1 **Metamorphism & Metamorphic Rocks**

**Earth, Chapter 8**

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 25ºC 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**

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- 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 ($H_2O$, $CO_2$)
  - 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 **Increasing Metamorphic Grade (continued)**

32 **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

34 **Quartzite**

35 **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*

38 **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

40 **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

45 **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

47 **Metamorphism Along a Fault Zone**

48 **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

49 **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

51 **Metamorphic Zones and Index Minerals**

52 **Metamorphic Zones and Index Minerals**

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55 **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*

56 **Metamorphic Facies**

57 **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

58 **Metamorphic Facies and Plate Tectonics**

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60 **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

61 **Minerals Used to Predict Metamorphic Environments**

62 ***End of Chapter 8***