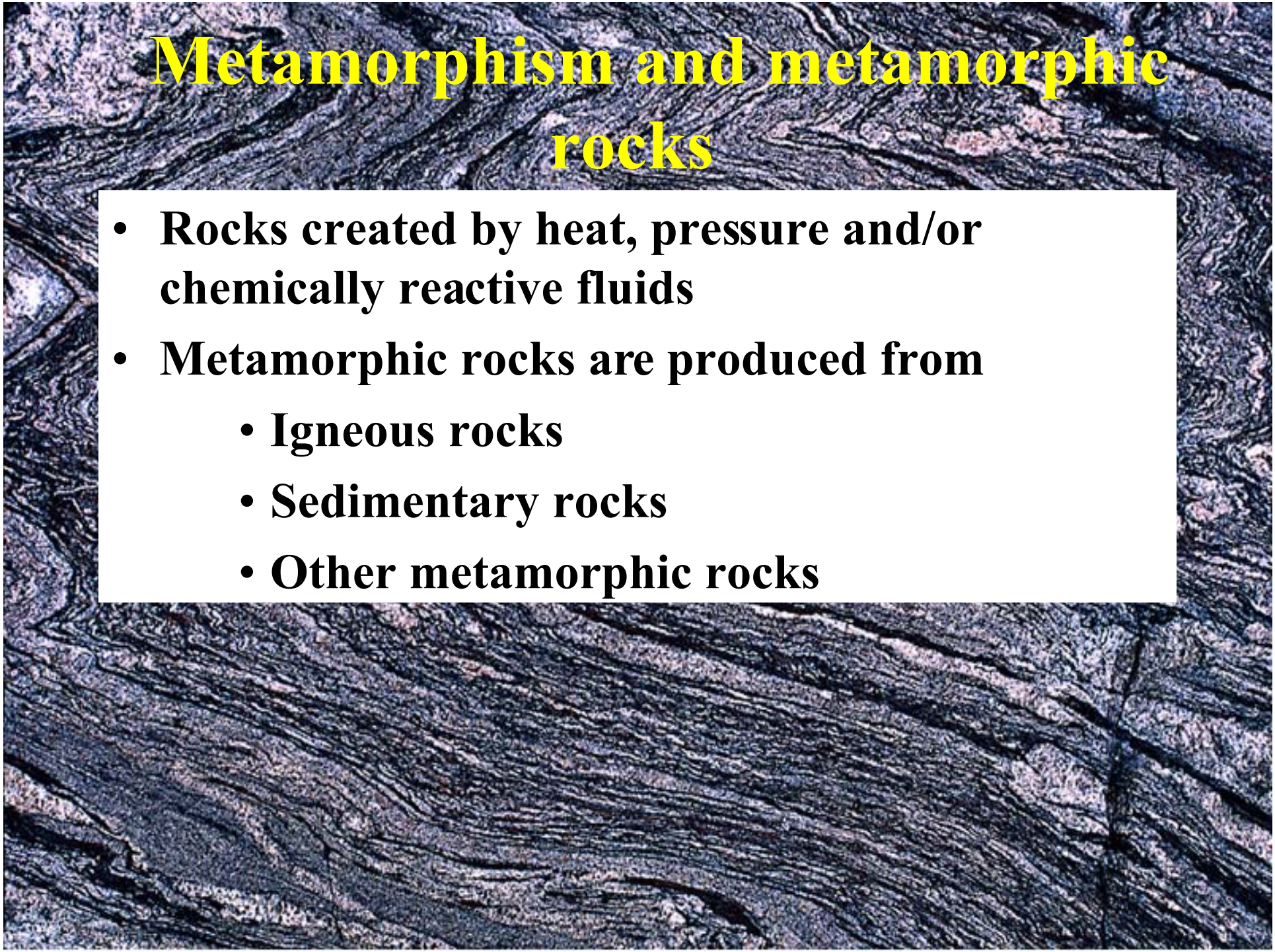


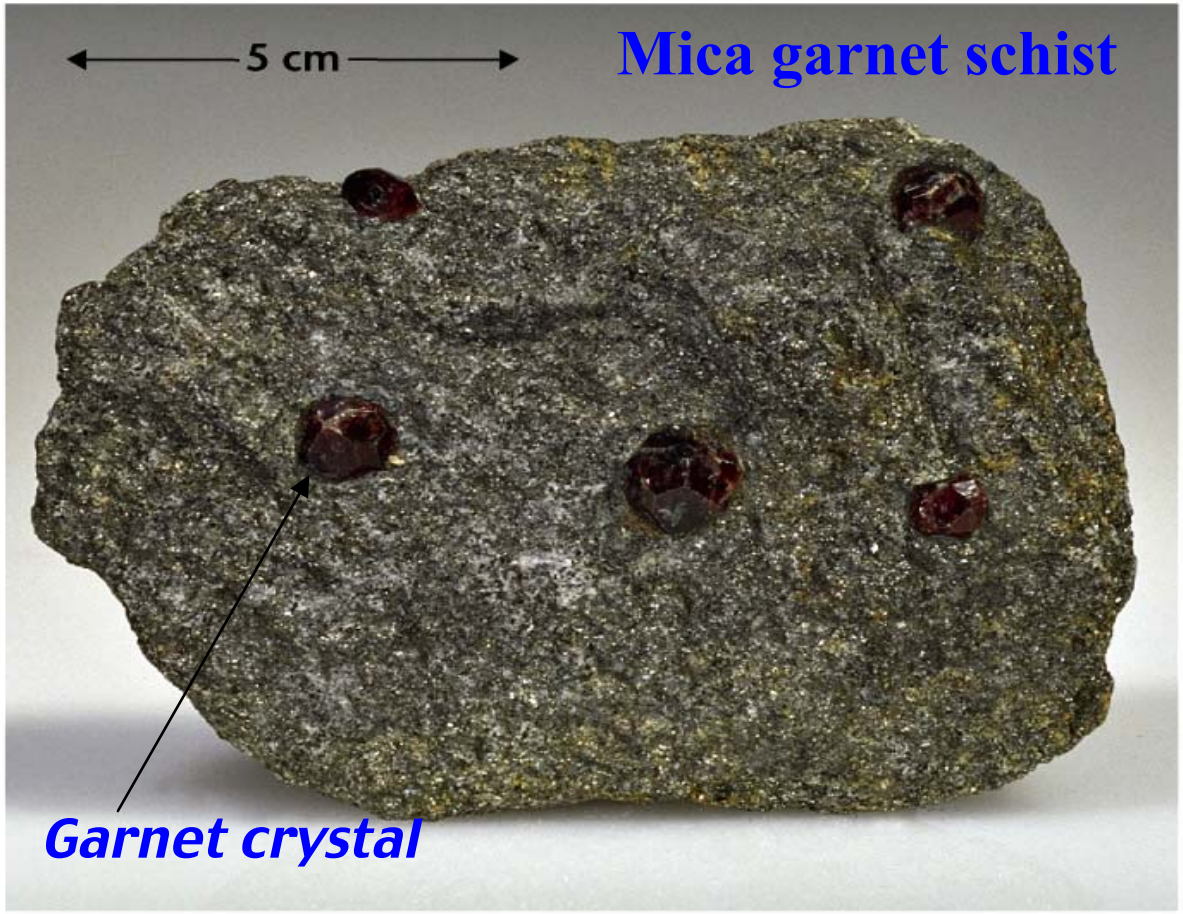
Metamorphism and metamorphic rocks

- Rocks created by heat, pressure and/or chemically reactive fluids
- Metamorphic rocks are produced from
    - Igneous rocks
    - Sedimentary rocks
    - Other metamorphic rocks

Metamorphism

- Metamorphism progresses incrementally from low-grade to high-grade
- During metamorphism (transformation) the rock remains essentially solid
- Metamorphism characterized by
    - Growth of new minerals from pre-existing minerals through recrystallization
    - Deformation of existing minerals
        - Change in shape
        - Change in orientation
- Metamorphic settings

Growth of new minerals



Deformation of rocks and minerals

Layers are folded and broken

Metamorphism settings

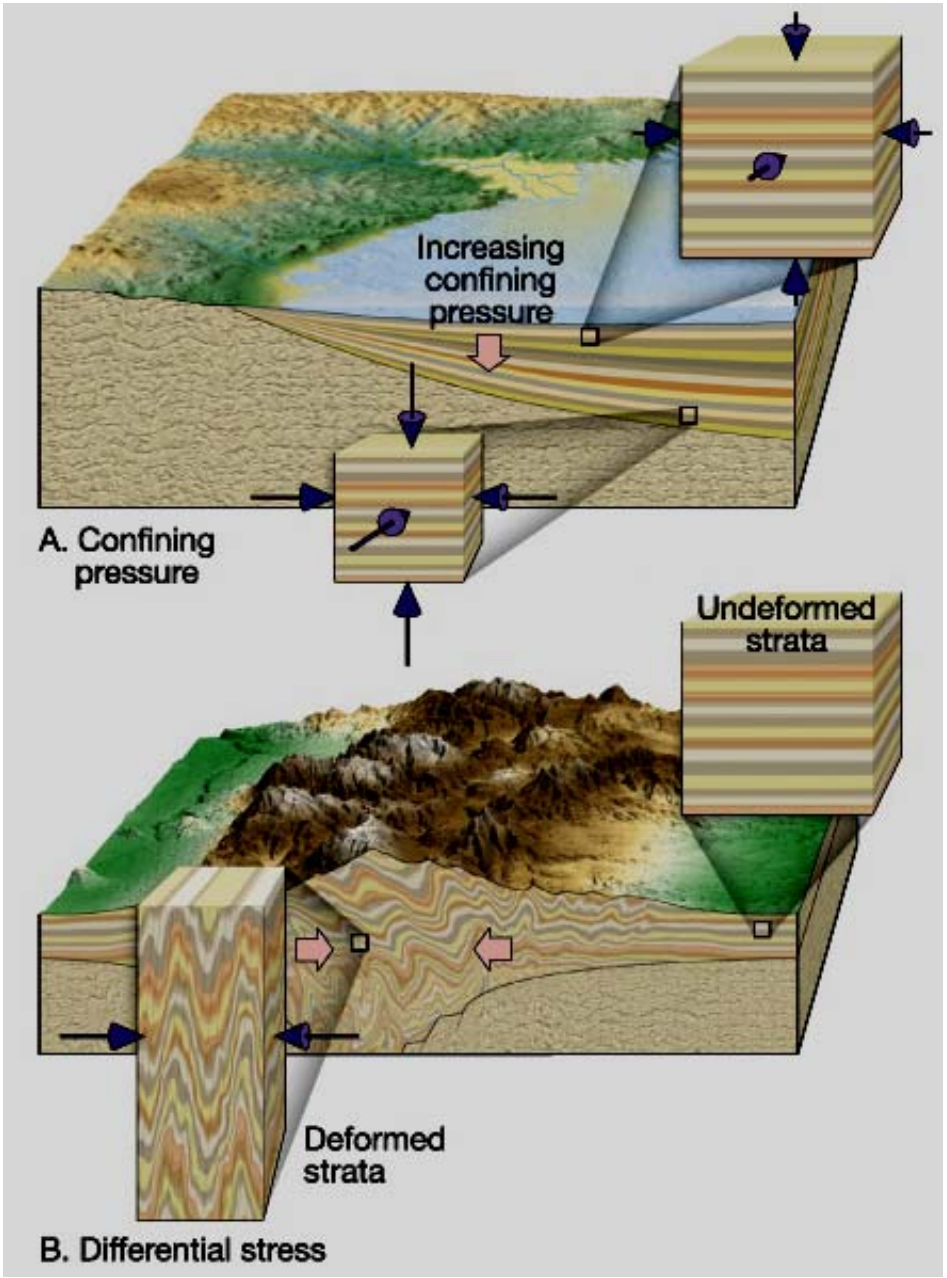
- **Contact or thermal metamorphism**
  - **Driven by a rise in temperature within the host rock**
- **Regional metamorphism**
  - **Occurs during mountain building**
  - **Produces the greatest volume of metamorphic rock**
- **Burial metamorphism**
  - **Occurs at bottom of thick sedimentary rock piles**
- **Hydrothermal metamorphism**
  - **chemical alterations from hot, ion-rich water**
- **Others**

Agents of metamorphism

- **Heat**
  - **The most important agent**
  - **Two sources of heat**
    - **Contact metamorphism – heat from magma**
    - **An increase in temperature with depth due to the geothermal gradient**
- **Pressure (stress)**
  - **Increases with depth**
- **Fluids**
  - **Helps transporting elements from one crystal to a new metamorphic crystal (enhances migration of ions0**
  - **Mainly water with other volatile components**

Origin of pressure in metamorphism

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



Importance of parent rock

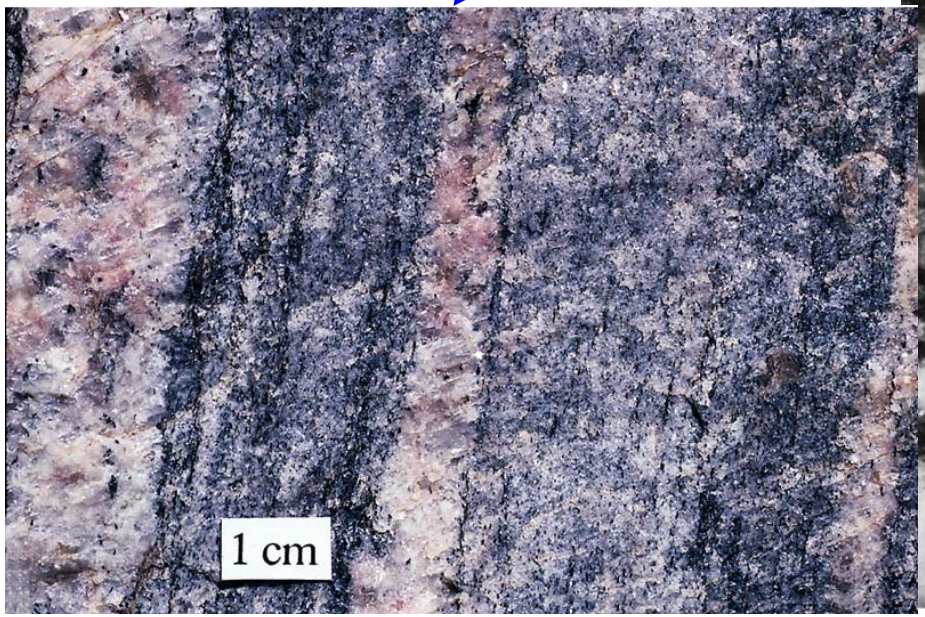
- **Most metamorphic rocks have the same overall chemical composition as the parent rock from which they formed**
- **Mineral makeup determines, to a large extent, the degree to which each metamorphic agent will cause change**

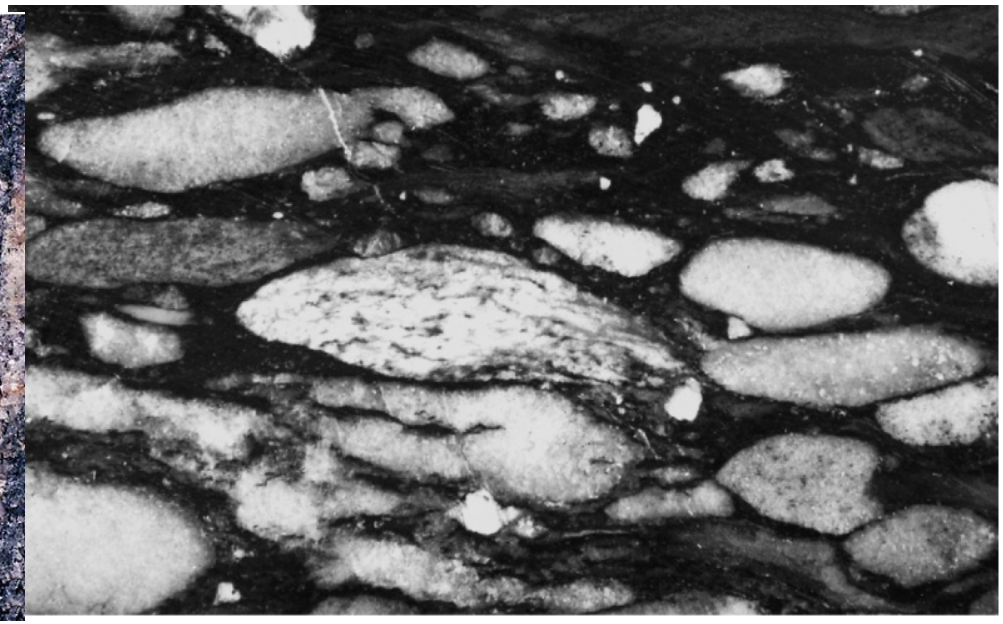
Metamorphic textures

- Texture refers to the size, shape, and arrangement of grains within a rock
- **Foliation** – any planar arrangement of mineral grains or structural features within a rock
    - Parallel alignment of platy and/or elongated minerals
    - Foliation can form through:
        - 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

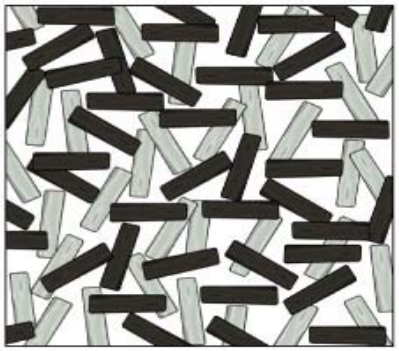
Examples of foliation

- **Parallel alignment of flattened mineral grains and pebbles**
- **Compositional banding**

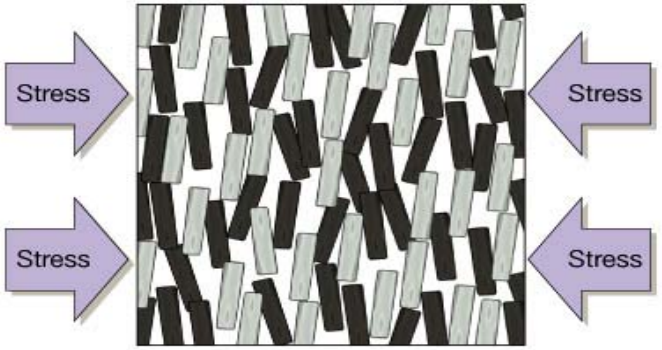




Development of foliation due to directed pressure (stress)

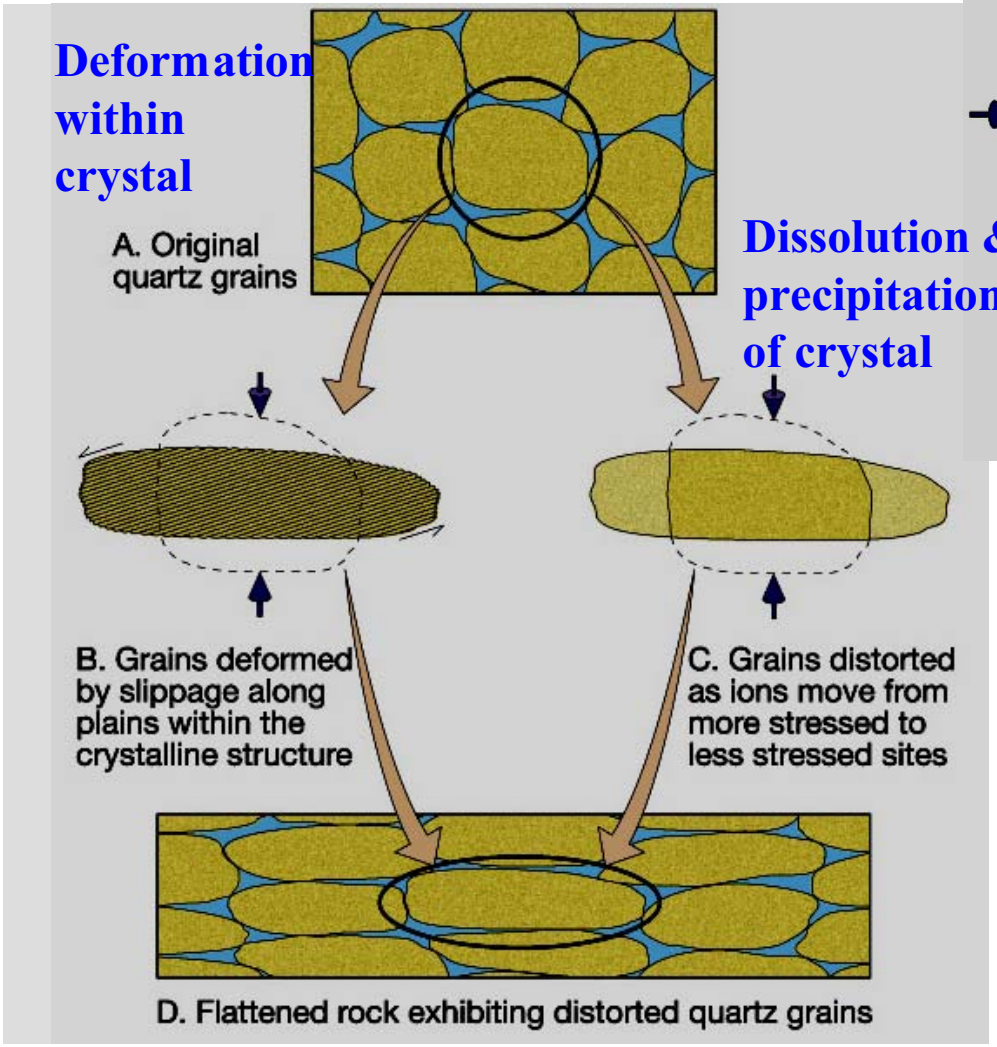


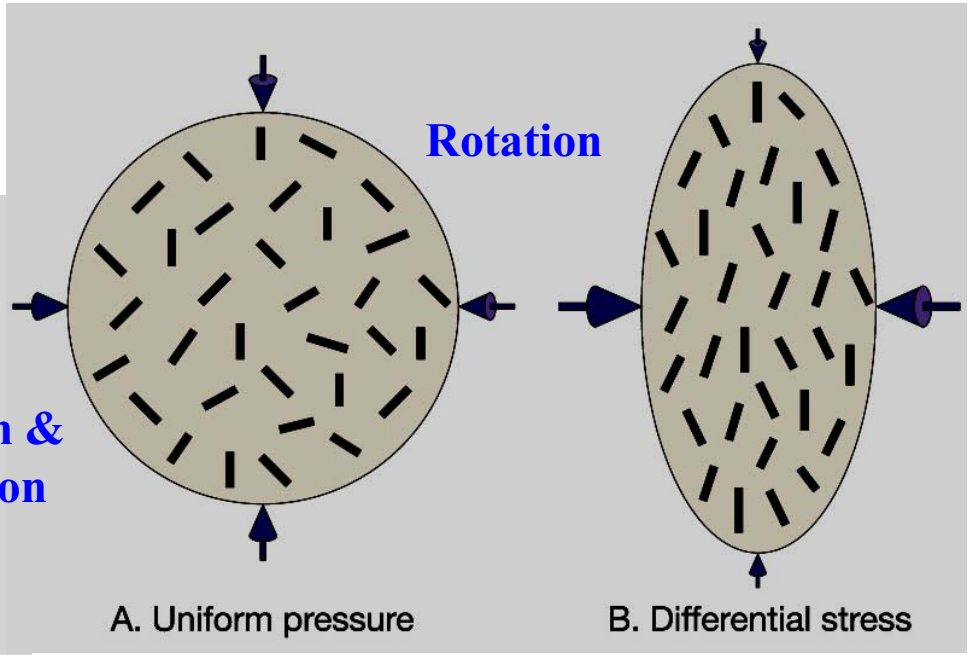
Before metamorphism



After metamorphism

Directed pressure (stress) effects on minerals





- **Rotation**
- **Deformation within crystal**
- **Dissolution and precipitation of crystal**

Foliated textures

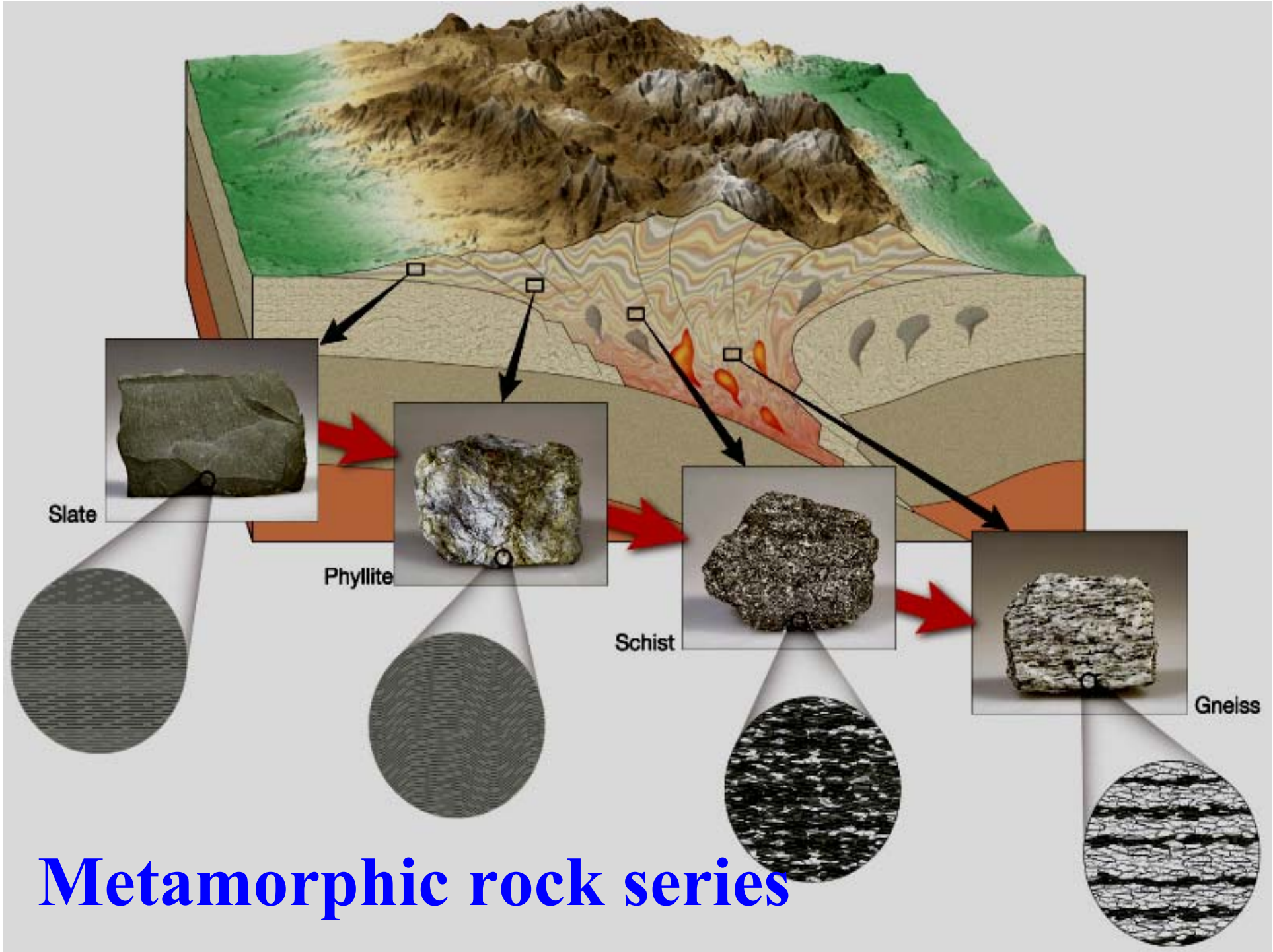
- Rock or slaty cleavage
    - Closely spaced planar surfaces along which rocks split
- Schistosity
    - Platy minerals are discernible with the unaided eye and exhibit a planar or layered structure
    - Rocks having this texture are referred to as schist
- Gneissic texture
    - Segregation of minerals leads to distinctive banded appearance

Non-foliated textures

- **Metamorphic rocks that lack foliation are referred to as nonfoliated**
- **Develop in environments where stress (deformation) is minimal**
- **Typically composed of minerals that exhibit equidimensional crystals**

Metamorphic rocks

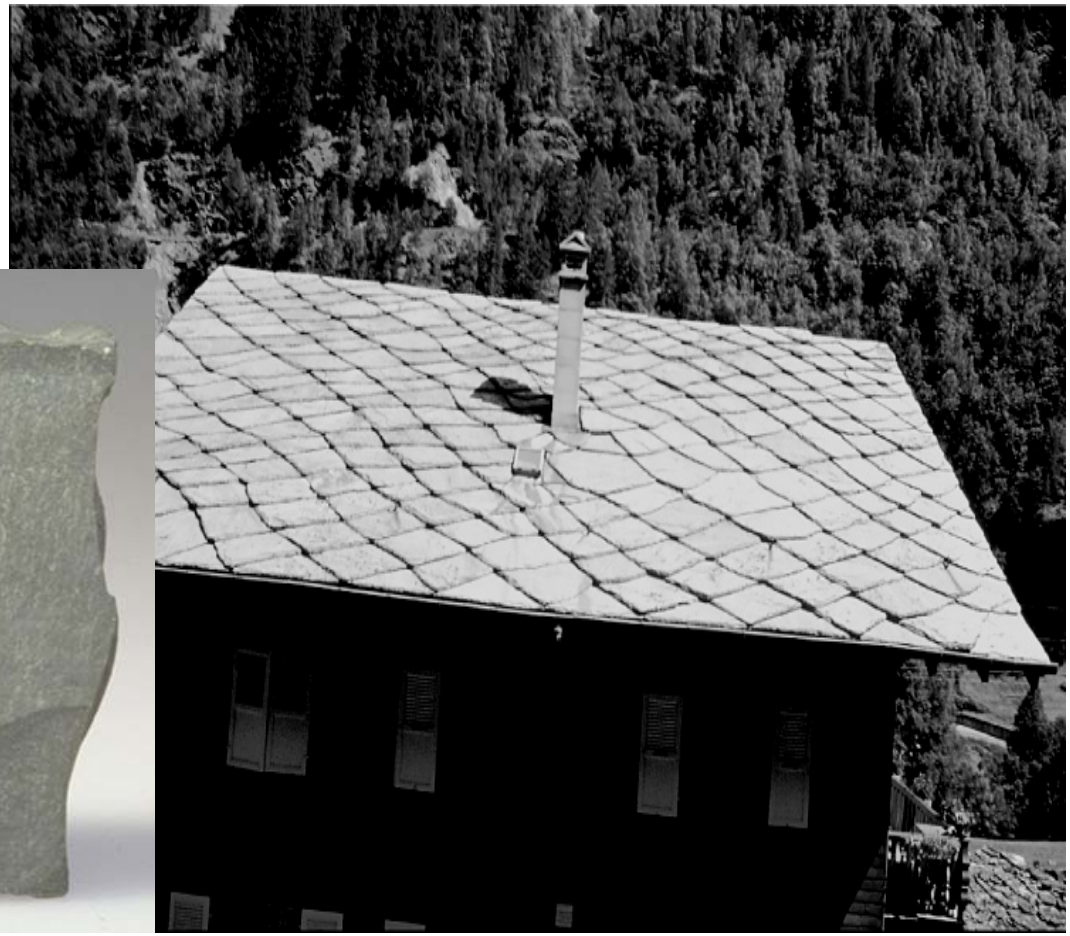
- **Main groups based on whether or not rocks are foliated**
- **Foliated rocks**
    - **In this group, changing degree of metamorphism leads to characteristic rock series**
    - **(Shale) slate → phyllite → schist → gneiss**
    - **(Basalt) greenschist → amphibolite**
    - **(Basalt) blueschist → eclogite**
- **Non-foliated rocks**
    - **Quartzite (sandstone)**
    - **Marble(limestone)**
    - **Hornfels (claystone)**
    - **Coal (peat)**



Metamorphic rock series

Slate

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



Phyllite

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

Schist

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

- **<u>Varieties</u>:**

•Mica schist (biotite, muscovite)
•Greenschist (green chlorite)
•Blueschist (blue amphibole)

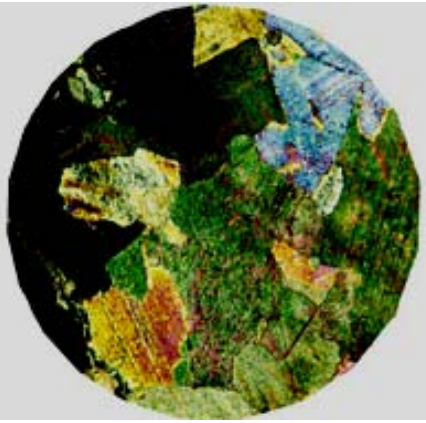
Gneiss

- **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**

Marble

- Metamorphosed limestone or dolostone
- Non-foliated
- Composed essentially of calcite or dolomite crystals
- Coarse, crystalline
- Used as a decorative and monument stone, table top
- Exhibits a variety of colors

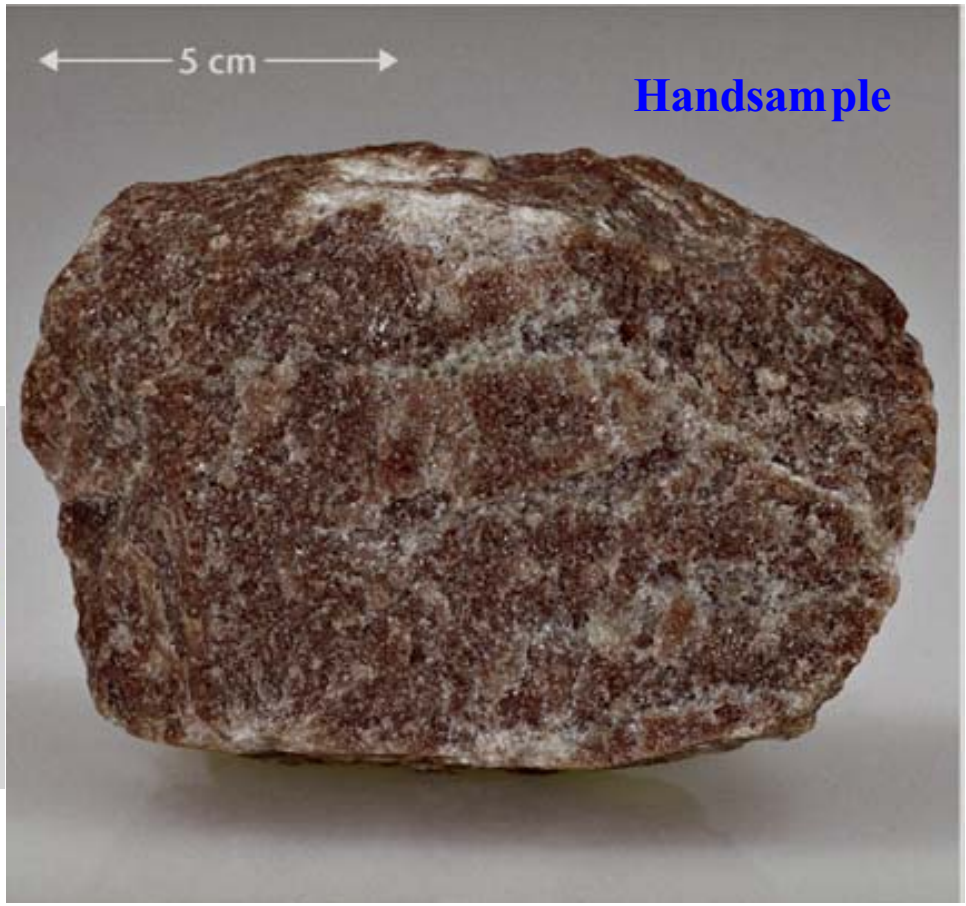
Microscopic picture



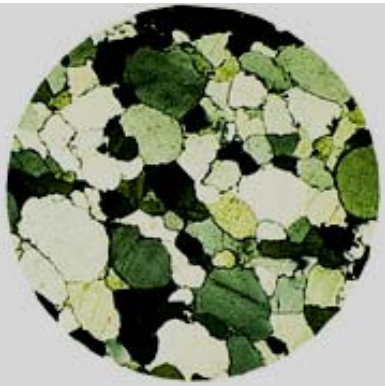
Photomicrograph (6.5x)

Quartzite

- Non-foliated
- Formed from a parent rock of quartz-rich sandstone
- Quartz grains are fused together
- Sugary texture



Microscopic picture



Photomicrograph (26.6x)
Sample width is 1.23 mm

Metamorphic rock systematics

Increasing Metamorphism

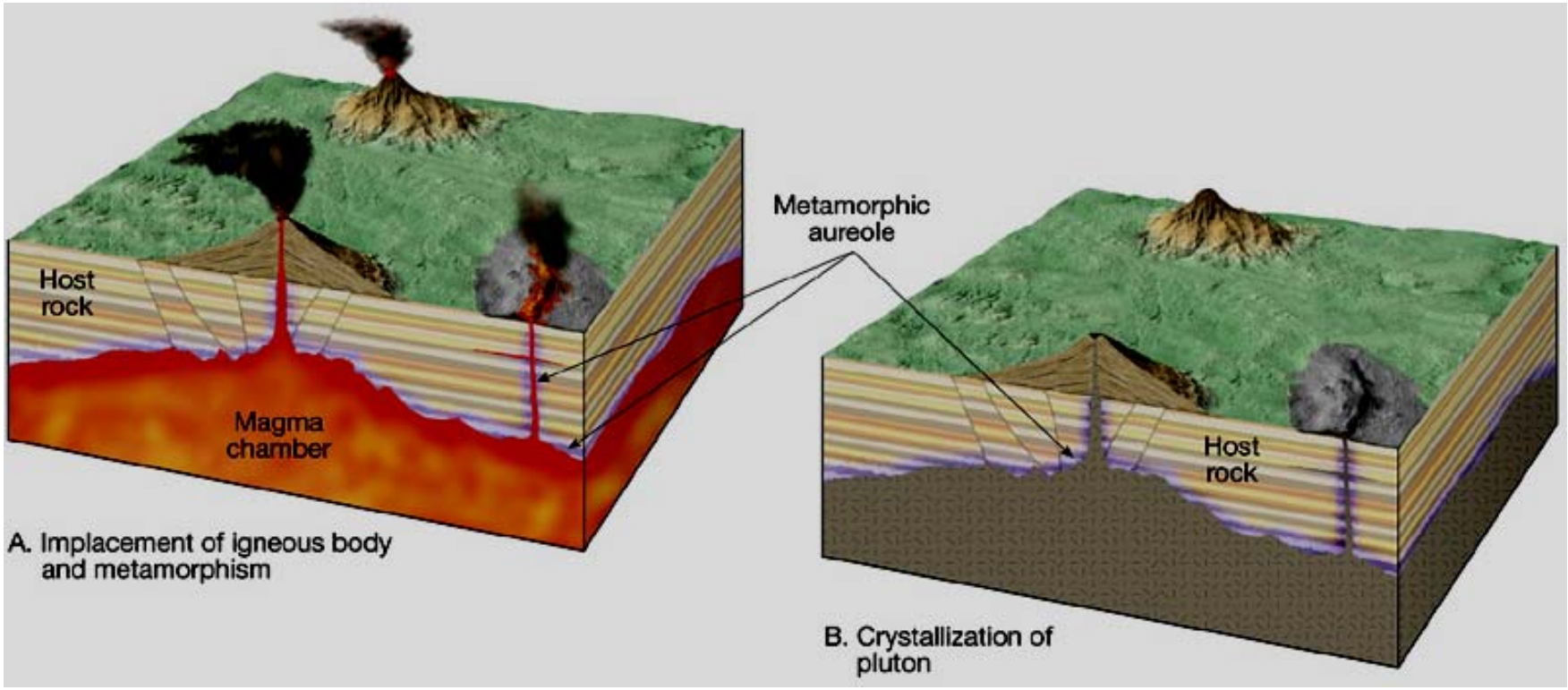
Rock Name	Texture	Grain Size	Comments	Parent Rock
Slate	Foliated	Very fine	Excellent rock cleavage, smooth dull surfaces	Shale, mudstone, or siltstone
Phyllite	Foliated	Fine	Breaks along wavey surfaces, glossy sheen	Slate
Schist	Foliated	Medium to Coarse	Micaceous minerals dominate, scaly foliation	Phyllite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

Metamorphic environments

- **Contact or thermal metamorphism (low P, high T)**
- **Regional metamorphism**
  - **Type A: Pressure and Temperature both increase comparable**
  - **Type B: Pressure increases relatively faster than temperature (high P, low T metamorphism)**
- **Burial metamorphism**
- **Others**
  - **Hydro-metamrophism**
  - **Shock-metamorphism**

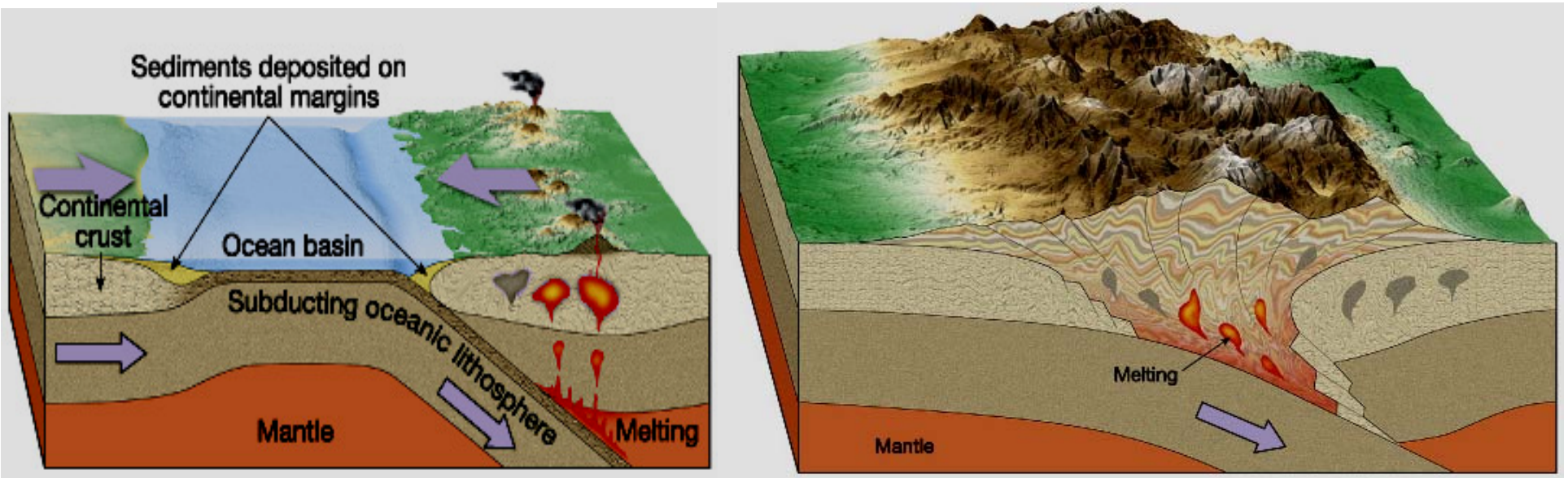
Contact metamorphism

- **Occurs due to a rise in temperature when magma invades a host rock**
- **A zone of metamorphism forms in the rock surrounding the magma**
- **Most easily recognized when it occurs at the surface, or in a near-surface environment**



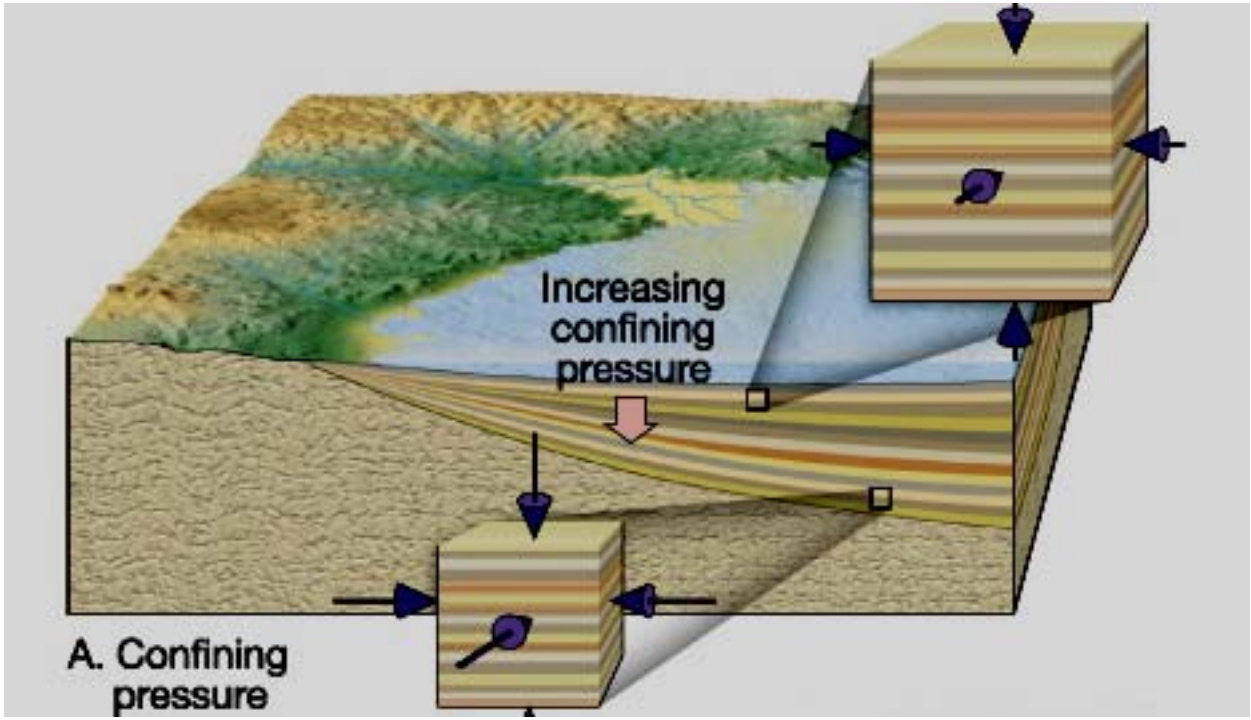
Regional Metamorphism

- **Regional metamorphism**
  - **Produces the greatest quantity of metamorphic rock**
  - **Associated with mountain building and the subducting plate (high P, low T metamorphism)**



Burial metamorphism

- **Associated with very thick sedimentary strata**
- **Required depth varies from one location to another depending on the prevailing geothermal gradient**



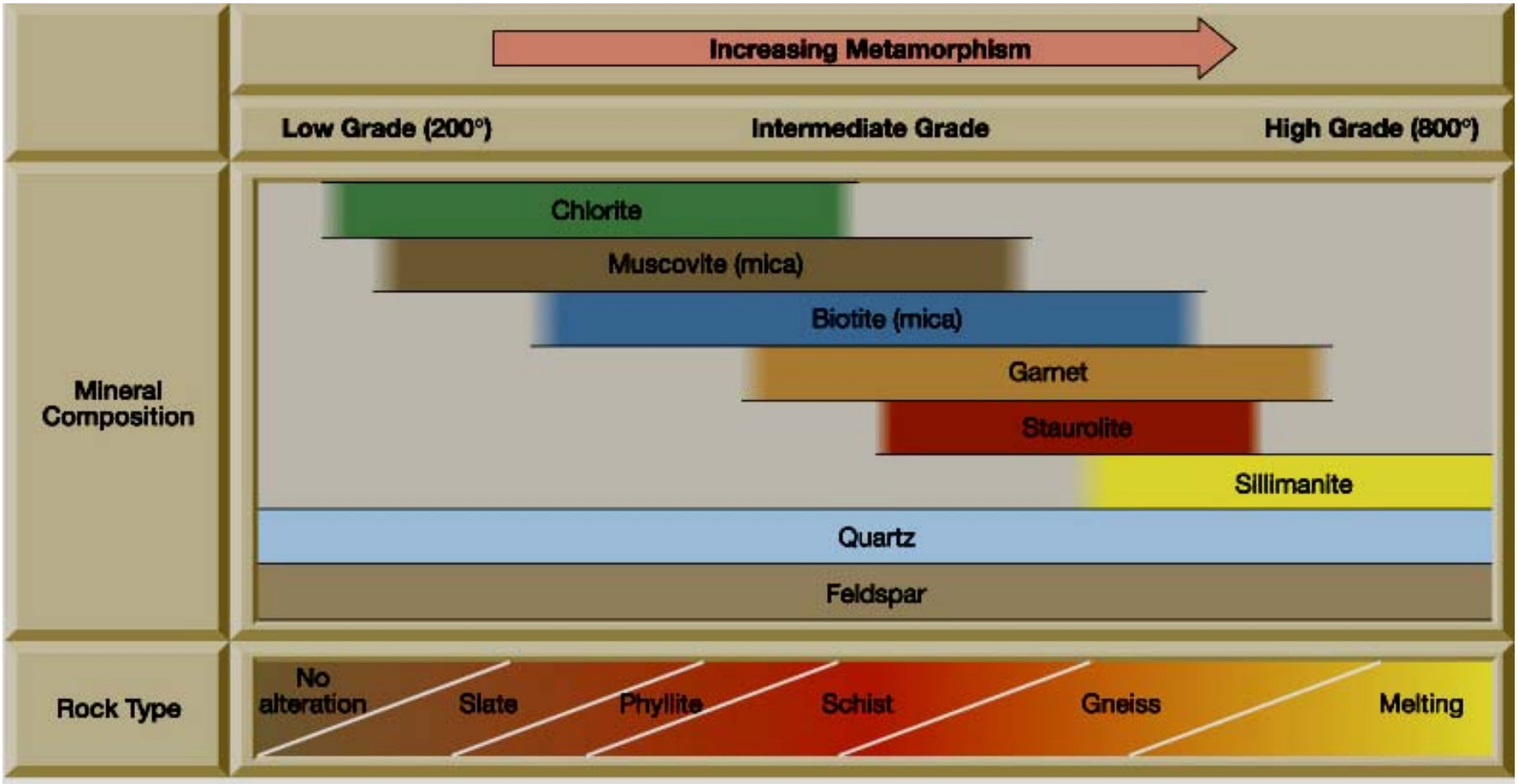
Other types of metamorphism

- **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**
- **Impact metamorphism**
  - **Occurs when high speed projectiles called meteorites strike Earth's surface**

Metamorphic zones

- Systematic variations in the mineralogy and often the textures of metamorphic rocks are related to the variations in the degree of metamorphism
- Changes in mineralogy occur from regions of low-grade metamorphism to regions of high-grade metamorphism
- Certain minerals, index minerals, are good indicators of the metamorphic conditions in which they form
- Highest degree of metamorphism
  - Transitional to igneous rocks
  - Indicate melting in certain bands
  - Rock called migmatites
  - Light bands are igneous components ("magma") along with areas of unmelted metamorphic rock

Metamorphic grade and index minerals



- E.g., chlorite indicates low Grade (low P, low T)
- garnet indicates high Grade (high P and/or high T)

Metamorphism and plate tectonics

- **Most metamorphism occurs along convergent plate boundaries**
  - **Compressional stresses deform the edges of the plate**
  - **Formation of the Earth's major mountain belts including the Alps, Himalayas, and Appalachians**

- **Large-scale metamorphism along subduction zones**
  - **Several metamorphic environments exist here**
  - **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 associated with plate tectonics