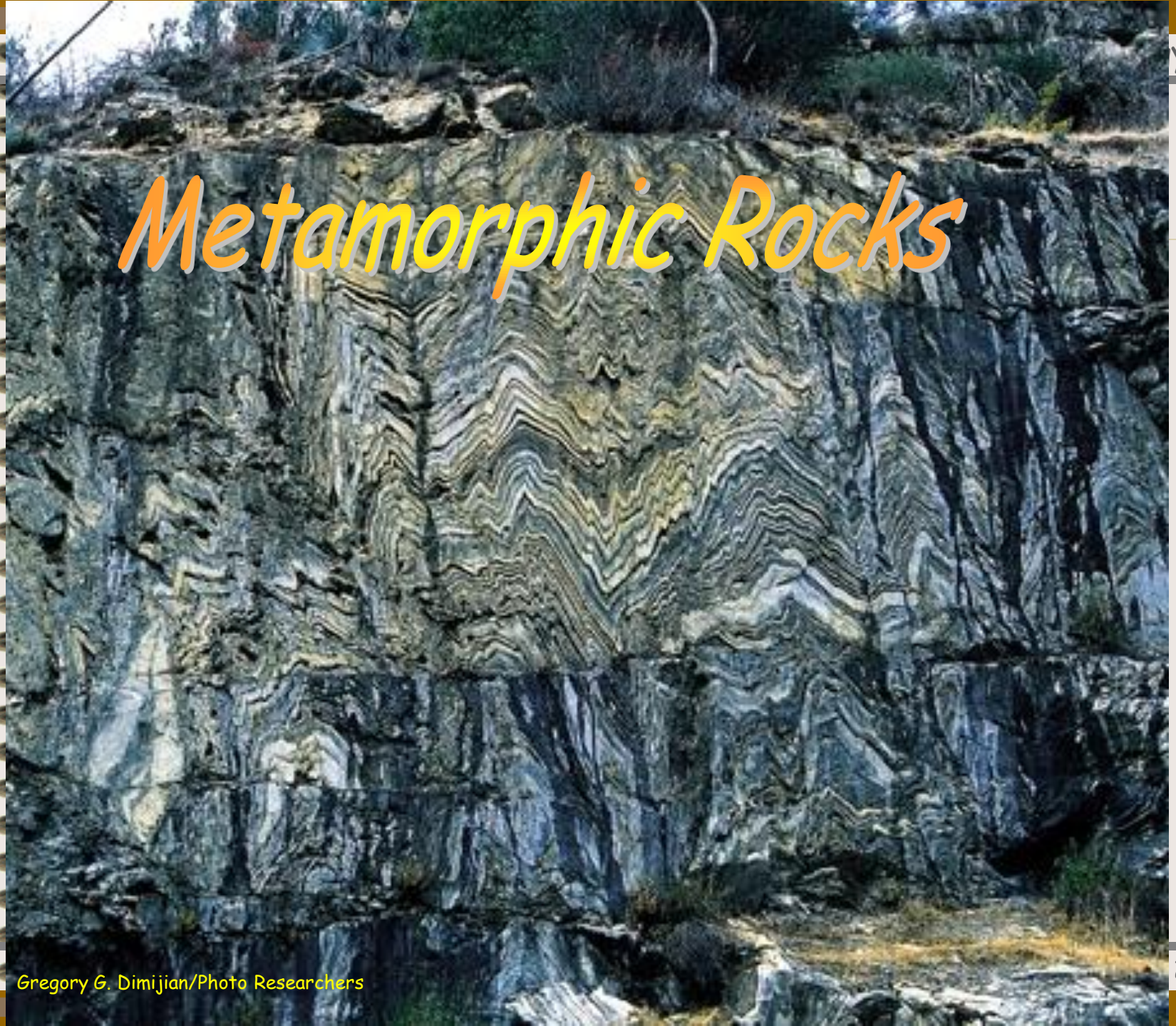
Chapter 9

Metamorphic Rocks

Metamorphic Rocks



Gregory G. Dimijian/Photo Researchers

Metamorphic rocks

- *Metamorphism*: to change form
- *Metamorphic rock*: any rock (sedimentary, volcanic, plutonic, metamorphic) that has undergone changes in texture or mineralogical composition in the *solid state*.

Metamorphic rocks

- Metamorphic rocks result from the partial or complete recrystallization of minerals in rocks over long periods of time.
- Rocks remain essentially solid during metamorphism.
- Metamorphism is a closed system process, and occurs with no addition or subtraction of elements from outside.

Metamorphic processes

HEAT: stability region of mineral sensitive to *T*.

PRESSURE: Increased *P* can come from any *directed stress* (burial). Stress will bring about a *preferred orientation* of minerals

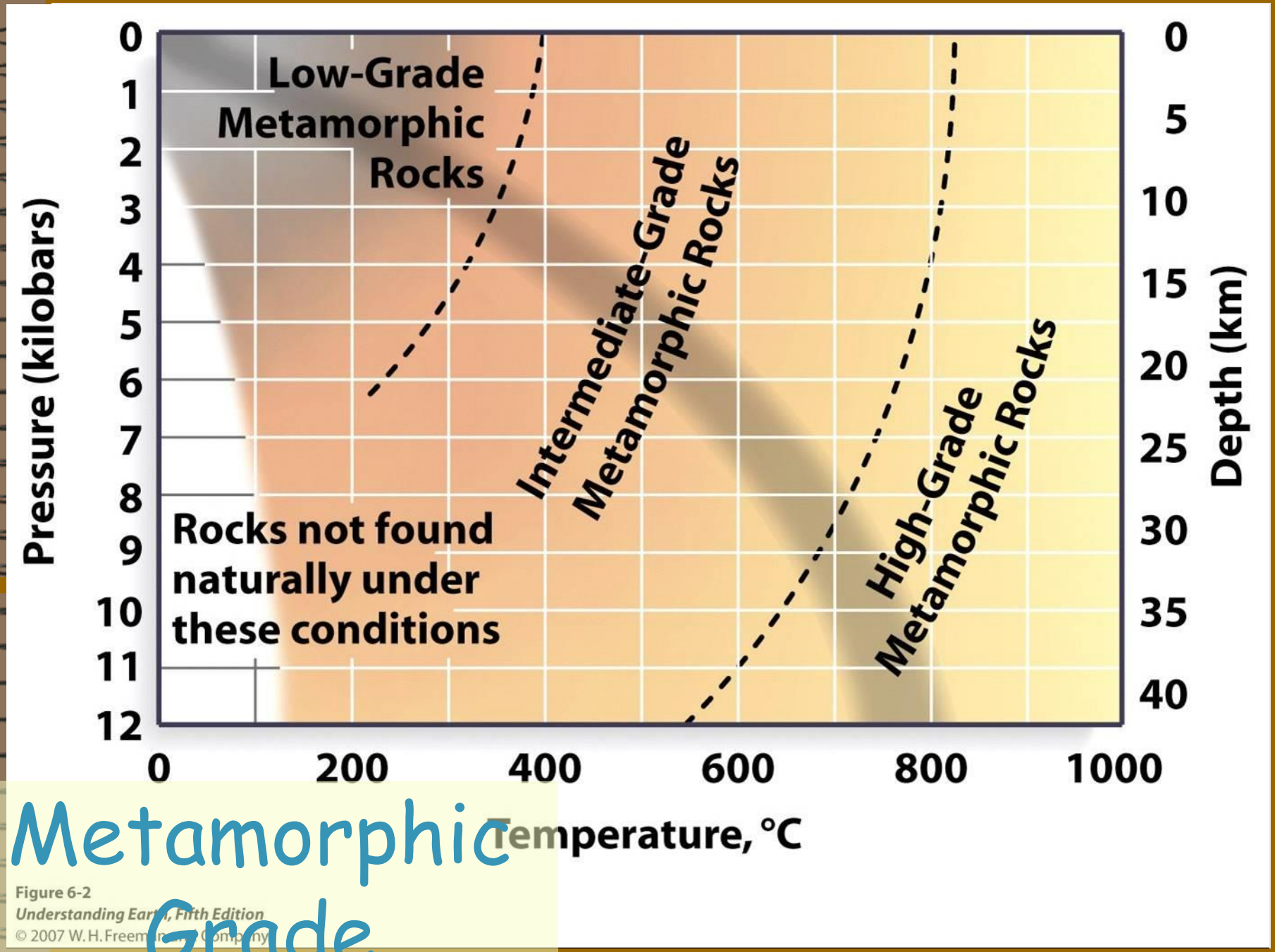
Metamorphic processes

FLUIDS (H_2O): acts as a catalyst during metamorphism; aids the exchange of ions between growing crystals. (*hydrothermal metamorphism*)

- *Metasomatism* is a special case of metamorphism in which *addition* or *subtraction* of elements form outside the system takes place.

Metamorphic grade

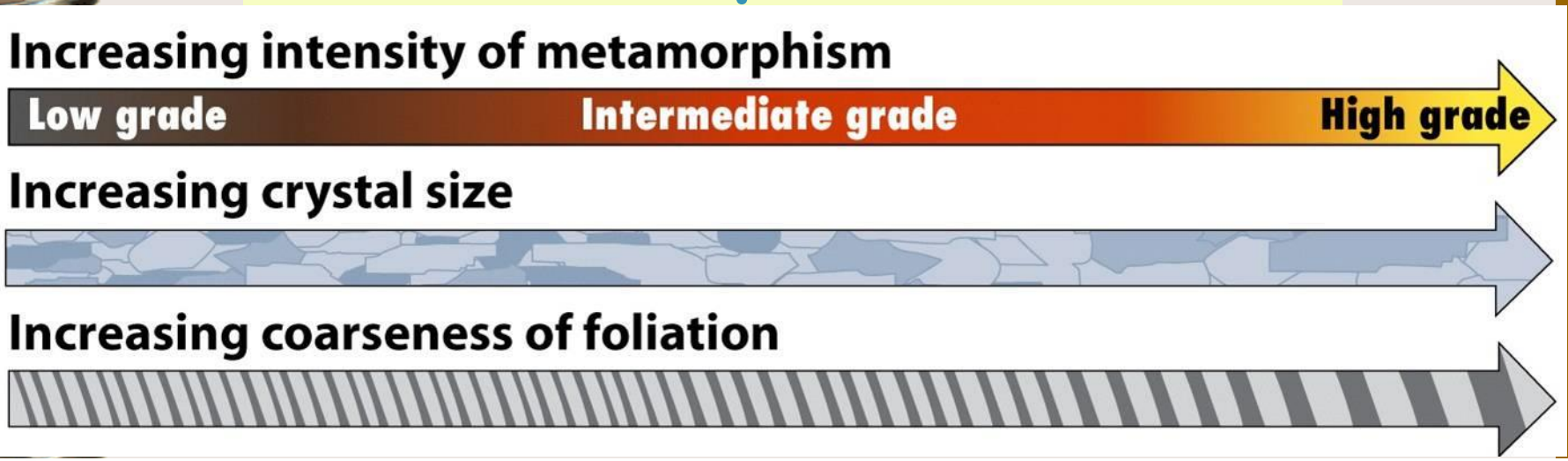
- Refers to the intensity of metamorphism.
  - High grade: high *T*, *P*
  - Low grade: low *T*, *P*
- The effect of heat only or heat and pressure cause textural and mineralogical transformations of the pre-existing rocks, giving metamorphic rocks.



Metamorphic Grade

Figure 6-2
Understanding Earth, Fifth Edition

Metamorphic Grade



8 Foliated rocks are classified by the degree of cleavage, schistosity, and banding, which corresponds to the intenstiy of metamorphism.

Metamorphic reactions

- *Mineralogical changes* (e.g., clay to mica): Many complicated reactions — depend on pressure, temperature, composition.
- Common metamorphic minerals include amphiboles, garnet, mica, staurolite, and kyanite.
- *Textural changes*: *recrystallization* (grain boundaries more compact) and *foliation* preferred orientation of minerals).

Metamorphic Foliation

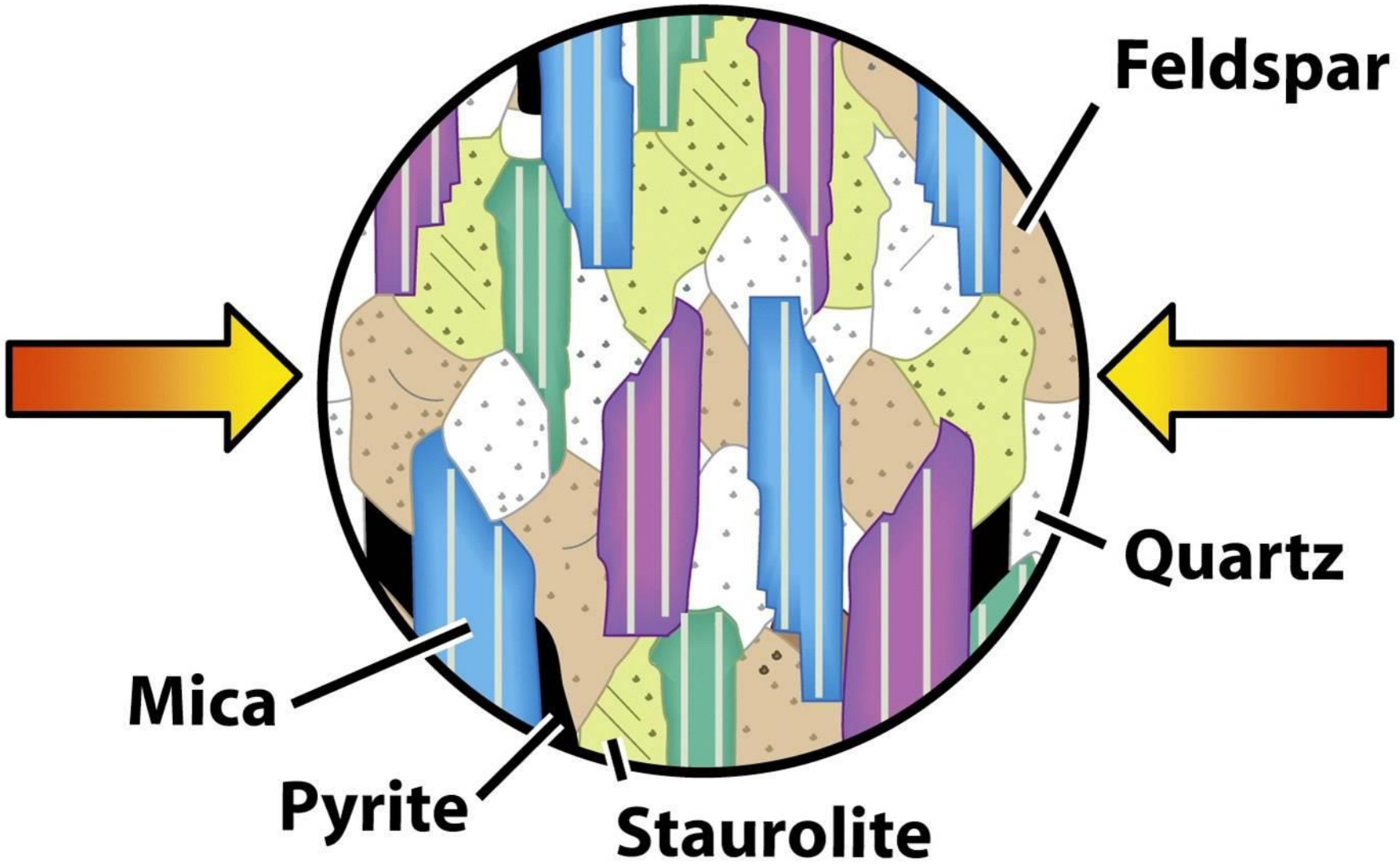


Figure 6-4b part 1
Understanding Earth, Fifth Edition

Metamorphic Foliation

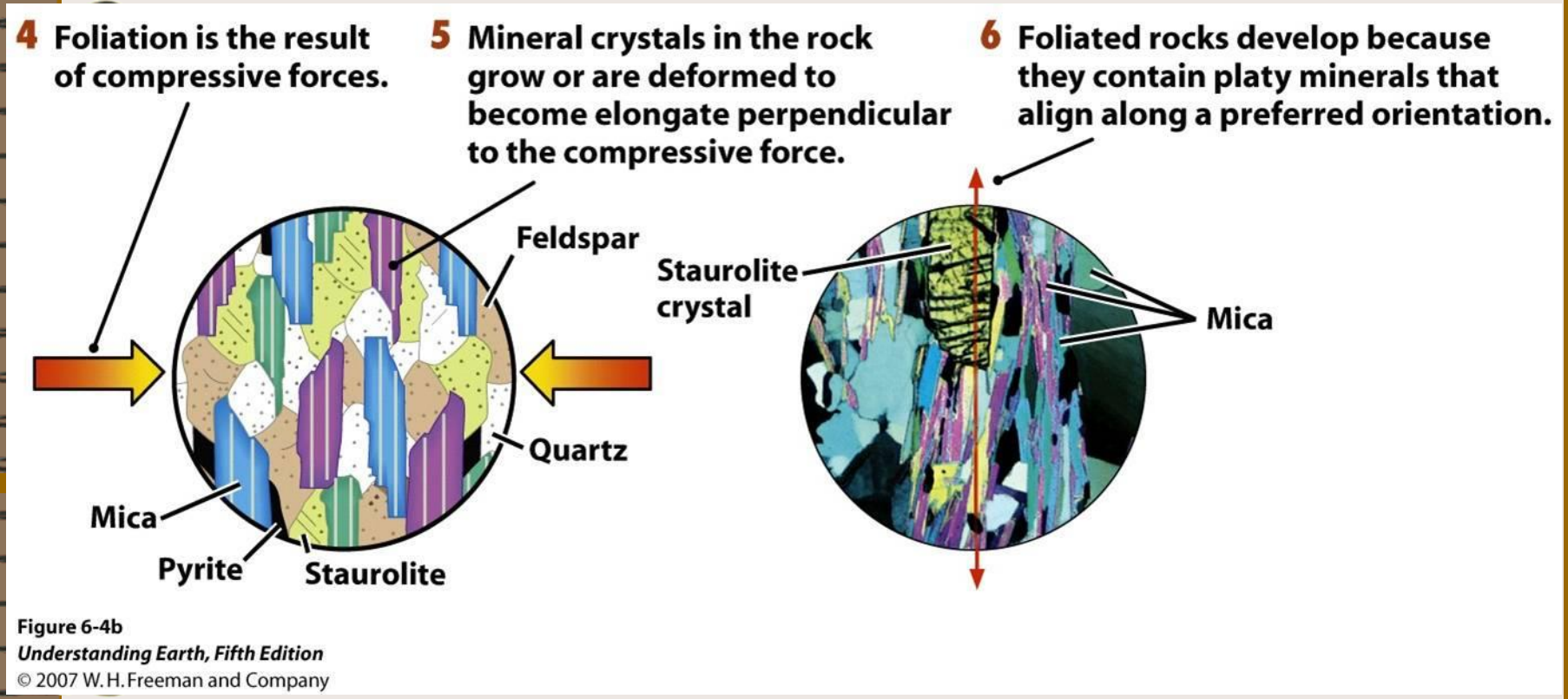


Figure 6-4b
Understanding Earth, Fifth Edition

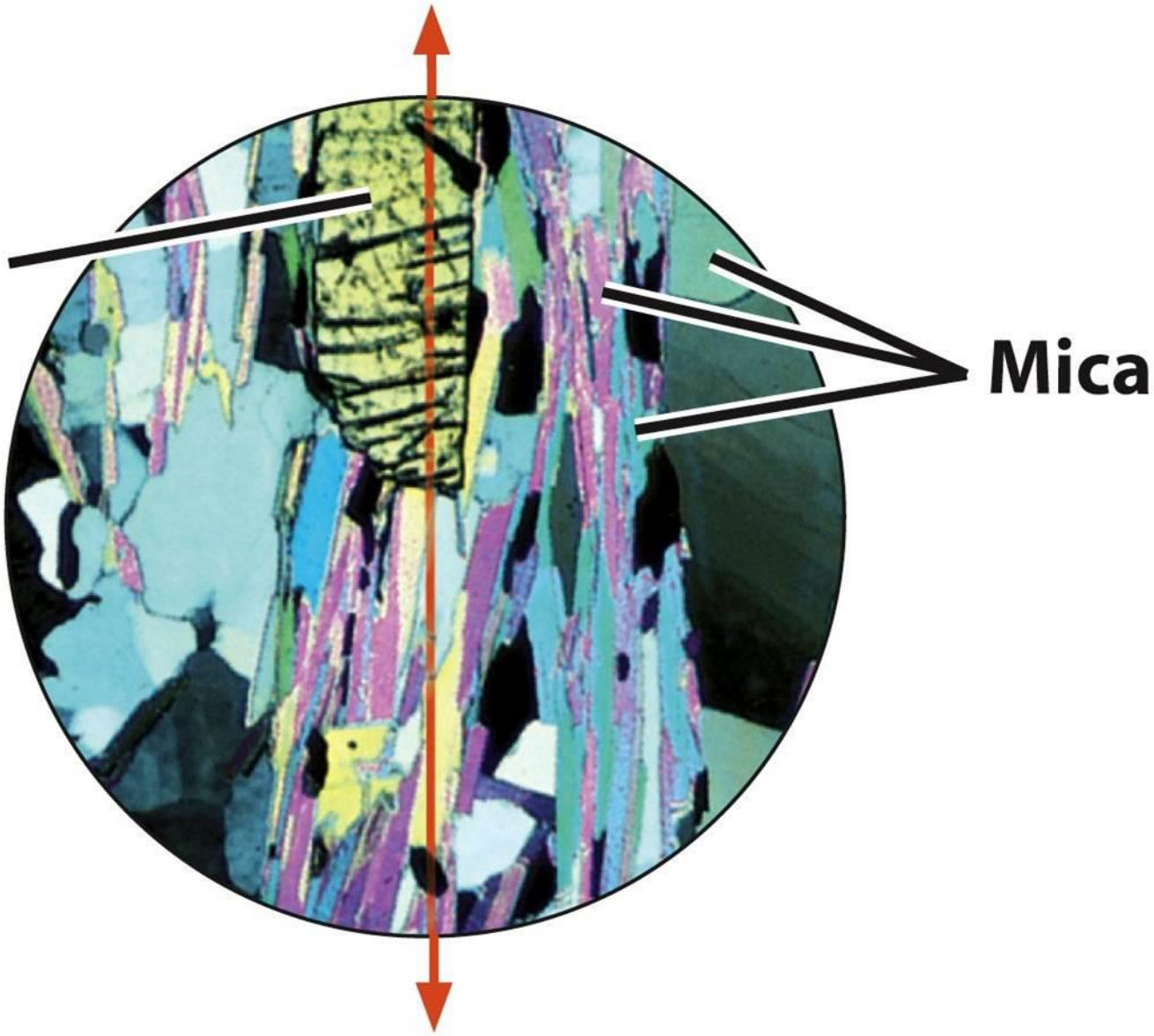
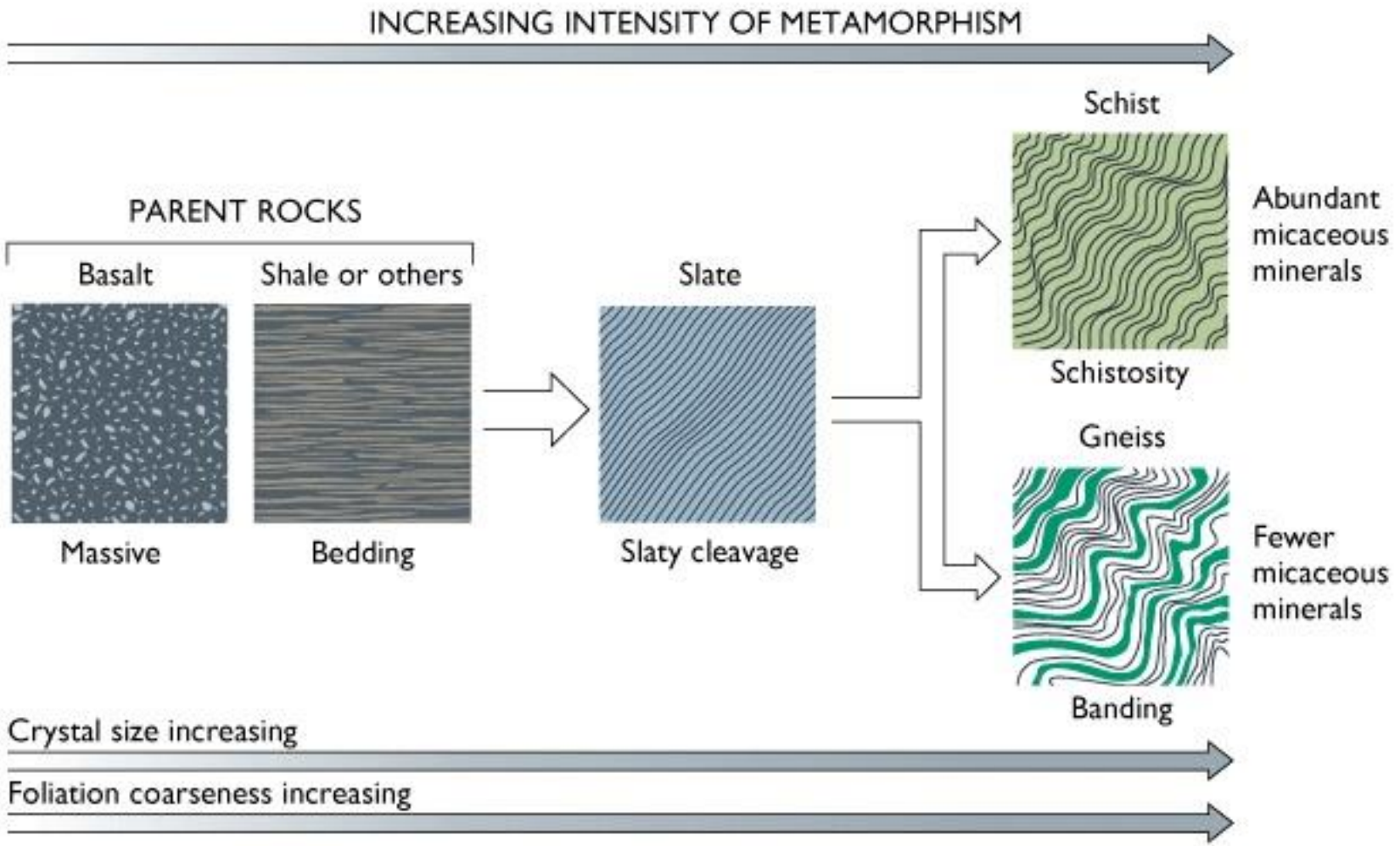


Figure 6-4b part 2
Understanding Earth, Fifth Edition

Classification of Foliated Rocks



How much can a rock change?

- The degree of metamorphism depends upon the extent of P&T, and is reflected in the Texture & Mineralogy of the metamorphic rocks.
- Low T&P result in the formation of *low-grade* metamorphic rocks, while high T&P give *high-grade* metamorphic rocks.
- Metamorphism destroys all sedimentary structures and fossils.

Changes in texture

- ✓ Grain size
- Recrystallization
- Mineral size can either decrease or increase.
- Polygonal crystals with triple junctions
- ✓ Orientation of minerals
- Recrystallization
- Directed stress will orient minerals: Foliation

Types of metamorphism

1. Regional: Widespread changes in temperature and pressure bring about changes in rocks due to tectonic forces.
2. Contact: Intrusion of magma against colder rocks (affected area is proportional to the size and temperature of the intrusion but always only a local phenomenon).

+ a 3rd type -- hydrothermal metamorphism, related to the change in the rocks as a result of the interaction between the fluids and the host rocks.

Characteristics of Metamorphic rocks

- Form adjacent to magmatic intrusions or within large mountain chains
- Formation of new minerals, occasionally cross-cutting old minerals.
- Presence of *foliation* (minerals aligned at specific preferred orientation, to the maximum stress forces) schistosity and slaty cleavage form during regional metamorphism
- Polygonal crystals with *triple junctions* form during recrystallization (in contact or thermal metamorphism only).

Contact (thermal) Metamorphic Rocks

- Form due to the effect of heat (from a nearby volcano or magma chamber).
- As a result, the host rocks are baked and develop new textures and mineralogical changes to reach equilibrium with the new conditions; i.e. they recrystallize.

Contact (thermal) Metamorphic Rocks

- Many new rocks form as a result

  -*Sandstone* recrystallizes into *quartzite* (polygonal crystals with triple junctions).

  -*Limestone* recrystallizes into *marble* with interlocking crystals.

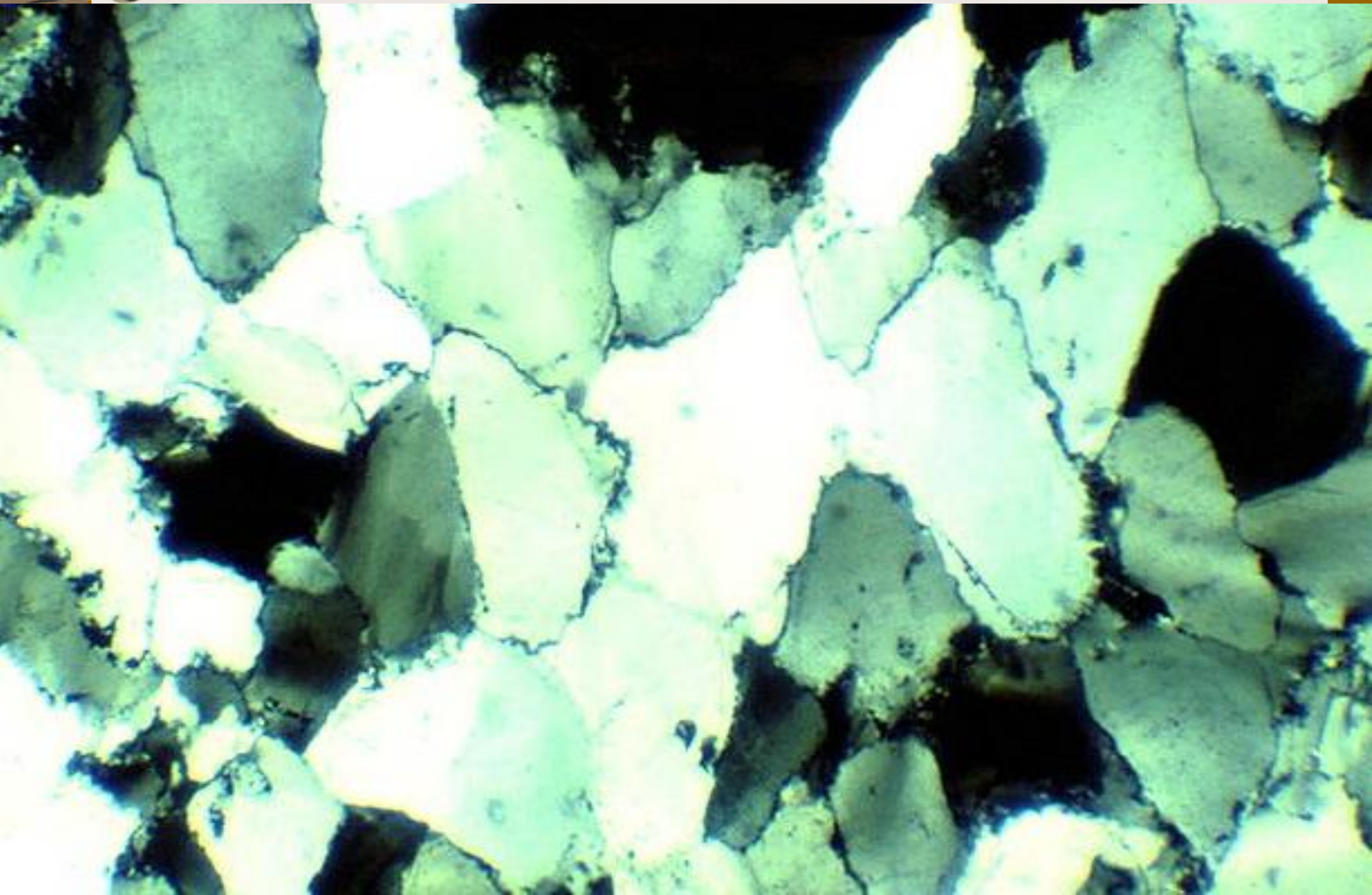
  -*Siliceous limestone* recrystallizes into *wollastonite marble*.

  - *Shale* recrystallizes into *hornfels*

Quartzite

Breck P. Kent

Quartzite in Thin Section



Marble

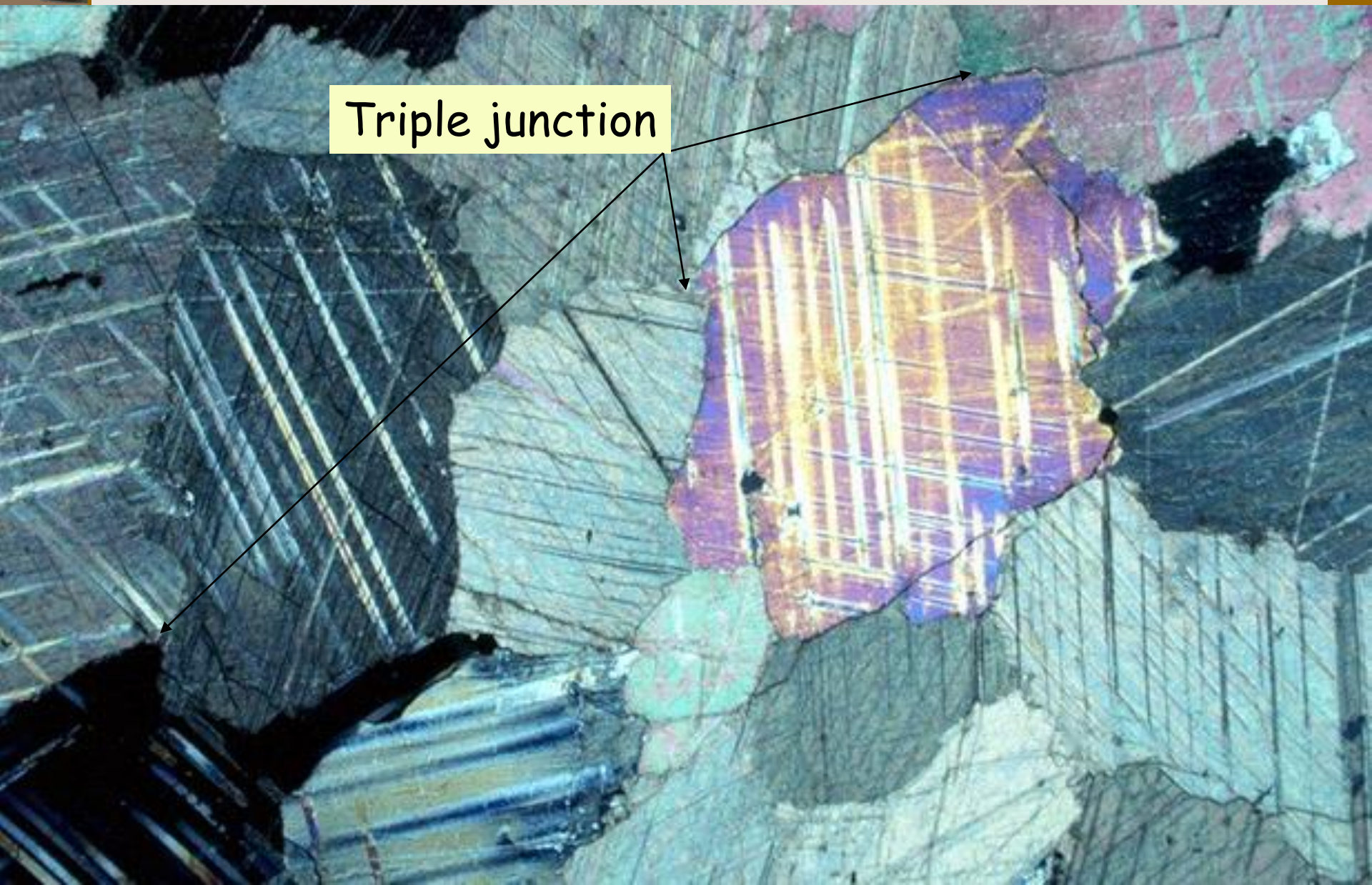
Breck P. Kent

Marble

Figure 6-5b
Understanding Earth, Fifth Edition

Marble in Thin Section

Sl.12



Regional metamorphic rocks

- Regional metamorphism takes place over an *extensive area* and is associated with the process of mountain building where very high T and P produce the greatest amount of metamorphic rocks.
- These rocks are deformed by *directional stress* resulting into a Foliated Fabric

Regional metamorphic rocks

- The stresses on the rocks induce the growth of new minerals with a parallel orientation where their length developed ⊥ to direction of maximum pressure.
- Four major types occur:

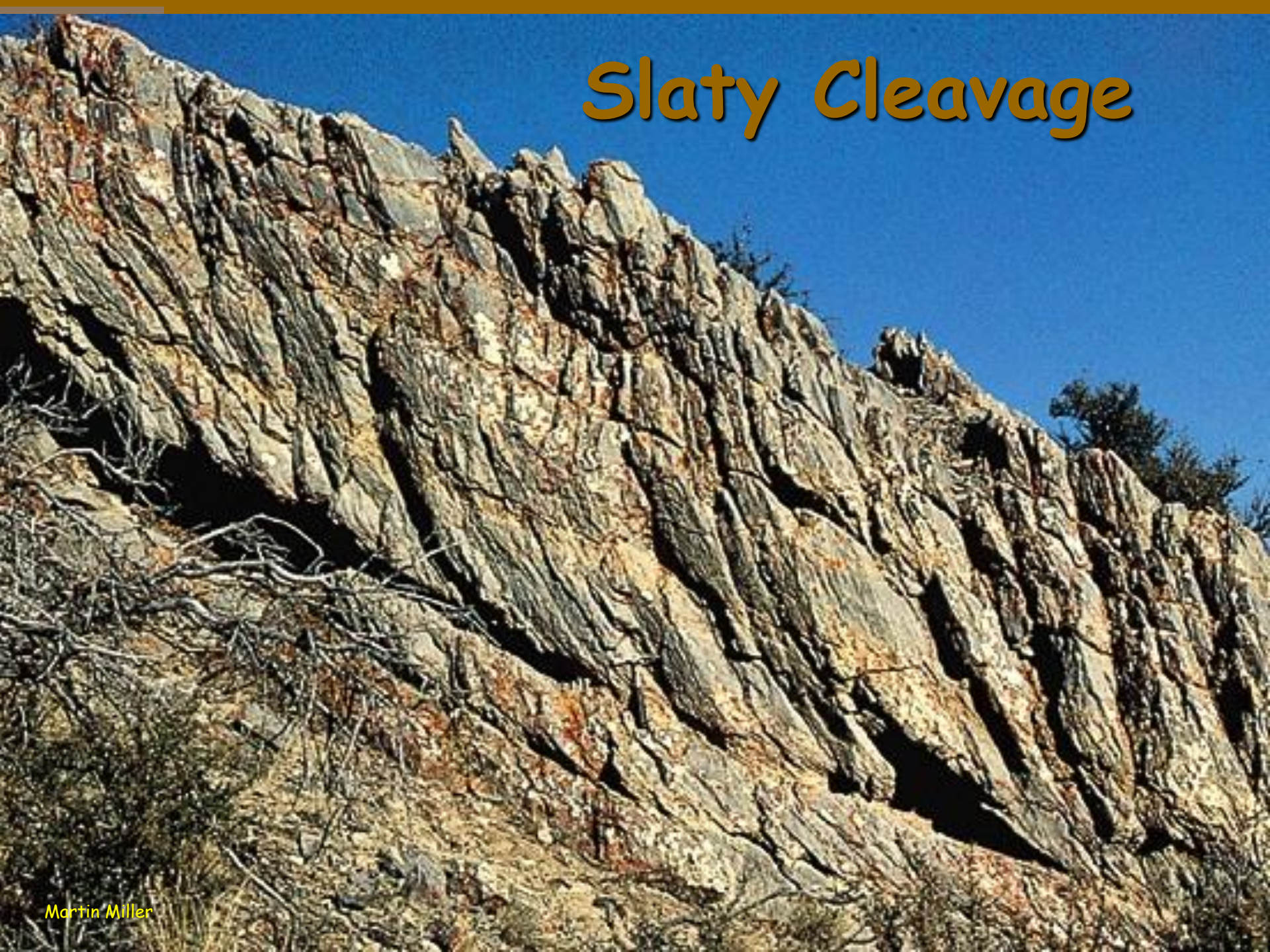
Low grade	Slate
↓	Phyllite
	Schist
	Gneiss
High grade	Migmatite

Regional Metamorphic Rocks

Slate is a low-grade regional metamorphic rock

- Very fine-grained crystalline, foliated metamorphic rock, showing *slaty cleavage* due to the metamorphism of shale.
- The minerals are recrystallized into finer sericite (mica) with their long axes perpendicular to the direction of maximum stress (P), thus developing a *preferred alignment* of minerals and a slaty cleavage.

Slaty Cleavage



Slaty cleavage planes

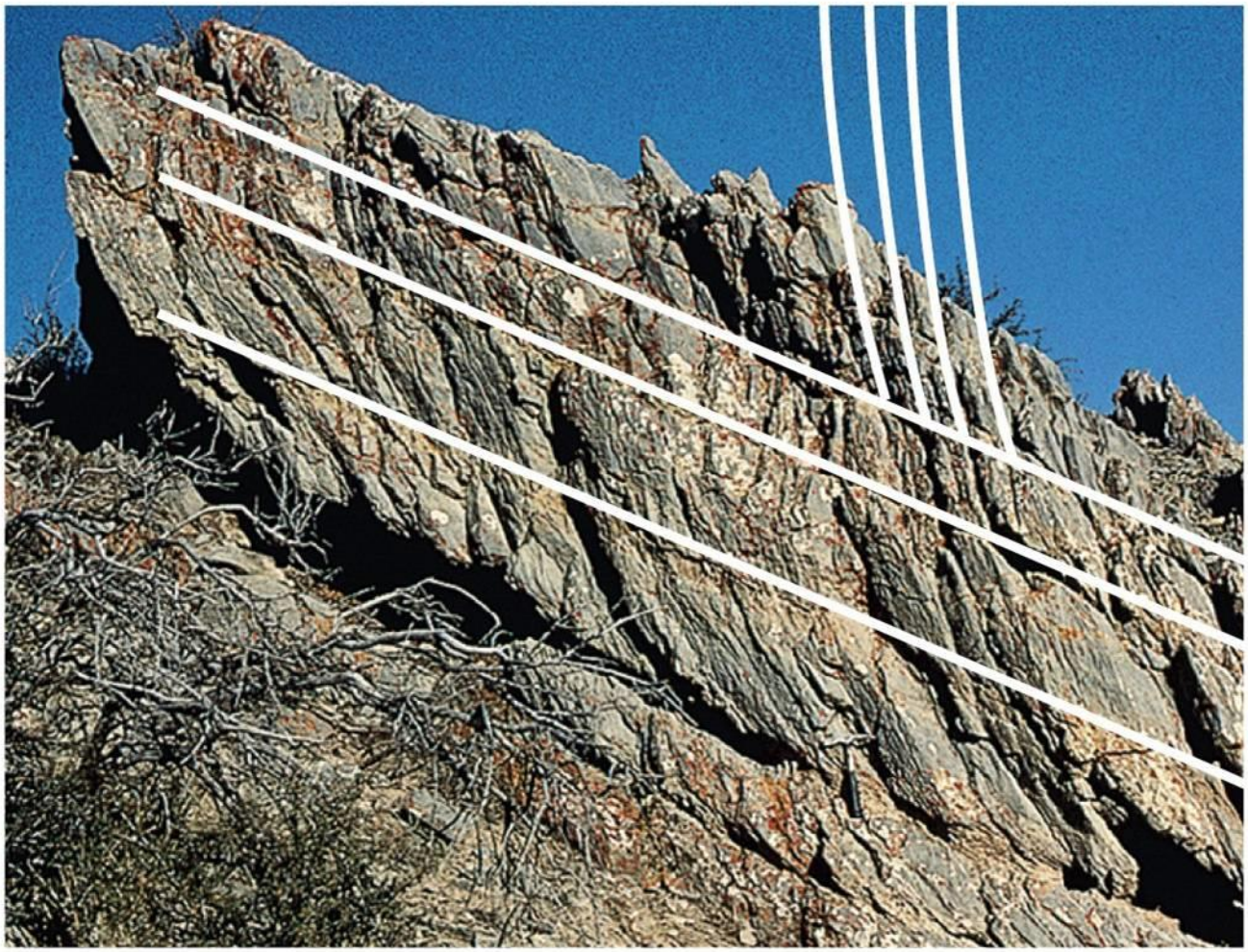


Figure 6-4a part 1
Understanding Earth, Fifth Edition

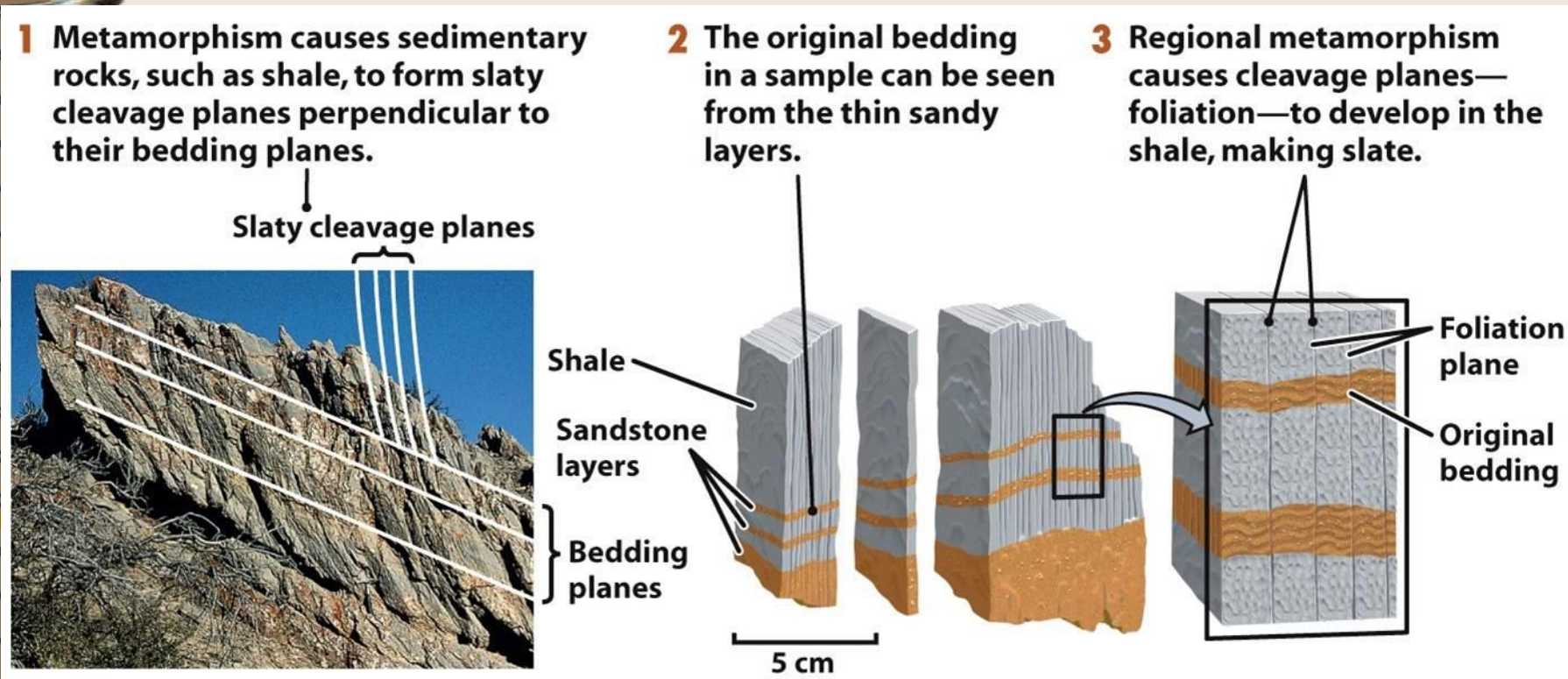


Figure 6-4a
Understanding Earth, Fifth Edition

Slate

Andrew J. Martinez/Photo Resrachers

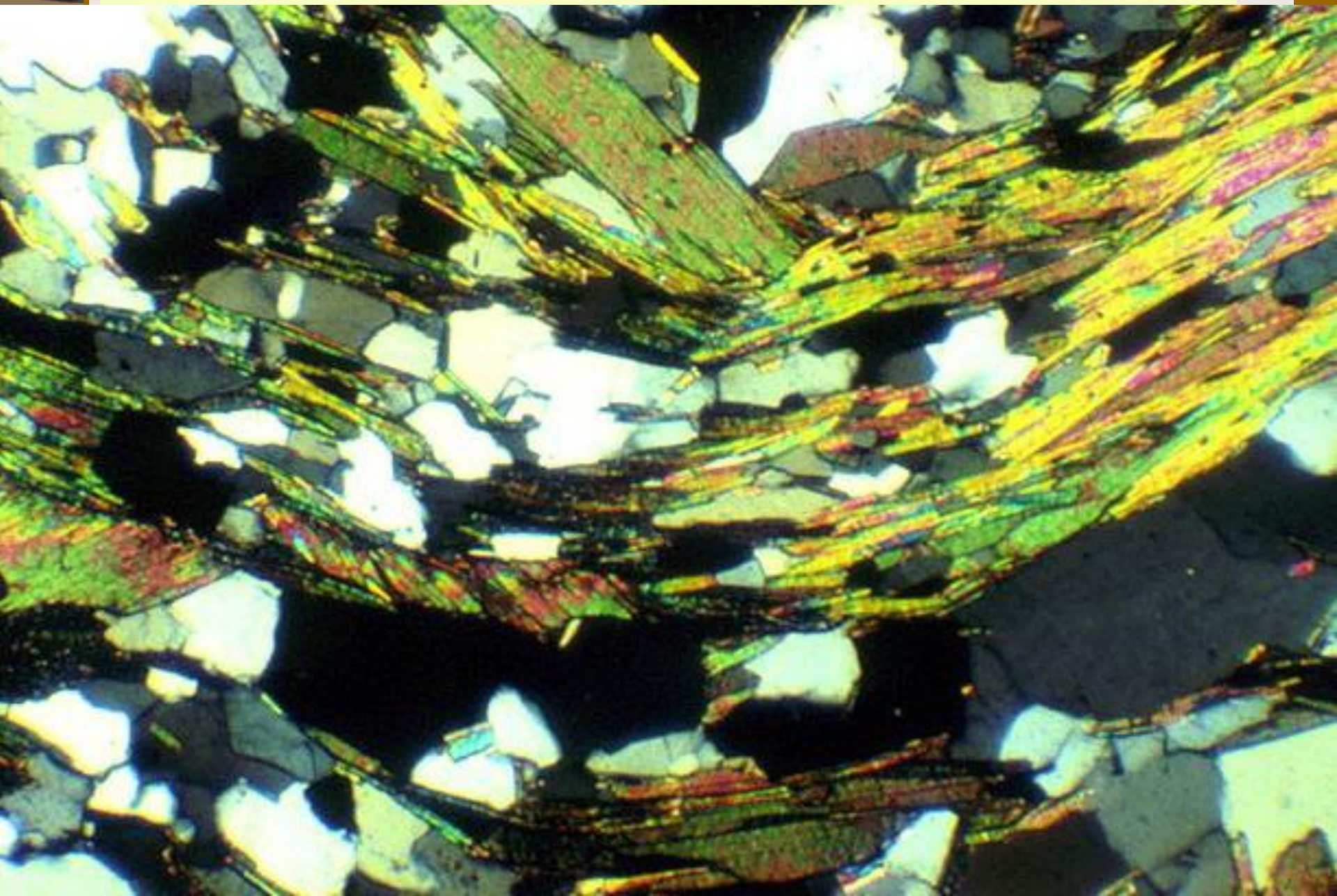
Regional Metamorphic Rocks

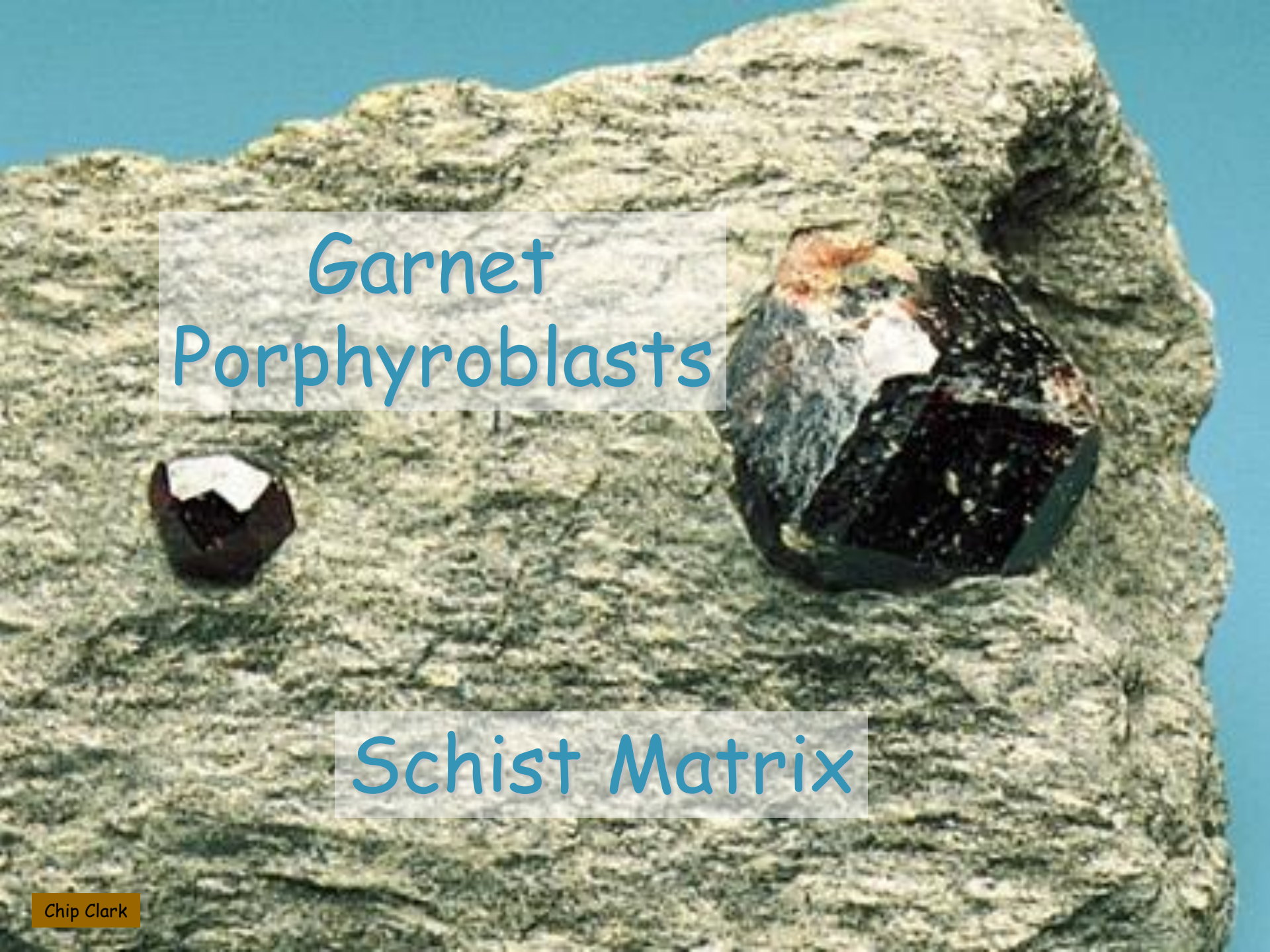
Phyllite With increasing stress & T, the slate continues to grow to larger muscovite and chlorite flakes to give fine-grained phyllite and then develops some shine.

Schist Moderately coarse-grained foliated regional metamorphic rock with foliae seen by the naked eye. Contain dark foliae (consisting of biotite, amphibole and muscovite), in addition to light colored foliae (made up of quartz and feldspar). Schists may also include garnet.

Schist

Schist in Thin Section




Garnet Porphyroblasts
Schist Matrix
Chip Clark

Regional Metamorphic Rocks

Gneiss

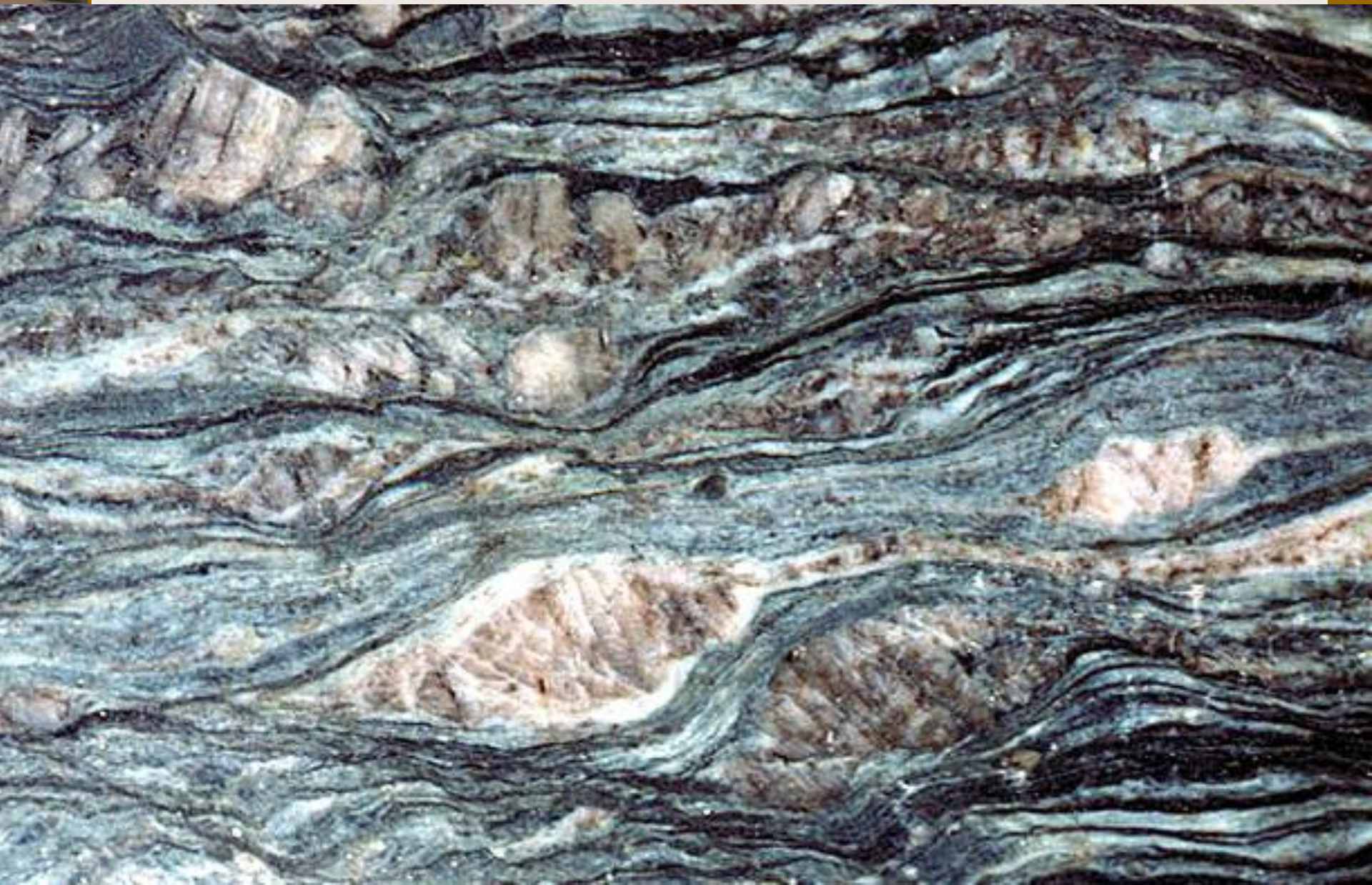
Coarse-grained foliated metamorphic rock, composed of alternating *dark foliae* (biotite, amphibole, and pyroxene) and *light foliae* (quartz, feldspar) commonly with garnet, formed at high grade of metamorphism. **Two** main varieties:

i. ***Orthogneiss*** is produced by high grade metamorphism of igneous parent rocks.

ii. ***Paragneiss*** produced from high grade metamorphism of sedimentary parent rocks.

Gneiss

Augen Mylonitic Gneiss



Regional Metamorphic Rocks

Migmatite

A composite rock containing an igneous component formed by small amount of melting and a high-grade metamorphic component in the form of layers crystallized from molten material and then subjected to high-grade regional metamorphism.

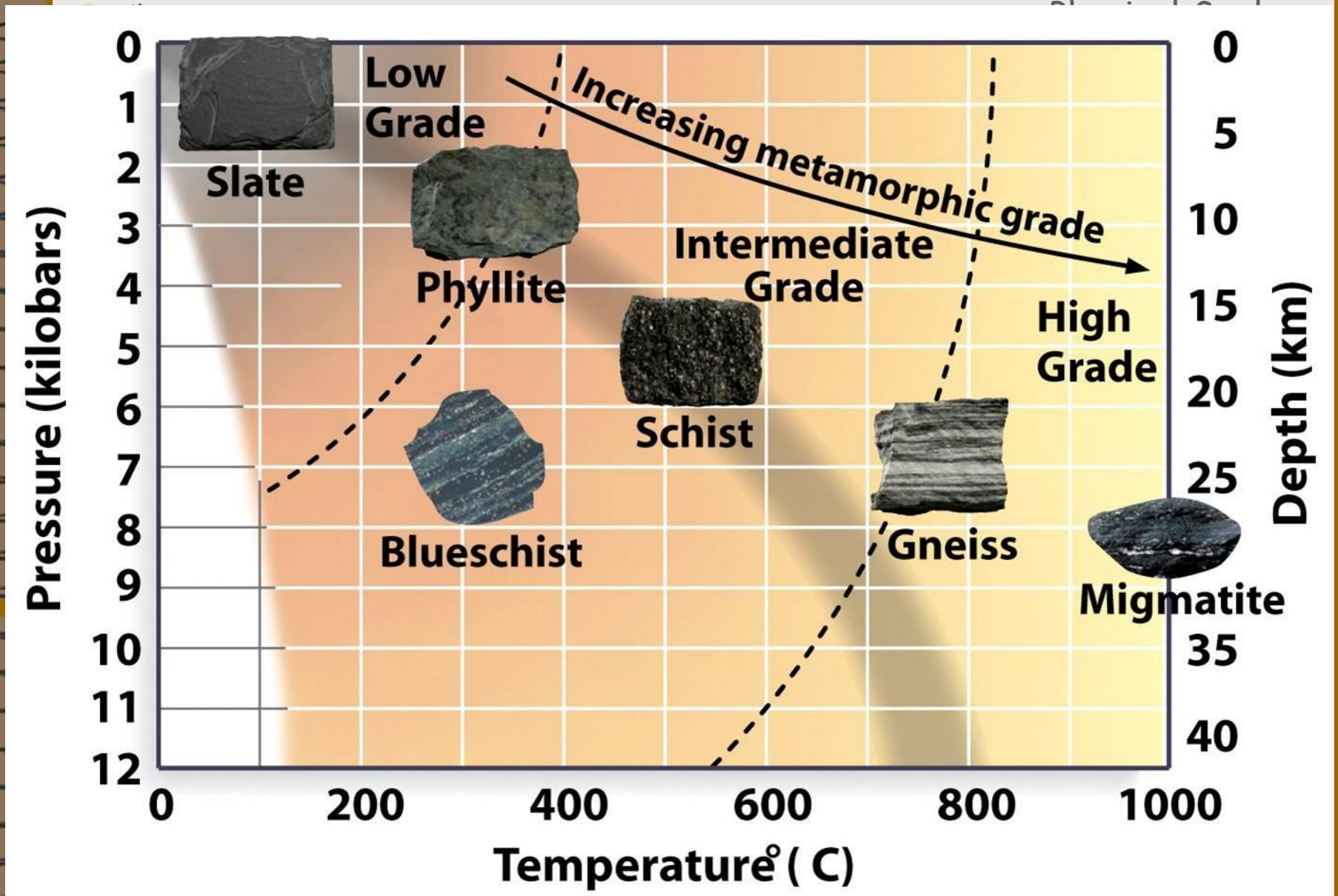


Figure 6-7b
Understanding Earth, Fifth Edition

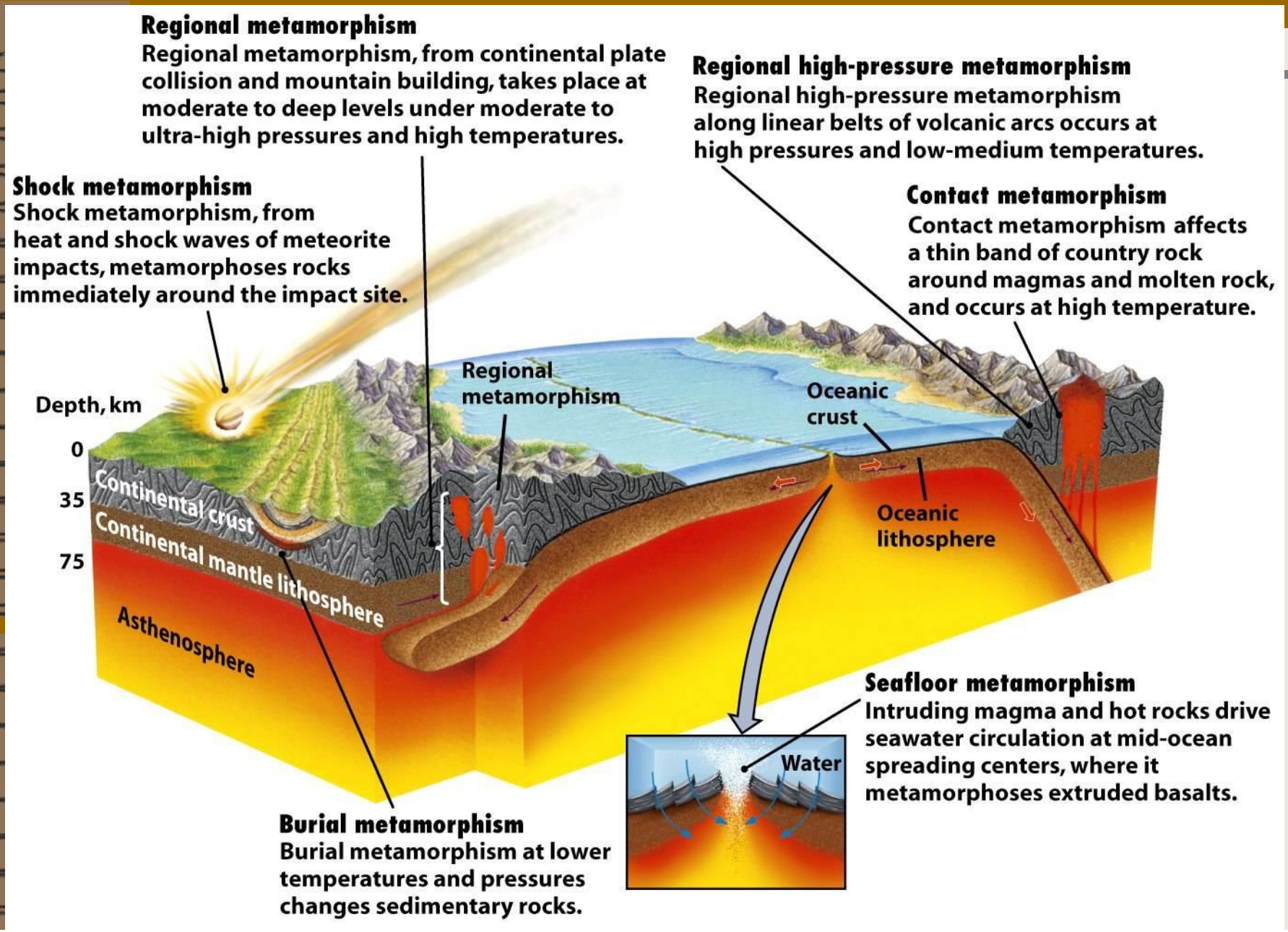


Plate Tectonics and Metamorphism

Plate Tectonics and Metamorphism

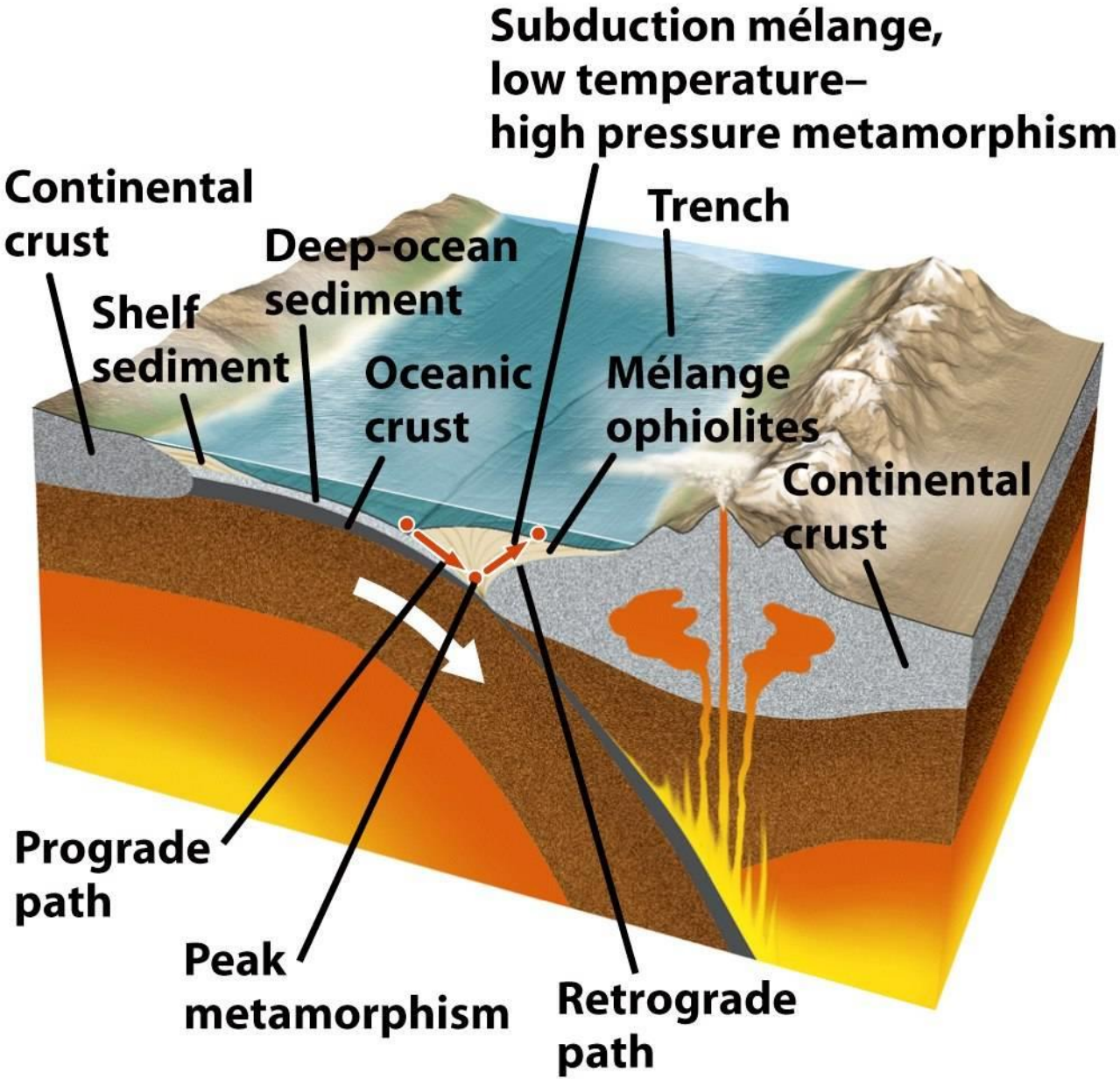


Plate Tectonics and Metamorphism

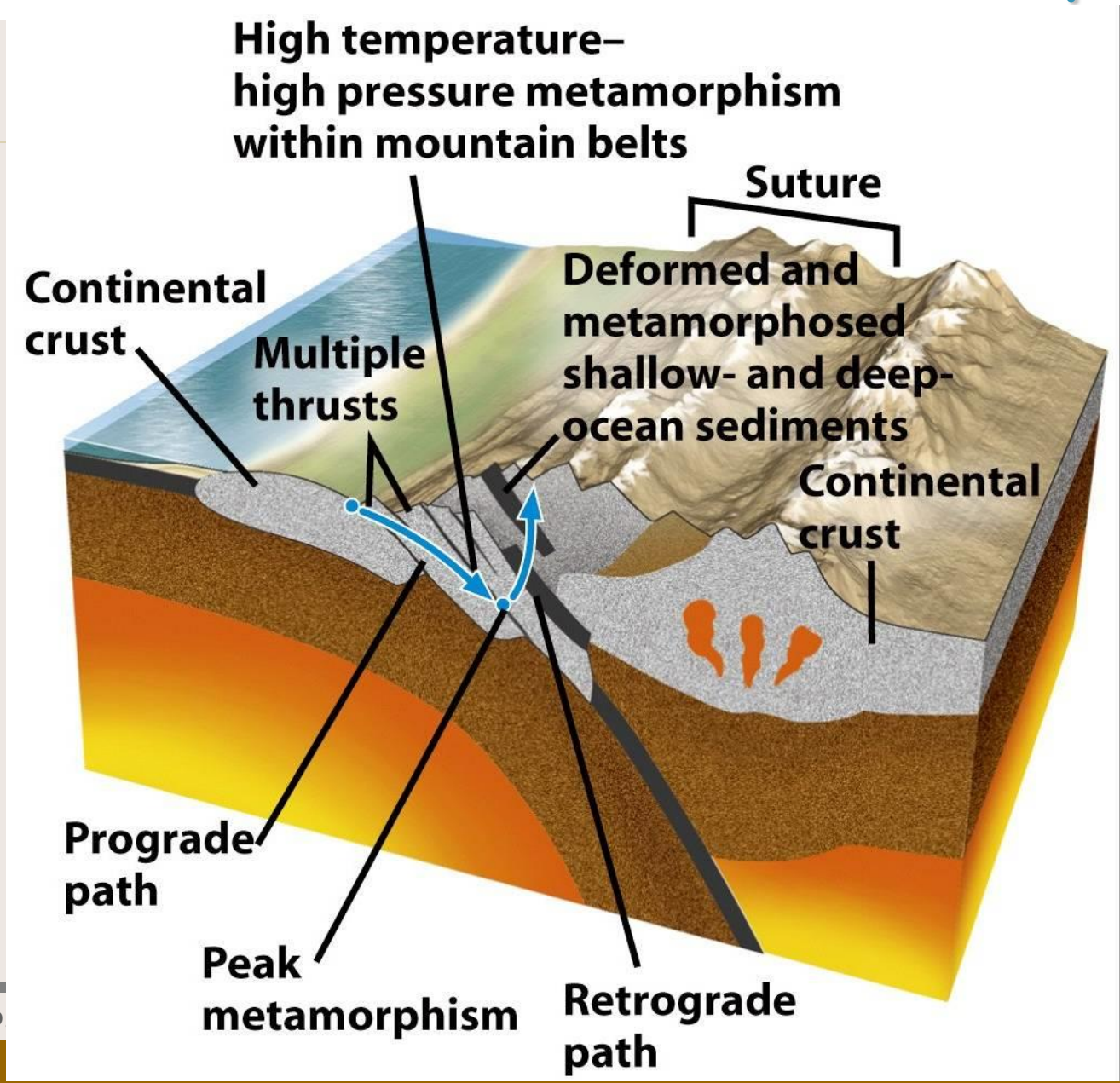


Table 6.1 Classification of Metamorphic Rocks by Texture

Classification	Characteristics	Rock Name	Typical Parent Rock
Foliated	Distinguished by slaty cleavage, schistosity, or gneissic foliation; mineral grains show preferred orientation	Slate	Shale, sandstone
		Phyllite	
		Schist	
		Gneiss	
Granoblastic (nonfoliated)	Granular, characterized by coarse or fine interlocking grains; little or no preferred orientation	Hornfels	Shale, volcanics
		Quartzite	Quartz-rich sandstone
		Marble	Limestone, dolomite
		Argillite	Shale
		Greenstone	Basalt
		Amphibolite[a]	Shale, basalt
		Granulite[b]	Shale, basalt
Porphyroblastic	Large crystals set in fine matrix	Slate to gneiss	Shale

[a]Typically contains much amphibole, which may show alignment of long, narrow crystals.
[b]High-temperature, high-pressure rock.

Table 6-1
Understanding Earth, Fifth Edition