



ECIV 3302
Engineering Geology

Chapter 7

METAMORPHISM AND METAMORPHIC ROCKS

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The materials are mostly adapted from the presentation of Stan & Cindy Hatfield

Metamorphism

- The transition of one rock into another by temperatures and/or pressures unlike those in which it formed
- Metamorphic rocks are produced from
 - Igneous rocks
 - Sedimentary rocks
 - Other metamorphic rocks

Metamorphism

- Metamorphism progresses incrementally from low-grade to high-grade
- During metamorphism the rock must remain essentially solid
- Metamorphic settings
 - **Contact or thermal metamorphism** – driven by a rise in temperature within the host rock

Metamorphism

■ Metamorphic settings

- **Hydrothermal metamorphism** – chemical alterations from hot, ion-rich water
- **Regional metamorphism**
 - Occurs during mountain building
 - Produces the greatest volume of metamorphic rock
 - Rocks usually display zones of contact and/or hydrothermal metamorphism

Agents of metamorphism

■ Heat

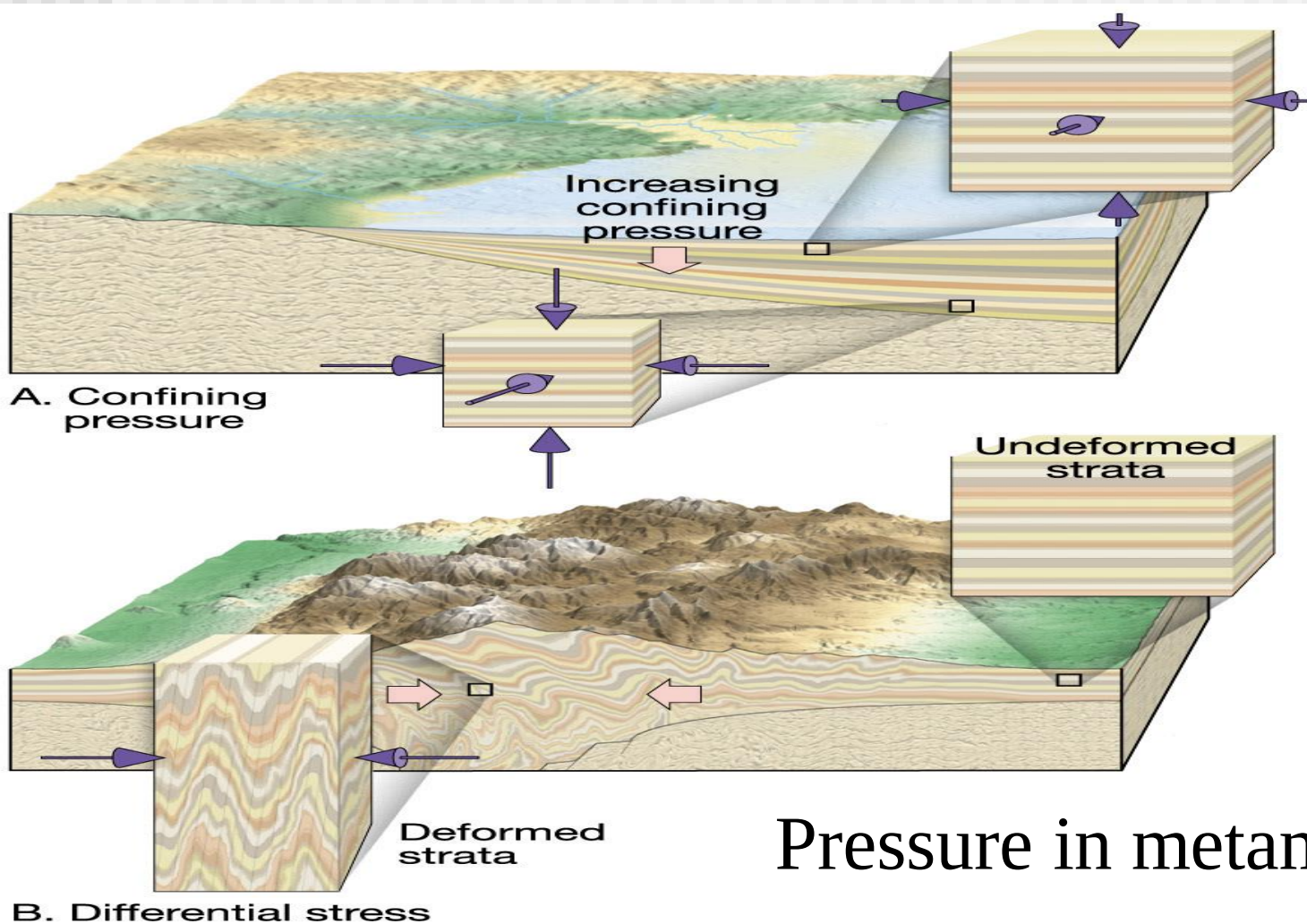
- Most important agent
- Recrystallization results in new, stable minerals
- Two sources of heat
 - Contact metamorphism – heat from magma
 - An increase in temperature with depth due to [the geothermal gradient](#)

Agents of metamorphism

■ Pressure and differential stress

- Increases with depth
- Confining pressure applies forces equally in all directions
- Rocks may also be subjected to differential stress which is unequal in different directions

Agents of metamorphism



Pressure in metamorphism

Agents of metamorphism

■ Chemically active fluids

- Mainly water with other volatile components
- Enhances migration of ions
- Aids in recrystallization of existing minerals

Agents of metamorphism

■ Chemically active fluids

- Sources of fluids
 - Pore spaces of sedimentary rocks
 - Fractures in igneous rocks
 - Hydrated minerals such as clays and micas

Agents of metamorphism

- The importance of parent rock
 - Most metamorphic rocks have the same overall chemical composition as the parent rock from which they formed
 - Mineral makeup determines, to a large extent, the degree to which each metamorphic agent will cause change

Metamorphic textures

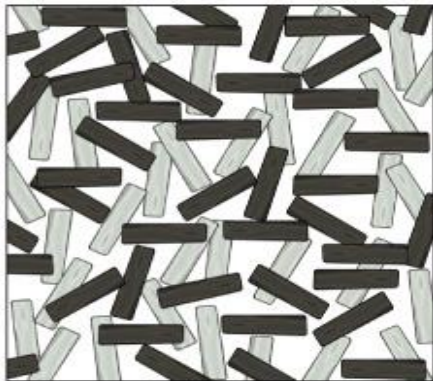
- Texture refers to the size, shape, and arrangement of mineral grains
- **Foliation** – any planar arrangement of mineral grains or structural features within a rock
 - Examples of foliation
 - Parallel alignment of platy and/or elongated minerals
 - Parallel alignment of flattened mineral grains and pebbles
 - Compositional banding
 - Slaty cleavage where rocks can be easily split into thin, tabular sheets

Metamorphic textures

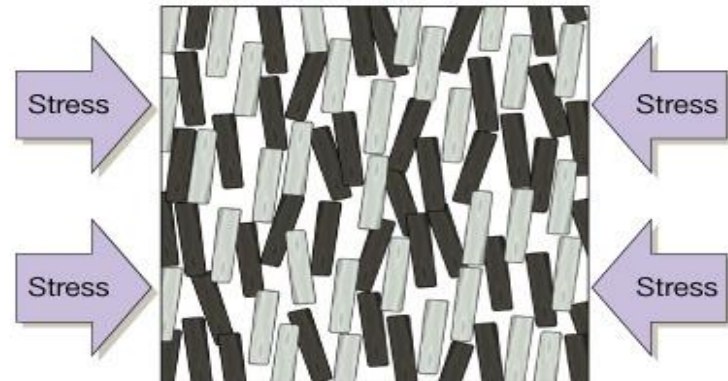
■ Foliation

- Foliation can form in various ways including
 - Rotation of platy and/or elongated minerals
 - Recrystallization of minerals in the direction of preferred orientation
 - Changing the shape of equidimensional grains into elongated shapes that are aligned

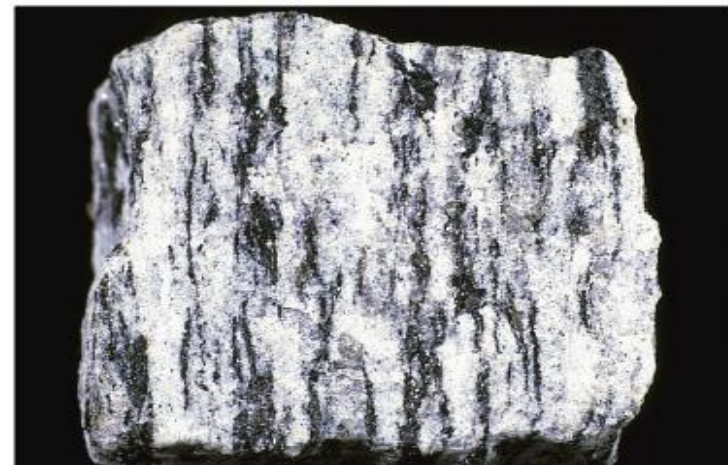
Metamorphic textures



Before metamorphism



After metamorphism



Foliation resulting from directed stress

Metamorphic textures

■ Foliated textures

- Rock or **slaty cleavage**
 - Closely spaced planar surfaces along which rocks split
 - Can develop in a number of ways depending on metamorphic conditions and parent rock
- **Schistosity**
 - Platy minerals are discernible with the unaided eye and exhibit a planar or layered structure
 - Rocks having this texture are referred to as **schist**

Metamorphic textures

■ Foliated textures

- Gneissic

- During higher grades of metamorphism, ion migration results in the segregation of minerals
- Gneissic rocks exhibit a distinctive banded appearance

Metamorphic textures

■ Other metamorphic textures

- Those metamorphic rocks that lack foliation are referred to as nonfoliated
 - Develop in environments where deformation is minimal
 - Typically composed of minerals that exhibit equidimensional crystals
- **Porphyroblastic** textures
 - Large grains, called **porphyroblasts**, surrounded by a fine-grained matrix of other minerals

Common metamorphic rocks

■ Foliated rocks

- Slate

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



Common metamorphic rocks

■ Foliated rocks

• Phyllite

- Gradation in the degree of metamorphism between slate and schist
- Platy minerals not large enough to be identified with the unaided eye
- Glossy sheen and wavy surfaces
- Exhibits rock cleavage
- Composed mainly of fine crystals of muscovite and/or chlorite



Common metamorphic rocks

■ Foliated rocks

• Schist

- Medium- to coarse-grained
- Platy minerals (mainly micas) predominate
- The term *schist* describes the texture
- To indicate composition, mineral names are used (such as mica schist)



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Garnet-mica schist

Common metamorphic rocks

■ Foliated rocks

- Gneiss

- Medium- to coarse-grained
- Banded appearance
- High-grade metamorphism
- Often composed of white or light-colored feldspar-rich layers with bands of dark ferromagnesian minerals

Classifying metamorphic rocks

Rock Name		Texture	Grain Size	Comments	Parent Rock
Slate	Increasing Metamorphism ↓	Foliated	Very fine	Excellent rock cleavage, smooth dull surfaces	Shale, mudstone, or siltstone
Phyllite			Fine	Breaks along wavy surfaces, glossy sheen	Slate
Schist			Medium to Coarse	Micaceous minerals dominate, scaly foliation	Phyllite
Gneiss			Medium to Coarse	Compositional banding due to segregation of minerals	Schist, granite, or volcanic rocks
Migmatite			Medium to Coarse	Banded rock with zones of light-colored crystalline minerals	Gneiss, schist
Mylonite	Weakly Foliated	Weakly Foliated	Fine	When very fine-grained, resembles chert, often breaks into slabs	Any rock type
Metaconglomerate			Coarse-grained	Stretched pebbles with preferred orientation	Quartz-rich conglomerate
Marble	Nonfoliated	Nonfoliated	Medium to coarse	Interlocking calcite or dolomite grains	Limestone, dolostone
Quartzite			Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone
Hornfels			Fine	Usually, dark massive rock with dull luster	Any rock type
Anthracite			Fine	Shiny black rock that may exhibit conchoidal fracture	Bituminous coal
Fault breccia			Medium to very coarse	Broken fragments in a haphazard arrangement	Any rock type

Common metamorphic rocks

■ Nonfoliated rocks

• Marble

- Coarse, crystalline
- Parent rock was limestone or dolostone
- Composed essentially of calcite or dolomite crystals
- Used as a decorative and monument stone
- Exhibits a variety of colors



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Common metamorphic rocks

■ Nonfoliated rocks

- Quartzite

- Formed from a parent rock of quartz-rich sandstone
- Quartz grains are fused together

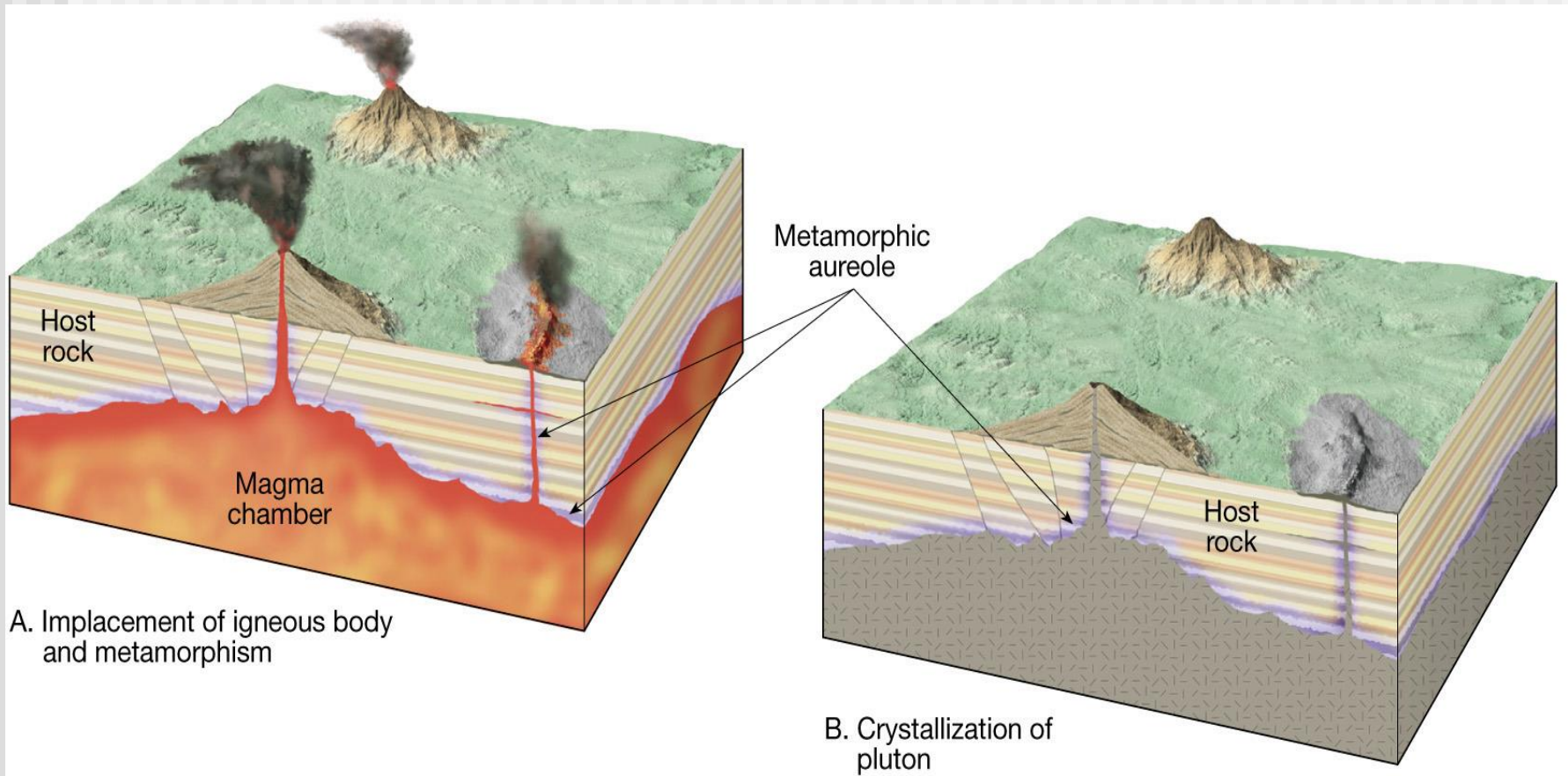


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Metamorphic environments

- **Contact or thermal metamorphism**
 - Result from a rise in temperature when magma invades a host rock
 - A zone of alteration called an **aureole** forms in the rock surrounding the magma
 - Most easily recognized when it occurs at the surface, or in a near-surface environment

Metamorphic environments

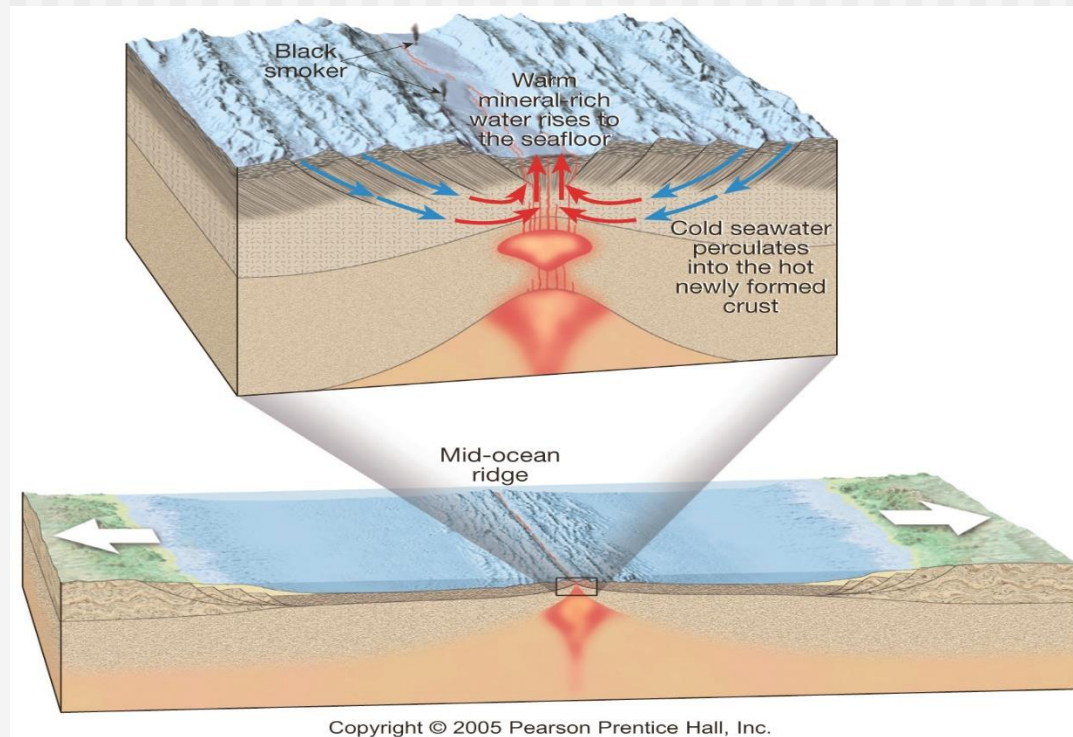


Contact metamorphism

Metamorphic environments

■ Hydrothermal metamorphism

- Chemical alteration caused when hot, ion-rich fluids, called hydrothermal solutions, circulate through fissures and cracks that develop in rock
- Most widespread along the axis of the mid-ocean ridge system



Metamorphic environments

■ Regional metamorphism

- Produces the greatest quantity of metamorphic rock
- Associated with mountain building

Metamorphic environments

■ Other metamorphic environments

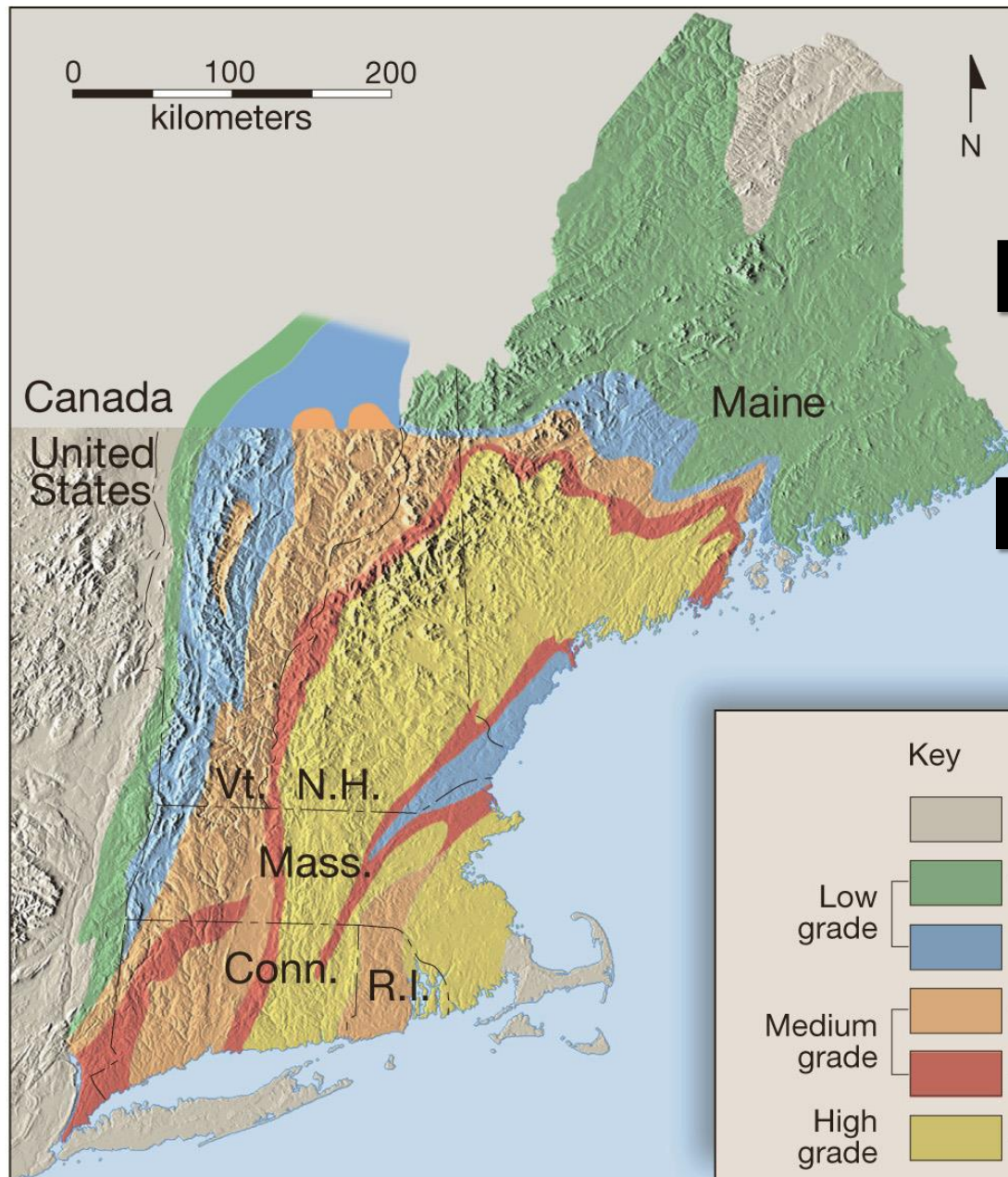
- Burial metamorphism
 - Associated with very thick sedimentary strata
 - Required depth varies depending on the prevailing geothermal gradient
- Metamorphism along fault zones
 - Occurs at depth and high temperatures
 - Pre-existing minerals deform by ductile flow
- Impact metamorphism
 - Occurs when high speed projectiles called meteorites strike Earth's surface
 - Products are called [impactites](#)

Metamorphic zones

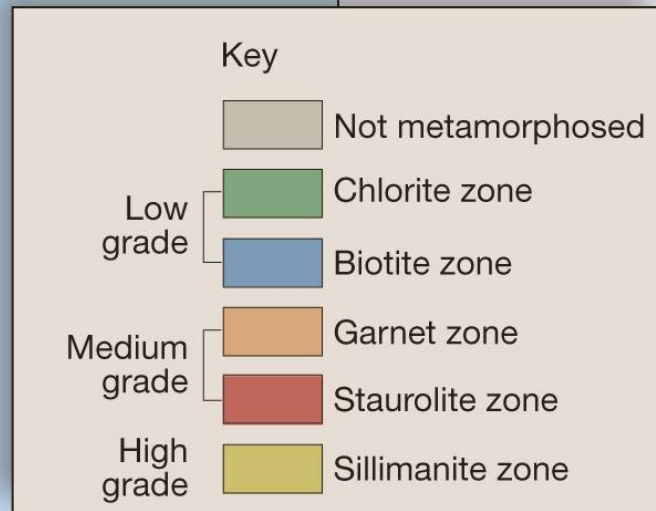
- Systematic variations in the mineralogy and textures of metamorphic rocks are related to the variations in the degree of metamorphism
- Index minerals and metamorphic grade
 - Changes in mineralogy occur from regions of low-grade metamorphism to regions of high-grade metamorphism

Metamorphic zones

- Index minerals and metamorphic grade
 - Certain minerals, called **index minerals**, are good indicators of the metamorphic conditions in which they form
 - **Migmatites**
 - Highest grades of metamorphism that is transitional to igneous rocks
 - Contain light bands of igneous components along with areas of unmelted metamorphic rock



Metamorphic zones in New England



Metamorphism and plate tectonics

- Most metamorphism occurs along convergent plate boundaries
 - Compressional stresses deform the edges of the plate
 - Formation of Earth's major mountain belts including the Alps, Himalayas, and Appalachians
- Large-scale metamorphism also occurs along subduction zones at convergent boundaries
 - Several metamorphic environments exist here
 - Important site of magma generation

Metamorphism and plate tectonics

- Metamorphism at subduction zones
 - Mountainous terrains along subduction zones exhibit distinct linear belts of metamorphic rocks
 - High-pressure, low-temperature zones nearest the trench
 - High-temperature, low-pressure zones further inland in the region of igneous activity

Metamorphic environments and plate tectonics

