temperature with depth (about 25°C per kilometer)
 - Contact metamorphism: rising mantle plumes

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- Confining Pressure
 - Forces are applied equally in all directions
 - Analogous to water pressure
 - Causes the spaces between mineral grains to close











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- Differential Stress
 - Forces are unequal in different directions
 - Stresses are greater in one direction
- Compressional stress
 - Rocks are squeezed as if in a vice
 - Shortened in one direction and elongated in the other direction
 - In high pressure and temperature environments rocks are *ductile* and will stretch, flatten, or fold


11 **Confining Pressure and Differential Stress**12 **Confining Pressure and Differential Stress**13 14 

- Chemically Active Fluids
 - Water becomes a hot ion-rich fluid
 - *Hydrothermal solution*
 - Enhances migration of ions
 - Aids in recrystallization of existing minerals
 - Can change overall chemical composition
 - In some environments, fluids can transport mineral matter over considerable distances

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- The Importance of Parent Rock
 - Most metamorphic rocks have the same overall chemical composition as the original parent rock
 - Except for loss/gain of volatiles (H₂O, CO₂)
 - Mineral makeup determines the degree to which each metamorphic agent will cause change
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- Texture describes the size, shape, and arrangement of mineral grains
 - Metamorphic rocks can display preferred orientation of minerals, where the platy mineral grains exhibit parallel to sub-parallel alignment
 - Called foliation
 - Describes any planar arrangement of mineral grains or structural features within a rock
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- Examples of foliation
 - Parallel alignment of platy and/or elongated minerals
 - Parallel alignment of flattened mineral grains or pebbles
 - Compositional banding of dark and light minerals
 - Cleavage where rocks can be easily split into slabs
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- Foliation can form in various ways, including:
 - *Rotation* of platy minerals
 - *Recrystallization* that produces new minerals perpendicular to the direction of maximum stress
 - *Flattening* spherically shaped grains
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- Foliated Textures
 - Rock or Slaty Cleavage
 - Rocks split into thin slabs
 - Develops in beds of shale with low-grade metamorphism
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- Foliated Textures
 - Schistosity
 - Platy minerals are discernible with the unaided eye
 - Mica and chlorite flakes begin to recrystallize into large muscovite and biotite crystals
 - Exhibit a planar or layered structure
 - Rocks having this texture are referred to as schist
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- Foliated Textures
 - Gneissic texture
 - During high-grade metamorphism, ion migration results in segregation of minerals into light and dark bands
 - Metamorphic rocks with this texture are called gneiss
 - Although foliated, gneisses do not split as easily as slates and schists
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- Other Metamorphic Textures
 - Nonfoliated metamorphic rocks are composed of minerals that exhibit equidimensional crystals and lack foliation
 - Develop in environments where deformation is minimal, and from parent rocks with equidimensional minerals (e.g., quartz and calcite)

- Porphyroblastic textures
 - Unusually large grains, called *porphyroblasts*, are surrounded by a fine-grained matrix of other minerals

26  **Garnet-Mica Schist**

27  **Common Metamorphic Rocks**

- Foliated Rocks
 - Slate
 - Very fine-grained, resembles shale
 - Most often generated from low-grade metamorphism of shale, mudstone, or siltstone
 - Phyllite
 - Degree of metamorphism between slate and schist
 - Platy minerals are larger than slate but not large enough to see with the unaided eye
 - Glossy sheen and wavy surfaces
 - Both slate and phyllite exhibit rock cleavage
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- Foliated Rocks
 - Schist
 - Medium- to coarse-grained
 - Parent rock is shale that has undergone medium- to high-grade metamorphism
 - The term *schist* describes the texture
 - Platy minerals (mainly micas) predominate
 - Can also contain porphyroblasts
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- Foliated Rocks
 - Gneiss
 - Medium- to coarse-grained metamorphic rock with a banded appearance
 - The result of high-grade metamorphism
 - Composed of light-colored, feldspar-rich layers with bands of dark ferromagnesian minerals
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30  **Increasing Metamorphic Grade**

31  **Common Metamorphic Rocks**

- Nonfoliated Rocks
 - Marble
 - Crystalline rock from limestone or dolostone parent
 - Main mineral is calcite
 - Calcite is relatively soft (3 on the Mohs scale)
 - Used as a decorative and monument stone
 - But... weathers easily in acid rain
 - Impurities in the parent rocks provide a variety of colors of marble

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- Nonfoliated Rocks
 - Quartzite
 - Formed from a parent rock of quartz sandstone
 - Quartz grains are fused together
 - Pure quartzite is white
 - Iron oxide may produce reddish or pink stains
 - Dark minerals may produce green or gray stains
 - Cross-bedding and other sedimentary structures can be preserved in quartzite

- Hornfels
 - Parent rock is shale or clay-rich rocks
 - Fine-grained with variable mineral composition
 - “Baked” by an intruding magma body

33 **Quartzite**

34 **Metamorphic Environments**

- Metamorphism occurs in a variety of environments
 - In the vicinity of plate margins
 - Associated with igneous activity
 - *Contact or thermal metamorphism*
 - *Hydrothermal metamorphism*
 - *Burial metamorphism*
 - *Subduction zone metamorphism*
 - *Regional metamorphism*

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- Contact, or Thermal, Metamorphism
 - Results from a rise in temperature when magma invades a host rock
 - Occurs in the upper crust (low pressure, high temperature)
 - The zone of alteration (aureole) forms in the rock immediately surrounding the magma
 - Aureoles consist of distinct *zones of metamorphism*

37 **Contact Metamorphism**

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- Hydrothermal Metamorphism
 - Chemical alteration caused by hot, ion-rich water circulating through pore spaces and rock fractures
 - Typically occurs along the axes of mid-ocean ridges
 - Black smokers are the result of the fluids gushing from the seafloor
 - Also occurs associated with hot springs and geysers

39 **Hydrothermal Metamorphism**

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- Burial Metamorphism
 - Associated with very thick sedimentary strata in a subsiding basin
 - Confining pressure and heat drive recrystallization
- Subduction Zone Metamorphism
 - Sediments and oceanic crust are subducted fast enough that pressure increases before temperature
 - Differential stress drives metamorphism

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- Regional Metamorphism
 - Common, widespread type of metamorphism
 - Produces the greatest quantity of metamorphic rock
 - Associated with mountain building and the collision of continental blocks
 - Crust is shortened, thickened, folded, and faulted

44 **Regional Metamorphism**

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- Metamorphism Along Fault Zones
 - Occurs at depth and high temperatures
 - Pre-existing minerals deform by ductile flow
 - Minerals form a foliated or lineated appearance

- Rocks formed in these regions are called mylonites
- Impact Metamorphism
 - Also called shock metamorphism
 - Occurs when *meteoroids* strike Earth's surface
 - Product of these impacts (called *impactites*) are fused fragmented rock plus glass-rich ejecta that resemble volcanic bombs

46 **Metamorphism Along a Fault Zone**

47 **Metamorphic Zones**

- Textural Variations
 - In areas where regional metamorphism has occurred, rock texture varies based on intensity of metamorphism
 - Slate is associated with low-grade metamorphism
 - Phyllite and schist are intermediate
 - Gneiss is associated with high-grade metamorphism

48 **Textural Variations Caused by Regional Metamorphism**

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- Index Minerals and Metamorphic Grade
 - Changes in mineralogy occur from regions of low-grade metamorphism to regions of high-grade metamorphism
 - Index minerals are good indicators of metamorphic grades, and thus zones of metamorphism
 - Migmatites are rocks that have been partially melted
 - Represent the highest grades of metamorphism
 - Transitional to igneous rocks

50 **Metamorphic Zones and Index Minerals**

51 **Metamorphic Zones and Index Minerals**

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54 **Interpreting Metamorphic Environments**

- Common Metamorphic Facies
 - Metamorphic rocks that contain the same mineral assemblage and formed in similar metamorphic environments
 - Mineral assemblages can be used to determine the pressure and temperature conditions the rock formed under
 - Metamorphic facies include:
 - *Hornfels, zeolite, greenschist, amphibolite, granulite, blueschist, and eclogite*

55 **Metamorphic Facies**

56 **Interpreting Metamorphic Environments**

- Metamorphic Facies and Plate Tectonics
 - High-pressure, low-temperature metamorphism is associated with the upper section of subduction zones
 - Regional metamorphism is associated with colliding continental blocks
 - Low pressure, low- to high-temperature metamorphism is associated with divergent plate boundaries

57 **Metamorphic Facies and Plate Tectonics**

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59 **Interpreting Metamorphic Environments**

- Mineral Stability and Metamorphic Environments
 - Some minerals are only stable at certain temperature and pressure regimes
 - Examples include andalusite, kyanite, and sillimanite, all having the same chemical composition but forming under different metamorphic conditions
 - Knowing the range of temperatures and pressures associated with mineral formation can

aid in interpreting the metamorphic environment

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60  **Minerals Used to Predict Metamorphic Environments**

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