1 **Metamorphism & Metamorphic Rocks**

Earth, Chapter 8

2 **Metamorphism: summary in haiku form**

Shape-shifters in crust.
Just add heat and/or pressure.
Keep it solid please!

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

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- 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
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6 **Metamorphic Grade**

7 **What Drives Metamorphism?**

- Heat
  - Most important agent
    - 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^{o} 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

9

- 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

10 **Confining Pressure and Differential Stress**

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- Chemically Active Fluids
  - Enhances migration of ions
  - Aids in recrystallization of existing minerals
  - 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
  - Mineral makeup determines the degree to which each metamorphic agent will cause change

13 **Metamorphic Textures**

- 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 subparallel alignment

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- Foliation describes any planar arrangement of mineral grains or structural features within a rock
  - 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
  - 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

16 **Solid State Flow**

17

- Foliated Textures
  - Rock or slaty cleavage
    - Rocks split into thin slabs
    - Develops in beds of shale with low-grade metamorphism

18 **Excellent Slaty Cleavage**

19 **Metamorphic Textures**

- 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

20

- Foliated Textures
  - Gneissic texture
    - During high-grade metamorphism, ion migration results in the segregation of minerals into light and dark bands
    - Metamorphic rocks with this texture are called gneiss
    - Although foliated, gneiss do not usually 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
  - Porphyroblastic textures
    - Unusually large grains, called porphyroblasts, are surrounded by a fine-grained matrix of other minerals

22 **Garnet-Mica Schist**

23 **Common Metamorphic Rocks**

- Foliated Rocks
  - Slate
    - Very fine-grained
    - Excellent rock cleavage
    - Most often generated from low-grade metamorphism of shale, mudstone, or siltstone

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- Foliated Rocks
  - 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
    - Exhibits rock cleavage

25

- 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

27 **Increasing Metamorphic Grade**

28 **Common Metamorphic Rocks**

- Nonfoliated Rocks
  - Marble
    - Crystalline rock from limestone or dolostone parent rock
    - Main mineral is calcite
      - Calcite is relatively soft (3 on the Mohs scale)
      - Used as a decorative and monument stone
    - Impurities in the parent rocks provide a variety of colors
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29

- Nonfoliated Rocks
  - Quartzite
    - Formed from a parent rock of quartz-rich 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

30 **Quartzite**

31

- Nonfoliated Rocks
  - Hornfels
    - Parent rock is shale or clay-rich rocks
    - “Baked” by an intruding magma body

32

33 **Metamorphic Environments**

- 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 surrounding the magma

34 **Contact Metamorphism**

35

- Hydrothermal Metamorphism
  - Chemical alteration caused by hot, ion-rich fluids 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

36 **Hydrothermal Metamorphism Along a Mid-Ocean Ridge**

37

- Burial Metamorphism
  - Associated with very thick sedimentary strata in a subsiding basin

    - Gulf of Mexico is an example
- Subduction Zone Metamorphism
  - Sediments and oceanic crust are subducted fast enough that pressure increases before temperature

38

- Regional Metamorphism
  - Produces the greatest quantity of metamorphic rock
  - Associated with mountain building and the collision of continental blocks

39 **Regional Metamorphism**

40

- Metamorphism Along Fault Zones
  - Occurs at depth and high temperatures
  - Preexisting minerals deform by ductile flow
    - Mylonites form in these regions of ductile deformation
- Impact Metamorphism
  - Occurs when meteorites strike Earth's surface
    - Product of these impacts are fused fragmented rock plus glass-rich ejecta that resemble volcanic bombs
      - Called impactiles

41 **Metamorphism Along a Fault Zone**

42 **Metamorphic Zones**

- Textural Variations
  - Slate is associated with low-grade metamorphism
  - Gneiss is associated with high-grade metamorphism
    - Phyillte and schist are intermediate

43 **Textural Variations Caused by Regional Metamorphism**

44

- 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 environments
  - Migmatites are rocks that have been partially melted
    - Represent the highest grades of metamorphism
    - Transitional to igneous rocks

45 **Metamorphic Zones and Index Minerals**

46 **Interpreting Metamorphic Environments**

- Metamorphic Facies
  - Metamorphic rocks that contain the same mineral assemblage and formed in similar metamorphic environments

47 **Metamorphic Facies**

48 **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
    - Examples include the Appalachian Mountains

49 **Metamorphic Facies and Plate Tectonics**

50 **Interpreting Metamorphic Environments**

- Mineral Stability and Metamorphic Environments

- Some minerals are stable at certain temperature and pressure regimes
  - Examples include the polymorphs andalusite, kyanite, and sillimanite
- Knowing the range of temperatures and pressures associated with mineral formation can aid in interpreting the metamorphic environment
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51 **Minerals Used to Predict Metamorphic Environments**

52 ***Metamorphic Rock Foliation***

53 ***Foliation***

54 ***End of Chapter 8***