FUNDAMENTALS OF EARTH SCIENCES (ESO 213A)

DIBAKAR GHOSAL
DEPARTMENT OF EARTH SCIENCES

Metamorphic rocks "Marbles"

Previous Class: Sedimentary rocks

An outline of the portion of the rock cycle that pertains to the formation of sedimentary rocks.

E.J.Tarbuck

Bob Gibbons/Alamy Images

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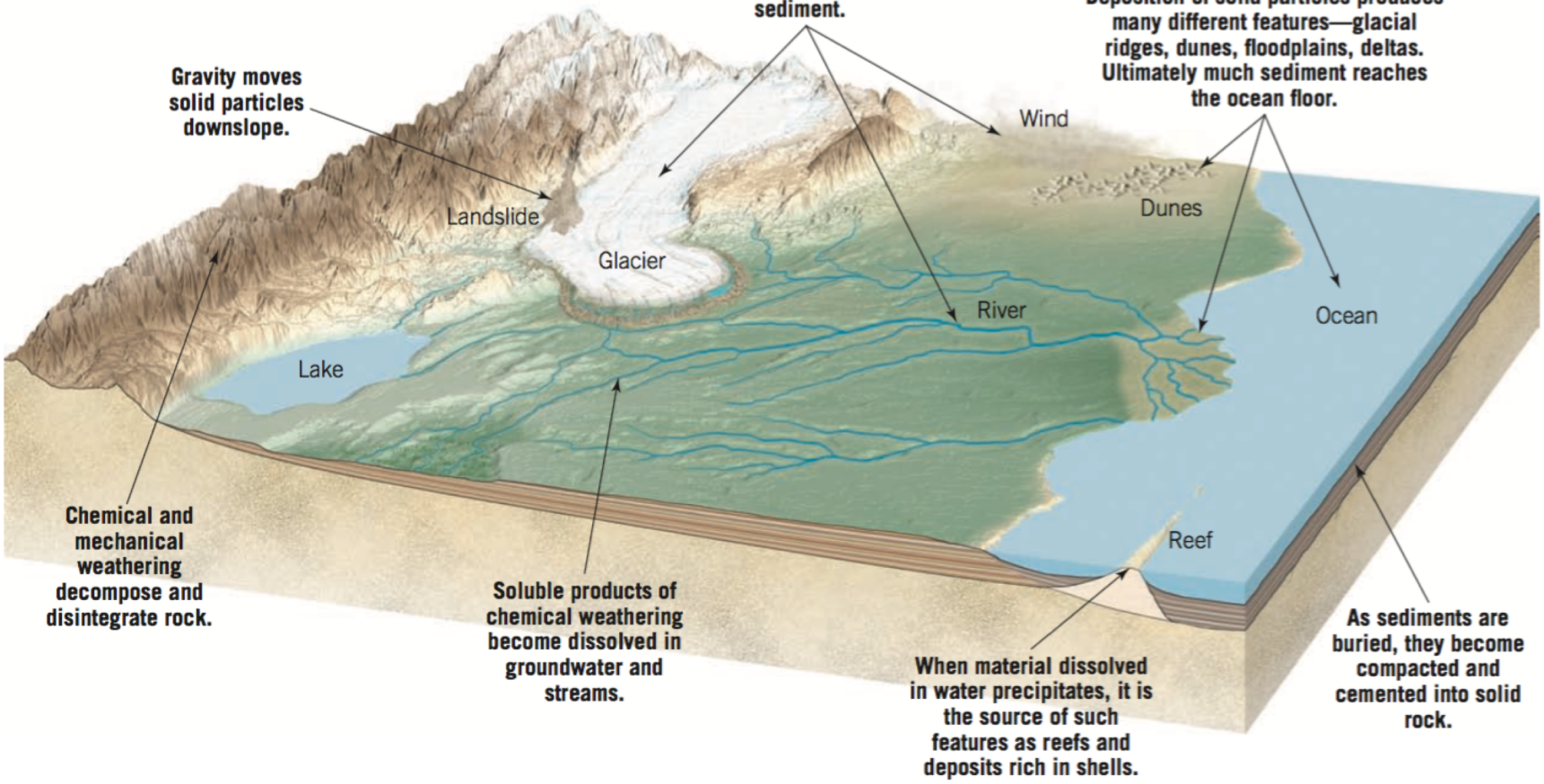
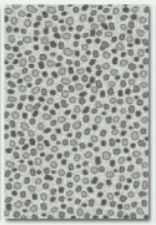
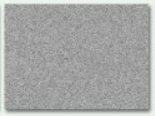


Classification of Sedimentary Rocks

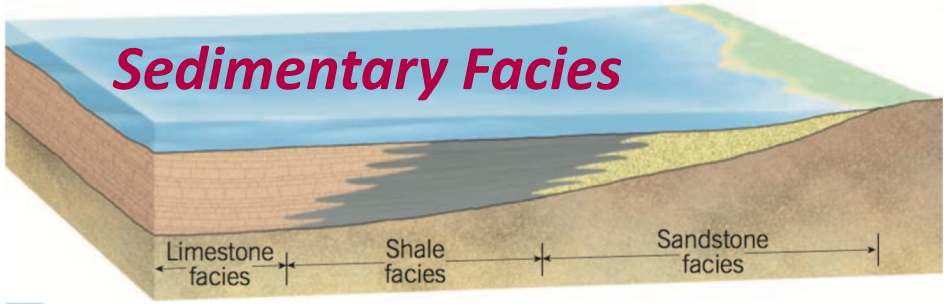
Detrital Sedimentary Rocks

Clastic Texture (particle size)		Sediment Name	Rock Name
Coarse (over 2 mm)		Gravel (Rounded particles)	**Conglomerate**
		Gravel (Angular particles)	**Breccia**
Medium (1/16 to 2 mm)		Sand (If abundant feldspar is present the rock is called **Arkose**)	**Sandstone**
Fine (1/16 to 1/256 mm)		Mud	**Siltstone**
Very fine (less than 1/256 mm)		Mud	**Shale or Mudstone**

Chemical and Organic Sedimentary Rocks

Composition	Texture	Rock Name	
Calcite, $CaCO_3$	Nonclastic: Fine to coarse crystalline	**Crystalline Limestone**	
		Travertine	
	Clastic: Visible shells and shell fragments loosely cemented	**Coquina**	**Biochemical Limestone**
	Clastic: Various size shells and shell fragments cemented with calcite cement	**Fossiliferous Limestone**	
	Clastic: Microscopic shells and clay	**Chalk**	
Quartz, SiO_2	Nonclastic: Very fine crystalline	**Chert (light colored) Flint (dark colored)**	
Gypsum $CaSO_4 \cdot 2H_2O$	Nonclastic: Fine to coarse crystalline	**Rock Gypsum**	
Halite, NaCl	Nonclastic: Fine to coarse crystalline	**Rock Salt**	
Altered plant fragments	Nonclastic: Fine-grained organic matter	**Bituminous Coal**	

Sedimentary Facies



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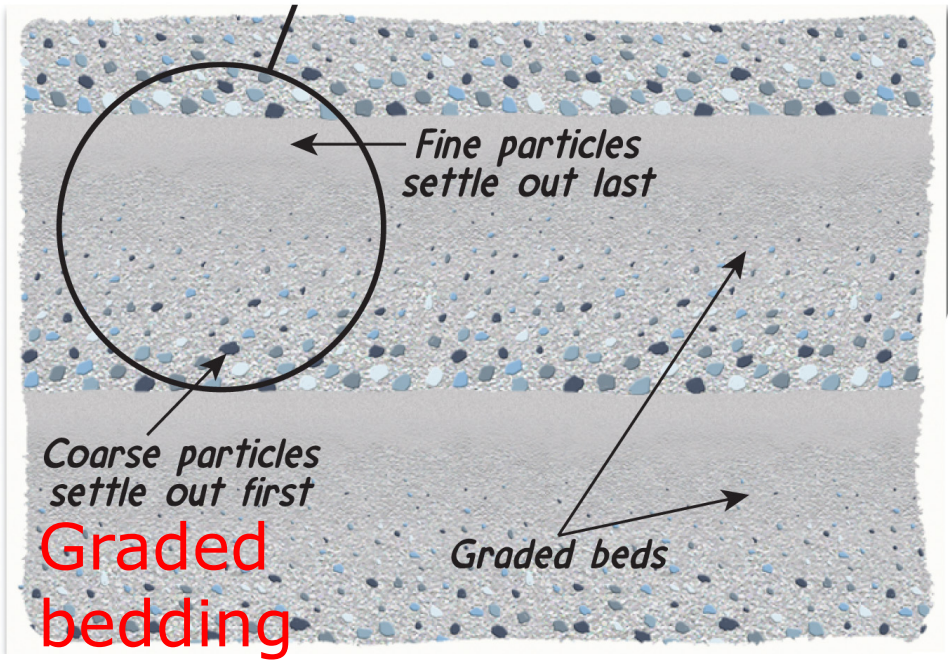


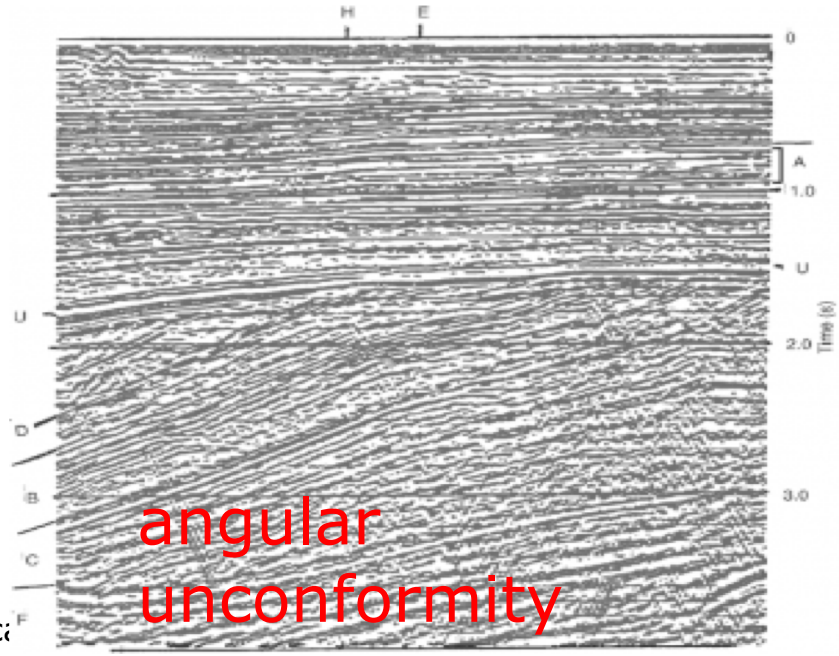
Graded bedding

Ripple marks

A.

Cross bedding

B.



angular unconformity

son Educa

Taj Mahal Constructed primarily of marble.

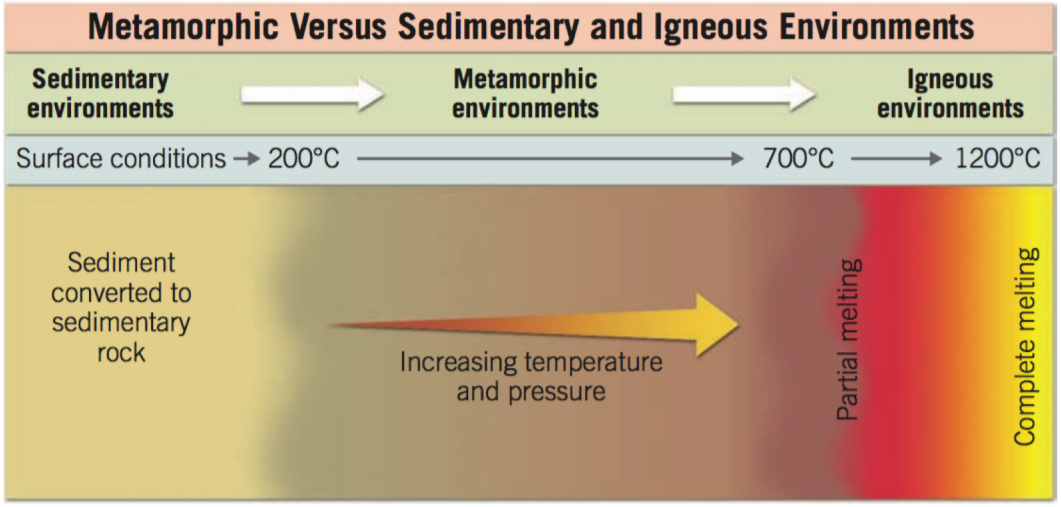
Metamorphic rocks

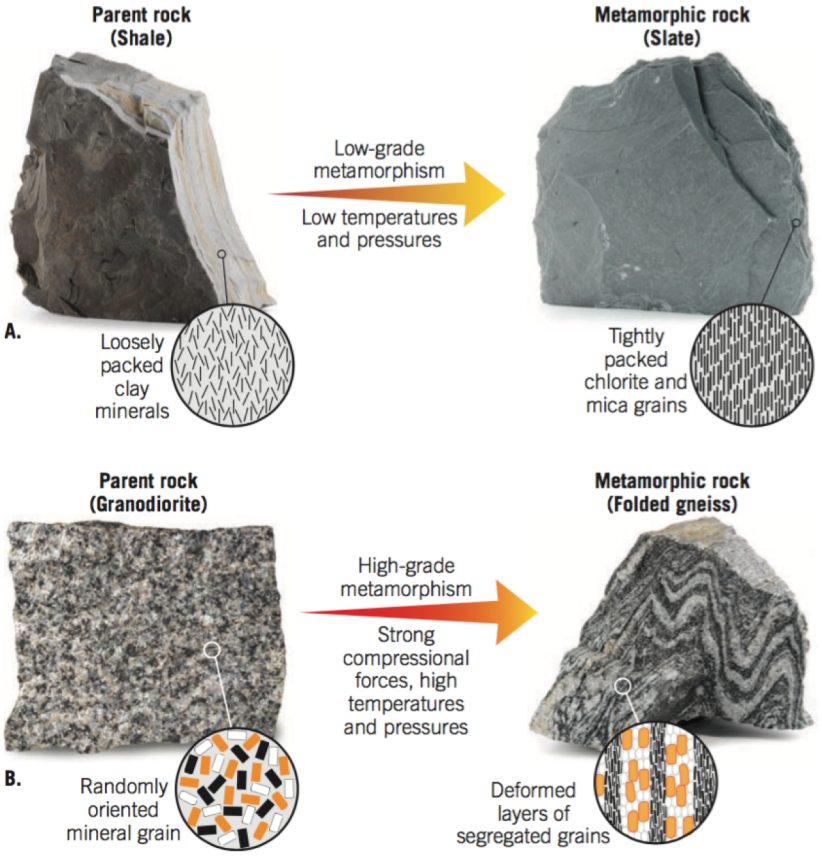
Metamorphism

Metamorphism is the transformation of one rock type into another rock type.

Metamorphic rocks are produced from pre-existing sedimentary and igneous rocks, as well as from other metamorphic rocks.

- **Metamorphism progresses occurs incremental from low grade to high grade.**
- **During metamorphism, the rock must remain essentially solid.**

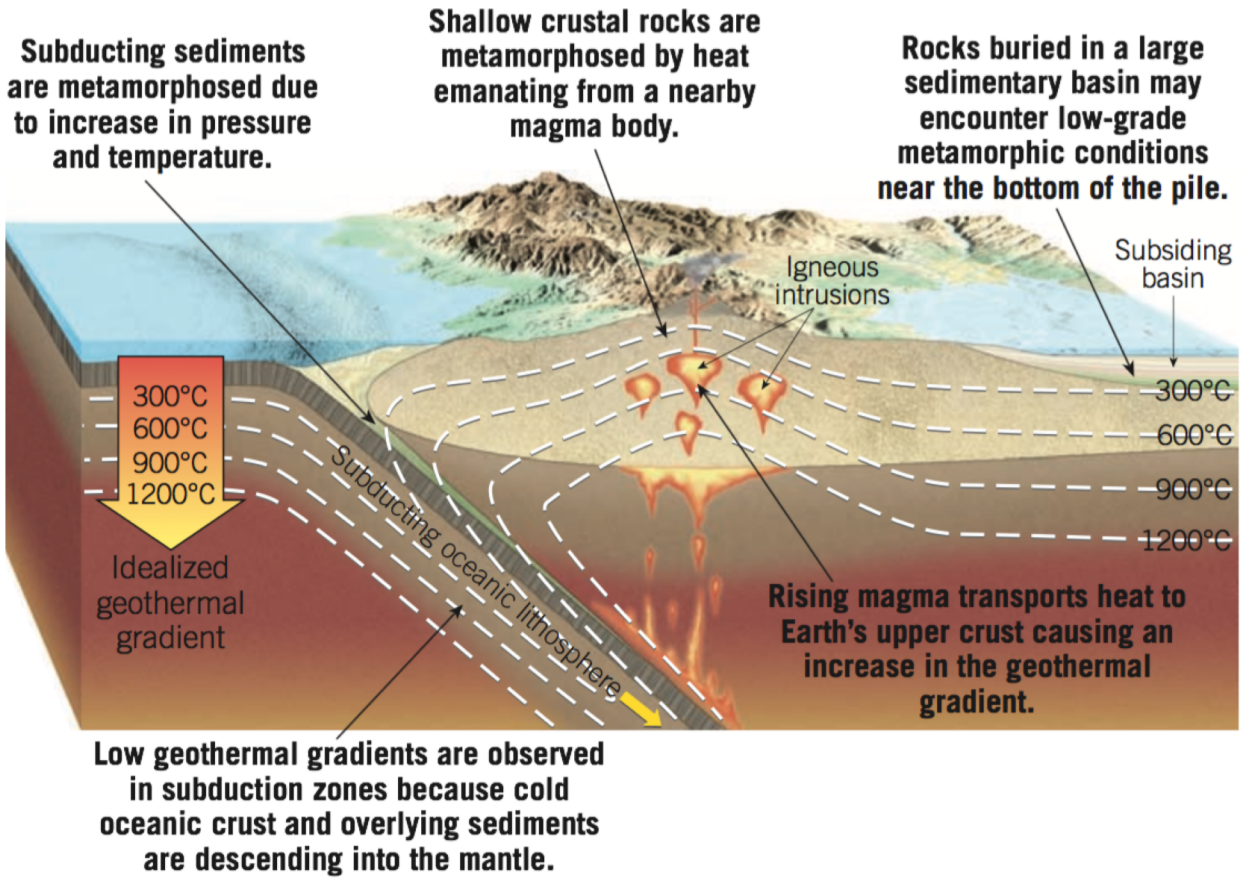




Agents of Metamorphism

I. Heat

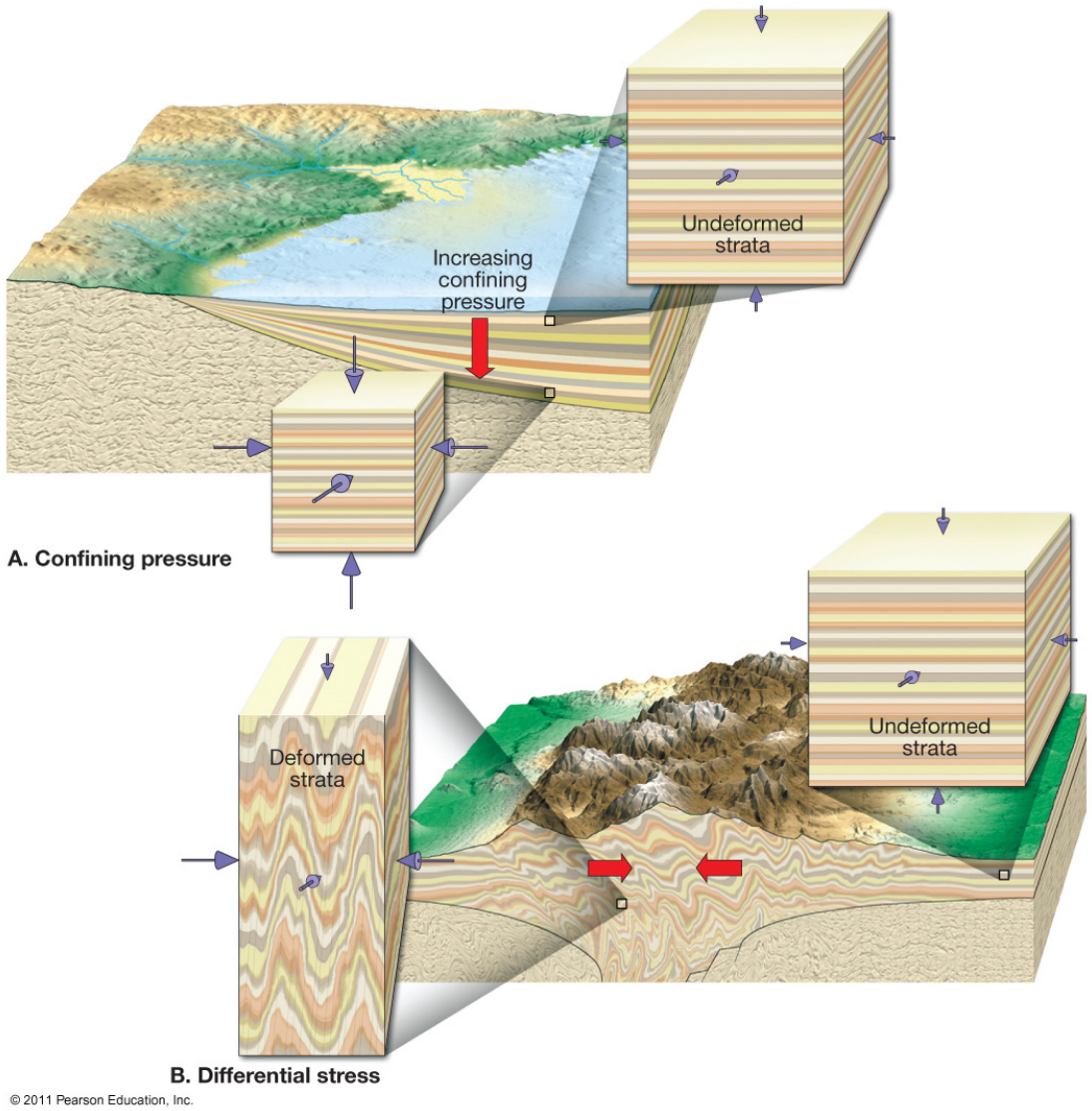
- **Most important agent**
- **Recrystallization results in new, stable minerals.**
- **Two sources of heat:**
  1. **Contact metamorphism—heat from magma**
  2. **An increase in temperature with depth—geothermal gradient**



Agents of Metamorphism

II. Confining Pressure and differential stress

- **Increases with depth**
- **Confining pressure applies forces equally in all directions (does not fold and deform rocks)**
- **Rocks may also be subjected to differential stress, which is unequal in different directions (folds and flattens rocks)**



Question

This metamorphic rock outcrop located in Purgatory Chasm in Newport, Rhode Island, is made of cobbles that are composed mainly of quartz.

Question 1 What name would you give to this metamorphic rock?

Question 2 Which set of arrows (red or black) best represents the direction of maximum directional stress?

Agents of Metamorphism

III. Chemically active fluids

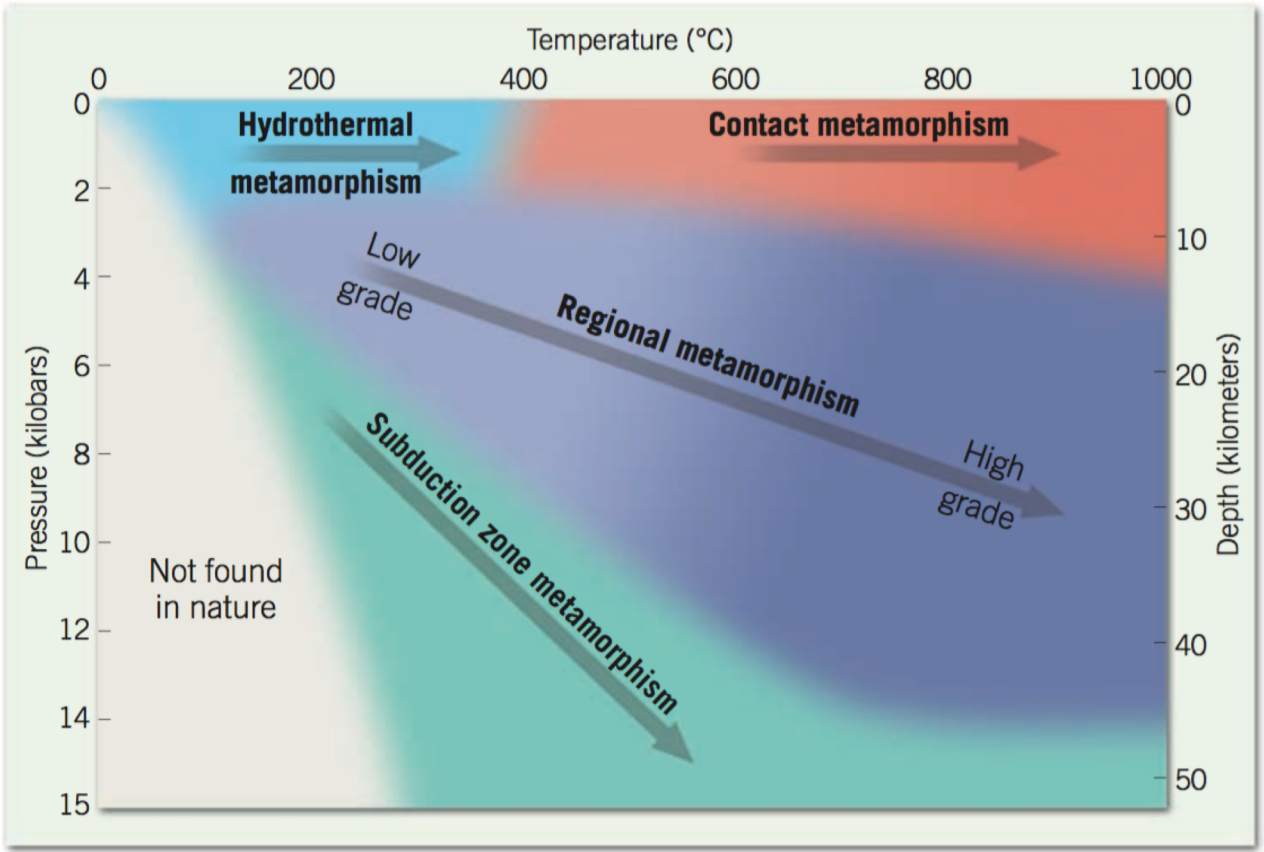
- **Mainly water**
- **Enhances migration of ions**
- **Aids in recrystallization of existing minerals**
- **Sources of fluids**
  - **Pore spaces of sedimentary rocks**
  - **Fractures in igneous rocks**
  - **Hydrated minerals such as clays, micas, amphiboles**

<u>Metasomatism Example</u>

$CaCO_3$ (Calcite) + SiO_2 = $CaSiO_3$ (Wollastonite) + CO_2

Metamorphic settings

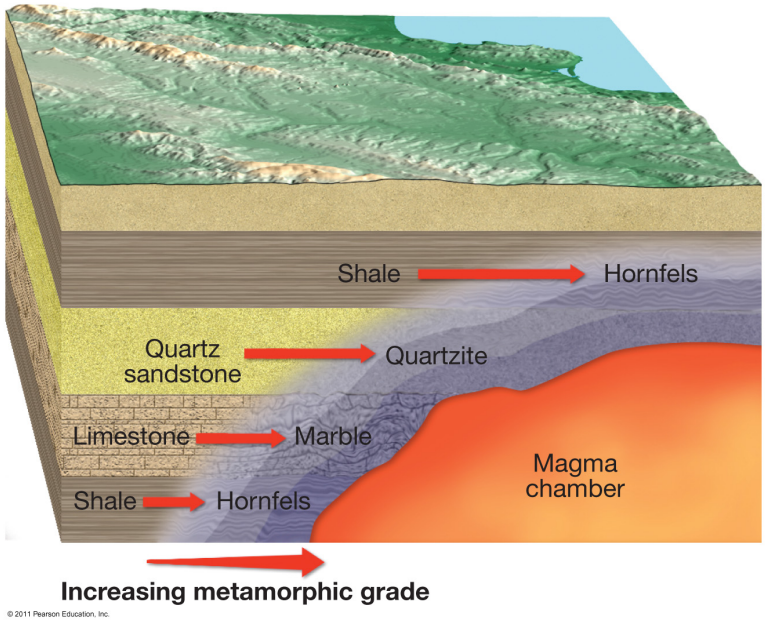
- **Contact or thermal metamorphism—driven by a rise in temperature within the host rock**
- **Hydrothermal metamorphism—chemical alterations from hot, ion-rich water**
- **Regional metamorphism**
  - **Occurs during mountain building**
  - **Produces the greatest volume of metamorphic rock**
  - **Rocks usually display zones of contact and/or hydrothermal metamorphism.**

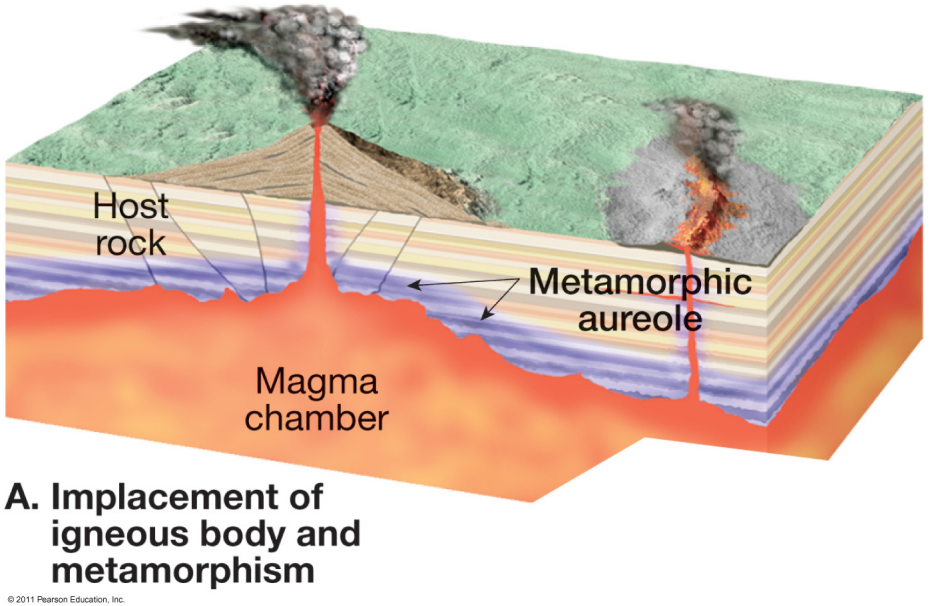


Metamorphic Environments

I. Contact or thermal metamorphism (High T and low P)

- Result from a rise in temperature when magma invades a host rock
- The zone of alteration (aureole) forms in the rock surrounding the magma.
- Most easily recognized when it occurs at or near Earth's surface.

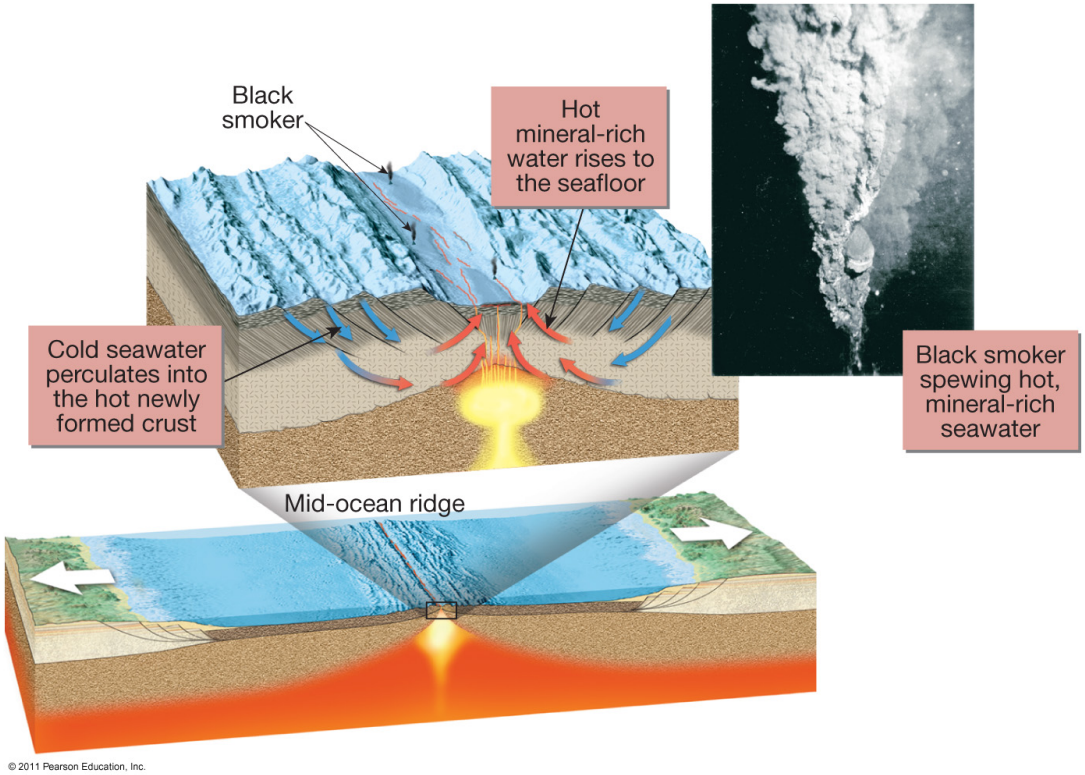




Metamorphic Environments

II. Hydrothermal metamorphism

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

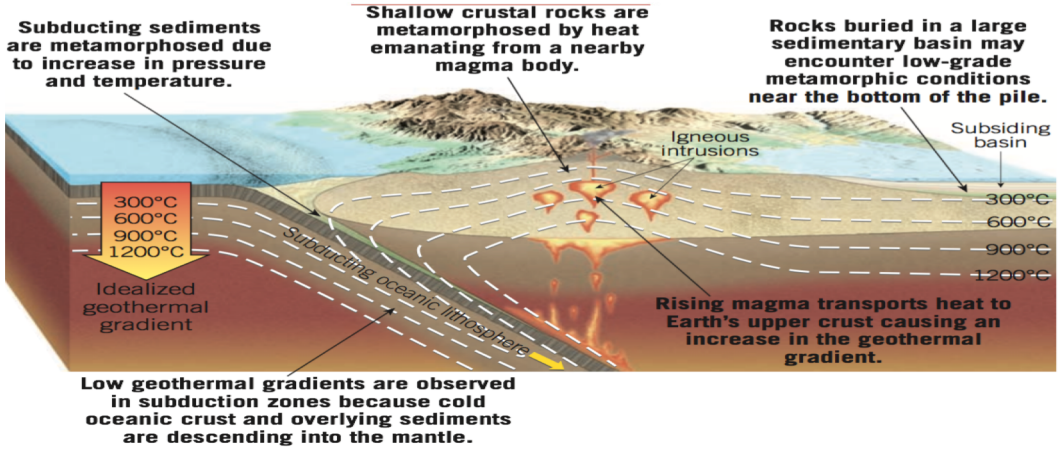


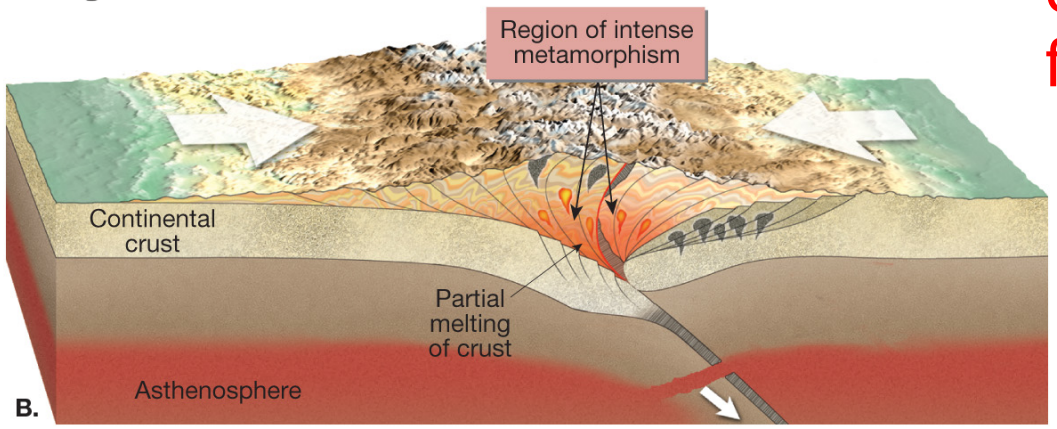
Hydrothermal solutions circulating through the seafloor remove large amounts of metals (Fe, Co, Ni, Ag, Au, Cu) from the newly formed crust.

Metamorphic Environments

III. Regional metamorphism (Low P,T→High P,T over large area)

- Produces the greatest quantity of metamorphic rock
- Associated with mountain building, burial and migrating fluid
- Deep in the roots of mountains, high temperatures cause the most intense metamorphic activity within a mountain belt





Mostly contain foliation

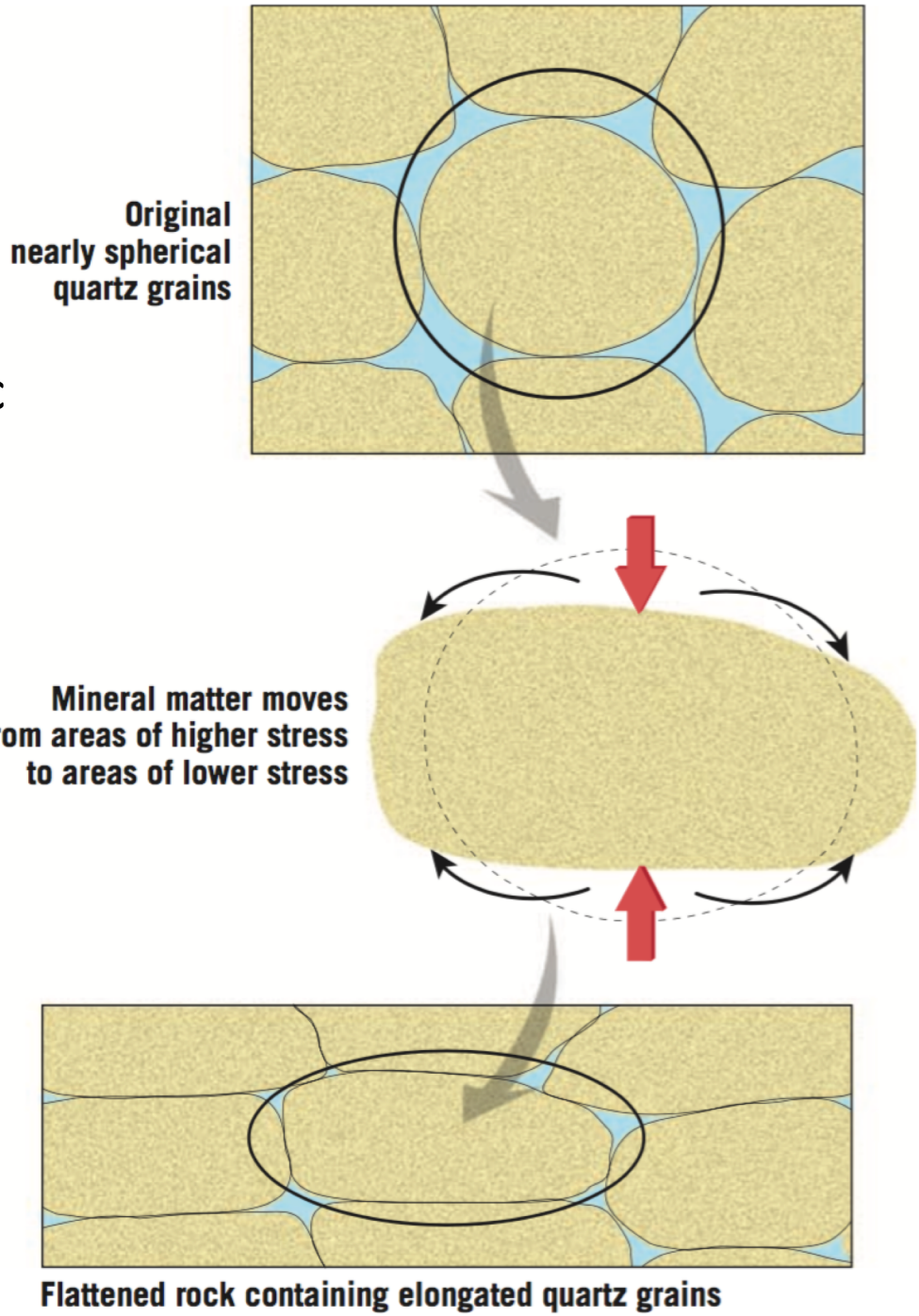
Processes for metamorphism

1. Recrystallization:
1 or more mineral breakdown to Form a new mineral

2. Solid-state flow: Slippage disrupting crystal lattice and atomic bonds

3. Pressure solution: The pressure causes the crystal contacts to dissolve and to precipitate else where in the rock mostly at low stressed zone.

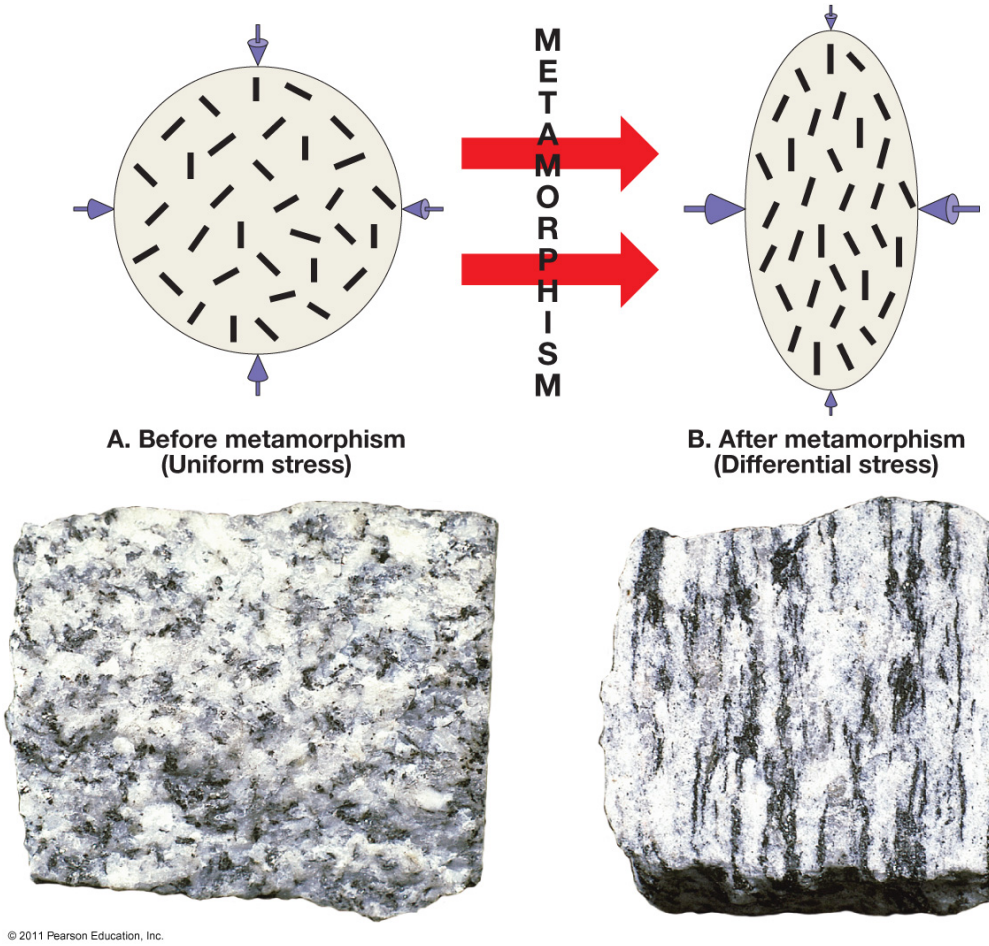
4. Remobilization: High P and T can cause certain minerals to breakdown allowing them to diffuse, dissolve and partially melt. The mineral then reprecipitate to low stressed zone.



Metamorphic Textures

Foliation (planner arrangement of minerals in a rock)

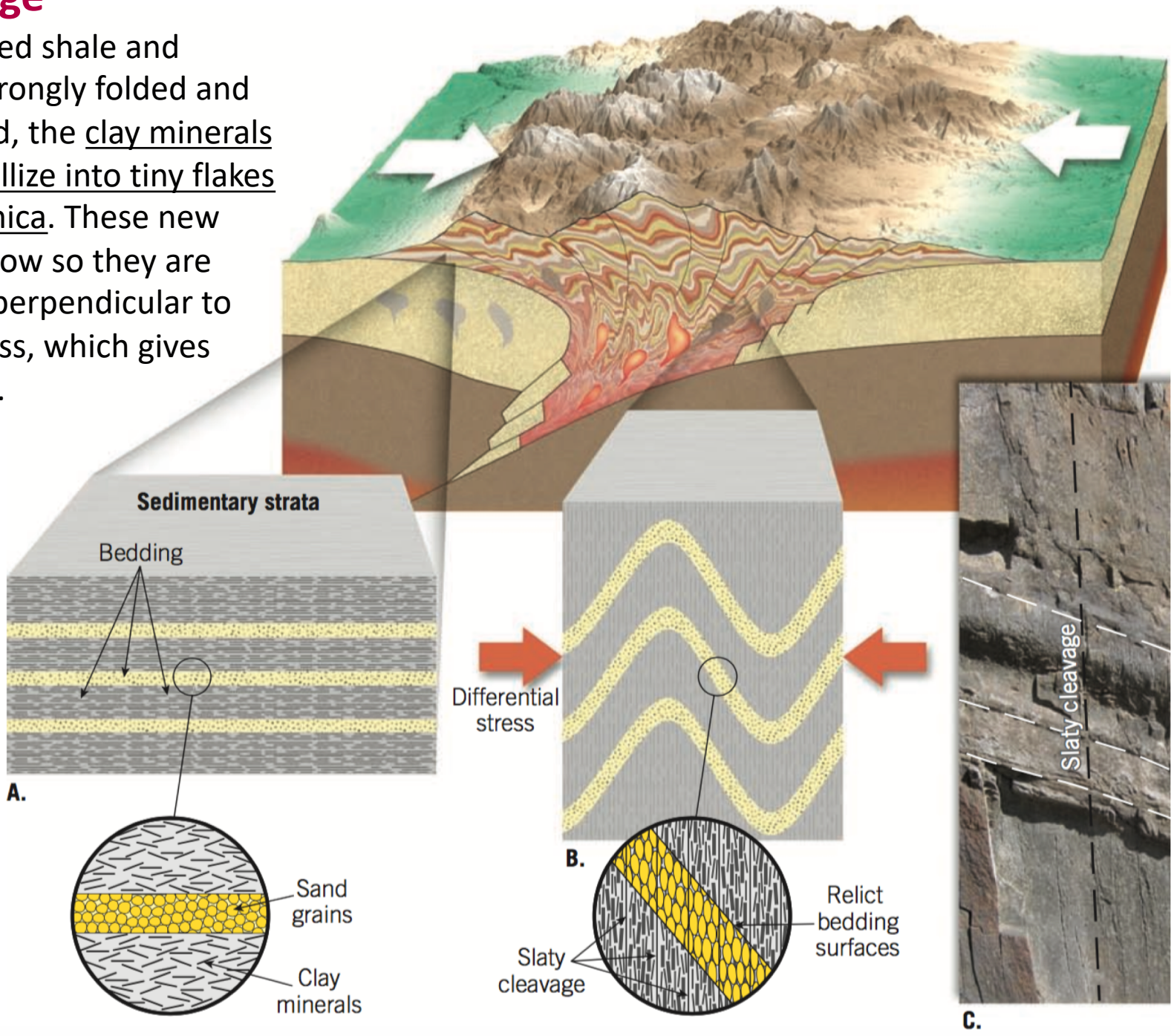
- **Examples of foliations**
  - **Parallel alignment of flattened / platy mineral grains and pebbles**
  - **Parallel alignment of elongated minerals**
  - **Compositional banding (separation of light and dark minerals causes a layered appearance)**
  - **Slaty cleavage where rocks can be easily split into thin, tabular sheets**



Foliation Resulting from Directed Stress

Slaty Cleavage

When interbedded shale and sandstone are strongly folded and meta-morphosed, the clay minerals begin to recrystallize into tiny flakes of chlorite and mica. These new platy minerals grow so they are aligned roughly perpendicular to the directed stress, which gives slate its foliation.



Metamorphic Textures

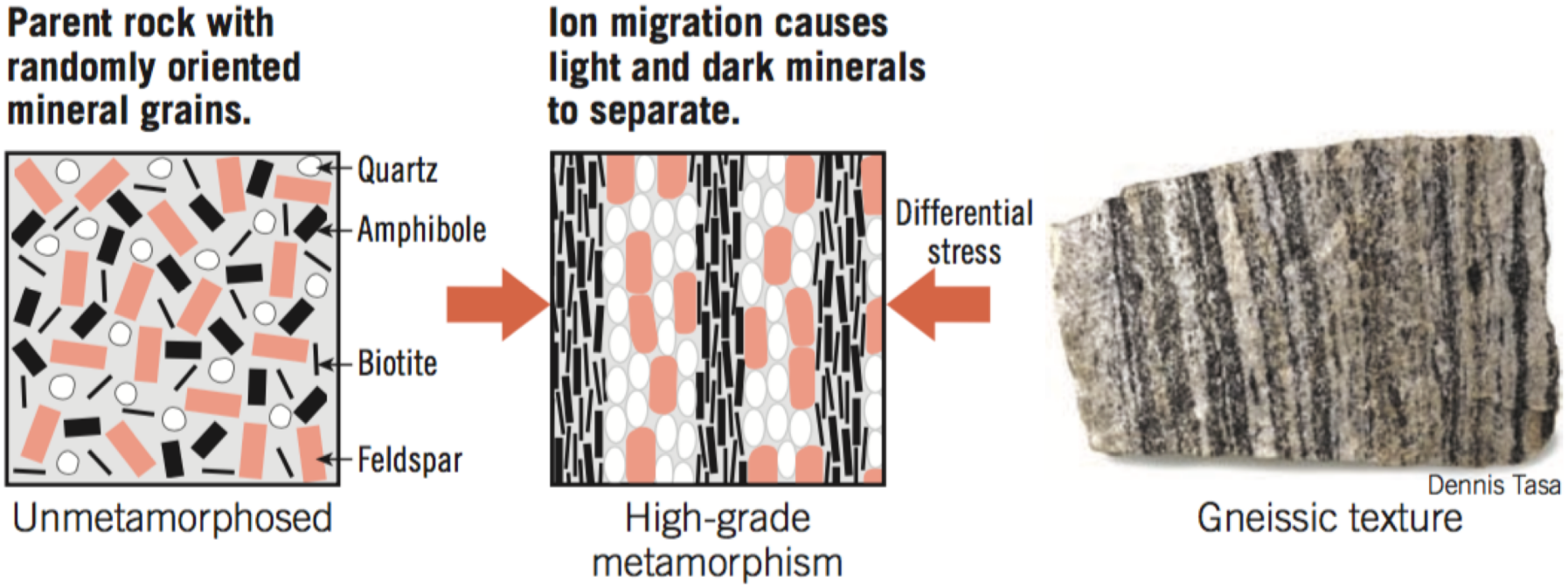
I. Foliated textures

- **Schistosity**
  - Platy minerals are visible with the unaided eye (medium- to high-grade metamorphism)
  - Mainly micas (muscovite, biotite)
  - Exhibit a planar or layered structure
  - Rocks having this texture are referred to as *SCHIST*

Metamorphic Textures

I. Foliated textures

- **Gneissic**
  - During higher grades of metamorphism, ion migration results in the segregation of minerals (dark biotite vs. light silicates).
  - Gneissic rocks exhibit a distinctive banded appearance.
  - Typical in case of *GNEISS*



Metamorphic Textures

Other metamorphic textures

- **II. Those metamorphic rocks that lack foliation are referred to as *nonfoliated (granoblastic)***
  - **Develop in environments where deformation is minimal**
  - **Typically composed of minerals that exhibit equidimensional crystals (e.g., quartz - *QUARTZITE*)**

Question

This metamorphic rock outcrop is found in the Southern Alps, located on the South Island of New Zealand. The continued growth of the Southern Alps is somewhat unique in that these mountains lie where the Pacific and Australian plates collide and simultaneously slide past one anther along a large transform fault called the Alpine Fault.

Question 1 Do the rocks in this outcrop display foliation?.

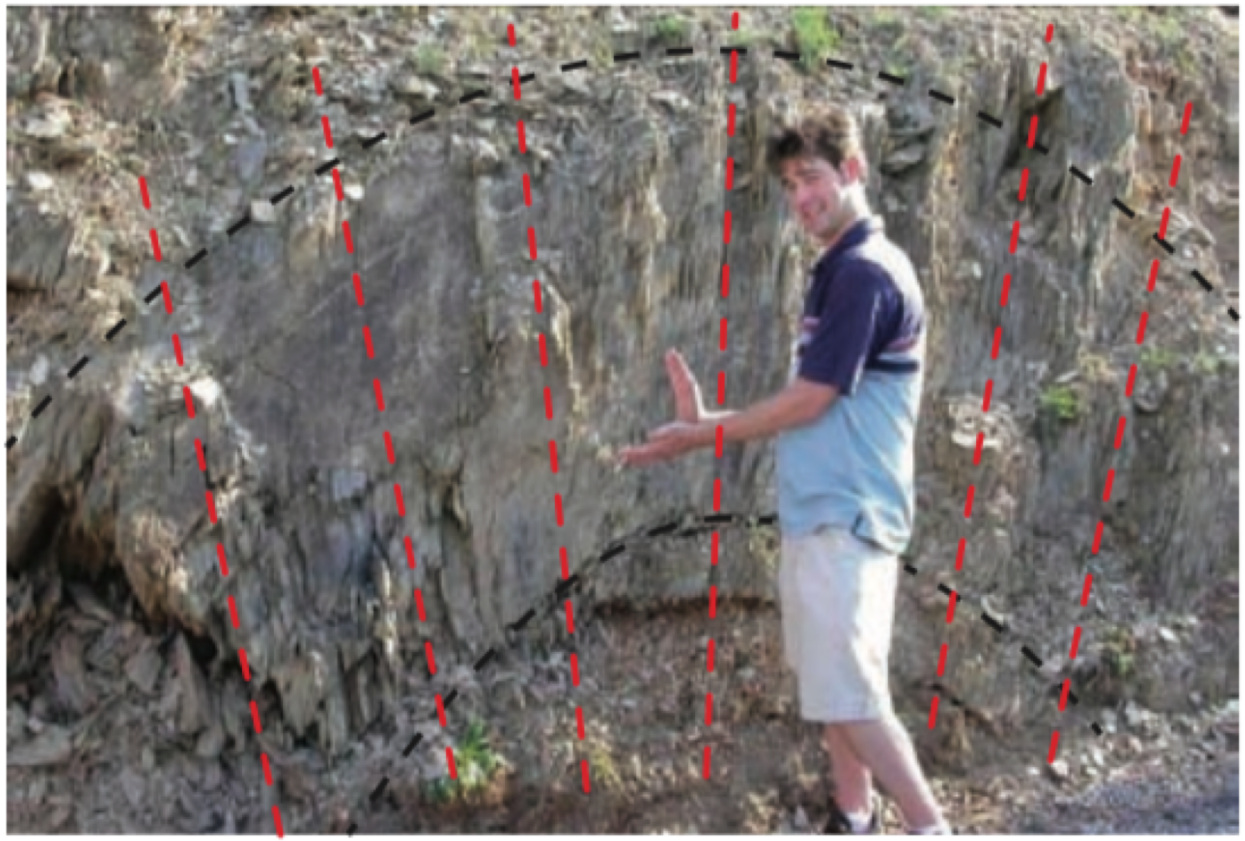
Question 2 Do these rocks appear to have experienced high-grade or low-grade metamorphism?

Question

The accompanying image shows folded and metamorphosed rock that displays slaty cleavage.

a. Which colored dashed lines (red or black) represent the slaty cleavage, and which represent relic bedding surfaces?

b. Was the maximum directional stress oriented horizontally or vertically?

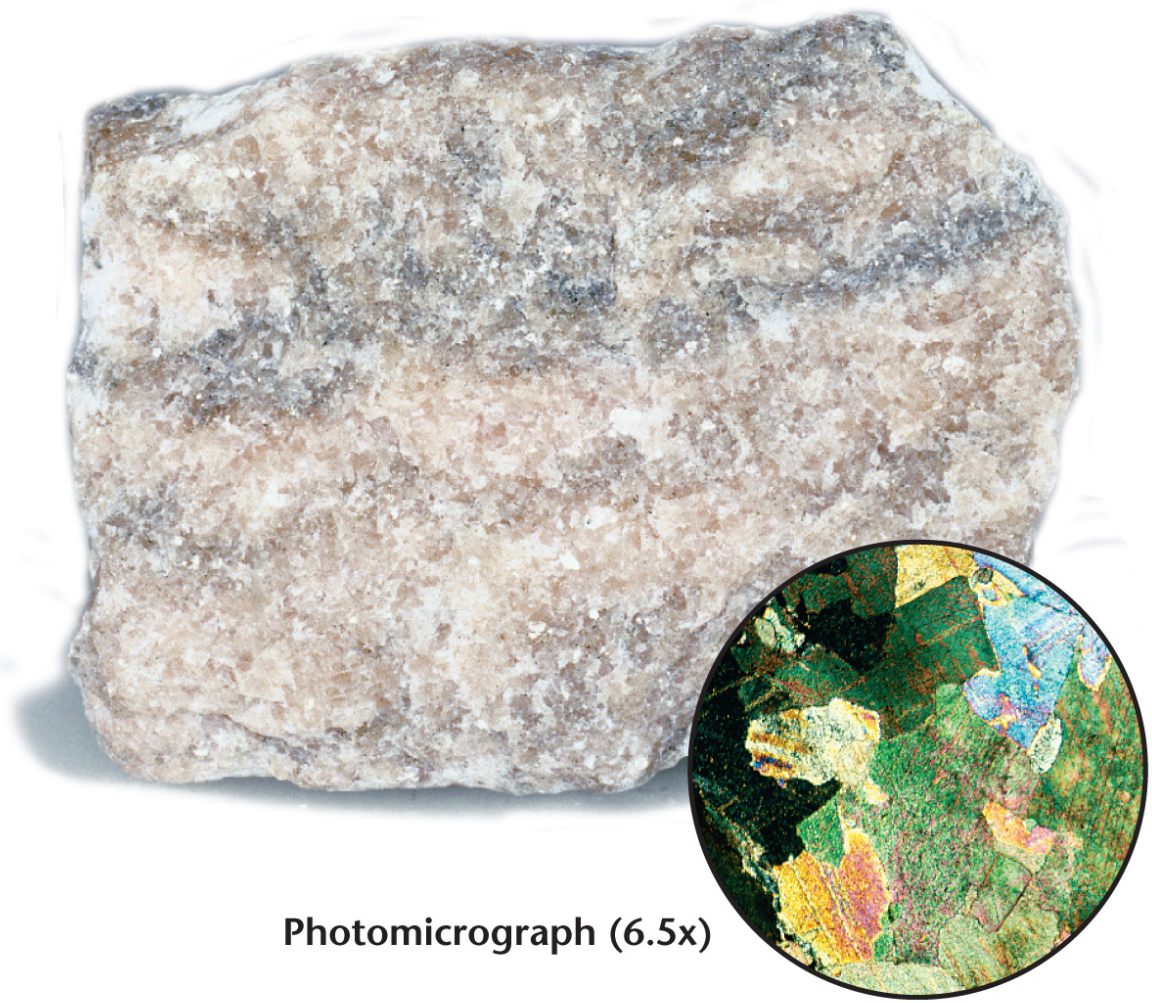


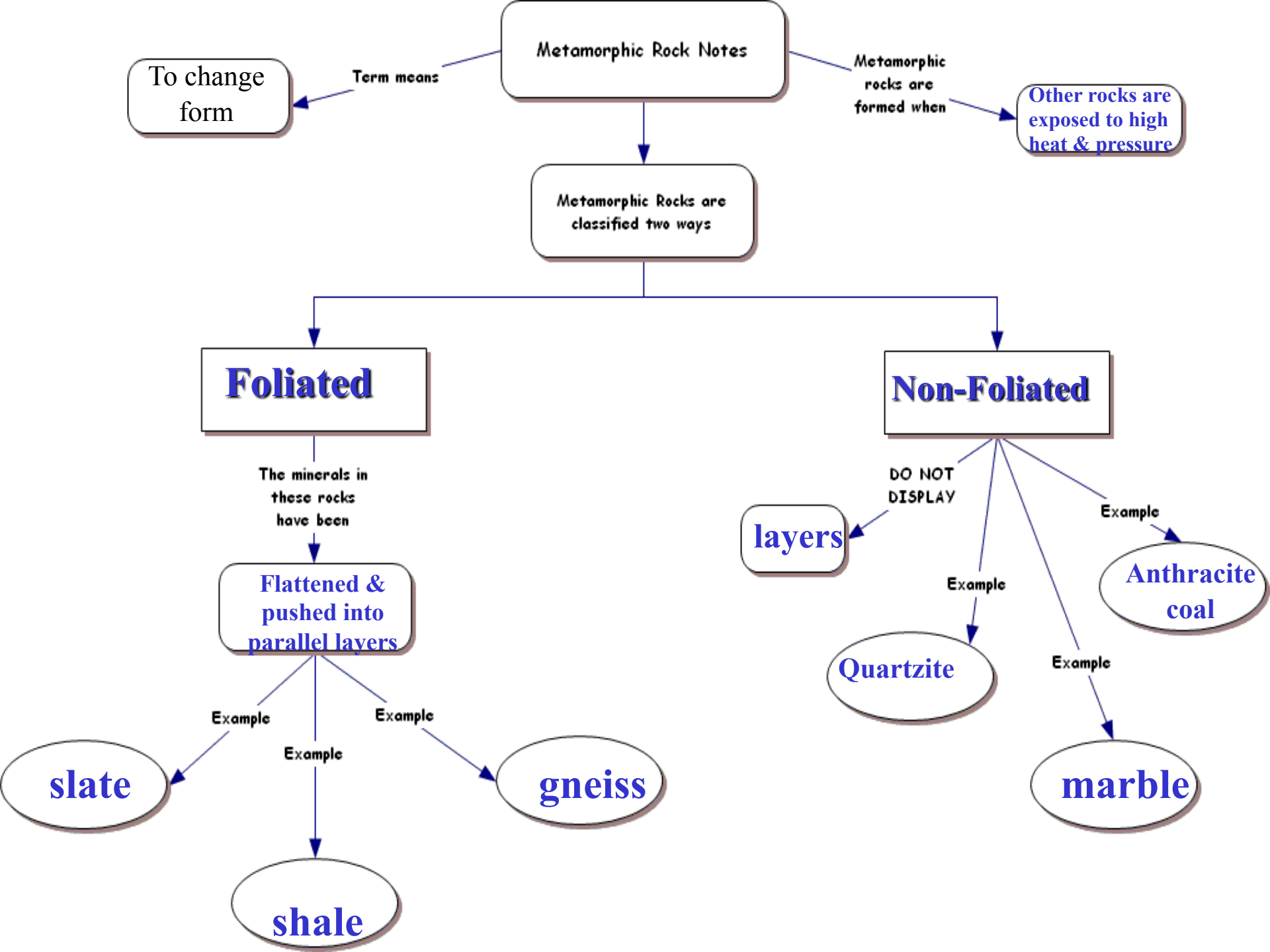
Callan Bentley

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




Metamorphic Rock Notes
Term means
To change form
Metamorphic rocks are formed when
Other rocks are exposed to high heat & pressure
Metamorphic Rocks are classified two ways
Foliated
Non-Foliated
The minerals in these rocks have been
Flattened & pushed into parallel layers
DO NOT DISPLAY
layers
Example
Anthracite coal
Example
Quartzite
Example
marble
Example
slate
Example
shale
Example
gneiss

Classifying Metamorphic Rocks

Rock Name	Texture	Grain Size	Comments	Original Parent Rock
Slate	Foliated	Very fine	Excellent rock cleavage, smooth dull surfaces	Shale, mudstone, or siltstone
Phyllite	Foliated	Fine	Breaks along wavy surfaces, glossy sheen	Shale, mudstone, or siltstone
Schist	Foliated	Medium to Coarse	Micaceous minerals dominate, scaly foliation	Shale, mudstone, or siltstone
Gneiss	Foliated	Medium to Coarse	Compositional banding due to segregation of minerals	Shale, granite, or volcanic rocks
Migmatite	Foliated	Medium to Coarse	Banded rock with zones of light-colored crystalline minerals	Shale, granite, or volcanic rocks
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

Increasing Metamorphism

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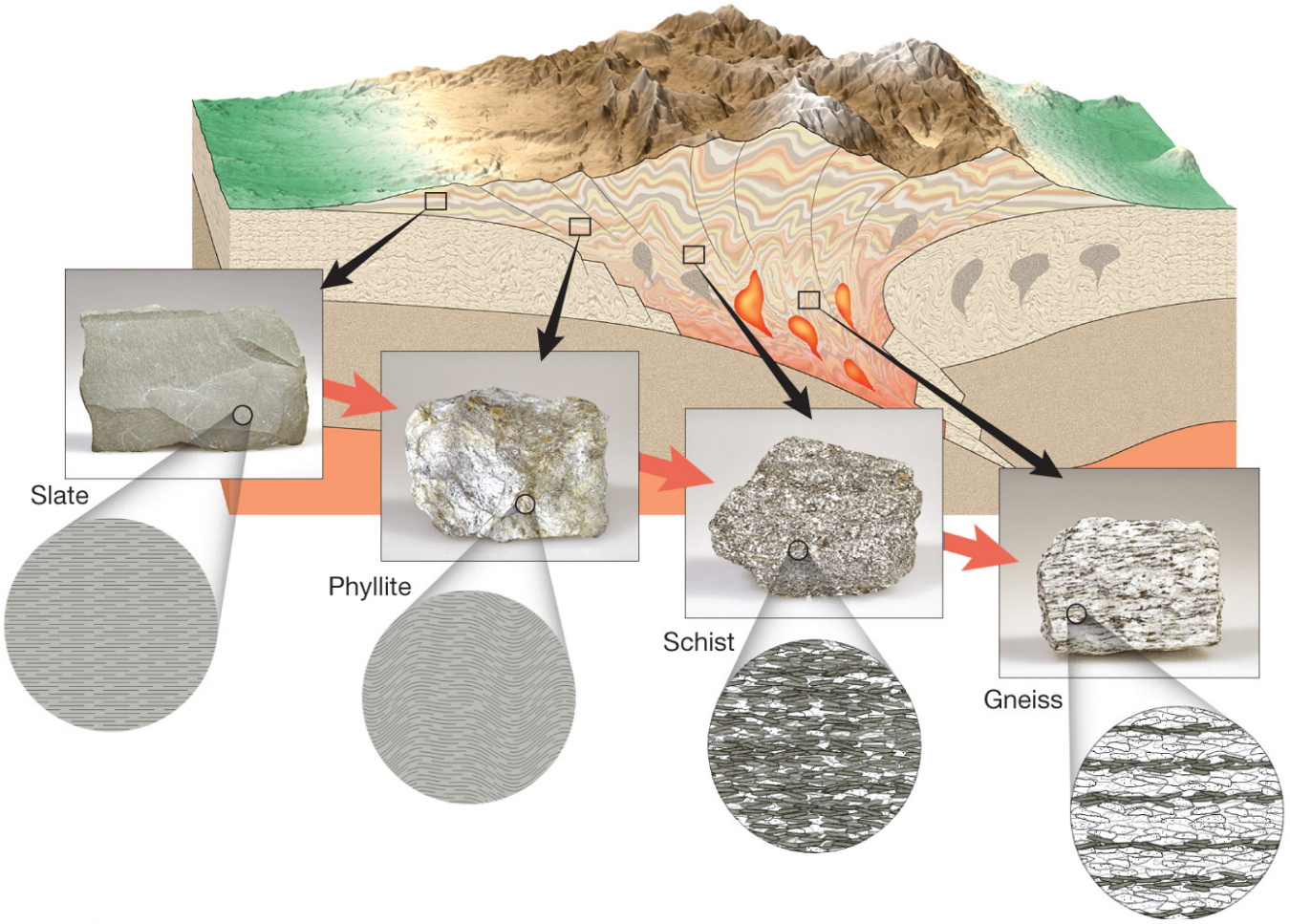
Metamorphic Zones

- Systematic variations in the mineralogy and textures of metamorphic rocks are related to the variations in the degree of metamorphism.

Starting rock:

SHALE



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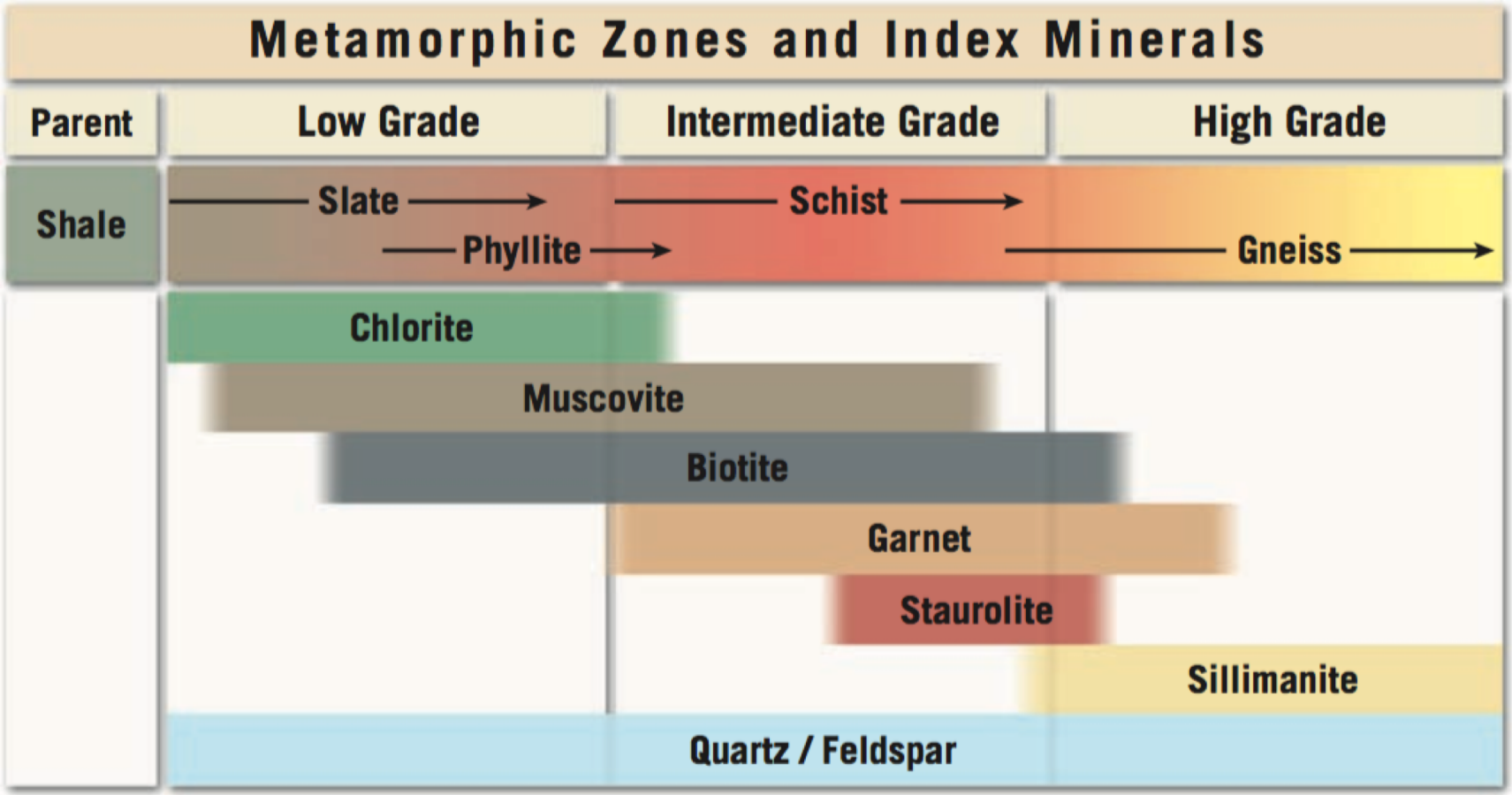
Metamorphic Zones

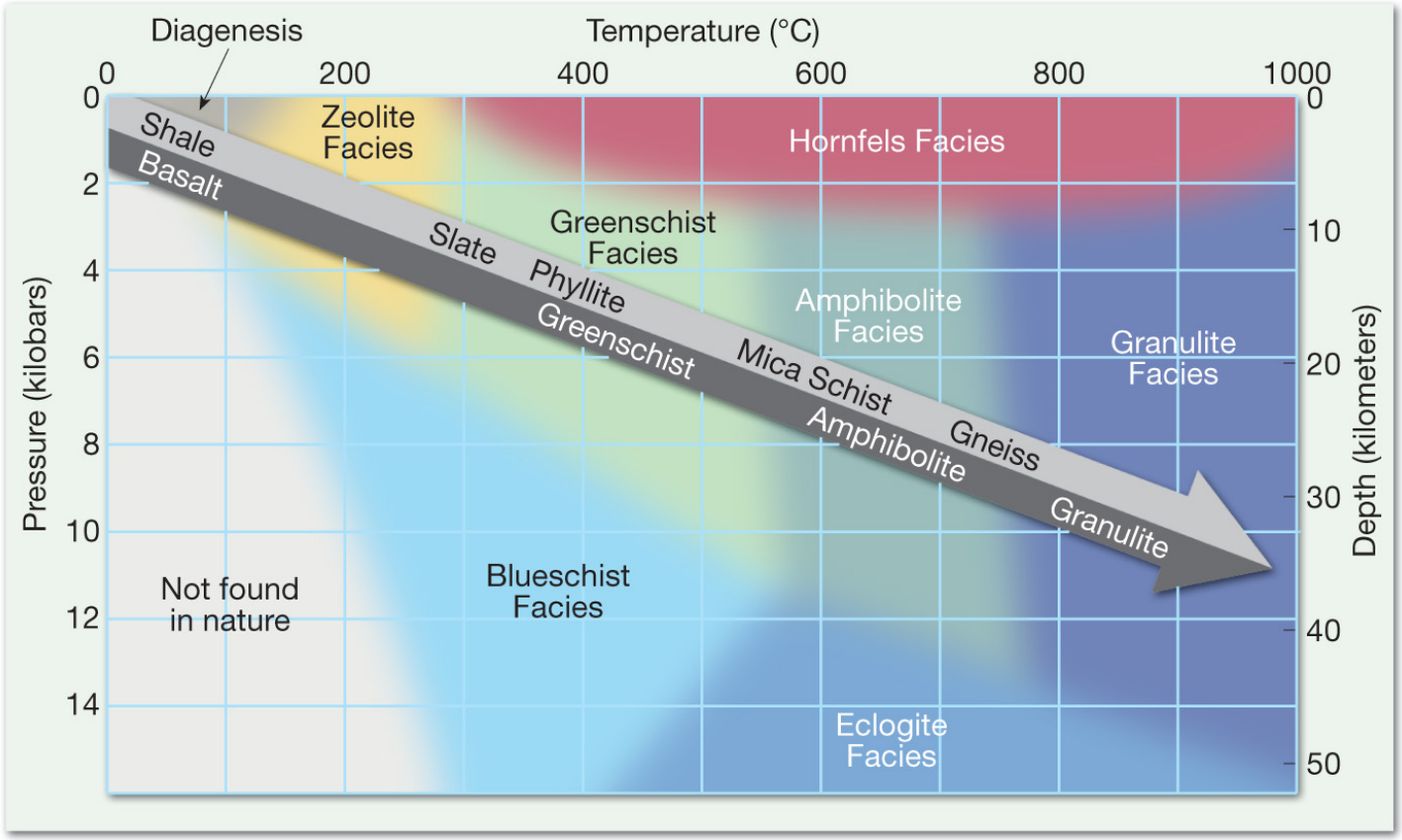
Index minerals and metamorphic grade

- **Changes in mineralogy occur from regions of low-grade metamorphism to regions of high-grade metamorphism.**

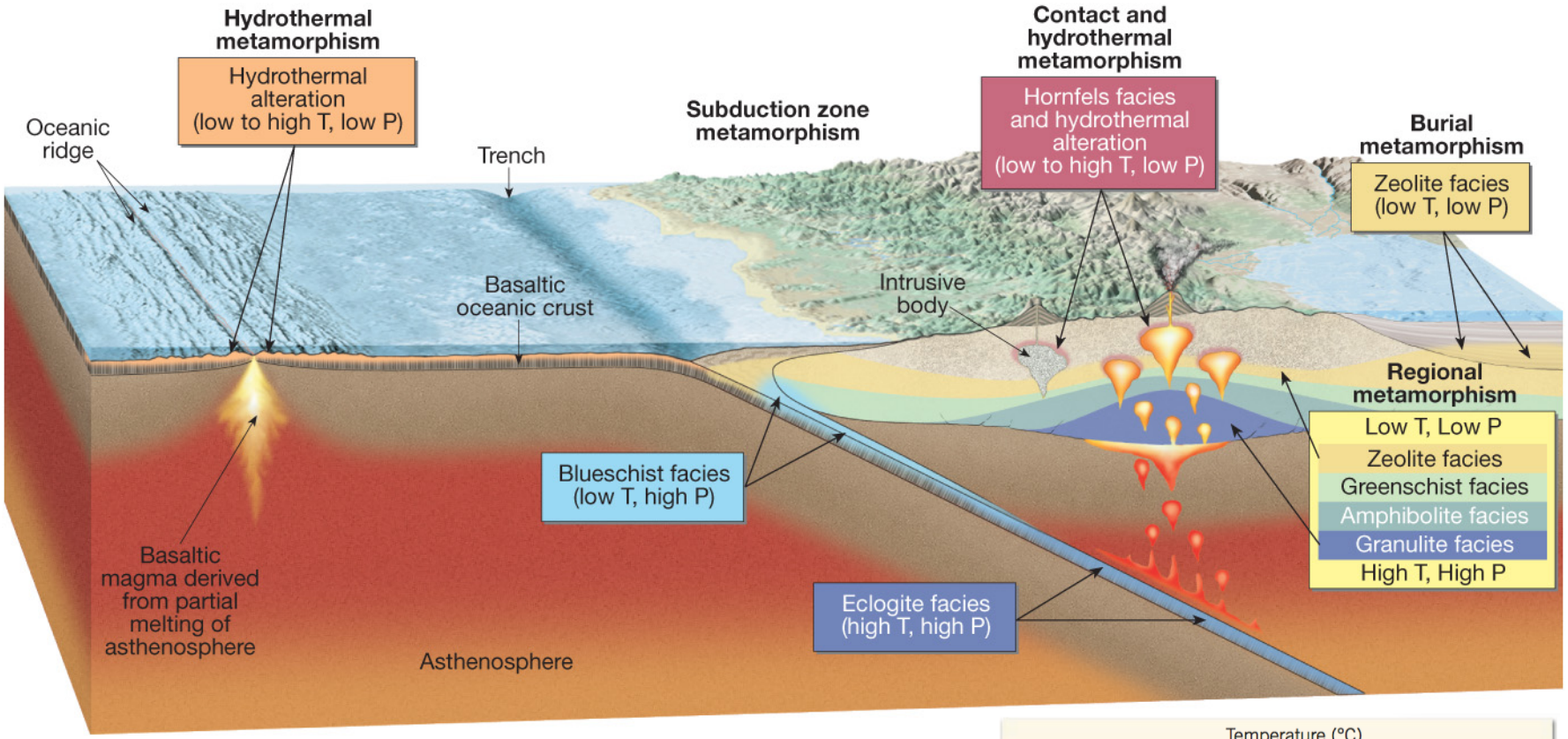


Metamorphic Facies

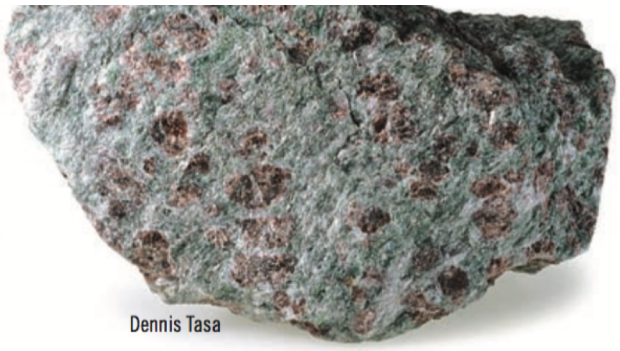
- Metamorphic rocks that contain the same assemblage of minerals
- Formed in very similar metamorphic environment
- Name based on minerals that define them



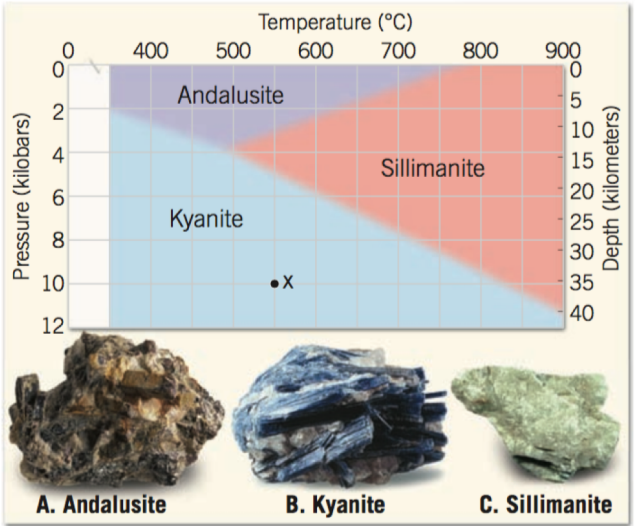
Metamorphic Facies and Plate Tectonics



A. Blueschist forms in low-temperature, high-pressure environments



B. Eclogite forms in high-temperature and extreme high-pressure environments



Question

Examine the accompanying close-up images of six different rocks labeled A–F.

Q1: Classify them as igneous, sedimentary, or metamorphic, based on texture.
(*Hint:* There are two of each rock type.)

Q2: Which figure show distinct foliation and high grade of metamorphism?