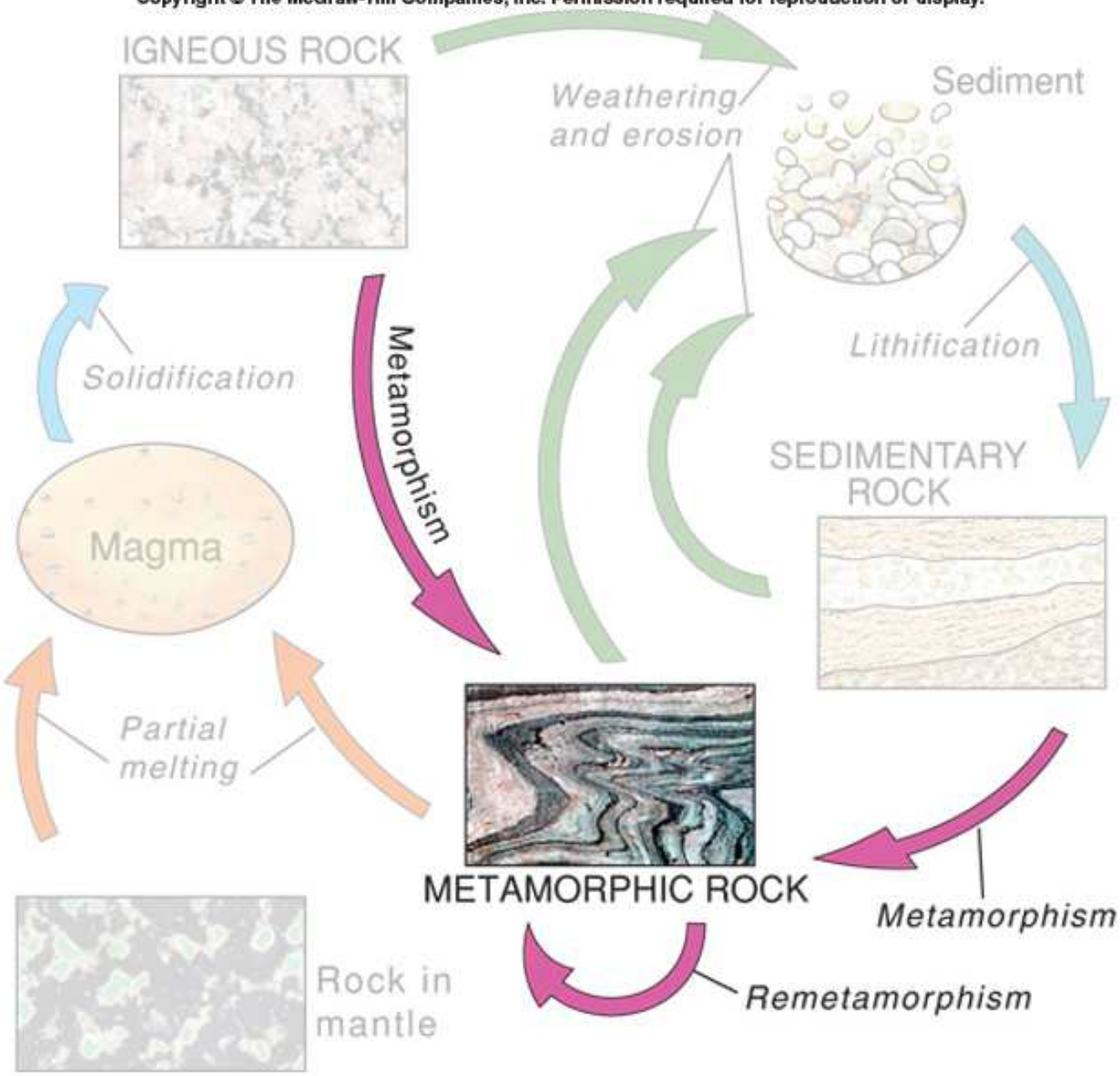
Metamorphism, Metamorphic Rocks, and Hydrothermal Rocks

Chapter 15



Metamorphic Rocks

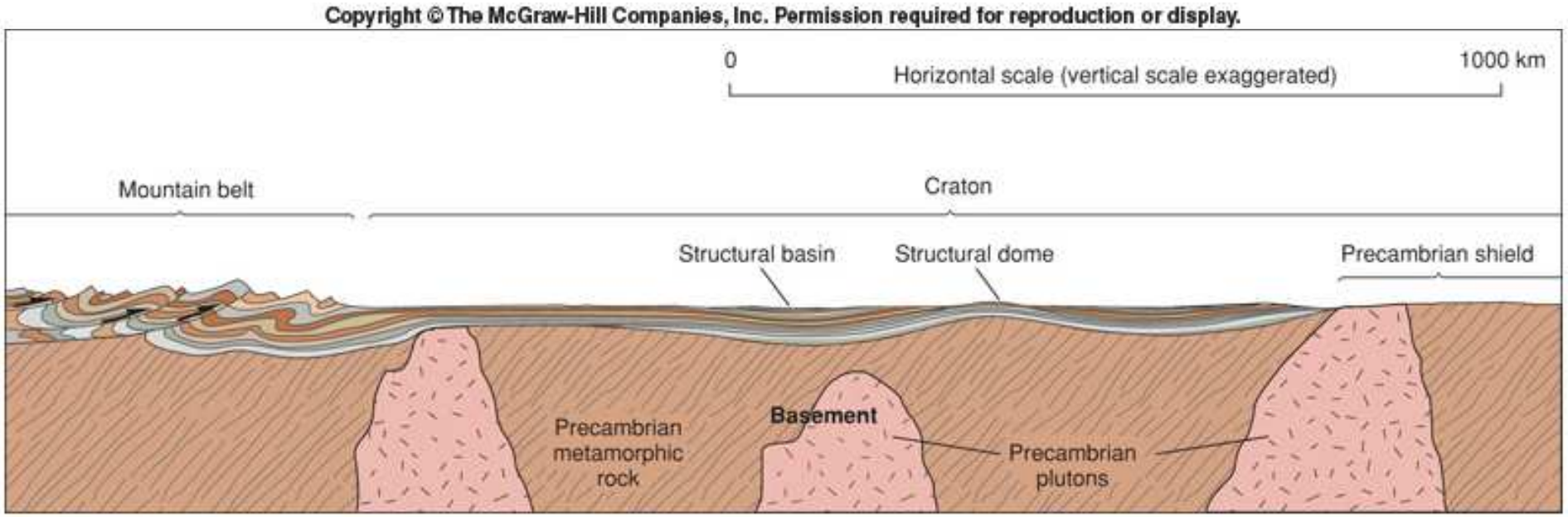
- *Metamorphism* refers to solid-state changes to rocks in Earth's interior
  - Produced by increased heat, pressure, or the action of hot, reactive fluids
  - Old minerals, unstable under new conditions, recrystallize into stable ones

- Rocks produced from pre-existing or *parent rocks* in this way are called *metamorphic rocks*

- Metamorphic rocks common in the old, stable cores of continents, known as *Craton*

Characteristics of Mountain Belts

- Ancient mountain belts (*billions* of years old) have eroded nearly flat to form the stable cores (*cratons*) of the continents
  - Primary rock type in cratons : ***metamorphic rocks***

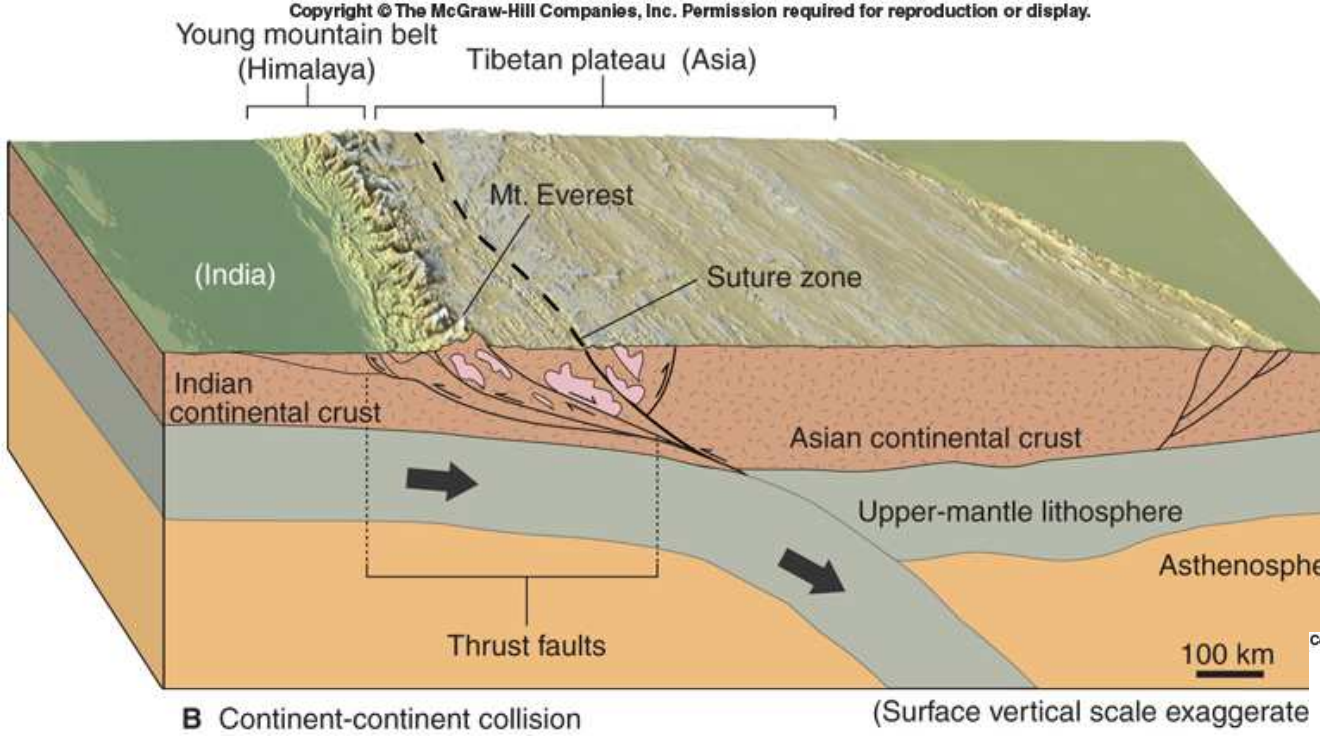


Relationship to Earth's Systems

- Metamorphism takes place ***at depth*** in the solid earth, so it involves no interaction between earth systems at the surface.

- However, the atmosphere may have been altered by metamorphism in the geologic past.

- Formation of Himalayan mountains.

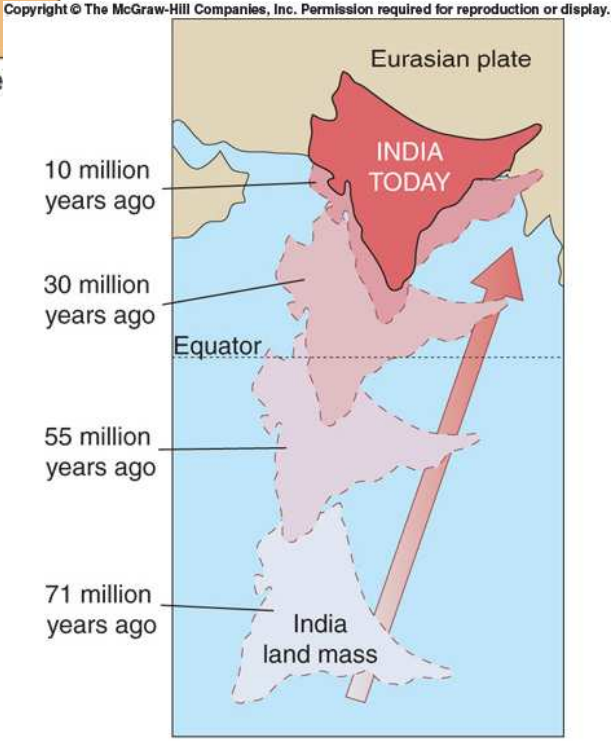


B Continent-continent collision

Greenhouse effect – Warmer climate during that part of Earth's history

$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$

Calcite Quartz Wollastonite carbon dioxide (a mineral)



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Metamorphism

- In previous chapters, we saw how deeply buried rocks melt to form magma when temperatures are hot enough

- What happens to rocks that are deeply buried but are not hot enough to melt completely?

- They become "**metamorphosed**"

- In nearly all cases, a metamorphic rock has a textural difference from the parent rock.

Limestone

Fine-grained

Marble

Crystalline

If the limestone is composed entirely of calcite, then metamorphism into marble involved no new minerals,
only a change in texture.

Metamorphism

Clay —Pressure→ Shale —Temp.→ Slate (mica)

(at equilibrium) (sedimentary) (metamorphic)



Factors Controlling Metamorphic Rock Characteristics

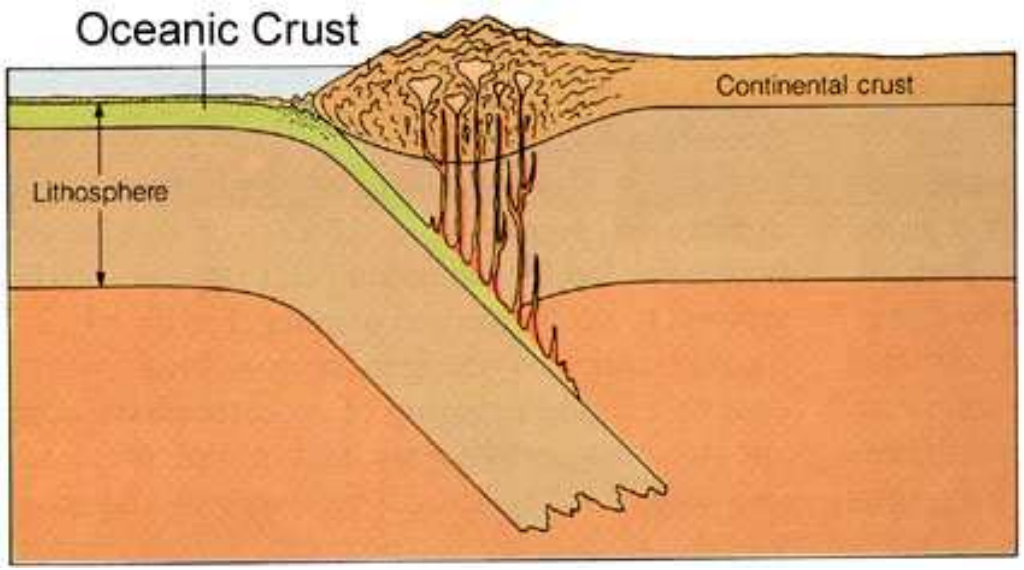
- Texture and mineral content of metamorphic rocks depend on:
  - Parent rock *composition*
  - *Temperature* during metamorphism
  - *Pressure* during metamorphism
  - Effects of *fluids*, such as water
  - *Time*

Factors Controlling Metamorphic Rock Characteristics

- ***Parent rock composition***
  - Usually no new material (other than water) is added to rock during metamorphism
  - Resulting metamorphic rock will have similar composition to parent rock

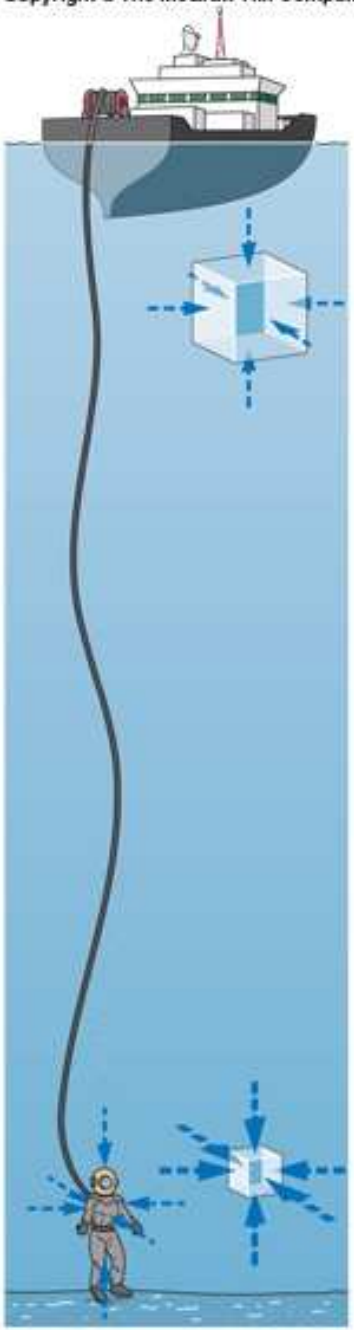
Factors Controlling Metamorphic Rock Characteristics

- ***Temperature*** during metamorphism
  - Heat for metamorphism comes from *Earth's deep interior*
  - All minerals stable over *finite temperature range*
  - If range exceeded, *new minerals* result
  - If temperature gets high enough, *melting* will occur



Factors Controlling Metamorphic Rock Characteristics

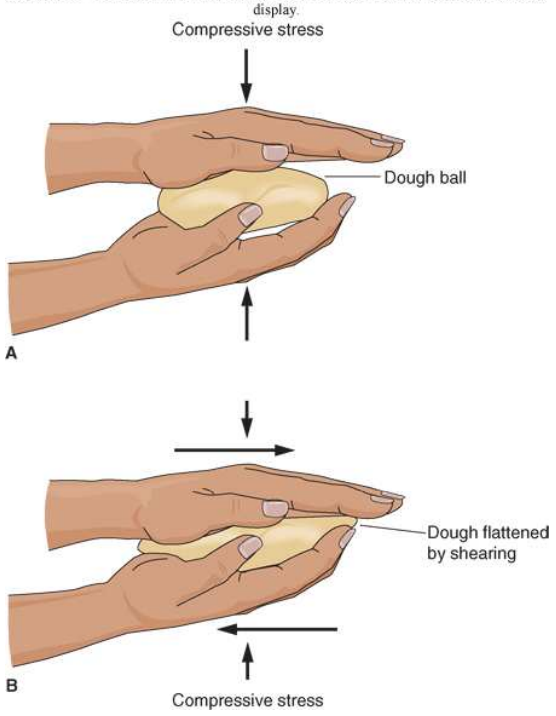
- *Pressure* during metamorphism
  - *Confining stress* applied equally in all directions
  - Pressure proportional to *depth* within the Earth
    - increases ~1 kilobar per 3.3 km of burial within the crust
  - High-pressure minerals more compact/more *dense*



A B
courtesy of the National Science Foundation-funded REVEL Project, University of Washington

Factors Controlling Metamorphic Rock Characteristics

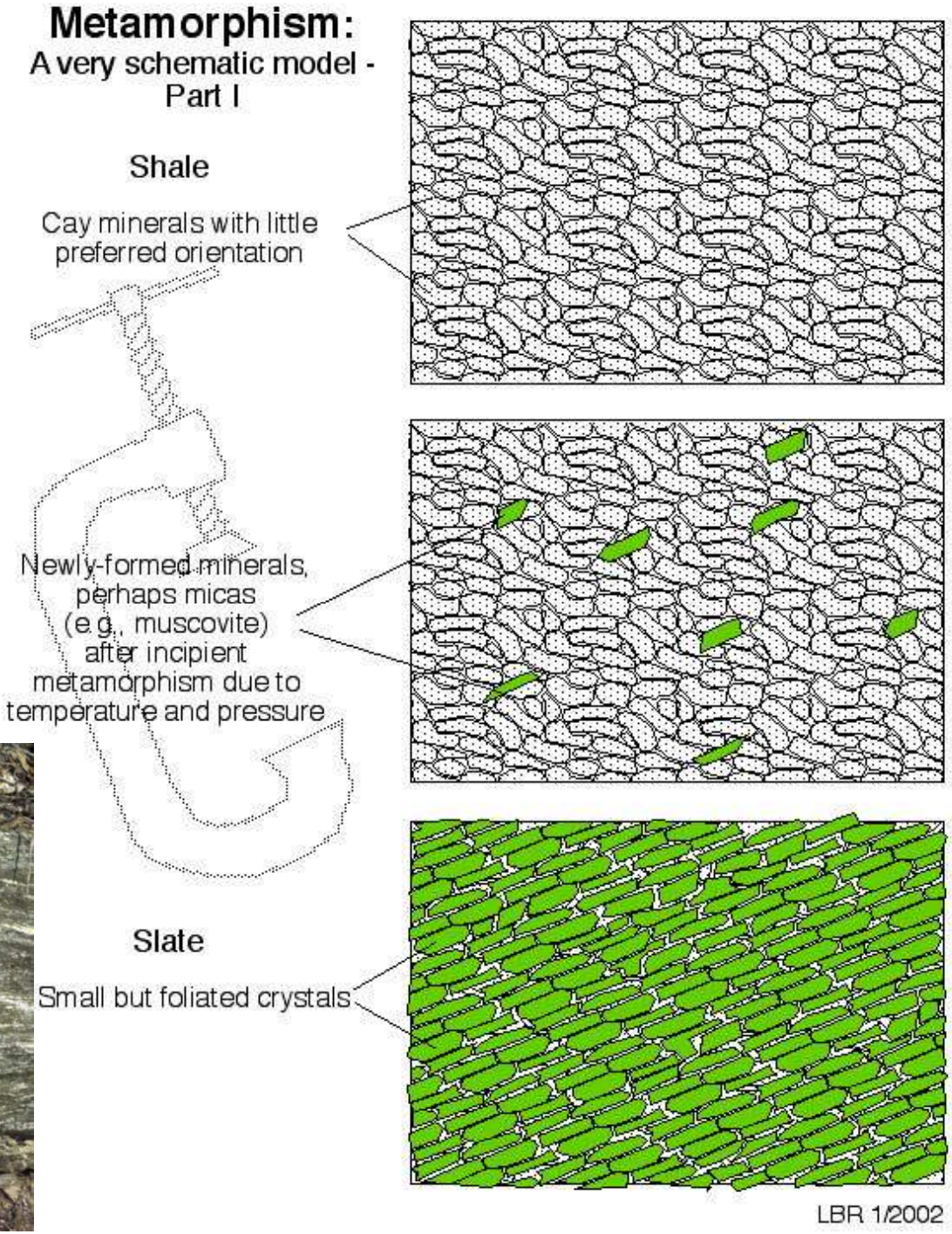
- *Pressure*
  - Often lead to forces that are not equal in all directions (*differential stress*)
  - *Compressive stress* causes flattening perpendicular to stress
  - *Shearing* causes flattening by sliding parallel to stress
  - Planar rock texture of aligned minerals produced by differential stress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

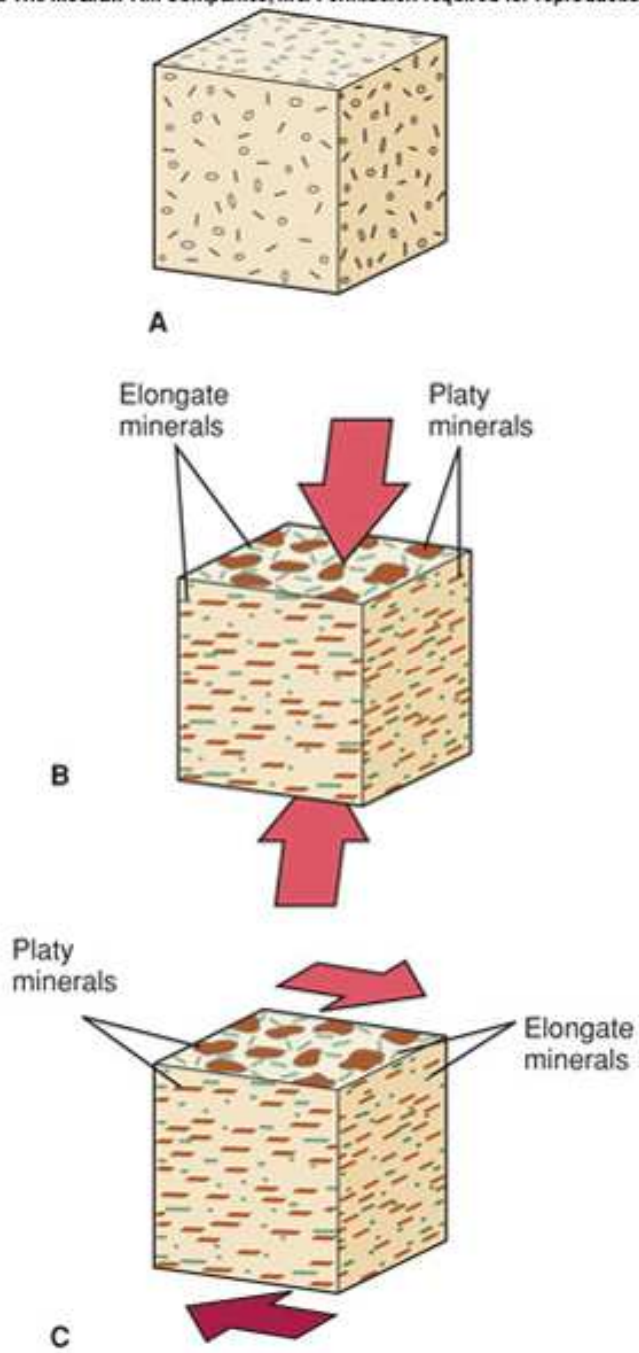


Foliation

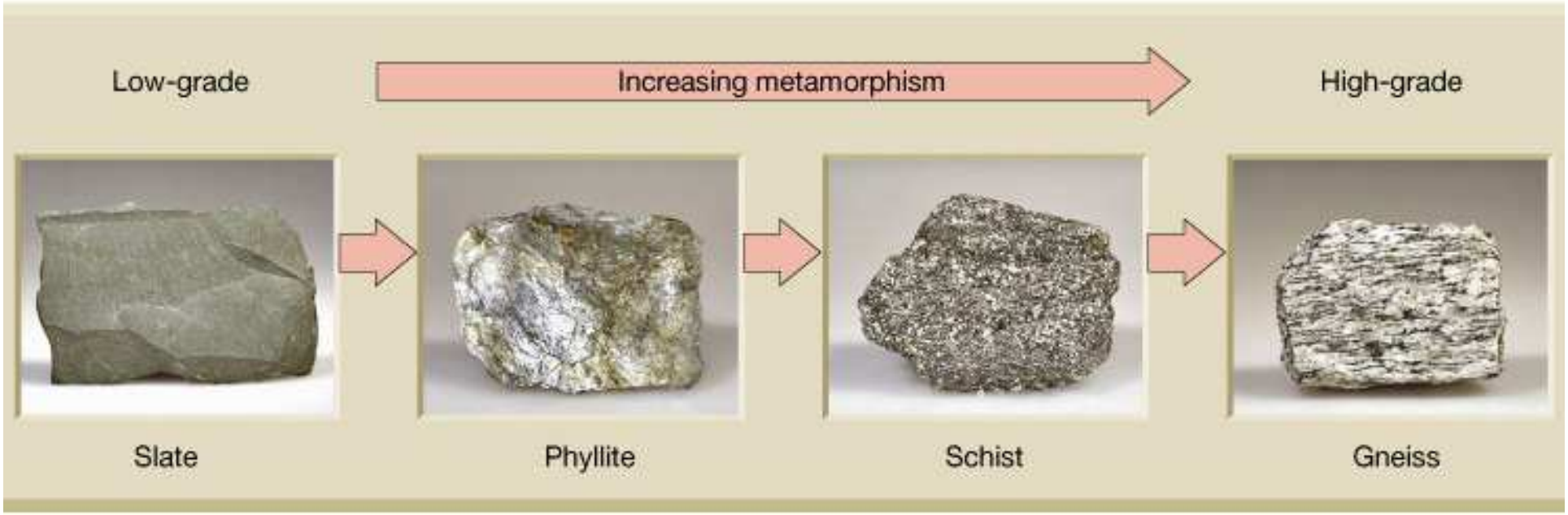
- When a rock has a planar texture, it is said to be ***foliated***.
- There are three very different textures (from lowest to highest degree of metamorphism) are all variation of foliation and are important in classifying metamorphic rocks.
- **Slaty texture**: If the rock splits easily along flat and parallel planes
- **Schistose**: If needle-shaped minerals have grown parallel to a plane
- **Gneissic**: If the new minerals separated into distinct (light and dark) bands.

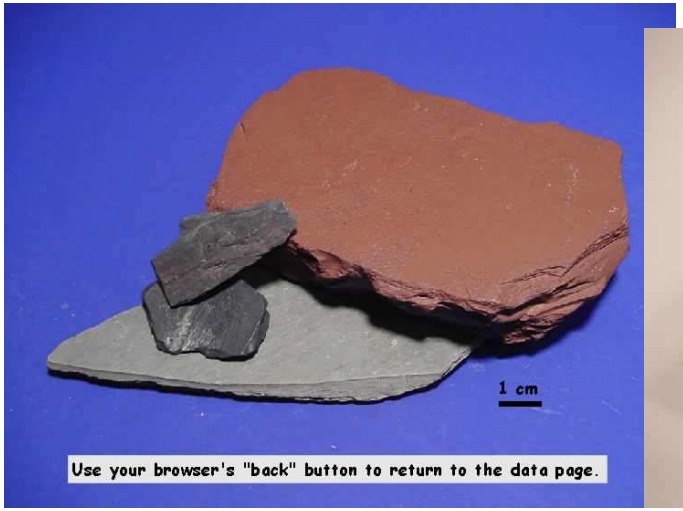
The formation of foliation

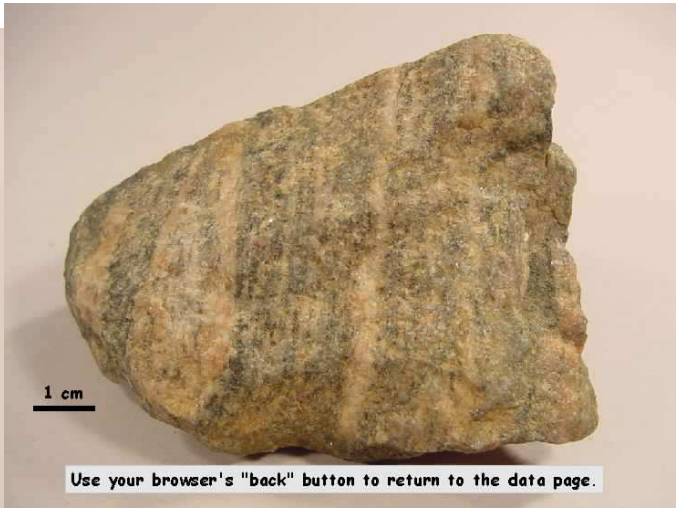




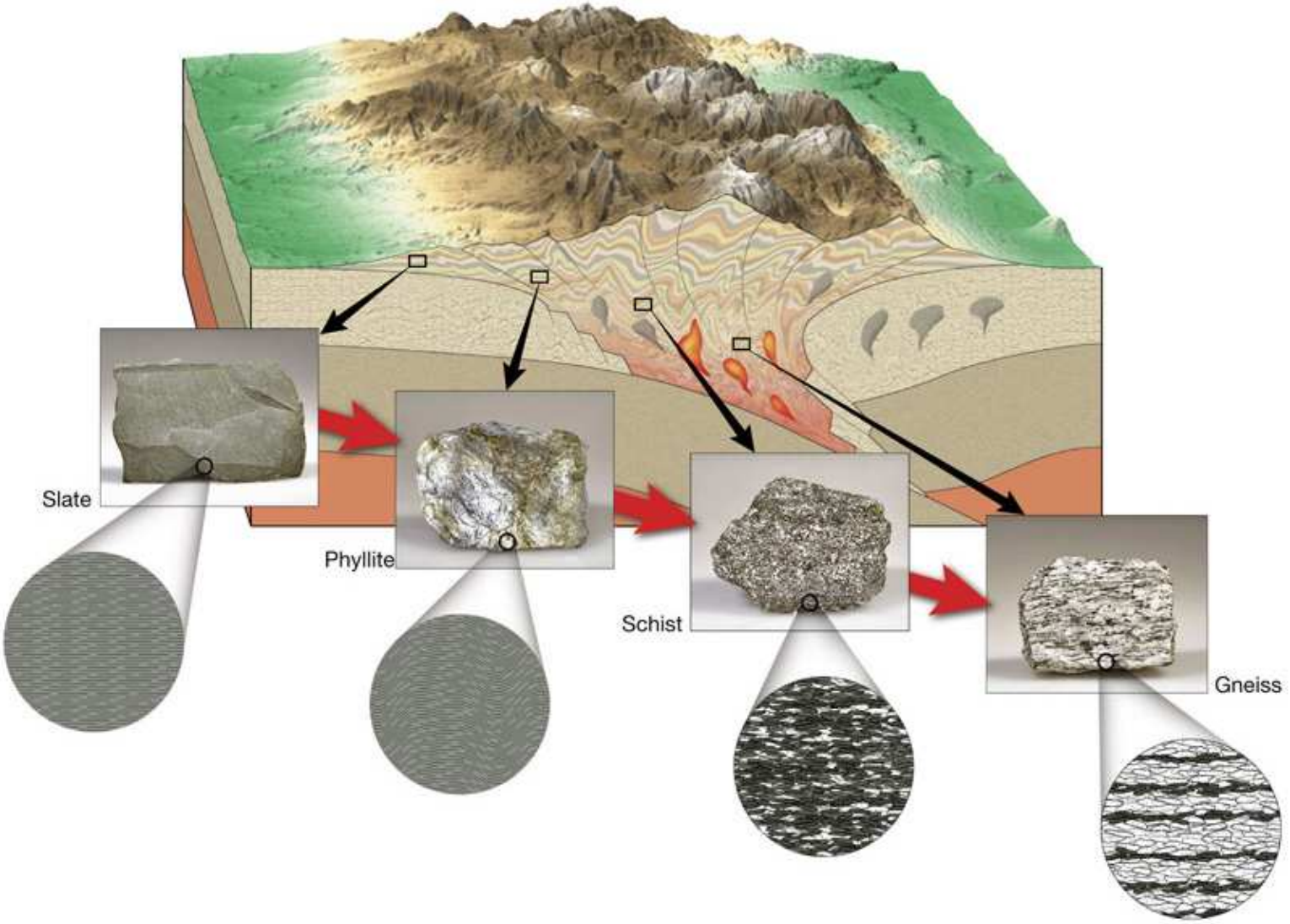
Foliated Rocks



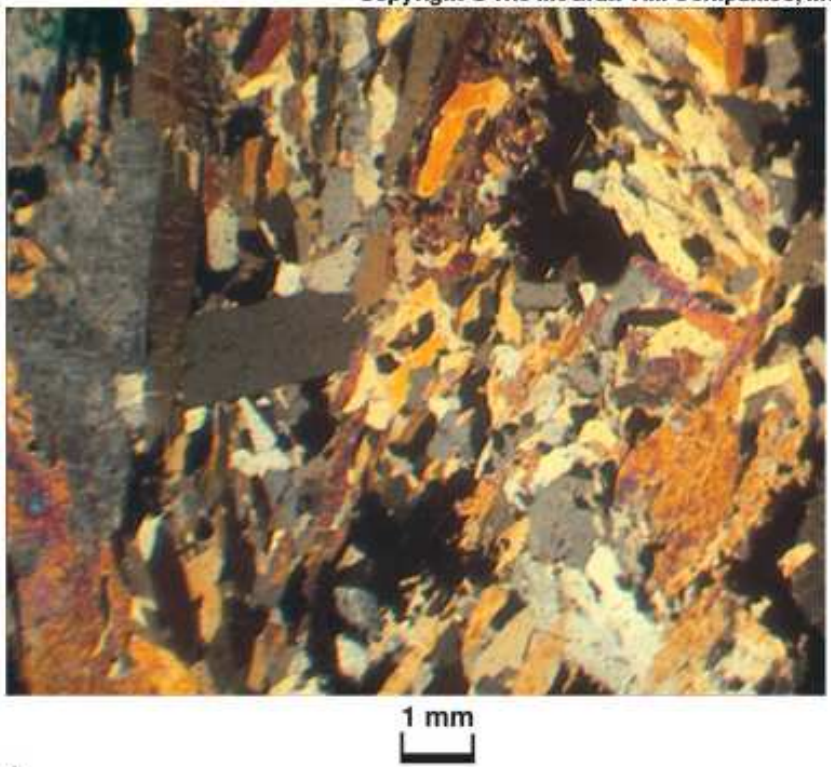




Metamorphic grades as indicators of the pressure and temperature where the rock formed, and of the tectonic setting



Non-foliated vs. foliated rock under microscope



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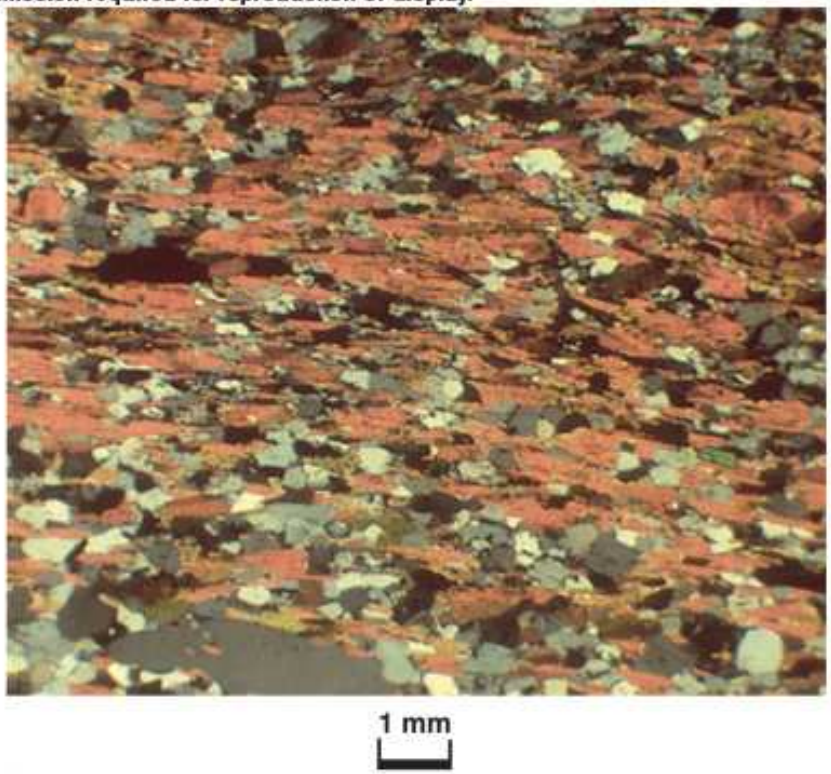

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Factors Controlling Metamorphic Rock Characteristics

- *Fluids*
  - Hot water (as vapor)
  - 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

Metamorphic Rock Classification

- Classification based on *rock texture*
  - *Foliated* (layered) vs. *non-foliated* (non-layered)
  - Foliated rocks named based on type of foliation (slaty, schistose, gneissic)
  - Non-foliated rocks named based on composition

TABLE 15.1 Classification and Naming of Metamorphic Rocks (Based Primarily on Texture)

Nonfoliated

Name Based on Mineral Content of Rock

Usual Parent Rock	Rock Name	Predominant Minerals	Identifying Characteristics
Limestone	Marble	Calcite	Coarse interlocking grains of calcite (or, less commonly, dolomite)
Dolomite	Dolomite marble	Dolomite	Calcite (or dolomite) has rhombohedral cleavage; hardness intermediate between glass and fingernail. Calcite effervesces in weak acid
Quartz sandstone	Quartzite	Quartz	Rock composed of interlocking small granules of quartz. Has a sugary appearance and vitreous luster; scratches glass
Shale	Hornfels	Fine-grained micas	A fine-grained, dark rock that generally will scratch glass. May have a few coarser minerals present
Basalt	Hornfels	Fine-grained ferromagnesian minerals, plagioclase	

Foliated

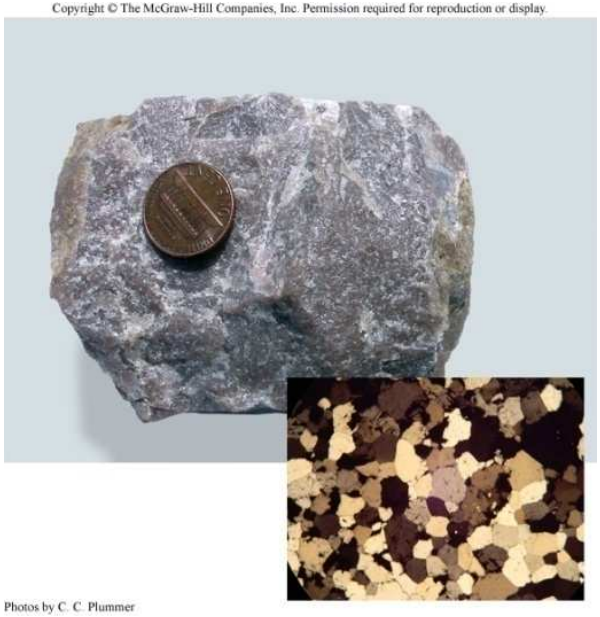
Name Based Principally on Kind of Foliation Regardless of Parent Rock. Adjectives Describe the Composition (e.g., biotite-garnet schist)

Texture	Rock Name	Typical Characteristic Minerals	Identifying Characteristics
Slaty	Slate	Clay and other sheet silicates	A very fine-grained rock with an earthy luster. Splits easily into thin, flat sheets
Intermediate between slaty and schistose	Phyllite	Mica	Fine-grained rock with a silky luster. Generally splits along wavy surfaces
Schistose	Schist	Biotite and muscovite amphibole	Composed of visible platy or elongated minerals that show planar alignment. A wide variety of minerals can be found in various types of schist (e.g., garnet-mica schist, hornblende schist, etc.).
Gneissic	Gneiss	Feldspar	Light and dark minerals are found in separate, parallel layers or lenses. Commonly, the dark layers include biotite and hornblende; the light-colored layers are composed of feldspars and quartz. The layers may be folded or appear contorted

Types of Metamorphism

- ***Contact metamorphism***
  - *High temperature* is dominant factor
  - 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)

Photo A by C. C. Plummer



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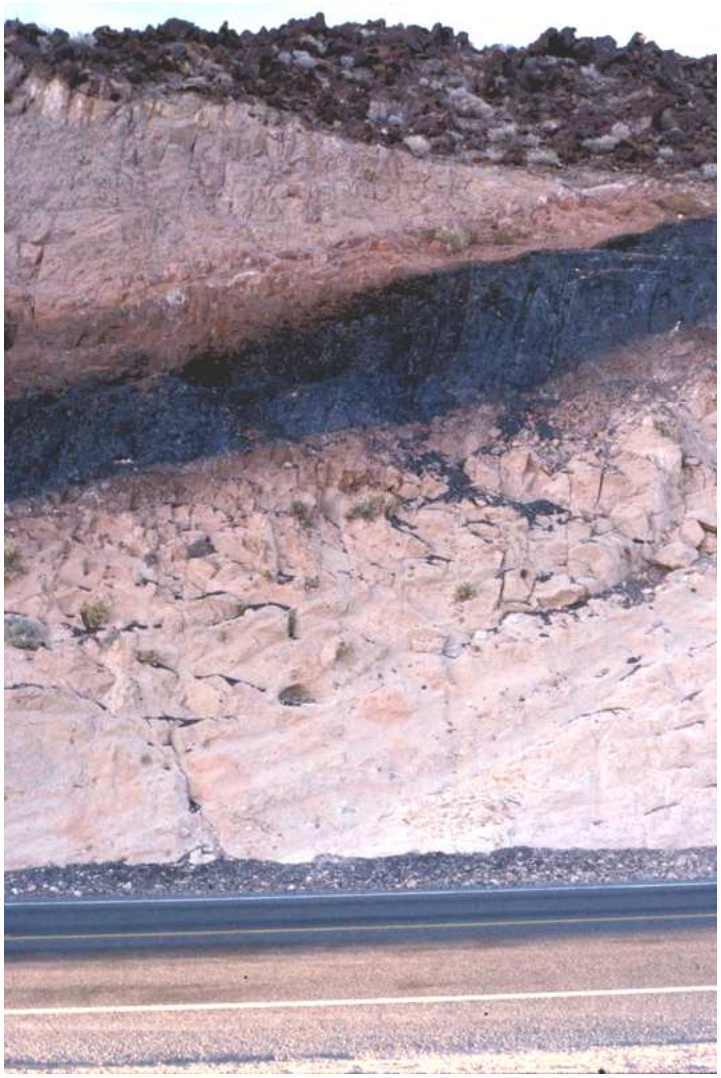
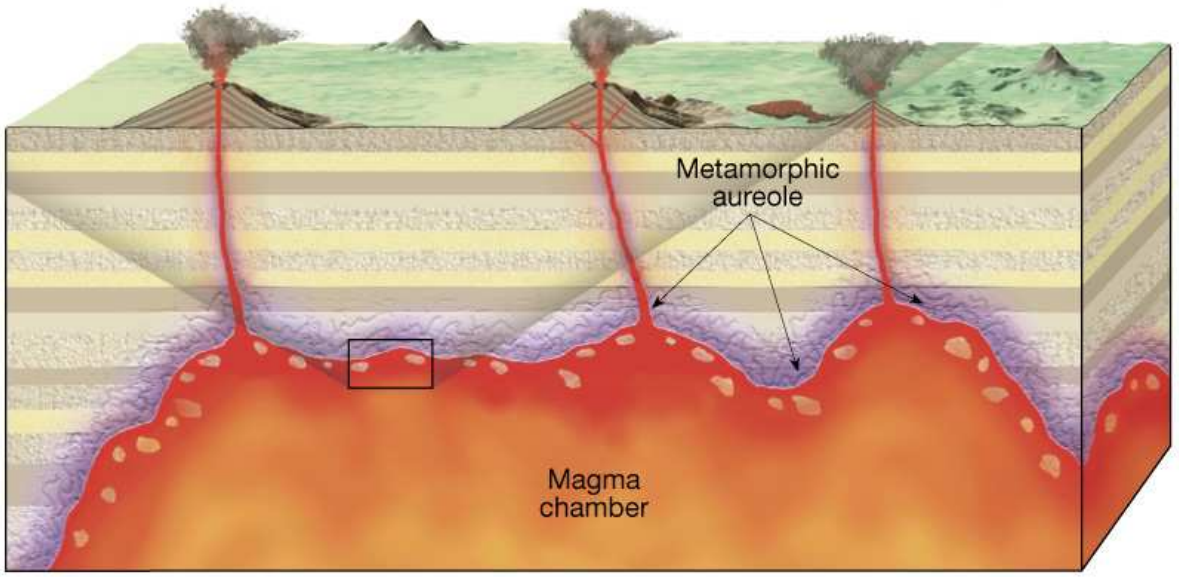
Contact Metamorphism

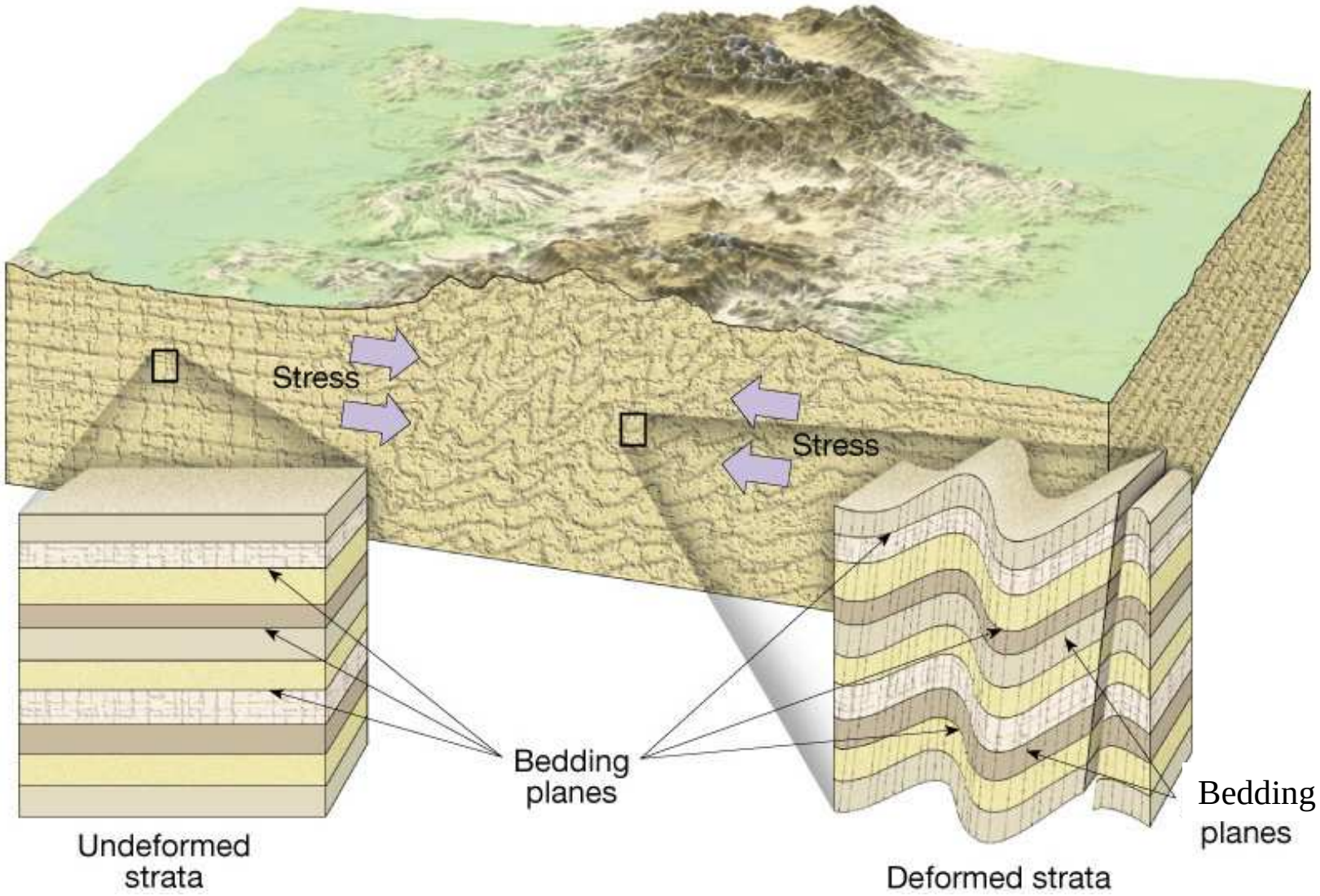




Types of Metamorphism

- *Regional metamorphism*
  - *High pressure* is dominant factor
  - Results in rocks with *foliated* textures
  - Prevalent in intensely deformed mountain ranges
  - May occur over wide temperature range
  - Higher pressure and temperature will produce increased *metamorphic grade*
  - Prograde metamorphism of shale produces:
    - *slate*
    - *phyllite*
    - *schist*
    - *gneiss*

Regional Metamorphism



Slate

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Phyllite

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Schist

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Gneiss

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Types of Metamorphism

- *Partial melting* during metamorphism produces *migmatites*
  - *Migmatites* exhibit both intrusive igneous and metamorphic textures

Photo by C. C. Plummer

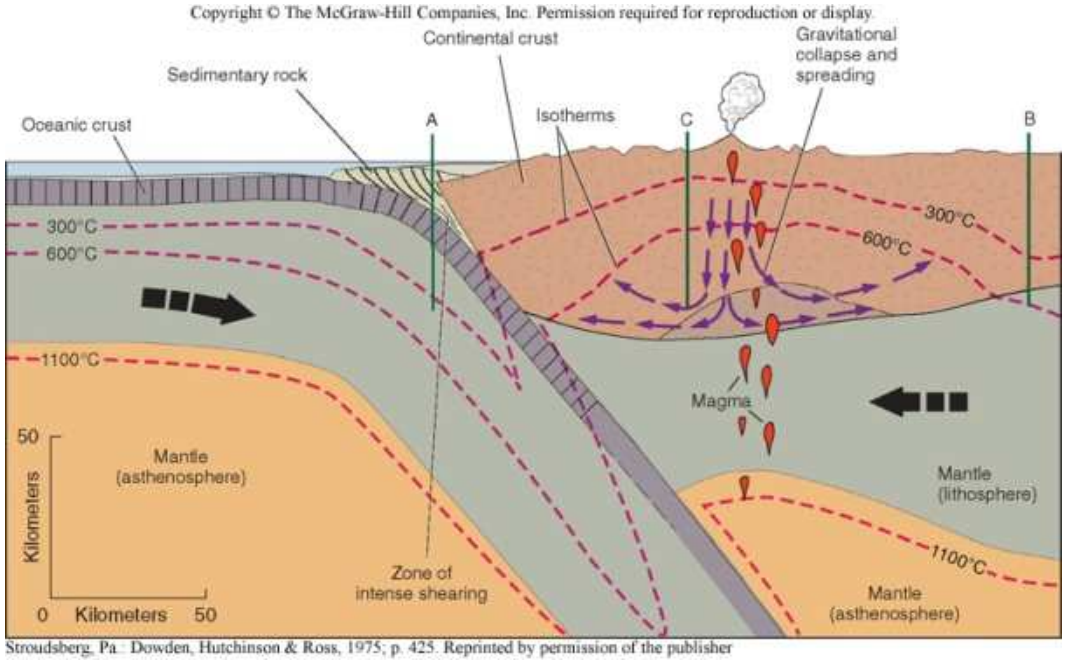
- *Shock metamorphism* is produced by rapid application of extreme pressure
  - Meteor impacts produce this
  - Shocked rocks are found around and beneath *impact craters*

Photo by Frank M. Hanna

Plate Tectonics and Metamorphism

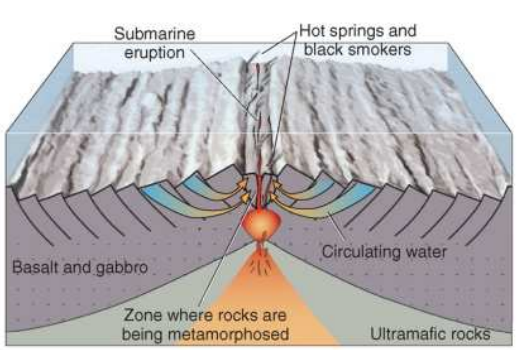
- Regional metamorphism associated with *convergent plate boundaries*
  - Pressure proportional to depth
  - Temperature varies laterally at convergent boundaries
  - Wide variety of

  metamorphic grade



Hydrothermal Processes

- Rocks precipitated from or altered by hot water are referred to as *hydrothermal*
  - Common at *divergent plate boundaries*
- Hydrothermal processes:
  - *Metamorphism*
    - Water transmits *pre-existing ions* between grains
  - *Metasomatism*
    - Water adds *new ions* to the rock
- Formation of *hydrothermal rocks*
    - Water passes through rocks and *precipitates new minerals* on walls of cracks and in pore spaces
    - *Metallic ore deposits* often form this way (*veins*)



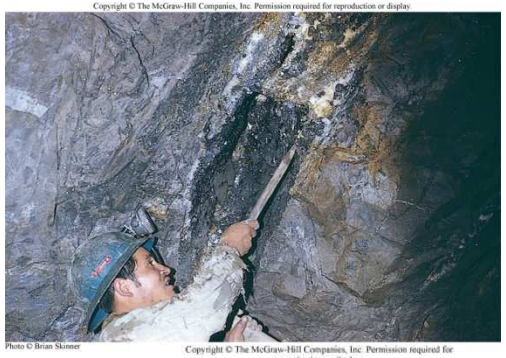


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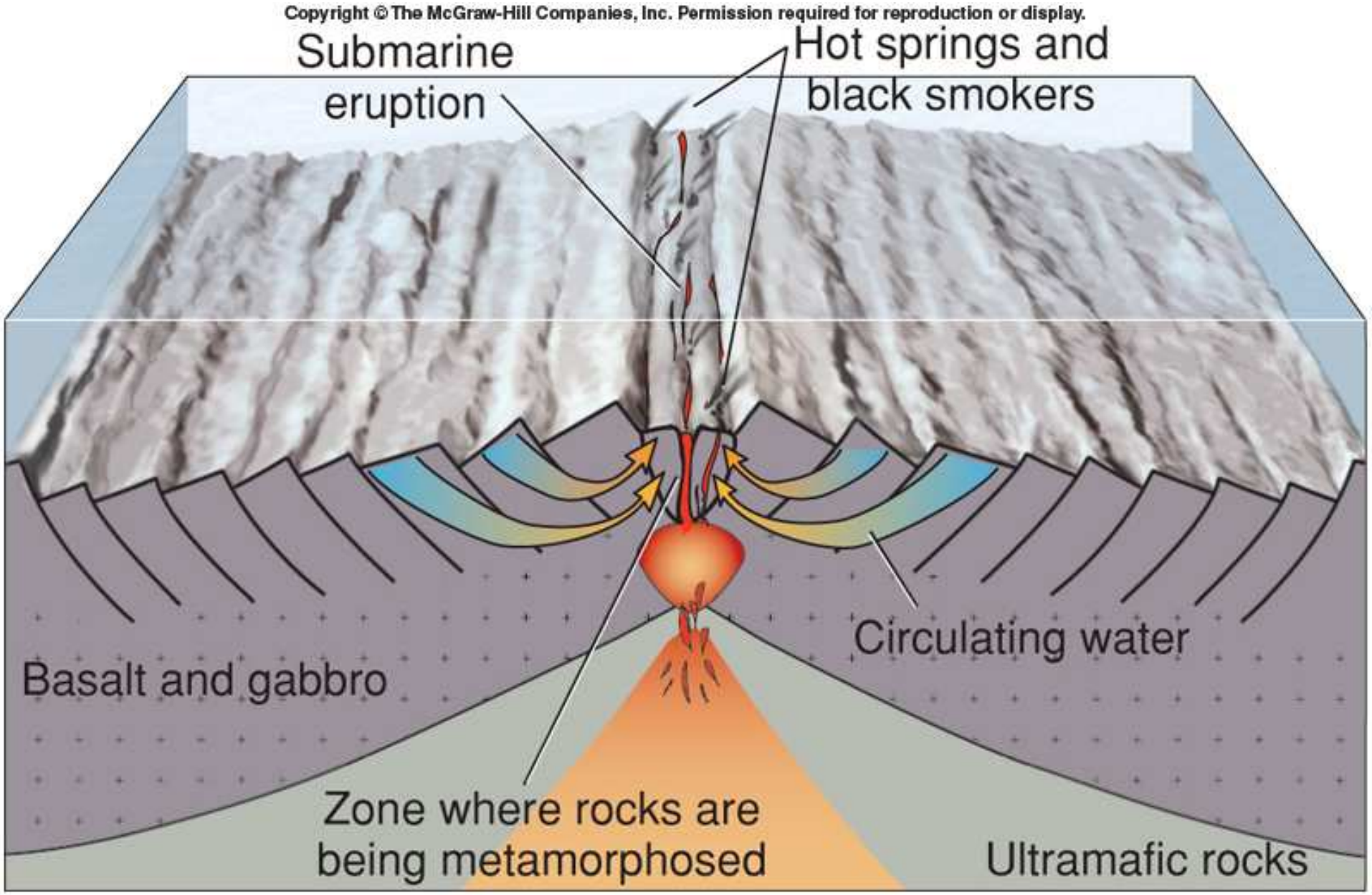
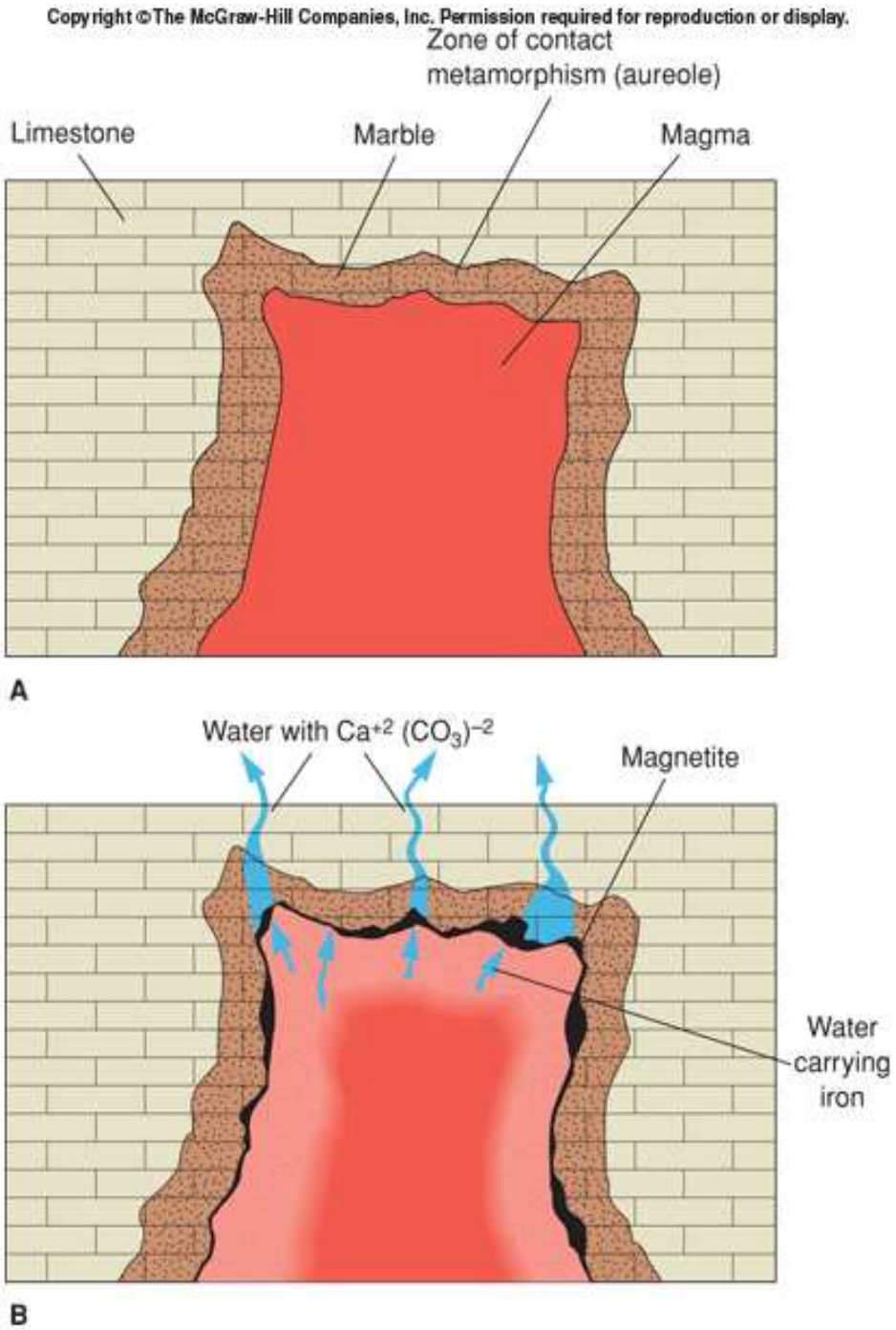
Photo courtesy of Kennecott Copper Company

At Divergent Boundaries

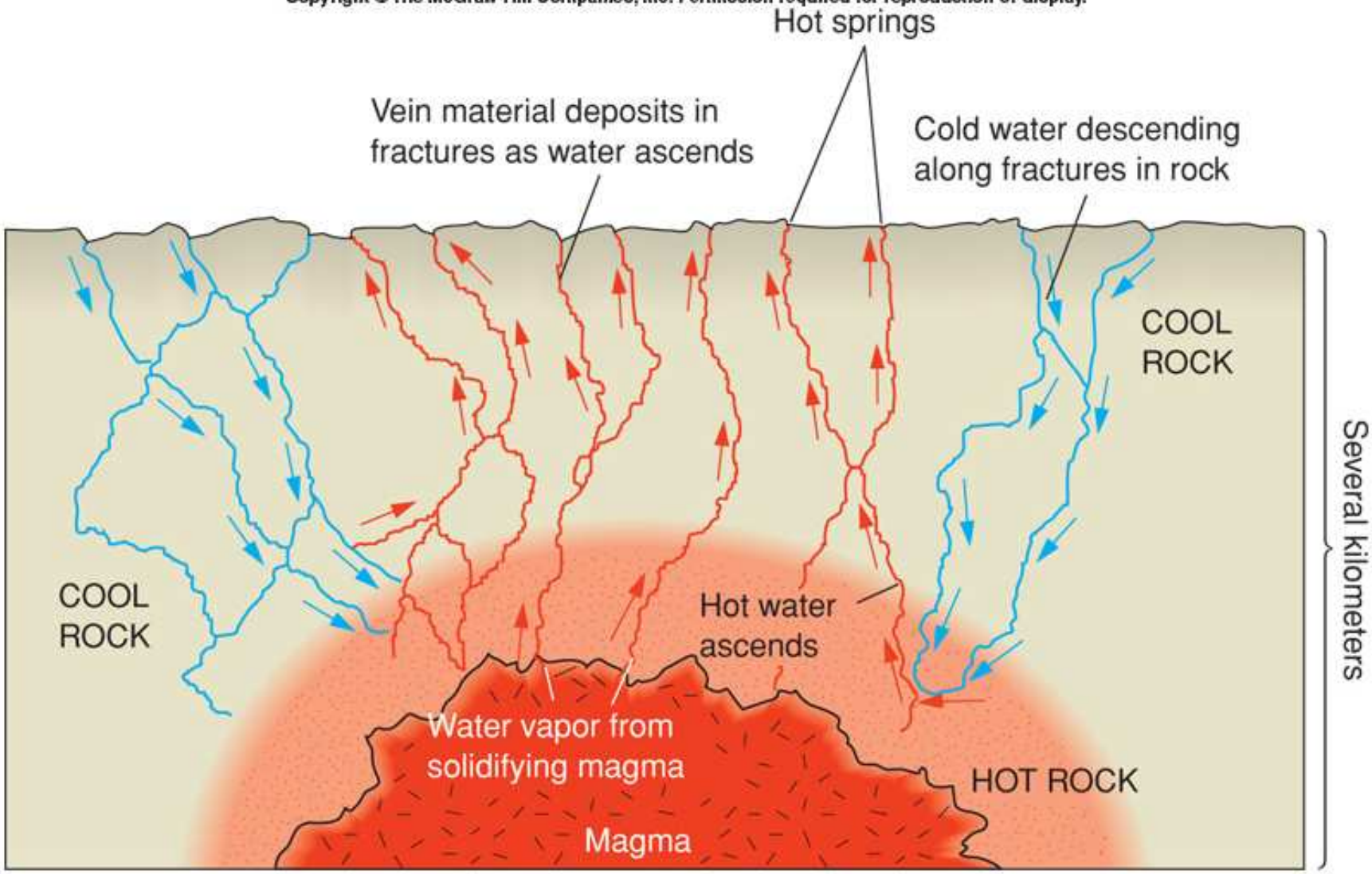


Contact Metasomatism

Metamorphism coupled with the introduction of ions from an external source



Hydrothermal Rocks



Hydrothermal Rocks

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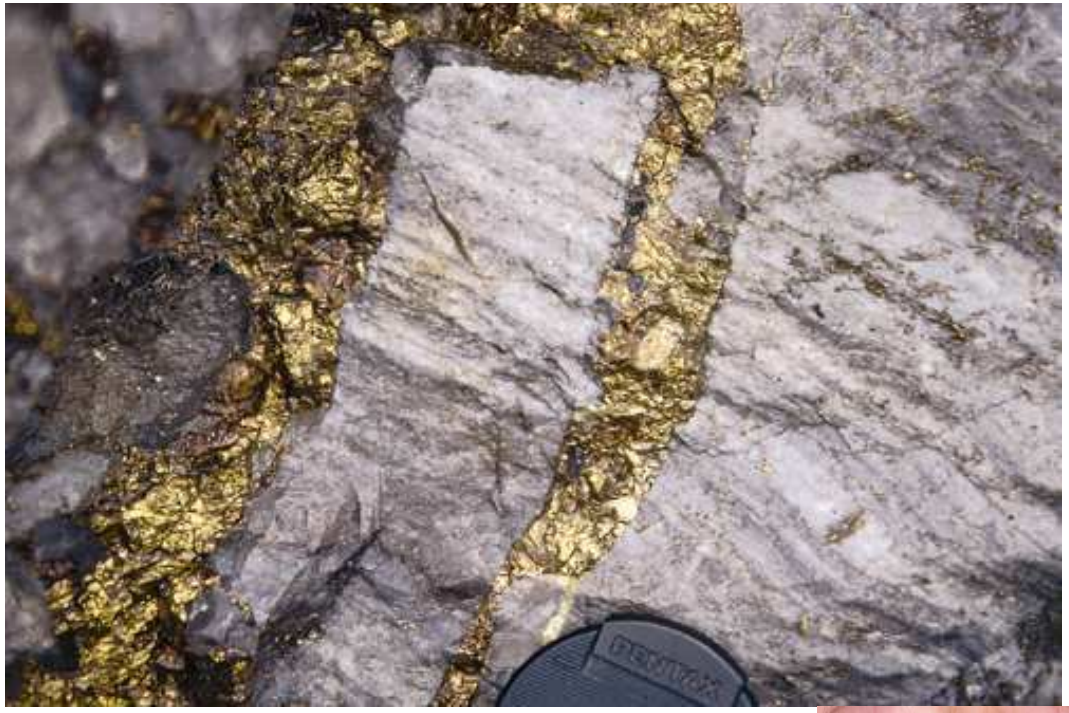

Gold Vein

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