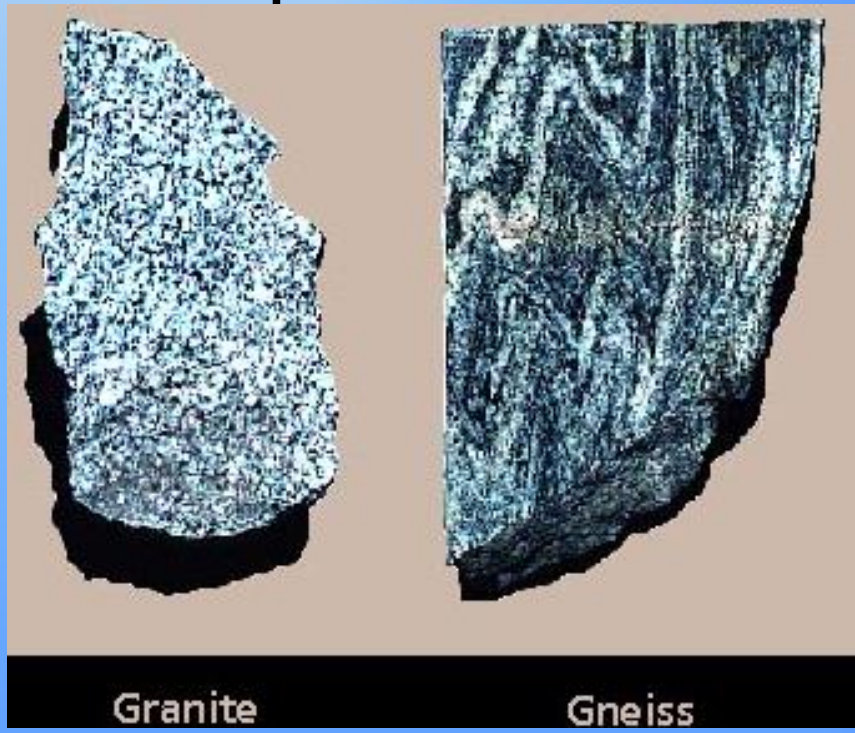
Metamorphic Rocks

- Metamorphic rocks
  - result from transformation **of other rocks**
  - in the solid state, **without melting**
- Changes resulting from metamorphism
  - compositional
    - **new minerals form**
  - textural
    - **minerals reorient**
    - minerals recrystallize
  - or both



Factors Controlling Metamorphic Rock Characteristics

A. **Parent** ***Rock Composition***

1. Usually no new elements or chemical compounds are added to the rock during metamorphism.

2. Mineral content is controlled by the chemical composition of the **parent rock.**

   a) Limestone ($CaCO_3$) cannot metamorphose into a silica-rich rock.

Agents of Metamorphism

- ***Heat*** provides new conditions
  - where different minerals may be stable
  - and increases the rate of chemical reactions

B. Temperature

1. A mineral is **stable** if, given enough time, **it does not react** with or convert to a new mineral or substance.

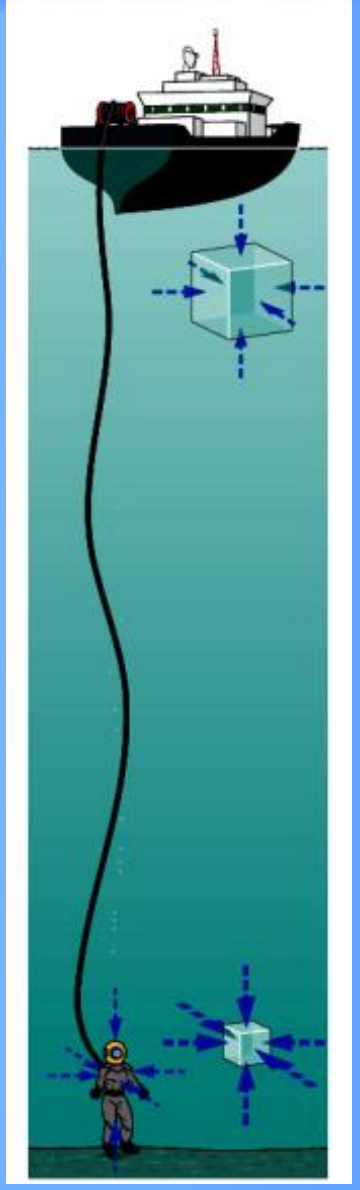
2. Any mineral is stable only within a given **temperature** range.

3. Some minerals are stable over a **wide** temperature range.
   a) Quartz is stable at Earth's surface up to about 800°C while at higher pressures remains stable to higher temperatures.
   b) Other minerals are stable over a temperature range of only 100°C to 200°C.
   c) If the temperature range at which a particular mineral is stable is known, the temperature of metamorphism for a rock containing that mineral can be deduced.

*** **4. Metamorphism does not melt the parent rock.**

C. *Pressure and Stress*

1. **Confining Pressure**
   a) Also called *geostatic* or *hydrostatic* (static) pressure
   b) Pressure applied **equally** on all surfaces of a body
   c) A function of depth from deep burial.
   d) **Density of newly formed minerals is higher.**



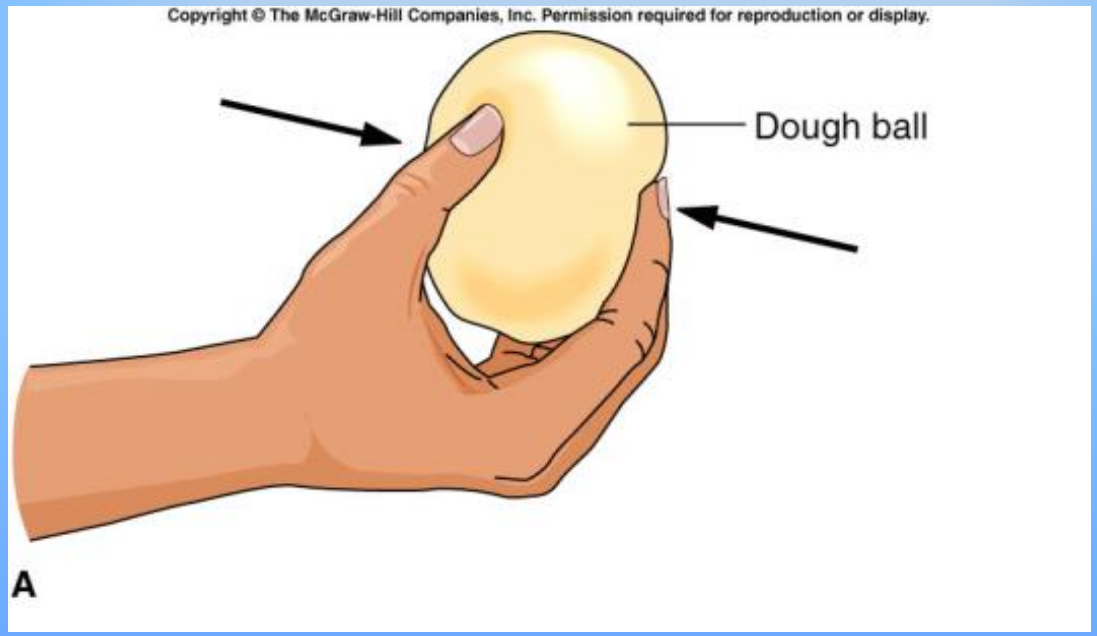
2. Differential Stress

a) The result of **tectonic** forces in crust.

b) Magnitude of the forces **varies** in **different directions**

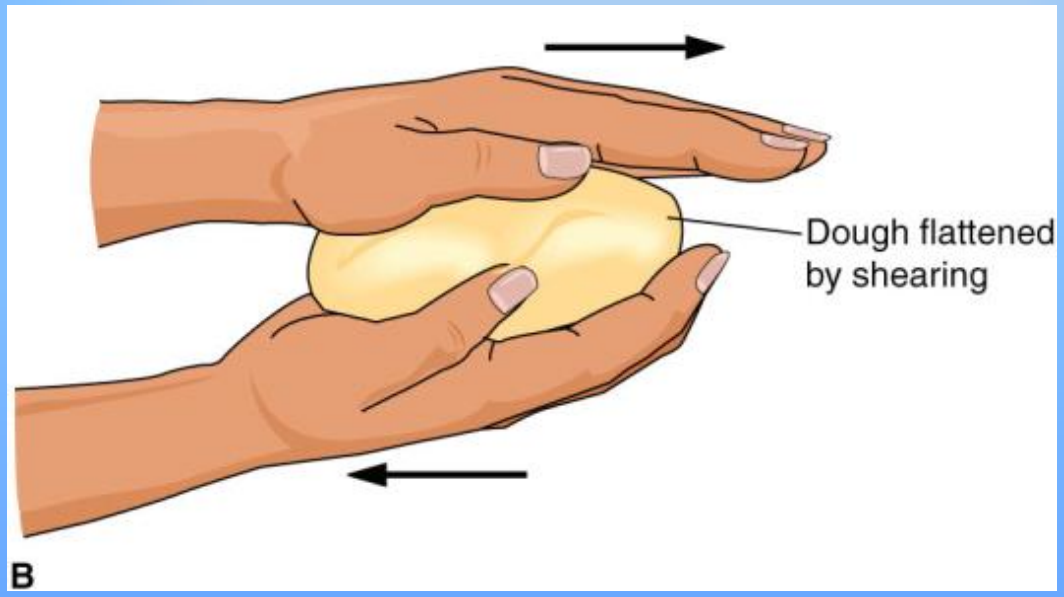
c) Compressive Stress

- Stress tends to deform objects into oblong or flattened forms



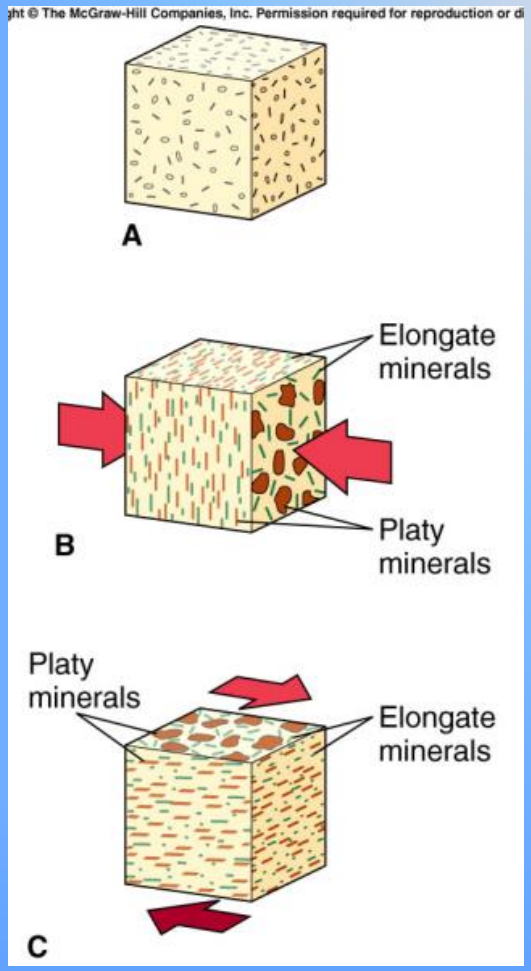
d) Shear Stress

- causes part of a body to move or slide relative to one another across a plane.



3. Foliation

Stress forces the constituents of the rock to become parallel to one another. When the rock has a planar texture, it is said to be **foliated.**

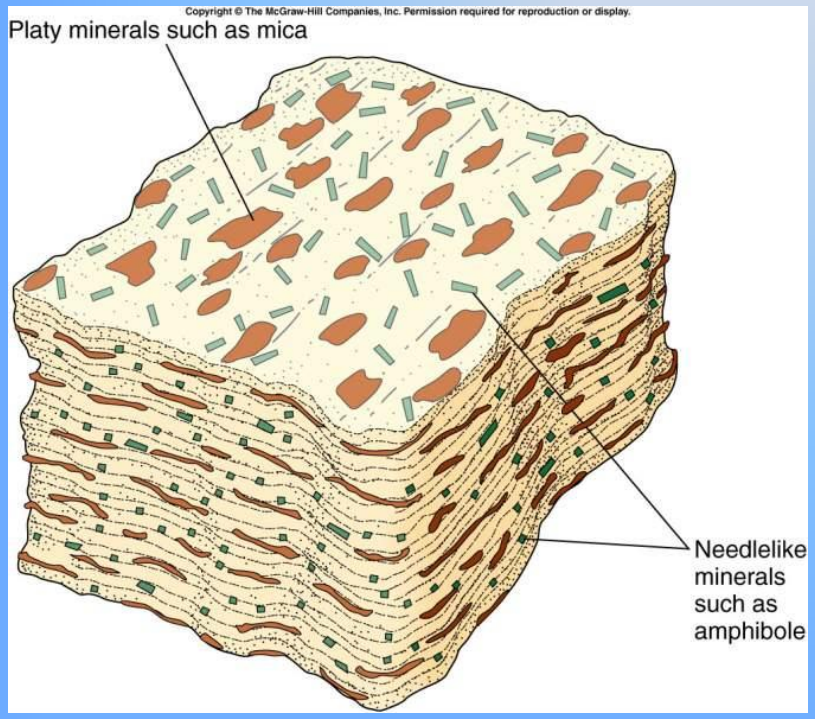


Platy minerals randomly oriented (e.g., clay minerals before metamorphism)

Platy minerals (e.g., mica) and elongate minerals (e.g., amphibole) have crystallized under the influence of compressive stress

Platy and elongate minerals developed while shearing is taking place

Foliation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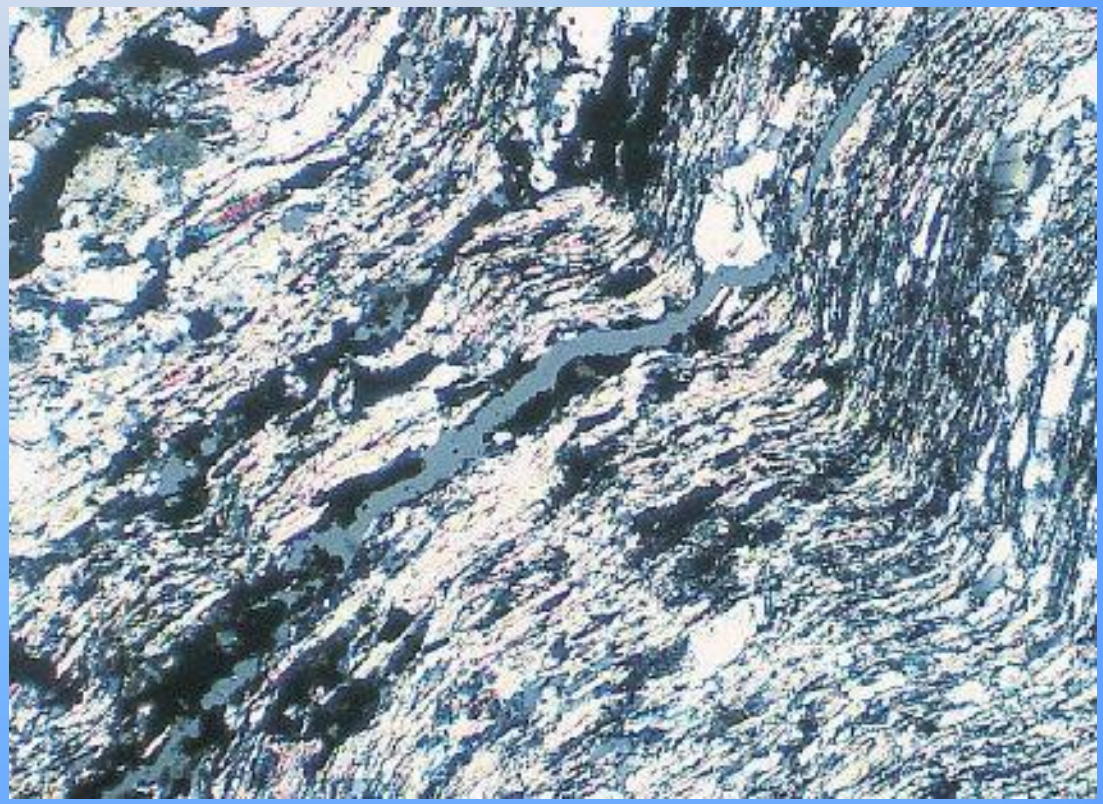
Platy minerals such as mica
Needlelike minerals such as amphibole

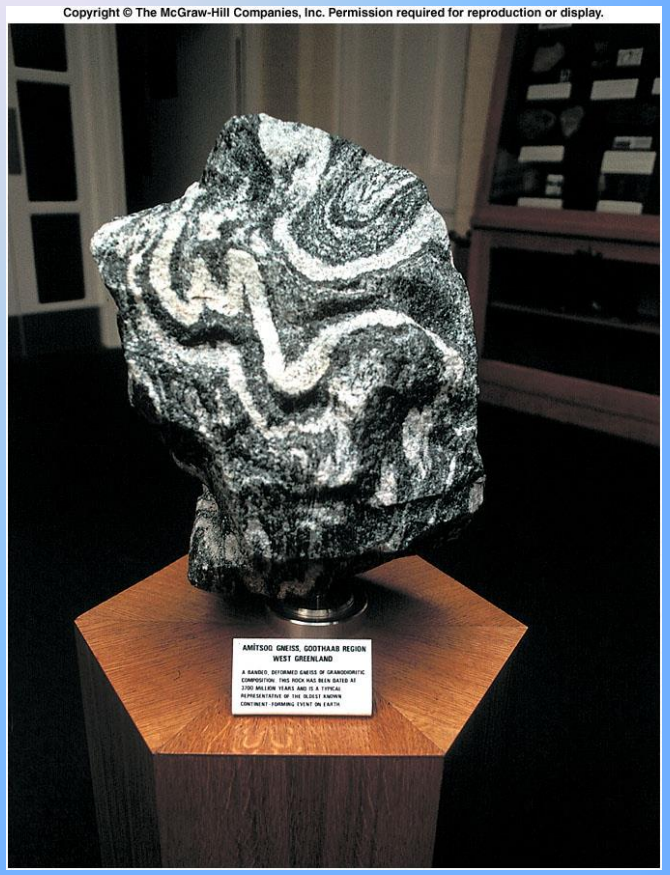
Formation of Foliation

- Microscopic view
  - of a metamorphic rock
  - with foliation
  - showing the parallel arrangement of minerals



Foliated Rocks

- Deformed rock



- Foliated rock from Greenland,
- 3.7 billion years old

4. Types of Foliation

a) **Slaty** **(slaty cleavage)**:

The rock splits easily along nearly flat and parallel planes. Preexisting, microscopic minerals (mainly micas) were pushed into alignment. Slaty cleavage is the product of low-grade metamorphism.

Types of Foliation

b) **Phyllitic** **Texture**:

A parallel, but wavy, foliation of fine-grained platy minerals (mainly micas and chlorite. Exhibits a shiny or glossy luster. Product of low-grade metamorphism.

Types of Foliation

c) **Schistose** **Texture (schistosity)**

Visible or needle-shaped minerals (medium-to-coarse grained) have grown essentially parallel to a plane due to differential stress. Intermediate to high grade metamorphism

Types of Foliation

d) **Gneissic** **Texture**

Parallel to subparallel layers alternating in different composition (light and dark). Develops if the rock becomes *plastic* (capable of being bent and molded under stress). The dark bands are usually ferromagnesium minerals and quartz, feldspars, or carbonate minerals usually form the light bands. Intermediate to high grade metamorphism.

Agents of Metamorphism

C. ***Fluids***

1. Hot water (as water vapor)

   - The most important fluid in metamorphic processes

   a) May trigger metamorphic chemical reactions
   b) Dissolves ions from one mineral, moves between grains and/or through cracks.
   c) Ions react elsewhere in the rock with other minerals that are stable.

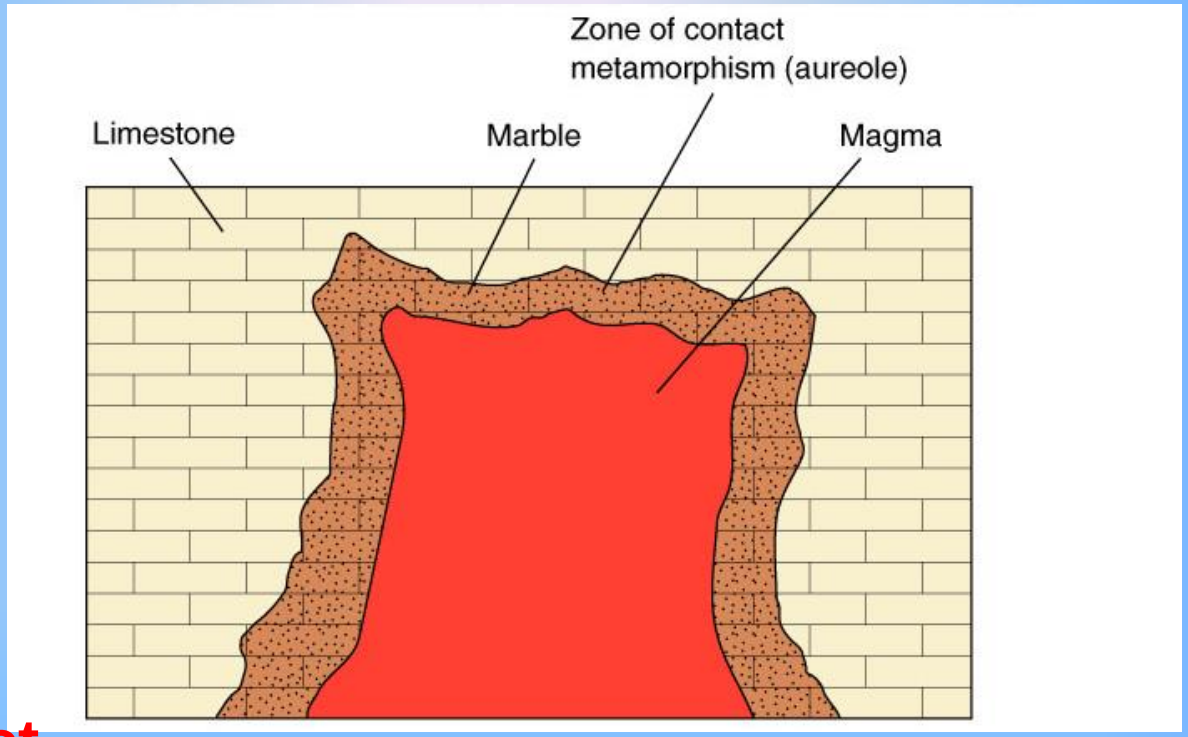
Fluids

2. Carbon dioxide is another gas that may play a role

Fluids . . .

- May be
  - Trapped in a parent sedimentary rock
  - Given off by a cooling pluton
  - Released from a mineral's crystal structure when it becomes unstable
- Initiates metamorphic chemical reactions

II. Types of Metamorphism



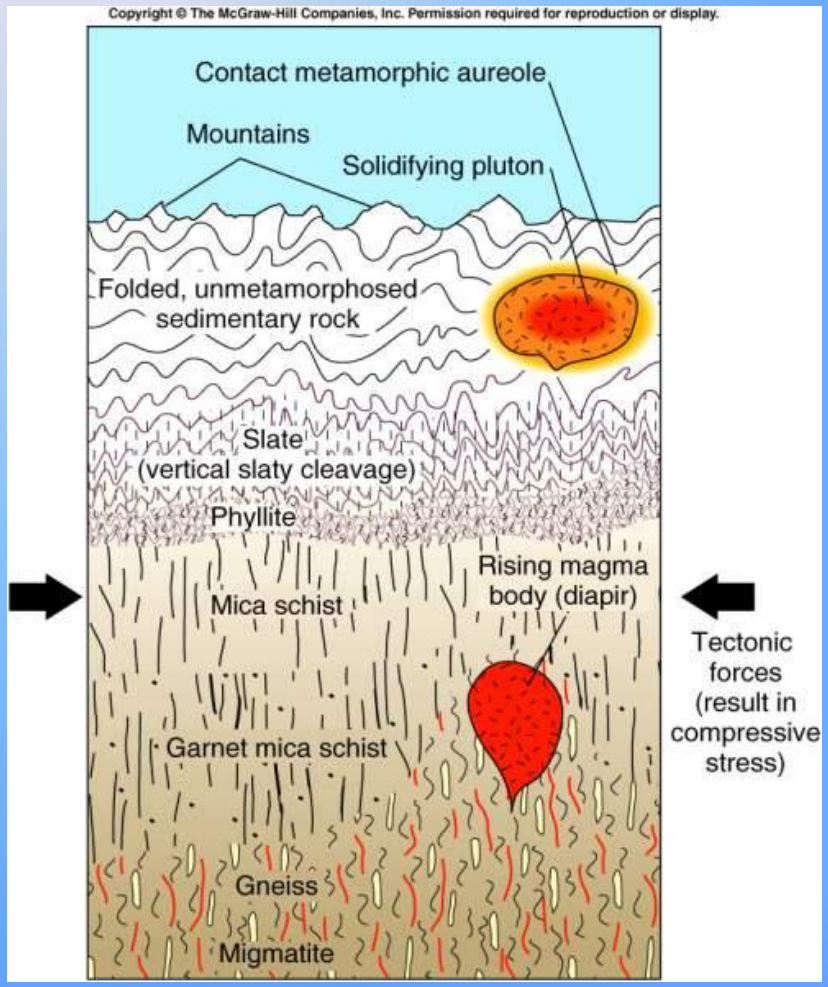
A. **Contact** **Metamorphism** (also referred to as *thermal* metamorphism)

1. **High** temperature is the dominant factor. **No melting** occurs.
2. Occurs when a body of magma intrudes relative cool country rock.
   a) The country rock adjacent to the intrusion is “baked”.
   b) The zone of contact metamorphism is also called an ***aureole***.
   c) The aureole is narrow (1 to 50 meters wide).
3. Confining pressure is low and differential stress is rarely significant, therefore, metamorphic rocks formed by contact metamorphism **are not foliated**.

B. Regional Metamorphism

1. Caused by relatively high temperature and confining pressure
   - Over very large areas, such as mountain ranges.
2. Regional metamorphic rocks are almost always foliated
   - From differential stress.
3. Associated with mountain formation.

Rock shown formed from shale



4. Prograde Metamorphism

- A rock recrystallizes into a higher-grade metamorphic rock.
- Result of burial to greater depths and being subjected to increasingly greater pressures and temperatures.

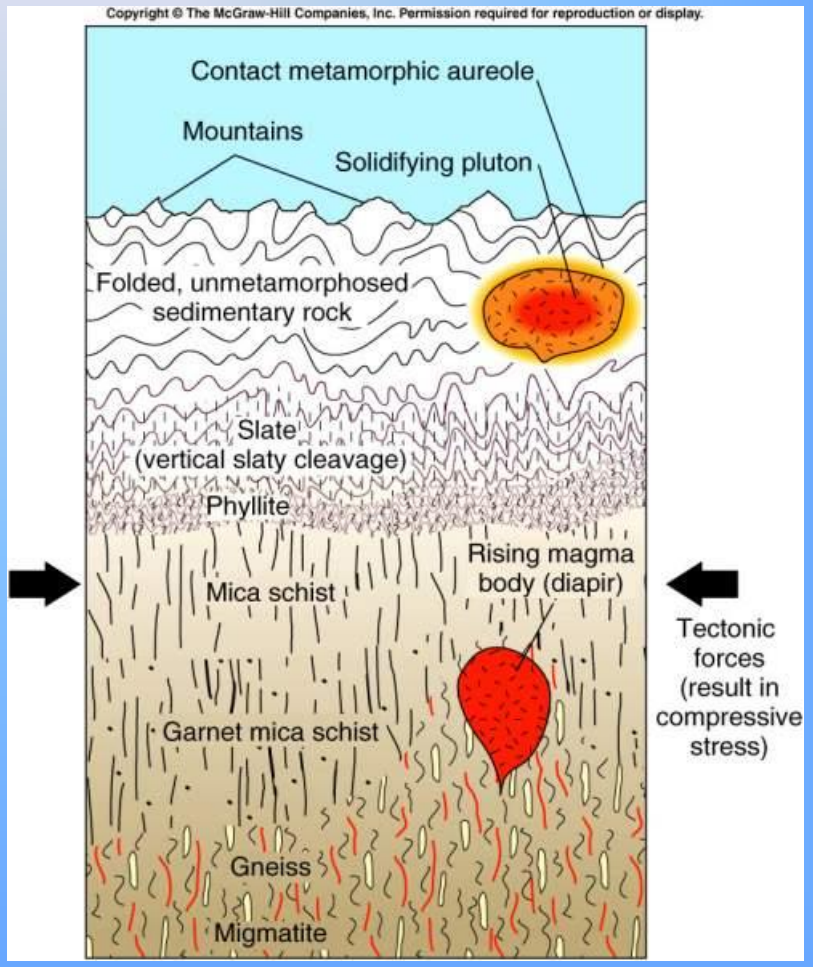
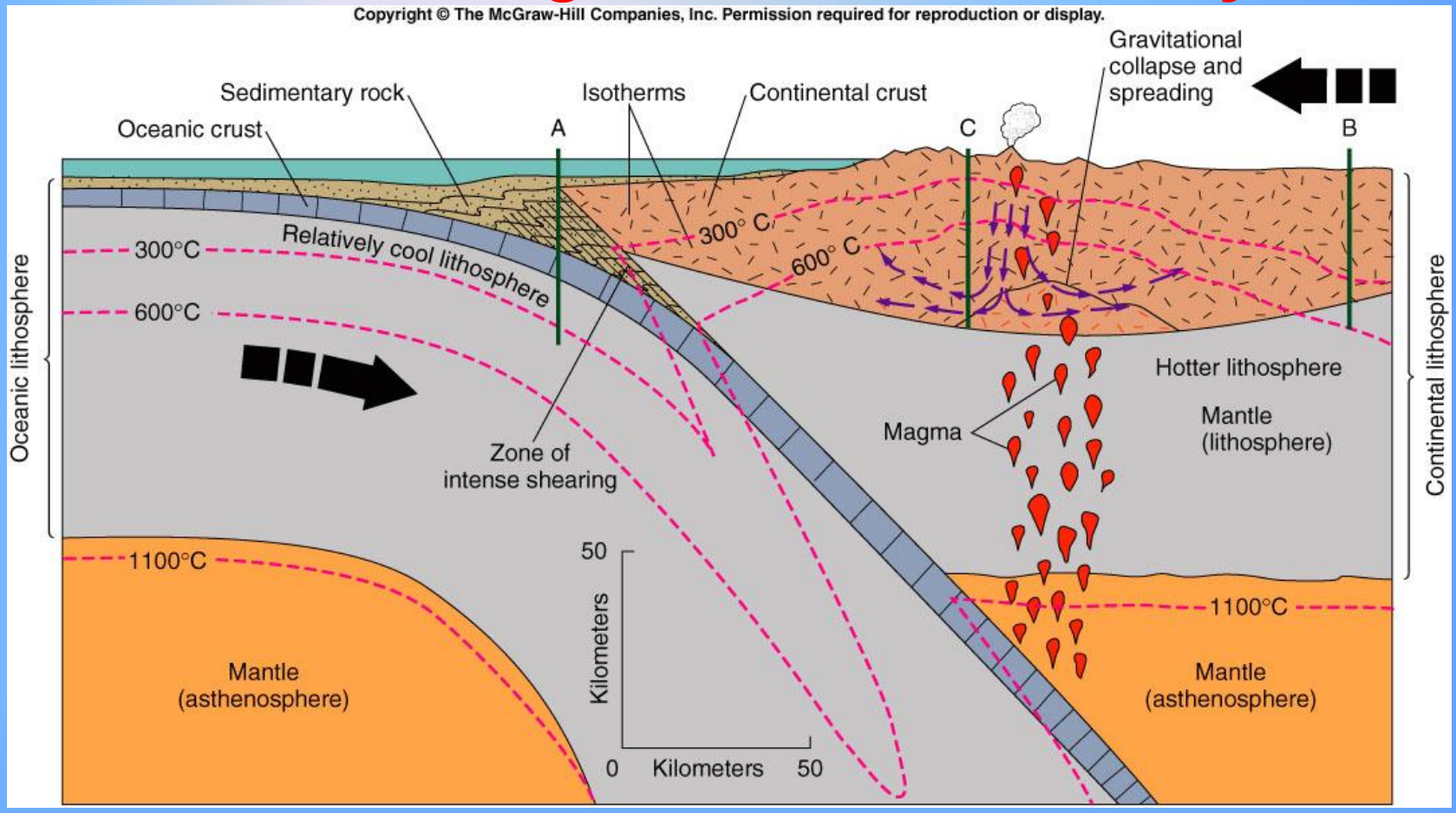


Plate Tectonics and Metamorphism

A. Plate tectonic theory accounts for the features observed in metamorphic rocks and relates their development to other activities in Earth. Plate tectonics explains

1. The deep burial of rocks originally formed at or near Earth's surface;
2. Intense squeezing necessary for the differential stress implied by foliated rocks;
3. The presence of water deep within the lithosphere;
4. The wide variety of pressures and temperatures believed to be present during metamorphism

B. Metamorphism Across a Convergent Plate Boundary



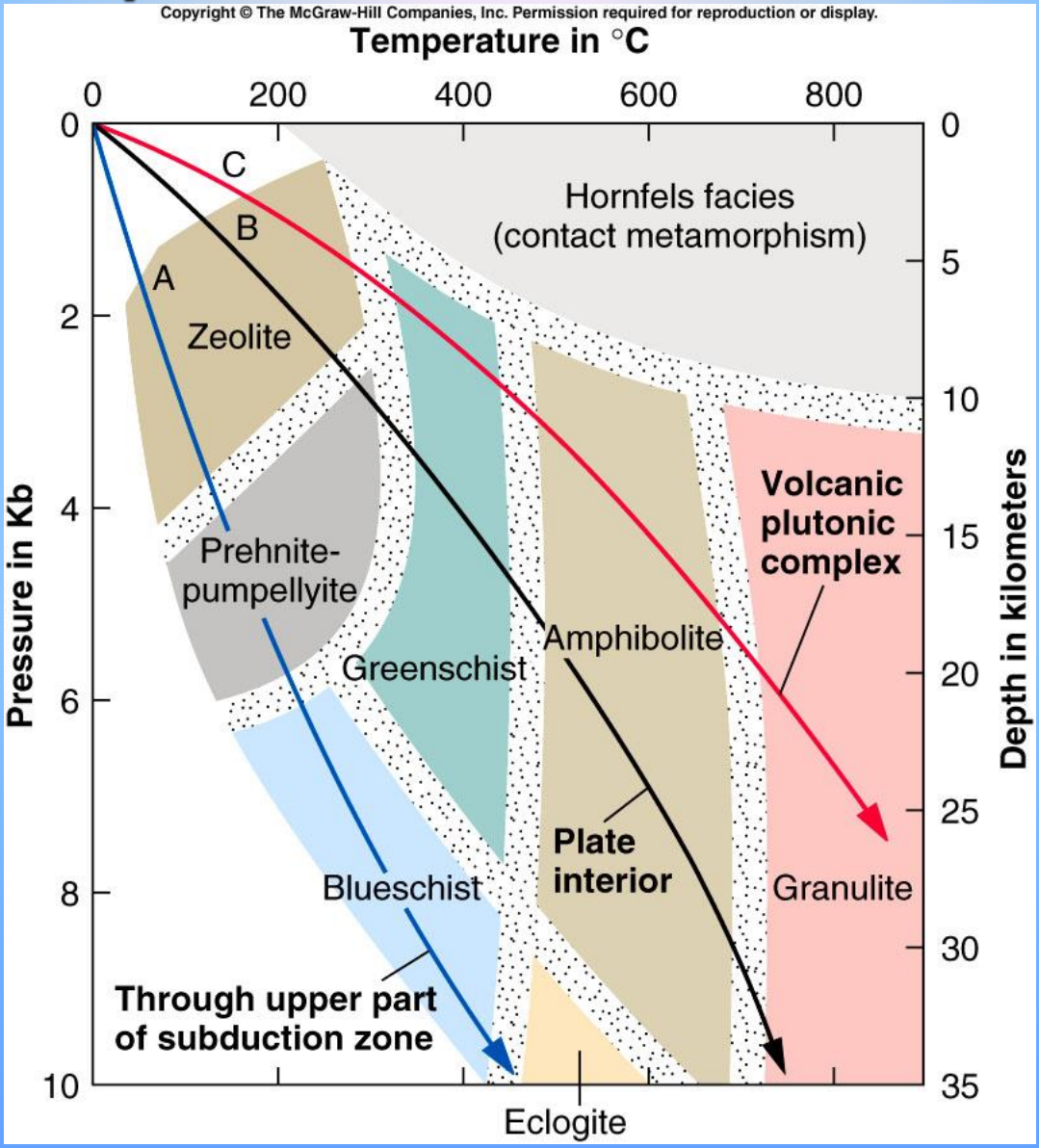
All rock hotter than 300º C or deeper than 5 km is likely to be undergoing metamorphism.

Metamorphic Facies and the Relationship to Plate Tectonics

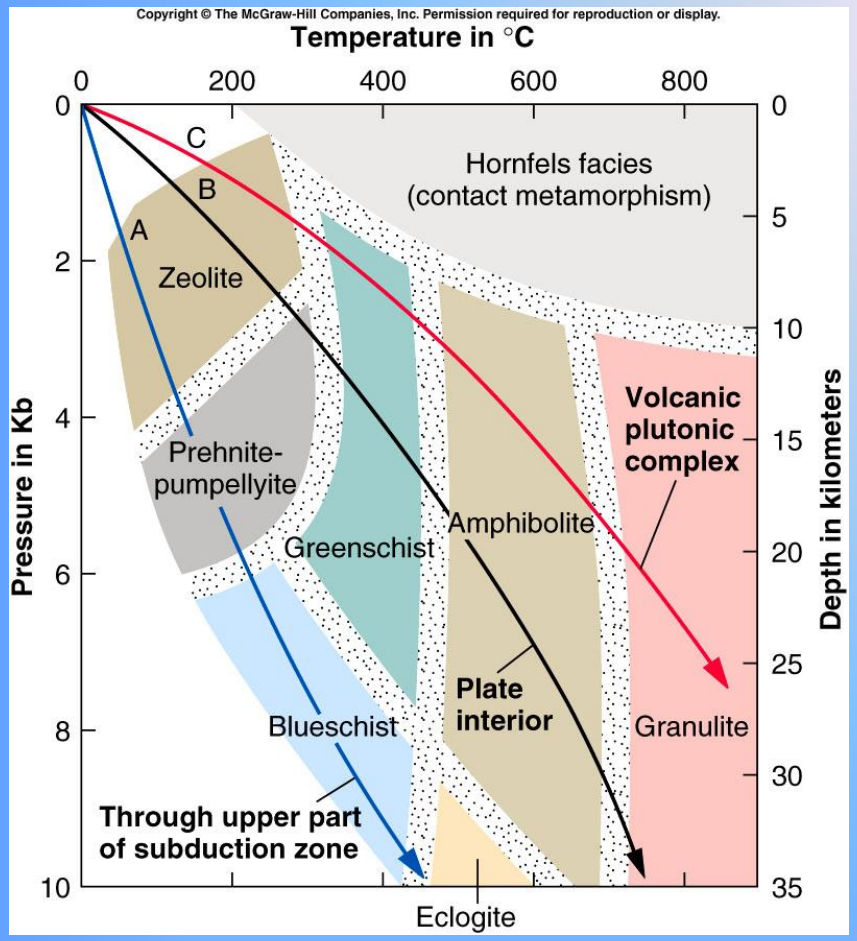
1. The term ***facies*** when applied to metamorphic and sedimentary rocks, implies a certain environment of formation.

2. Rocks having the same grouping of minerals (*mineral assemblages*) are regarded as belonging to the same ***metamorphic facies***. This implies that they formed under similar conditions of **temperature** and **pressure**

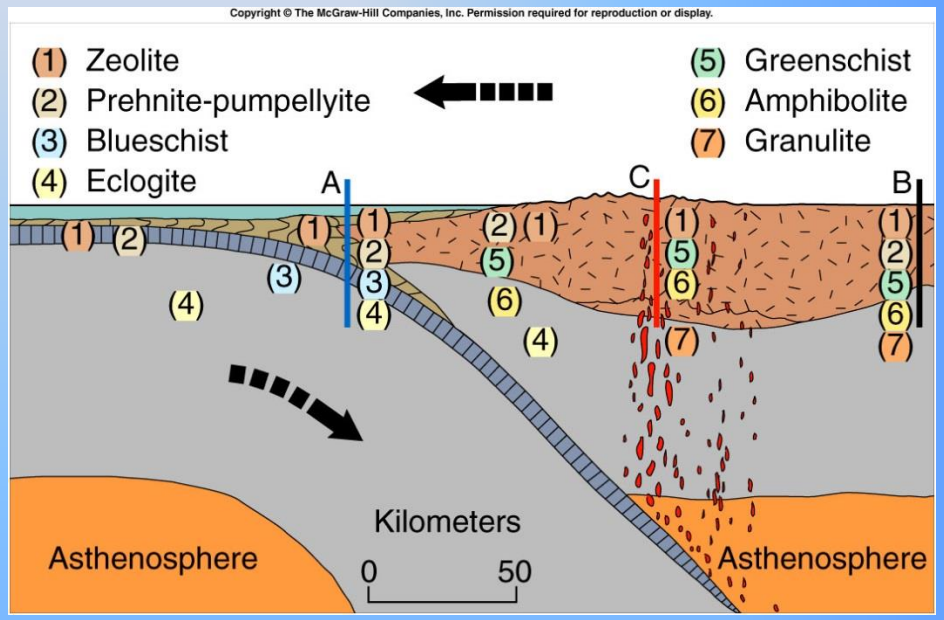
Metamorphic Facies and Plate Tectonics



Metamorphic Facies and Plate Tectonics



Arrows represent increases in temperature with depth



Distribution of facies across a convergent plate boundary

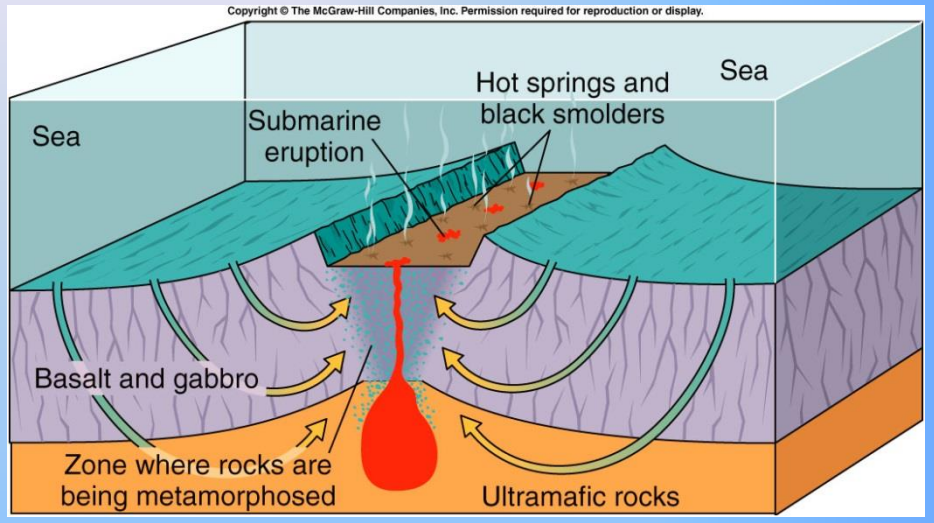
IV. Hydrothermal Processes

- ***Hydrothermal*** *rocks* are rocks that have been formed entirely by precipitation of ions derived from hot water (hydrothermal solutions).

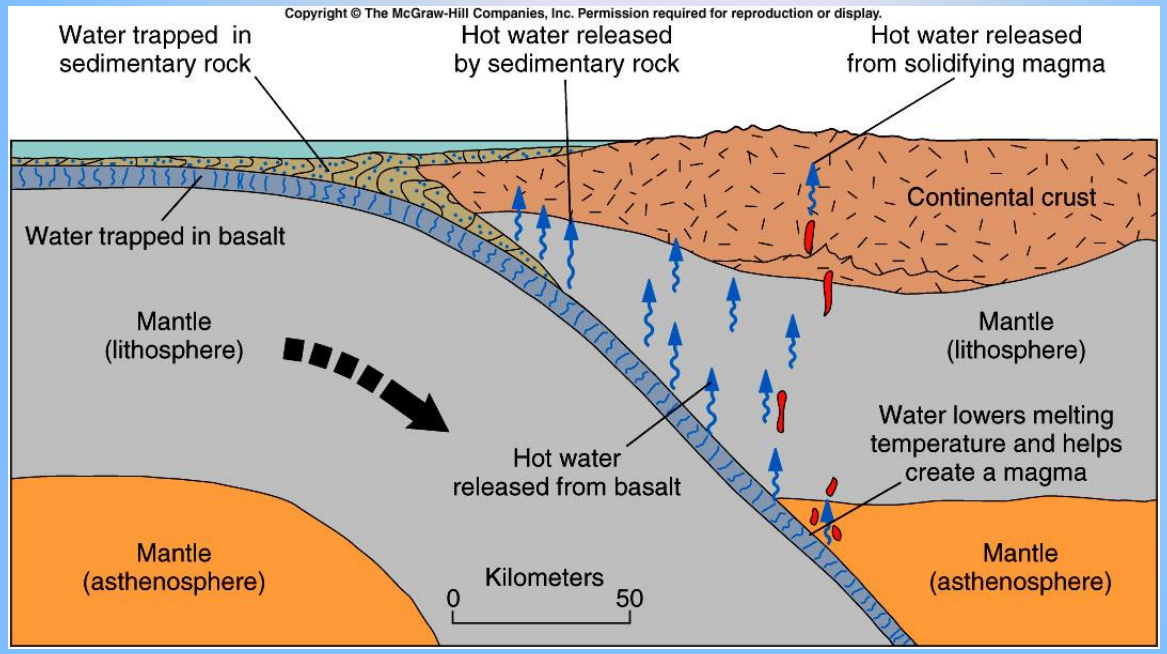
- These processes are particularly important at mid-ocean ridges.

A. Hydrothermal Vents ("Black Smokers")

- Cold seawater moves down through cracks
  - It is cycled upwards by heat from magma.
  - Olivine and pyroxene become converted to *hydrous* minerals (amphibole)
  - If later subducted, water may be released and help melt rock creating magma
- "Black Smoker" - "Smoke is from metallic sulfide minerals precipitating into the cold water



B. Water at Convergent Boundaries

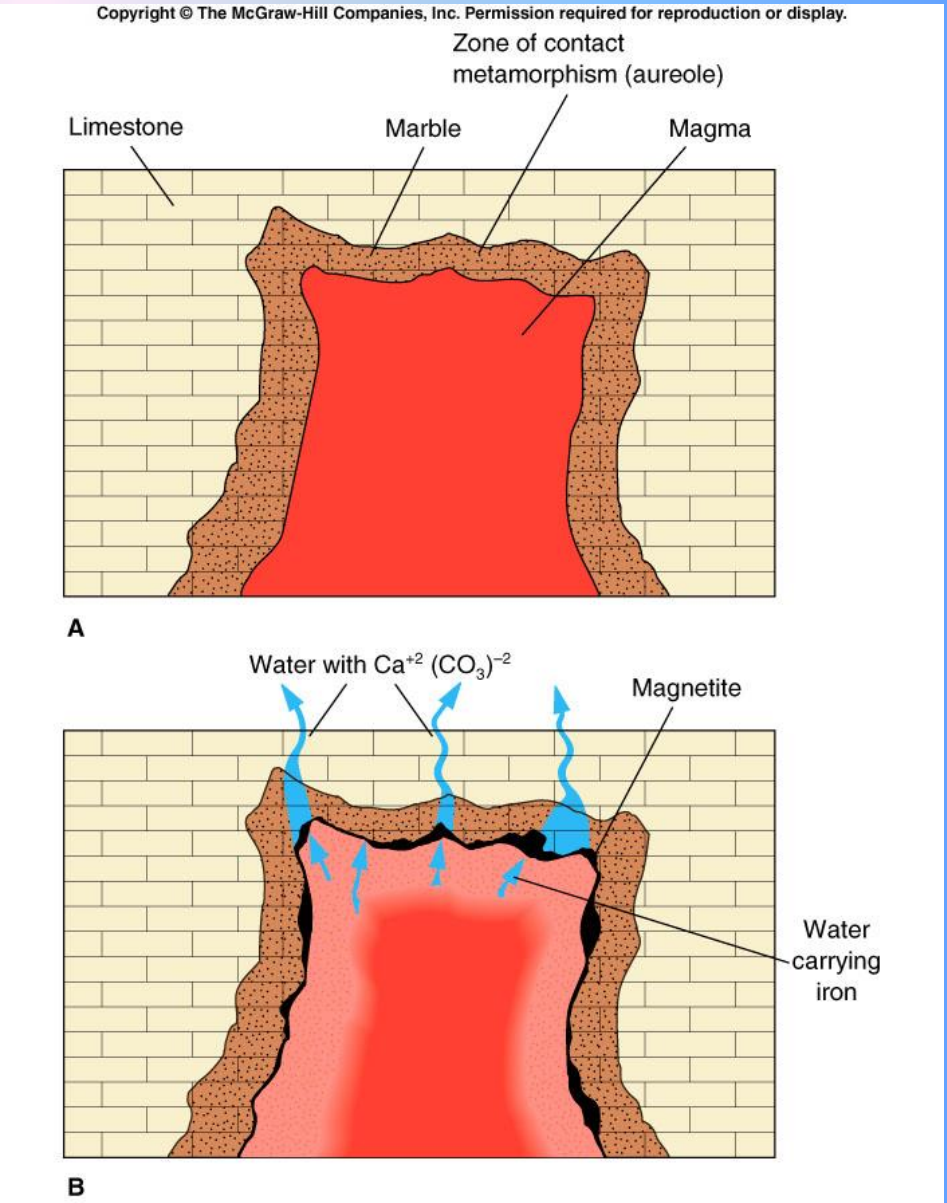


- At depths of up to 30 km
  - Pressure and hot temperatures cause hydrous minerals to recrystallize and release water
  - Water vapor ascends through cracks dissolves minerals, and carries the ions to interact with surrounding rocks.

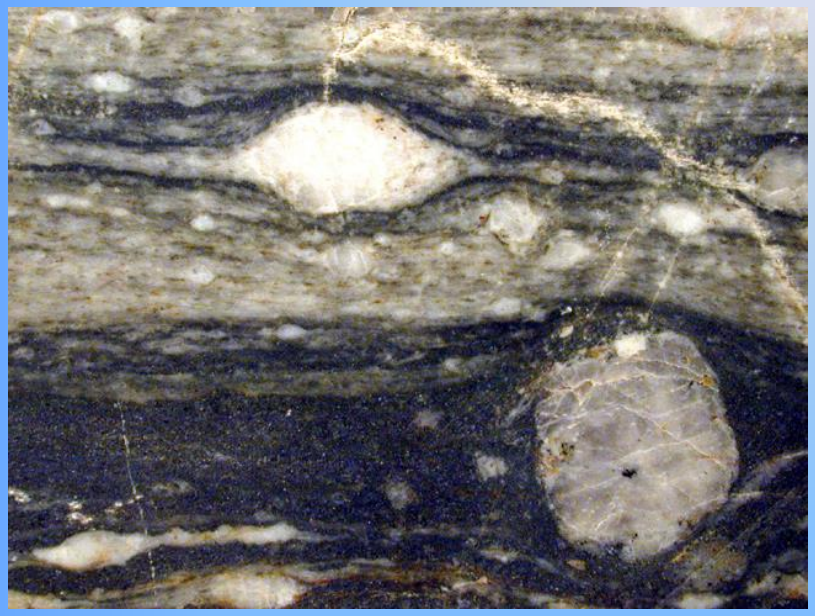
C. Metasomatism

- Ions are brought in by water from outside the immediate environment.
- They are incorporated into newly crystallizing minerals.
- Simultaneously, hot water may dissolve minerals that were part of the rock and remove them.

➢With contact metamorphism the source of the water carrying ions is the intruding magma



Metasomatism Associated with Regional Metamorphism

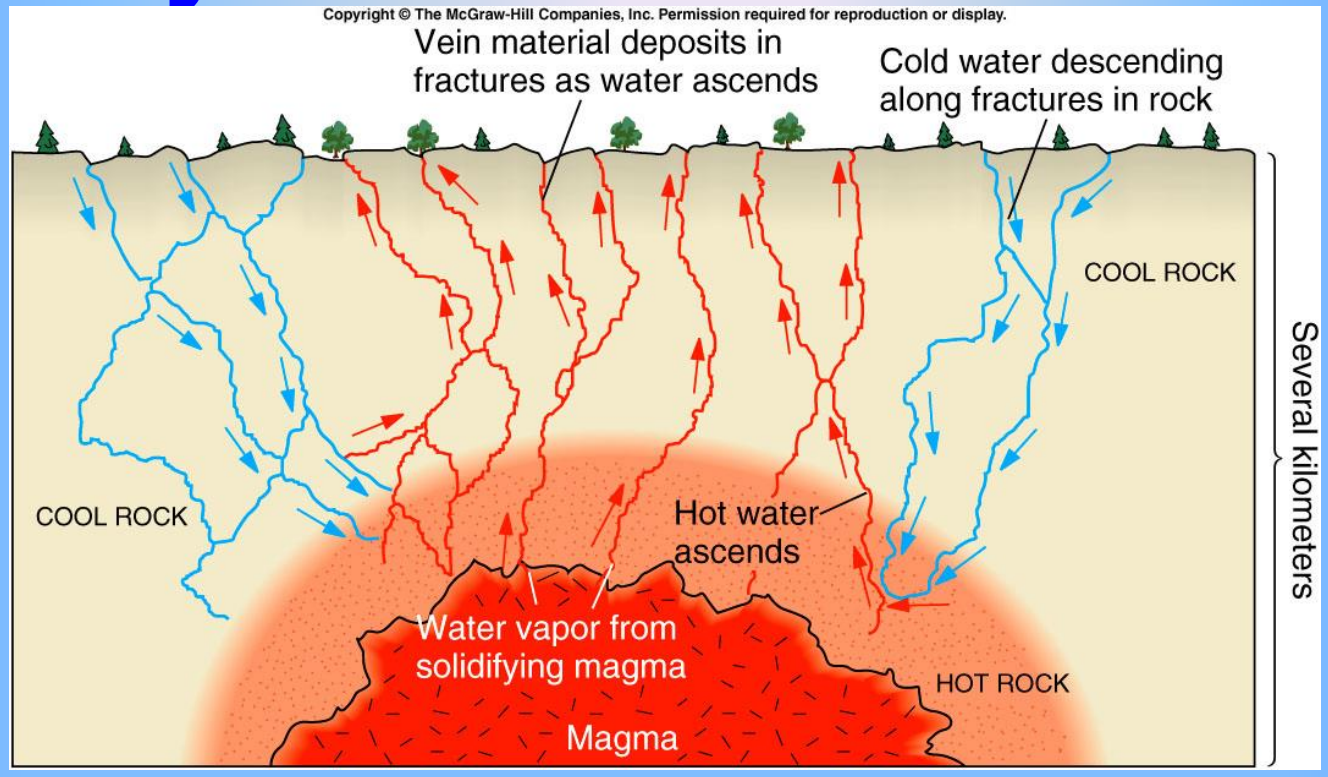


- Hot water travels through the rock while it's forming.
- Ions (K^+, Na^+, and SiO_4^{-4}) participate in metamorphic reactions
- Large crystals of feldspar grow due to the addition of the K or Na ions.

D. Hydrothermal Processes

1. Hydrothermal rocks are most commonly found in veins.
2. Quartz grains are common where igneous activity has occurred.
3. Ore deposits in veins are economically important
   - Zinc
   - Lead
   - Silver,
   - Gold
   - Other metals

Hydrothermal Veins



- Quartz veins are most common
  - As water vapor ascends it cools
  - Silicon and oxygen leave solution and cake onto walls of cracks as silica
- Veins can also be calcite and other minerals

Identification of Metamorphic Rocks

Slate

- Very fine-grained and breaks into flat pieces

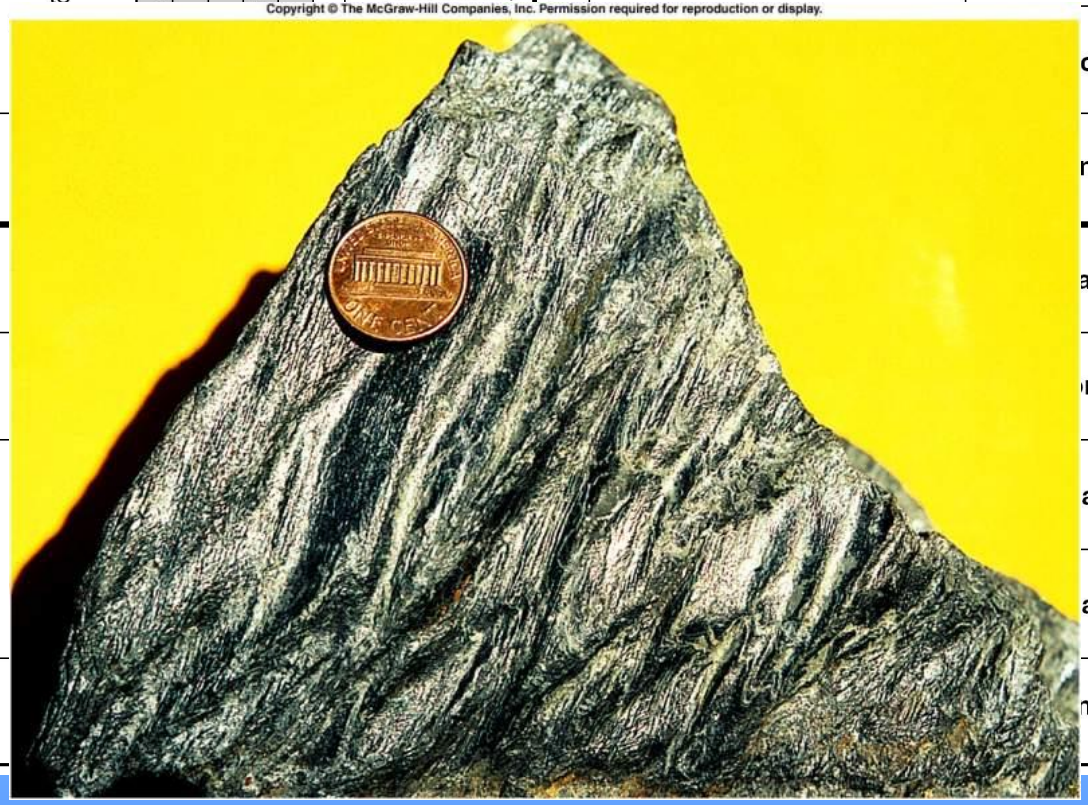
Scheme for Metamorphic Rock Identification

TEXTURE	GRAIN SIZE	COMPOSITION	TYPE OF METAMORPHISM	COMMENTS	ROCK NAME	MAP SYMBOL
FOLIATED — MINERAL ALIGNMENT	Fine	MICA, QUARTZ, FELDSPAR, AMPHIBOLE, GARNET, ...	Regional (Heat and pressure increases)	Low-grade metamorphism of shale	**Slate**	
FOLIATED — MINERAL ALIGNMENT	Fine to medium	MICA, QUARTZ, FELDSPAR, AMPHIBOLE, GARNET, ...	Regional (Heat and pressure increases)			

- Fine-grained (coarser than slate)
- Silky luster
- Wrinkled

Scheme for Metamorphic Rock Identification

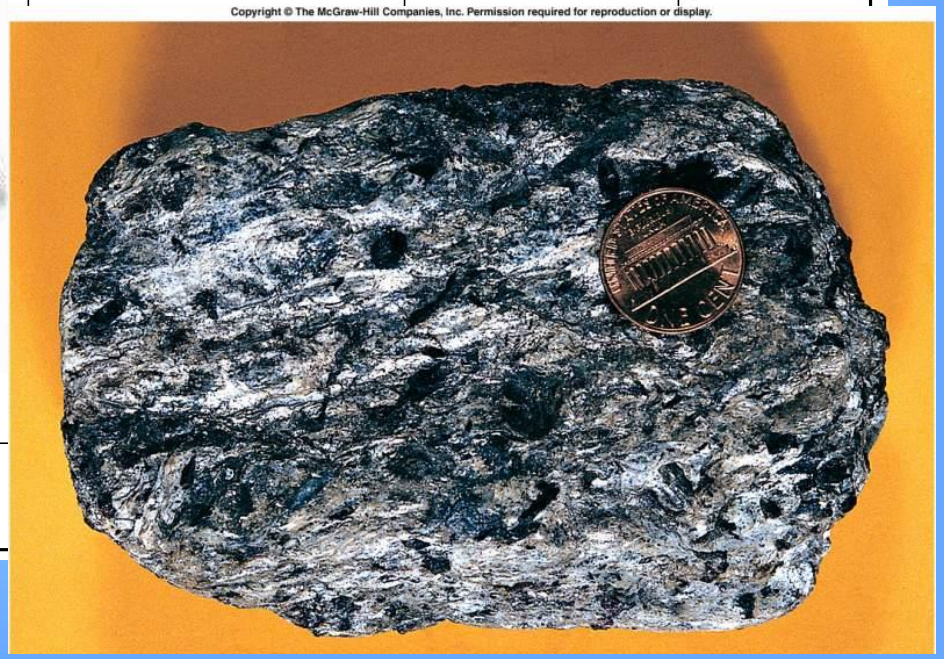
TEXTURE		GRAIN SIZE	COMPOSITION	TYPE OF METAMORPHISM	COMMENTS	ROCK NAME	MAP SYMBOL
FOLIATED	MINERAL ALIGNMENT	Fine		Regional (Heat and pressure increases)	Low-grade metamorphism of shale	Slate	
		Fine to			Foliation surfaces shiny from microscopic mica crystals	Phyllite	
						chist	
	BAND-ING					neiss	
NONFOLIATED						acite coal	
						rnfels	
						artzite	
						arble	
						nglomerate	



Cleary visible platy or elongate minerals

Scheme for Metamorphic Rock Identification

TEXTURE	GRAIN SIZE	COMPOSITION	TYPE OF METAMORPHISM	COMMENTS	ROCK NAME	MAP SYMBOL
FOLIATED — MINERAL ALIGNMENT	Fine	MICA, QUARTZ, FELDSPAR, AMPHIBOLE, GARNET, XENE	Regional (Heat and pressure increases)	Low-grade metamorphism of shale	**Slate**	
	Fine to medium			Foliation surfaces shiny from microscopic mica crystals	**Phyllite**	
				Platy mica crystals visible from metamorphism of clay or feldspars	**Schist**	
				High-grade metamorphism; mineral types segregated into bands	**Gneiss**	
	Coarse	Calcite and/or dolomite	or contact			
	Coarse	Various minerals				



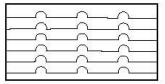
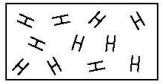
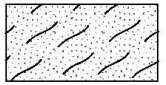
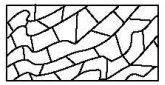
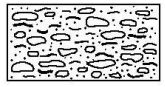
Alternating dark and light bands of minerals

Scheme for Metamorphic Rock Identification

TEXTURE	GRAIN SIZE	COMPOSITION	TYPE OF METAMORPHISM	COMMENTS	ROCK NAME	MAP SYMBOL
FOLIATED — MINERAL ALIGNMENT	Fine	CA / Z / R / LE	Regional (Heat and pressure increases)	Low-grade metamorphism of shale	Slate	
	Fine to medium			Foliation surfaces shiny from microscopic mica crystals	Phyllite	
				Platy mica crystals visible	Schist	
BAND-ING	M				Gneiss	
NONFOLIATED					racite coal	
					ornfels	
					uartzite	
	c				Marble	
	C				onglomerate	

No mineral alignment, layering or banding

Scheme for Metamorphic Rock Identification

TEXTURE	GRAIN SIZE	COMPOSITION	TYPE OF METAMORPHISM	COMMENTS	ROCK NAME	MAP SYMBOL
FOLIATED — MINERAL ALIGNMENT	Fine	MICA, QUARTZ, FELDSPAR, AMPHIBOLE, GARNET, PYROXENE	Regional (Heat and pressure increases)	Low-grade metamorphism of shale	**Slate**	
	Fine to medium			Foliation surfaces shiny from microscopic mica crystals	**Phyllite**	
				Platy mica crystals visible from metamorphism of clay or feldspars	**Schist**	
FOLIATED — BAND-ING	Medium to coarse			High-grade metamorphism; mineral types segregated into bands	**Gneiss**	
NONFOLIATED	Fine	Carbon	Regional	Metamorphism of bituminous coal	**Anthracite coal**	
	Fine	Various minerals	Contact (heat)	Various rocks changed by heat from nearby magma/lava	**Hornfels**	
	Fine to coarse	Quartz	Regional or contact	Metamorphism of quartz sandstone	**Quartzite**	
		Calcite and/or dolomite		Metamorphism of limestone or dolostone	**Marble**	
	Coarse	Various minerals		Pebbles may be distorted or stretched	**Metaconglomerate**	

Metamorphism of Bituminous Coal

Scheme for Metamorphic Rock Identification

TEXTURE		GRAIN SIZE	COMPOSITION	TYPE OF METAMORPHISM	COMMENTS	ROCK NAME	MAP SYMBOL
FOLIATED	MINERAL ALIGNMENT	Fine	MICA, QUARTZ, FELDSPAR, AMPHIBOLE, GARNET, PYROXENE	Regional (Heat and pressure increases)	Low-grade metamorphism of shale	**Slate**	
		Fine to medium			Foliation surfaces shiny from microscopic mica crystals	**Phyllite**	
					Platy mica crystals visible from metamorphism of clay or feldspars	**Schist**	
	BAND-ING	Medium to coarse			High-grade metamorphism; mineral types segregated into bands	**Gneiss**	
NONFOLIATED		Fine	Carbon	Regional	Metamorphism of bituminous coal	**Anthracite coal**	
		Fine	Various minerals	Contact (heat)	Various rocks changed by heat from nearby magma/lava	**Hornfels**	
		Fine to coarse	Quartz	Regional or contact	Metamorphism of quartz sandstone	**Quartzite**	
			Calcite and/or dolomite		Metamorphism of limestone or dolostone	**Marble**	
		Coarse	Various minerals		Pebbles may be distorted or stretched	**Metaconglomerate**	

Bituminous Coal

Anthracite Coal

Hornfels is a nondescript rock which varies widely in appearance.

or Metamorphic Rock Identificat

TYPE OF METAMORPHISM	COMMENTS
Regional (Heat and pressure increases)	Low-grade metamorphism of shale
	Foliation surfaces shiny from microscopic mica crystals
	Platy mica crystals visible from metamorphism of clay or feldspars
	High-grade metamorphism; mineral types segregated into bands

NONFOLIATED	Fine		Anthracite coal
	Fine		Hornfels
	Fine to coarse		Quartzite
		Cal	Marble
	Coarse		Metaconglomerate

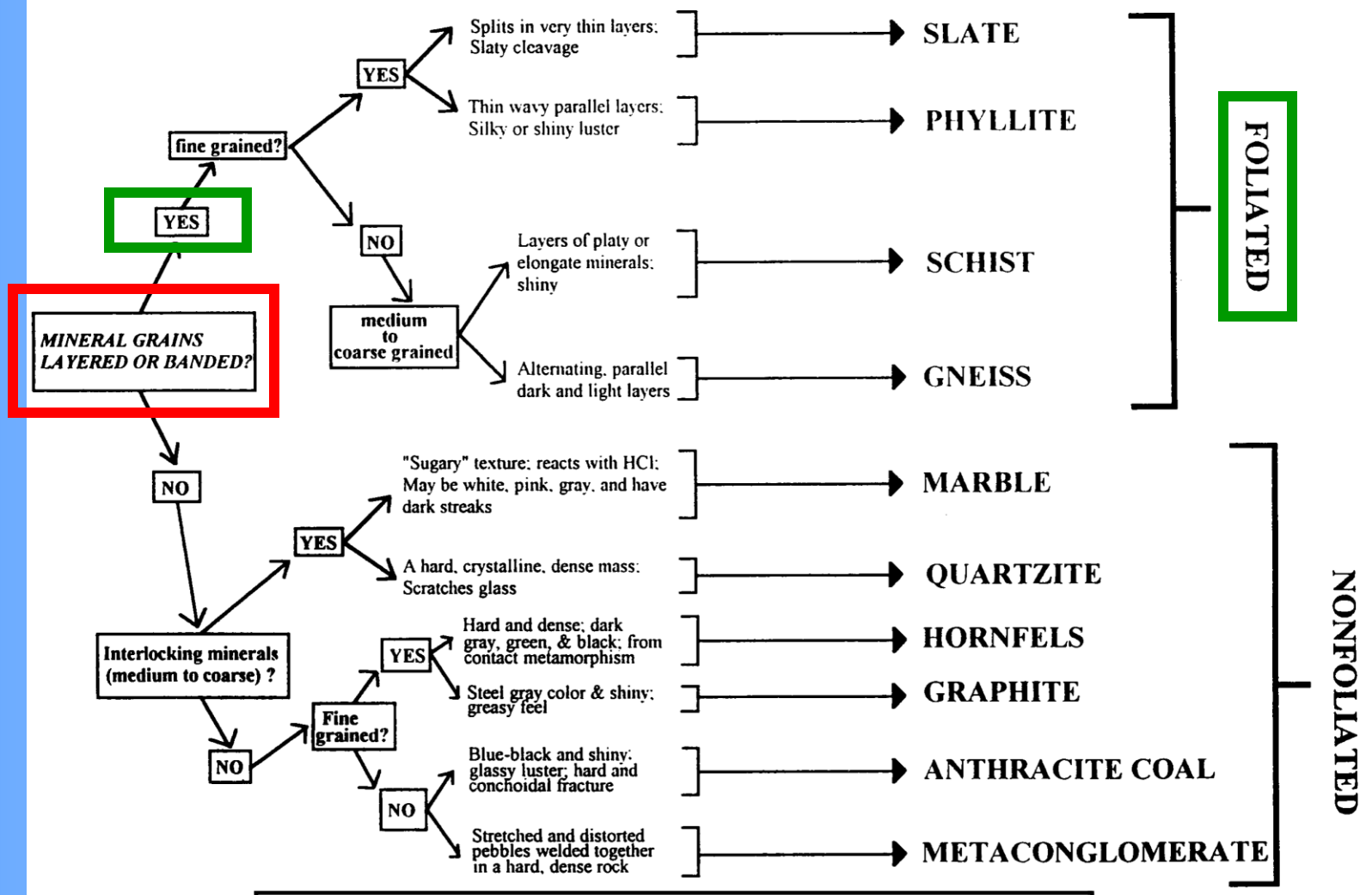
			TYPE OF METAMORPHISM		
	BAND-ING	Medium to coarse	QUA / FELDS / AMPH / GARN / PYROXENE	Regional (Heat and pressure increases)	
NONFOLIATED	Fine	Carbon	Regional	Metamorphism of bituminous coal	**Anthracite coal**
	Fine	Various minerals			**Hornfels**
	Fine to coarse	Quartz			**Quartzite**
		Calcite and/ dolomite			**Marble**
	Coarse	Various minerals			**etaconglomerate**

amorphic Rock Identification

	BANDING	Medium to coarse	F, A, C, PYROX		COMMENTS	ROCK NAME	MAP SYMBOL
NONFOLIATED		Fine	Carbon	Regional			
		Fine	Various minerals	Contact (heat)	magma/lava		
		Fine to coarse	Quartz	Regional or contact	Metamorphism of quartz sandstone	**Quartzite**	
			Calcite and/or dolomite		Metamorphism of limestone or dolostone	**Marble**	
		Coarse	Various minerals		Pebbles may be distorted or stretched	**Metaconglomerate**	

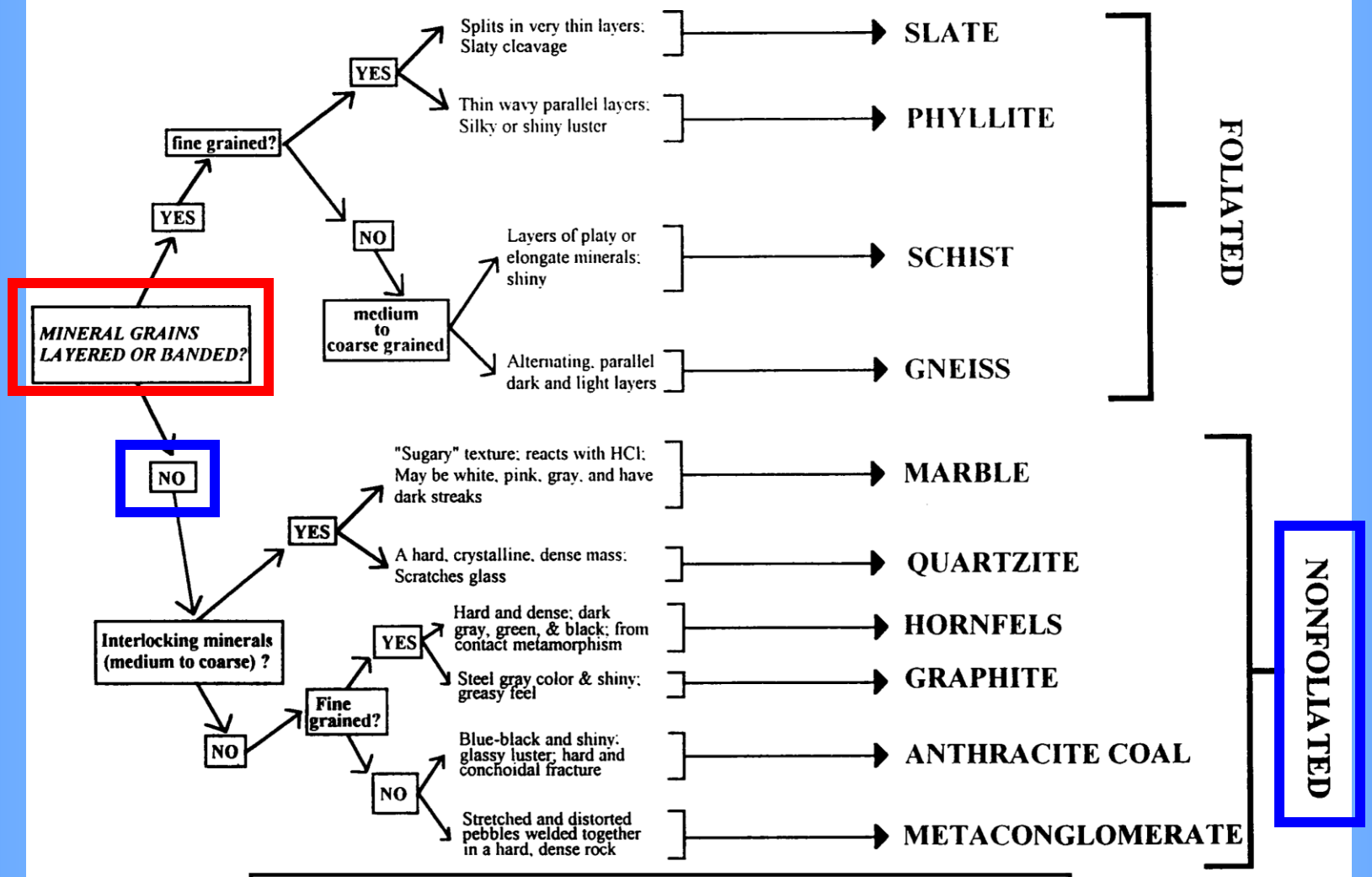
TEXTURE						MAP SYMBOL
FOLIATED	MINERAL ALIGNMENT					
	BAND-ING					
NONFOLIATED	Fine to coarse	Quartz	Regional or contact	Metamorphism of quartz sandstone	**Quartzite**	
		Calcite and/or dolomite		Metamorphism of limestone or dolostone	**Marble**	
	Coarse	Various minerals		Pebbles may be distorted or stretched	**Metaconglomerate**	

METAMORPHIC ROCK IDENTIFICATION



From "Explorations in Earth Science" (Osmun, Vorwald, and Wegner, 2004)

METAMORPHIC ROCK IDENTIFICATION



Metamorphic Identification – A Summary

A. First consider the kind of texture (*nonfoliated* vs. *foliated*)

B. If the rock is foliated:

1. Determine the type of foliation.

2. Add adjectives to describe it's **abundant minerals** (i.e., *Garnet-mica schist* or *hornblende schist*).

C. If the rock is nonfoliated it is named on the basis of its **mineral properties** (i.e., *quartzite* or *marble*)