Metamorphic Rocks, Processes, and Resources

Metamorphic rocks are rocks changed from one form to another by intense heat, intense pressure, and/or the action of hot fluids.

Protolith or parent rock is the rock type that a metamorphic rock was before it was subjected to metamorphic conditions.

Protoliths can be any rock from the three main rock categories: Igneous, Sedimentary and Metamorphic

Metamorphic grade refers to the temperature and pressure under which a rock was metamorphosed, considered low grade or high grade. Since metamorphic minerals in a rock form under specific conditions, they are used to identify the temperature and pressure of the metamorphic conditions.

Metamorphic rock fabrics and textures

Foliated rocks have a ‘fabric’, called a foliation, caused by the parallel alignment of mineral grains. Non-foliated rocks do not have a fabric, and their massive appearance resembles sedimentary rocks.

Textures of Foliated Metamorphic Rocks (listed from lowest grade to highest)

1. Slate has a parallel foliation of fine-grained, platy minerals (e.g. micas).
2. Phyllite has a parallel foliation of very fine-grained minerals. The rock will commonly have wrinkled surfaces and a silky sheen.
3. Schist has a foliation or mineral alignment of medium to coarse-grained minerals.
4. Gneiss has a sometimes discontinuous banding of light-colored medium to coarse-grained minerals (e.g. quartz and feldspar) and dark-colored minerals (e.g. pyroxene and hornblende).

Textures of Non-Foliated Metamorphic Rocks

1. Fine-grained can be “sugary” with fine grained crystals or “massive”, in which individual intergrown crystals are hard to discern.
2. Medium to coarse-grained may be “sandy” with crystals that are sand-sized, or coarser depending on the protolith.

• Metamorphism refers to solid-state changes to rocks in Earth’s interior
  – Produced by changes in temperature, pressure, or the action of hot, reactive fluids
  – Old minerals, unstable under new conditions, recrystallize into stable ones
  – Rocks produced from pre-existing or parent rocks in this way are called metamorphic rocks
• Metamorphic rocks are common in the old, stable cores of continents, known as cratons
Factors Controlling Metamorphic Rock Characteristics

- Texture and mineral content of metamorphic rocks depend on:
  - Parent rock composition
  - Temperature and pressure during metamorphism
  - Effects of tectonic forces
  - Effects of fluids, such as water
- Parent rock composition
  - Usually no new elements (other than water) are added to rocks during metamorphism
  - Resulting metamorphic rock must have very similar elemental composition to that of parent rock
- Temperature during metamorphism
  - Heat for metamorphism comes primarily from outward flow from Earth's deep interior
  - All minerals stable over finite temperature range
  - If range exceeded, new mineral structures result
  - If temperature gets high enough, melting will occur – igneous rock
- Pressure during metamorphism
  - Confining pressure is pressure applied equally in all directions
  - Pressure generally proportional to depth of burial within the Earth
  - Metamorphic pressure typically increases 1 kilobar per 3.3 km of burial within the crust
  - High-pressure minerals have more compact structure/higher density

Tectonic forces
- Often lead to forces that are not equal in all directions (differential stress)
- Compressive stress causes flattening perpendicular to stress
- Shearing causes flattening by sliding parallel to stress
- Planar rock texture of aligned minerals produced by differential stress is known as foliation
  - Foliation increases with pressure and time

Fig. 1: The effect of tectonic forces on a rock with originally random grain orientation. (from McGraw Hill)
Fig. 2: Schematic representation of a foliated metamorphic rock (from McGraw Hill).

- **Fluids**
  - Hot water (as vapor) is most important
  - Rising temperature causes water to be released from unstable minerals
  - Hot water very reactive; acts as rapid transport agent for mobile ions

- **Time**
  - Metamorphism, particularly from high pressures, may take millions of years
  - Longer times allow newly stable minerals to grow larger and increase foliation

Classification based on rock texture

- *Foliated* (layered - preferred orientation of minerals) vs.
- *Non-foliated* (non-layered)
- Foliated rocks named based on type of foliation (slaty, schistose, gneissic)
- Non-foliated rocks named based on composition
## Classification of metamorphic rocks

<table>
<thead>
<tr>
<th>Nonfoliated</th>
<th>Metamorphic rock</th>
<th>Dominant minerals</th>
<th>Distinguishing characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parent rock</strong></td>
<td><strong>Metamorphic rock</strong></td>
<td><strong>Dominant minerals</strong></td>
<td><strong>Distinguishing characteristics</strong></td>
</tr>
<tr>
<td>Limestone, dolomite</td>
<td>Marble, dolomite marble</td>
<td>Calcite or dolomite</td>
<td>Coarse, interlocking grains with rhombohedral cleavage, effervesces in acid</td>
</tr>
<tr>
<td>Quartz sandstone</td>
<td>Quartzite</td>
<td>Quartz</td>
<td>Interlocking grains of granular quartz, hard, scratches glass</td>
</tr>
<tr>
<td>Shale, basalt</td>
<td>Hornfels</td>
<td>Fine-grained micas</td>
<td>Fine-grained dark rock, may have some coarser minerals present, usually scratches glass</td>
</tr>
</tbody>
</table>

<table>
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<td><strong>Parent rock</strong></td>
<td><strong>Metamorphic rock</strong></td>
<td><strong>Dominant minerals</strong></td>
<td><strong>Characteristics</strong></td>
</tr>
<tr>
<td>Shale</td>
<td>Slate</td>
<td>Clay minerals, micas</td>
<td>Fine grained, splits easily, sharper sound than shale</td>
</tr>
<tr>
<td>Shale</td>
<td>Phyllite</td>
<td>Micas</td>
<td>Fine-grained rock with silky luster, usually splits along wavy surfaces</td>
</tr>
<tr>
<td>Shale</td>
<td>Schist</td>
<td>Biotite, muscovite, amphiboles, quartz, feldspars</td>
<td>Composed of visible platy or elongated minerals, planar alignment</td>
</tr>
<tr>
<td>Shale</td>
<td>Gneiss</td>
<td>Feldspars, micas, quartz</td>
<td>Light and dark minerals separated into bands</td>
</tr>
<tr>
<td>Basalt</td>
<td>Amphibolite, amphibole schist</td>
<td>Amphiboles, plagioclase</td>
<td>Dark rock with elongated amphibole grains, may sometimes lack distinctive foliation</td>
</tr>
</tbody>
</table>

### Types of Metamorphism

- **Contact metamorphism**
  - High temperature - dominant factor causing metamorphism
  - No directed pressure - produces non-foliated rocks
  - Occurs adjacent to magma bodies intruding cooler country rock
  - Occurs in narrow zone (~1-100 m wide) known as contact aureole
  - Rocks may be fine- (e.g., hornfels) or coarse-grained (e.g., marble, quartzite)
- **Regional metamorphism**
  - *High directed pressure* and temperature - dominant factors causing metamorphism
  - Results in rocks with *foliated* textures
  - Prevalent in intensely deformed mountain ranges
  - May occur over wide temperature range
  - Increasing pressure and temperature will produce increasing *metamorphic grade*
  - Prograde metamorphism of shale produces:
    - *slate*
    - *phyllite*
    - *schist*
    - *gneiss*
Plate Tectonics and Metamorphism

- Regional metamorphism associated with convergent plate boundaries
  - Pressure generally proportional to depth
  - Temperature at given depth varies laterally at convergent boundaries
  - Wide variety of temperature/pressure-specific mineral assemblages or metamorphic facies is produced

Fig. 4: Regional metamorphism in a continent-continent collision zone. Note that some melt has formed as well as seen in a rising magma diapir. (from McGraw-Hill)

Fig. 5: A convergent boundary released hot fluids of sedimentary rocks and basalts being subducted aid in metamorphism, metasomatism, and the formation of ore veins (from McGraw-Hill)
List of Metamorphic rock samples in this lab

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Metamorphic rock name</th>
<th>Parent rock/ Protolith</th>
<th>mineralogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>slate</td>
<td>shale</td>
<td>Clay minerals, mica</td>
</tr>
<tr>
<td>2</td>
<td>phyllite</td>
<td>shale</td>
<td>micas</td>
</tr>
<tr>
<td>3</td>
<td>schist</td>
<td>shale</td>
<td>Micas, quartz, feldspars</td>
</tr>
<tr>
<td>4</td>
<td>gneiss</td>
<td>shale</td>
<td>Micas, quartz, feldspars</td>
</tr>
<tr>
<td>5</td>
<td>amphibolite</td>
<td>basalt</td>
<td>Amphibole, plagioclase</td>
</tr>
<tr>
<td>6</td>
<td>marble</td>
<td>limestone</td>
<td>calcite</td>
</tr>
<tr>
<td>7</td>
<td>quartzite</td>
<td>sandstone</td>
<td>quartz</td>
</tr>
<tr>
<td>8</td>
<td>serpentinite</td>
<td>Ultramafic rock</td>
<td>serpentine</td>
</tr>
</tbody>
</table>

Assignments:

Familiarize yourself with the metamorphic reference rock samples provided, then answer the questions below.

1. Compare the following rocks:

<table>
<thead>
<tr>
<th></th>
<th>Minerals</th>
<th>Textures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schist</td>
<td></td>
<td></td>
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<tr>
<td>Gneiss</td>
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</table>

Which one do you think has formed under more pronounced metamorphic conditions?

2. Explain how foliation develops in a metamorphic rock. Why doesn't it form in some metamorphic rocks, for example in quartzites?

3. What are the driving forces of metamorphism?
4. Where in the US, would you expect lots of metamorphic rocks? Why there?

5. What does the distribution of the metamorphic rocks in the US tell you about the tectonic history of the US?

6. Unknowns. Identify the supplied metamorphic rock unknowns. List the characteristics you used for identification.

<table>
<thead>
<tr>
<th>Metamorphic rock name</th>
<th>Protolith</th>
<th>Mineral content</th>
<th>Characteristics used in identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNK-1</td>
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<td>UNK-2</td>
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<td>UNK-3</td>
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<td>UNK-4</td>
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<tr>
<td>UNK-5</td>
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