

Chapter 8



Metamorphism and Metamorphic Rocks

Introduction

- **Metamorphism** - The transformation of rocks, usually beneath Earth's surface, as the result of heat, pressure, and/or fluid activity, produces metamorphic rocks
- During metamorphism, rocks are subjected to sufficient heat, pressure and/or fluid activity to change their mineral composition or texture, or both.
- All this occurs below the melting point in the solid state.

Introduction

- Metamorphism is also responsible for producing a number of economically valuable materials, like slate
- Metamorphism is an important process that is closely related to plate tectonics, the growth of continents, and even climate change.



Introduction

- Distribution of Metamorphic Rocks - Shields and Cores of Mountain Ranges



The Agents of Metamorphism

- The principal agents of metamorphism are *heat, pressure, fluid activity and time*.
- Intrusive magmas, lava flows or deep burial provide heat which causes metamorphism.
- Pressure is produced by overlying rocks (lithostatic) or is differential pressure produced by various stresses.
- Fluid activity increases the rate of metamorphism and brings new elements.
- Time is also important, as the more time involved, the greater the degree of metamorphism produced.

The Agents of Metamorphism

- Heat - an important agent of metamorphism because heat increases the rate of reactions
- Sources of heat include:
 - Extrusive lava
 - Intrusive magma
 - Deep burial

The Agents of Metamorphism

- Pressure – Two types, lithostatic and differential
- Lithostatic pressure is a uniform field of pressure experienced by most rocks beneath Earth's surface – pressure is equal in all directions. Sometimes called confining pressure.
- Differential pressure is a non-uniform field of pressure; the pressure acting on a rock in some directions is stronger than it is in others.

The Agents of Metamorphism

- Pressure – lithostatic vs. differential

http://geophysics.ou.edu/geol114/notes/met_rx/df_diff_stress.ppt

The Agents of Metamorphism

- Fluid Activity – accelerates chemical changes and can cause new minerals to form by bringing new elements and allowing for easier ion exchange to occur during metamorphism.
- Sources of fluids include:
 - Pore spaces in sedimentary rocks
 - Magma

The Agents of Metamorphism

- Time – makes a large difference in the final metamorphic rock product.
- More time under lower pressures and temperatures can produce a large amount of metamorphism.
- Less time, even under high temperatures and pressures, may not produce as much change.
- Time is *always* important in altering or changing rocks.

The Agents of Metamorphism

- The type of metamorphism that results largely depends on which of the three main agents was dominant.

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The Seven Types of Metamorphism

- Regional metamorphism
- Contact
- Dynamic
- Hydrothermal
- Burial
- High Pressure and Ultra-High Pressure
- Shock Metamorphism

The Seven Types of Metamorphism

- Regional metamorphism - the most common type of metamorphism.
- Regional metamorphism occurs when high temperatures and pressures are imposed over a broad area of the crust.
- Older igneous, sedimentary and metamorphic textures are destroyed.
- Volcanic arcs (High T, Moderate to Low P), Subduction Zones (Moderate T, High P), and Continent-Continent Collision zones (Very High P, High T).

The Seven Types of Metamorphism

- Contact Metamorphism – occurs under conditions of high temperature and lower pressure.
- They are arrayed in aureoles, or metamorphosed zones, around plutons and other intrusive igneous bodies. They also occur at the base of lava flows.

The Seven Types of Metamorphism

- Factors Affecting Contact Metamorphism
- The Size, Temperature and Composition of the intrusion.
- The Composition of the Country Rock.
- The amount of Fluids available for metamorphic alteration.

The Seven Types of Metamorphism

- Dynamic metamorphism is associated with
- Faults, and
- Areas where high pressure builds up in the crust, but the temperature is low, such as in the accretionary wedges at convergent plate boundaries.

The Seven Types of Metamorphism

- Dynamic metamorphism
- The type of pressure is differential, in other words the amount is different in different directions.

http://www.ncc.edu/home/bentley/pgeoblog2008_03_01_archive.html

<http://ic.ucc.edu/~casey/war110/Lectures/Foliation&lineation/>

The Seven Types of Metamorphism

- Hydrothermal metamorphism - Occurs through the interaction of hot fluids with country rock. On the sea floor, this happens when basalts are altered to serpentine.

<http://www.geol.umd.edu/~jmerck/geol100/lectures/16.html>

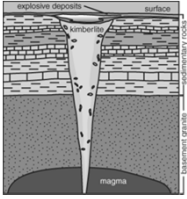
<http://www.abdn.ac.uk/meteorology/typhoon/typhoon.htm>

The Seven Types of Metamorphism

- Burial metamorphism
 - Deep burial of sedimentary rocks and the increased pressure and temperatures – makes non-layered metamorphic rocks.
 - Sedimentary structures can be preserved, although the minerals change.
 - Used in oil industry to determine if temperatures were too high to form petroleum (different minerals form under different conditions).

The Seven Types of Metamorphism

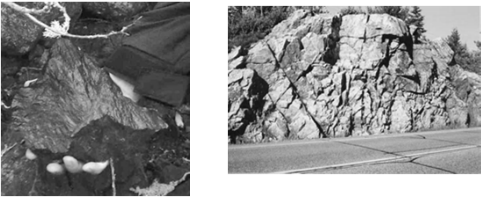
- High Pressure or Ultra-High Pressure metamorphism – Occurs at depths greater than 30 km. At 120+ km and 800+ degrees diamonds can form. Brought to surface in narrow pipes called kimberlites.



http://www.kgs.ku.edu/Publications/ClearRecord/2000/v08_1/1Page1.html

The Seven Types of Metamorphism

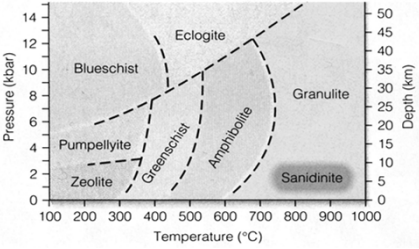
- Shock metamorphism - Occurs when a meteorite impacts the Earth.
 - Results in fracturing, shatter cones and new minerals.



http://tdaweb.nrc.ca/wiki/index.php/768b-Cdable-Articles-Introduction

Metamorphic Zones and Facies

- Metamorphic facies – refers to a group of rocks containing a distinctive mineral assemblage formed under similar conditions of temperature and pressure.

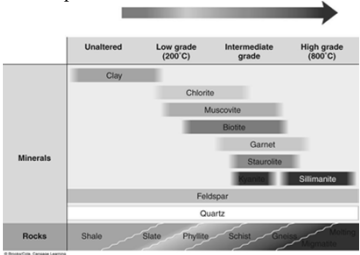


Metamorphic Zones and Facies

- Index Minerals and Metamorphic Grade
 - Metamorphic grade – the degree of metamorphic change a rock has undergone.
 - Index minerals – certain minerals are known to only form under specific temperatures and pressure.

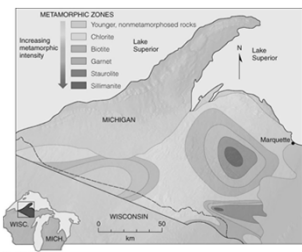
Metamorphic Zones and Facies

- Index Minerals typically don't form in carbonate or quartz-rich parent rocks.



Metamorphic Zones and Facies

- Metamorphic zone – a belt of rocks showing roughly the same degree of metamorphism

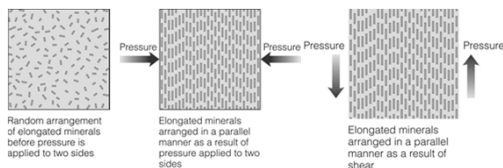


Metamorphic Zones and Facies

- How do metamorphic zones and metamorphic facies differ?
 - Metamorphic zones show the gradational metamorphic change within a single rock composition.
 - Metamorphic facies are groups of many different rock compositions whose mineral contents all indicate common temperature and pressure conditions during metamorphism.

How are Metamorphic Rocks Classified?

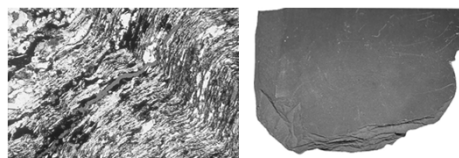
- Metamorphic rocks are classified principally according to texture. The two types are Foliated and Nonfoliated.



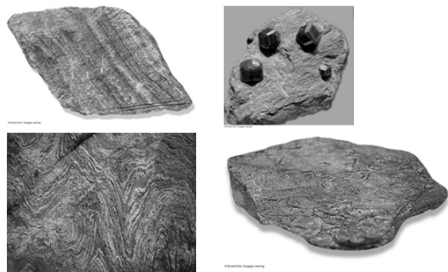
Foliated textures form via differential pressure.

How are Metamorphic Rocks Classified?

- **Foliated Metamorphic Rocks**
 - Foliated texture is produced by the preferred orientation of platy minerals.
 - Foliated metamorphic rocks form a graded series of grain size and/or development of foliation, from slate, to phyllite, to schist, and finally to gneiss.

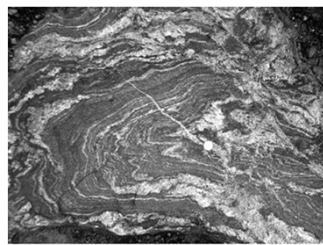


Examples of Foliated Metamorphic Rocks



How are Metamorphic Rocks Classified?

- Migmatite – contain streaks of granite



How are Metamorphic Rocks Classified?

- **Nonfoliated Metamorphic Rocks**

Limestone $\xrightarrow{\text{Metamorphism}}$ Marble $\xrightarrow{\text{Metamorphism}}$ Quartzite
 Quartzite $\xrightarrow{\text{Metamorphism}}$ Quartz

- Nonfoliated textures do not exhibit preferred orientation of minerals.
- Common nonfoliated metamorphic rocks are marble, quartzite, greenstone, and hornfels.

How are Metamorphic Rocks Classified?

Texture	Metamorphic Rock	Typical Mineral	Metamorphic Grade	Characteristics of Rocks	Parent Rock
Foliated	Slate	Clays, micas, chlorite	Low	Fine-grained, splits easily into flat pieces	Mudrocks, volcanic ash
	Phyllite	Fine-grained quartz, mica, chlorite	Low to medium	Fine-grained, glossy or lustrous sheen	Mudrocks
	Schist	Micas, chlorite, quartz, feldspar, hornblende, garnet, staurolite, graphite	Low to high	Distinct foliation, minerals visible	Mudrocks, carbonates, mafic igneous rocks
	Gneiss	Quartz, feldspar, hornblende, micas	High	Segregated light and dark bands visible	Mudrocks, sandstones, felsic igneous rocks
	Amphibolite	Hornblende, plagioclase	Medium to high	Dark, weakly foliated	Mafic igneous rocks
Nonfoliated	Migmatite	Quartz, feldspar, hornblende, micas	High	Streaks or lenses of granite intermixed with gneiss	Felsic igneous rocks mixed with sedimentary rocks
	Marble	Calcite, dolomite	Low to high	Interlocking grains of calcite or dolomite, reacts with HCl	Limestone or dolomite
	Quartzite	Quartz	Medium to high	Interlocking quartz grains, hard, dense	Quartz sandstone
	Greenstone	Chlorite, epidote, hornblende	Low to high	Fine-grained, green	Mafic igneous rocks
	Hornfels	Micas, garnets, andradite, cordierite, quartz	Low to medium	Fine-grained, equidimensional grains, hard, dense	Mudrocks
Anthracite	Carbon	High	Black, lustrous, subconchoidal fracture	Coal	

Plate Tectonics and Metamorphism

- Metamorphism can occur along all types of plate boundaries, but is most common and extensive along convergent boundaries.

Relationship of facies to major tectonic features at a convergent plate boundary

Abbreviations:

- ▲ amphibolite facies
- blueschist facies
- contact metamorphic zone
- eclogite facies
- granulite facies
- high-temperature amphibolite facies
- granulite facies
- jadeite-pumpellyite facies
- garnite facies

Plate Tectonics and Metamorphism

- Metamorphic rocks formed near the surface and within an oceanic-continental convergent plate boundary zone result from low temperature and high pressure conditions - Blueschist facies metamorphism

Pressure (kbar) vs. Temperature (°C) vs. Depth (km)

Plate Tectonics and Metamorphism

- Higher temperatures and pressures existing at depth within such plate boundaries produce higher grades of metamorphism in a subducting oceanic plate.

Pressure (kbar) vs. Temperature (°C) vs. Depth (km)

Metamorphism and Natural Resources

Economic mineral resources which are associated with metamorphic rocks include tin, copper, iron, lead, tungsten and zinc (fluids during contact metamorphism; Hydrothermal systems = Cyprus-type deposits)


Copper Ore

Tin Ore

http://library.thinkquest.org/06aug/0045/Natural_Resources.html
<http://www.antiquest.com/company.html>


Metamorphism and Natural Resources

Mineral resources which are metamorphic rocks include marble and slate.



Metamorphism and Natural Resources

- Mineral resources which are metamorphic minerals include graphite, talc, asbestos and garnet.



The Rock Cycle

- The Rock Cycle
- Any rock can be altered into any other type of rock.
- Each rock is formed by specific processes; those processes can create new rocks of different types – or even the *same* type.

The Rock Cycle

Rock Forming Processes

- Igneous: Melting and Crystallization
- Sedimentary: Weathering, Transportation, Deposition, Lithification
- Metamorphic: altered by Heat, Pressure, Fluid Activity, Time

