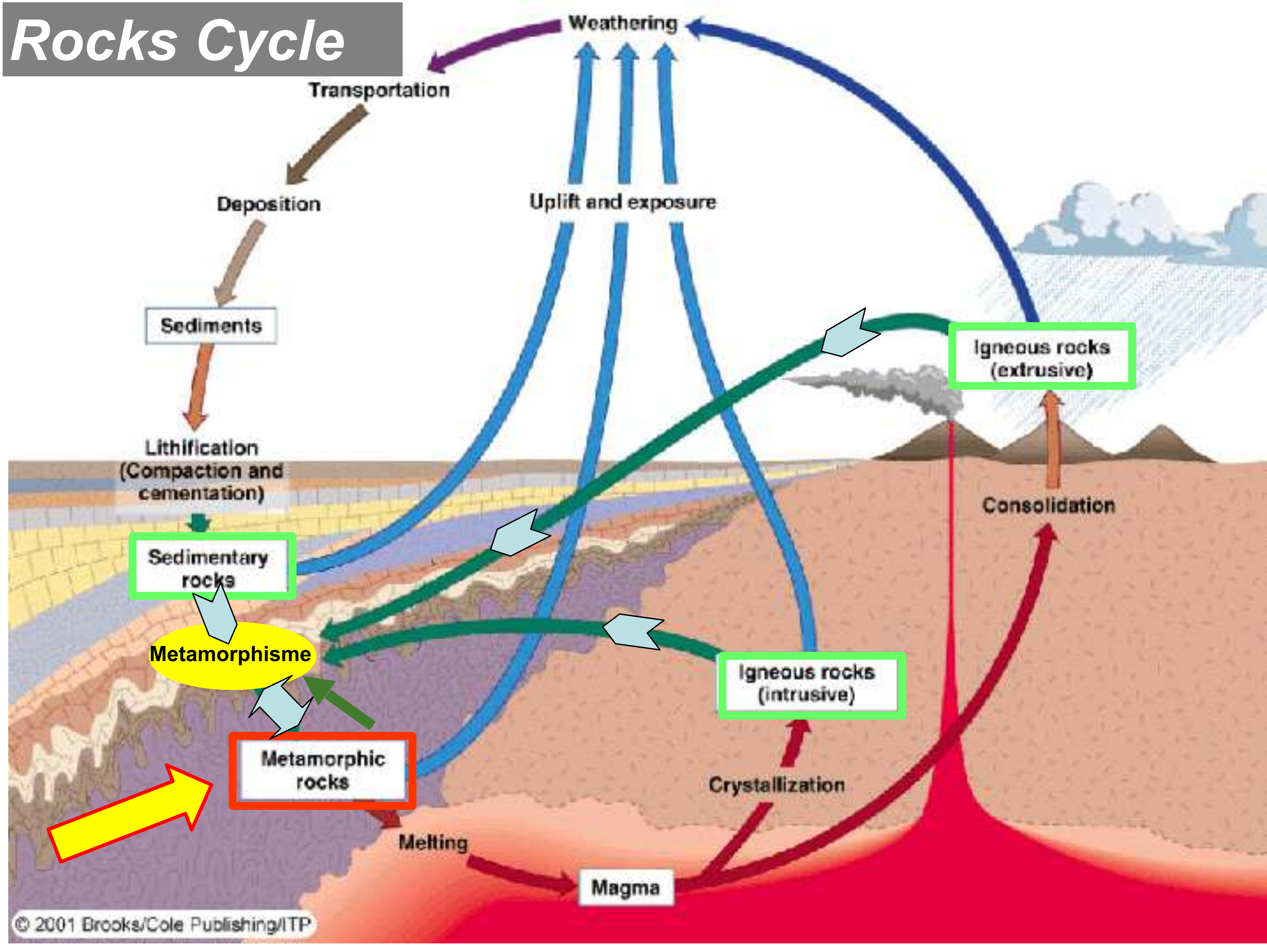
Module 8

Metamorphic Rocks

Rocks Cycle


Weathering
Transportation
Deposition
Uplift and exposure
Sediments
Lithification
(Compaction and
cementation)
Sedimentary
rocks
Igneous rocks
(extrusive)
Consolidation
Metamorphisme
Igneous rocks
(intrusive)
Metamorphic
rocks
Crystallization
Melting
Magma

METAMORPHIC ROCKS

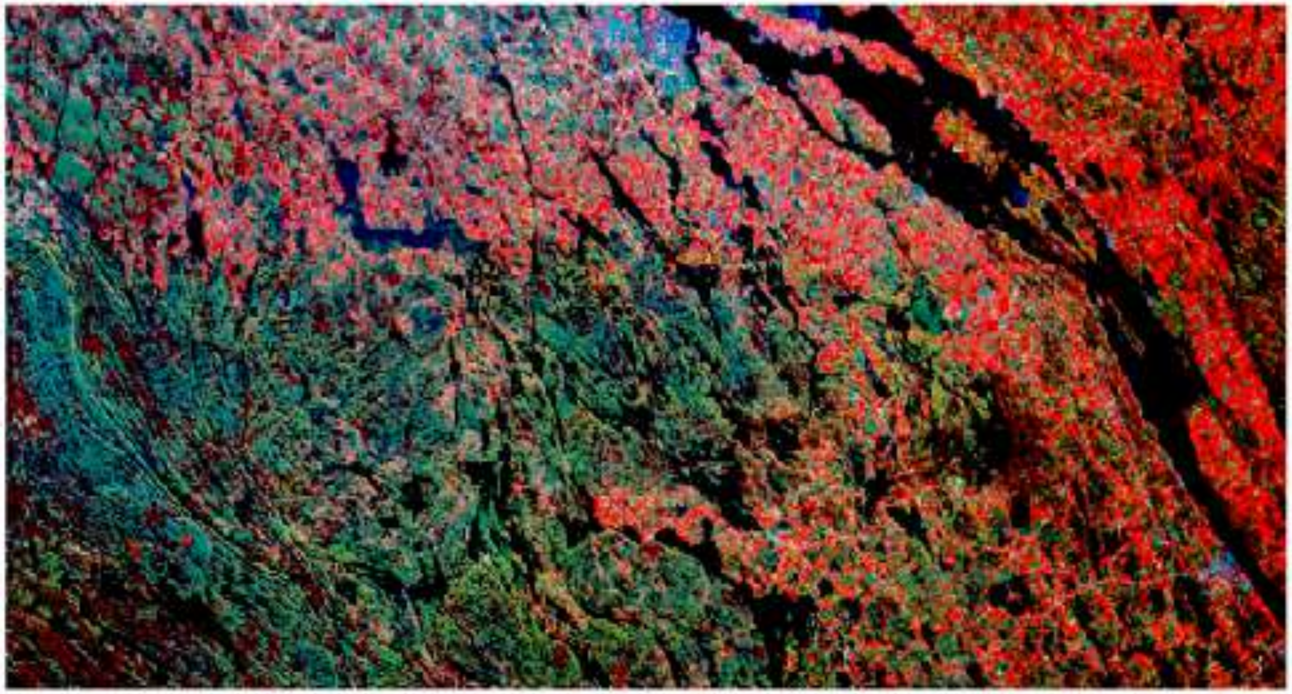
Metamorphic rocks form by recrystallization in the solid state because of changes in temperature, pressure, or the composition of pore fluids. New minerals form that are in equilibrium with the new environment, and a new rock texture develops in response to the growth of new minerals.

Hamblin, 2009

METAMORPHIC ROCKS

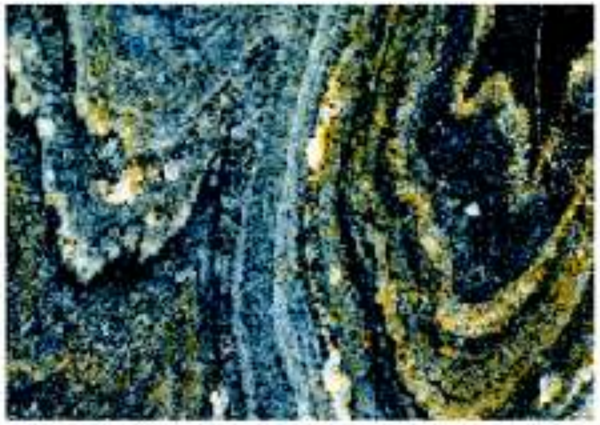
- **Metamorphic rocks are changed rocks (of pre-existing rocks)**

- **The *protolith* (the *parent rock*) is the preexisting rock from which the metamorphic rock was formed**
- **They are *formed in the solid state* in response to the following *principal agents of metamorphism*:**
  - **Change in *pressure (P)***
  - **Change in *temperature (T)***
  - **Change in *P* & *T***



(A) Satellite image of metamorphic rocks in the Canadian Shield. Note the complex folds and fractures resulting from extensive crustal deformation while the rocks were at high temperature and pressure. *(Courtesy of National Air Photo Library, Department of Energy, Mines, and Resources, Canada)*

(B) Outcrop of metamorphic rocks at 5500-m level of Mount Everest in Tibet. The foliation in this rock formed by shear during the collision of India and Asia.



(C) Hand sample of a highly metamorphosed rock. Note that recrystallization in the solid state has concentrated light and dark minerals into layers which were then deformed and folded.

METAMORPHIC ROCKS

Metamorphism may cause a change in a rock's, related with:

- ***Structure/Texture***
- ***Mineral assemblage***
- ***Composition (slightly)***
- ***All of the above***

Factors That Control the Characteristics of Metamorphic Rocks

1. **Protolith Composition (original rock)**
2. **Pressure (P)**
3. **Temperature (T)**
4. **Time (scale in million years)**

Factors That Control the Characteristics of Metamorphic Rocks

1. Protolith Composition

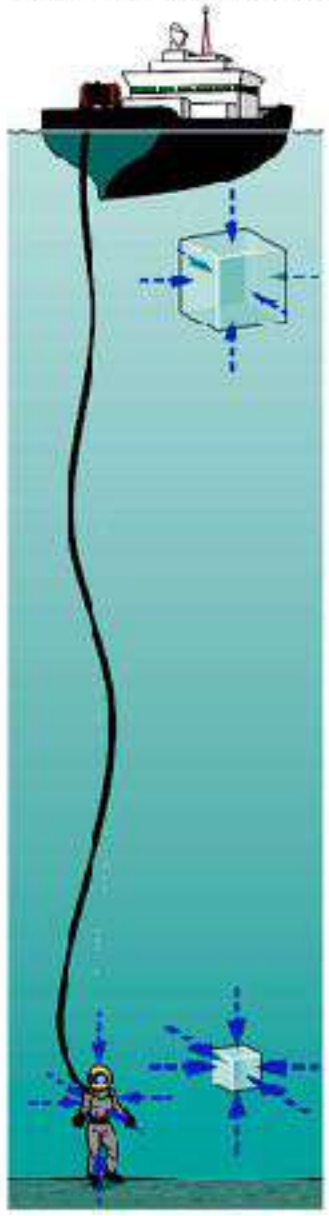
- **Mafic protoliths (basalt, diabase, and gabbro) yield a dark charcoal gray mafic metamorphic rock called *amphibolite***
- **Felsic protoliths (granite, rhyolite, mudstone, sandstone, conglomerate, breccia) yield light colored tan, silver, light to medium gray, etc. felsic metamorphic rocks**

Factors That Control the Characteristics of Metamorphic Rocks

2. Pressure (stress)

- Increasing pressure flattens grains, crushes grains (reduces size), causes shearing
- Confining pressure, associated with depth of burial, is equal in all directions
- Differential pressure is not equal in all directions
  - Produces foliation (parallel alignment of grains)
  - Pure shear = compression, flattens grains
  - Simple shear = skewing, stretches grains, produces lineation, aligns elongate grains in direction of transport

Factors That Control the Characteristics of Metamorphic Rocks



Confining Pressure

Pressure is equal in all directions

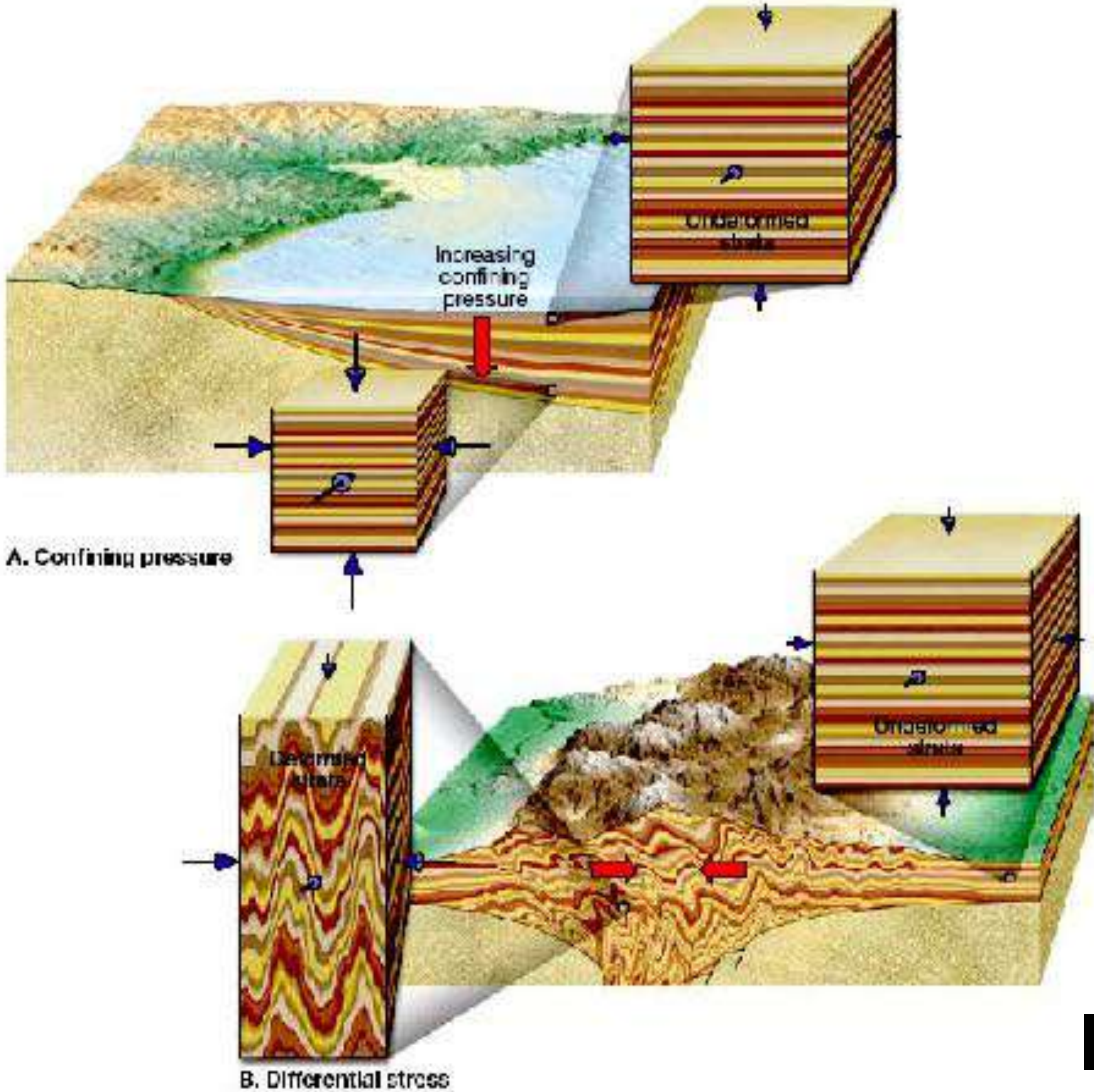


FIGURE 7.3 Confining pressure and differential stress as metamorphic agents. A. In a depositional environment, as confining pressure increases, rocks deform by decreasing in volume. B. During mountain building, rocks subjected to differential stress are shortened in the direction that pressure is applied and lengthened in the direction perpendicular to that force.

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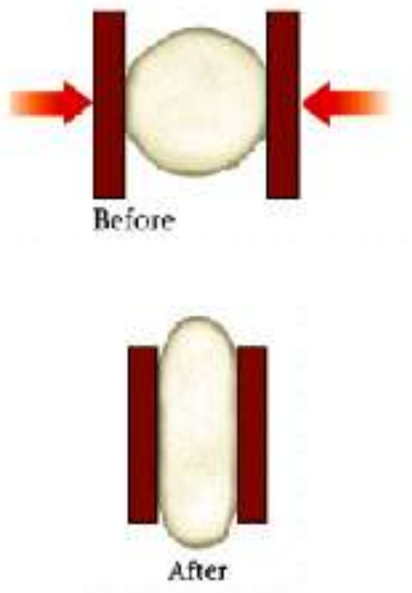
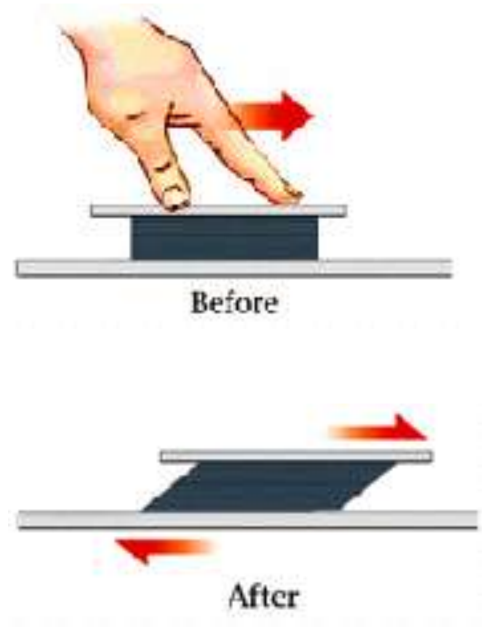
Factors That Control the Characteristics of Metamorphic Rocks

- **Differential pressure**
  - **Is *not* equal in all directions**
  - **Leads to *formation of foliation* by either**
    - ***Pure shear (flattening)***
    - ***Simple shear (skewing)***



Pure shear (flattening)



Simple shear (skewing)

Factors That Control the Characteristics of Metamorphic Rocks

Type of foliation

- **Slaty Cleavage – Alignment of small mica flakes**
- ***Schistosity* – Alignment of large mica flakes**
- ***Gneissic Banding* – segregation of felsic and mafic minerals into alternating light and dark bands**

Factors That Control the Characteristics of Metamorphic Rocks

Foliation: Development of Slaty Cleavage

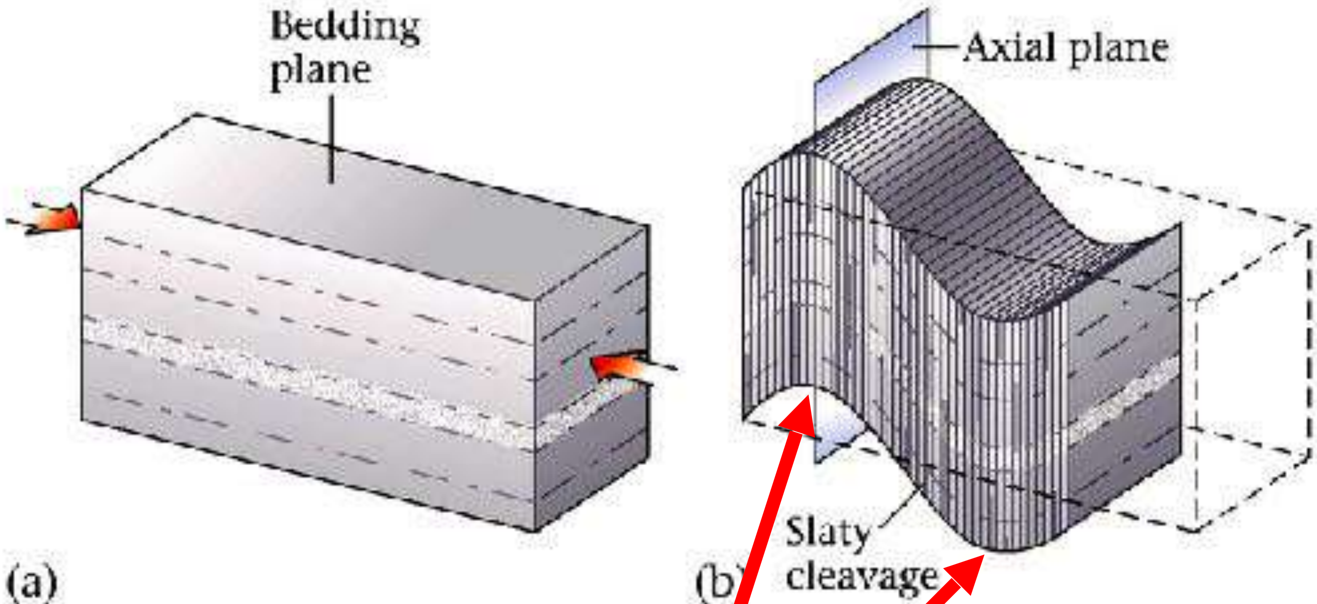


FIGURE 8.9

Earth: Portrait of a Planet, 2nd Edition
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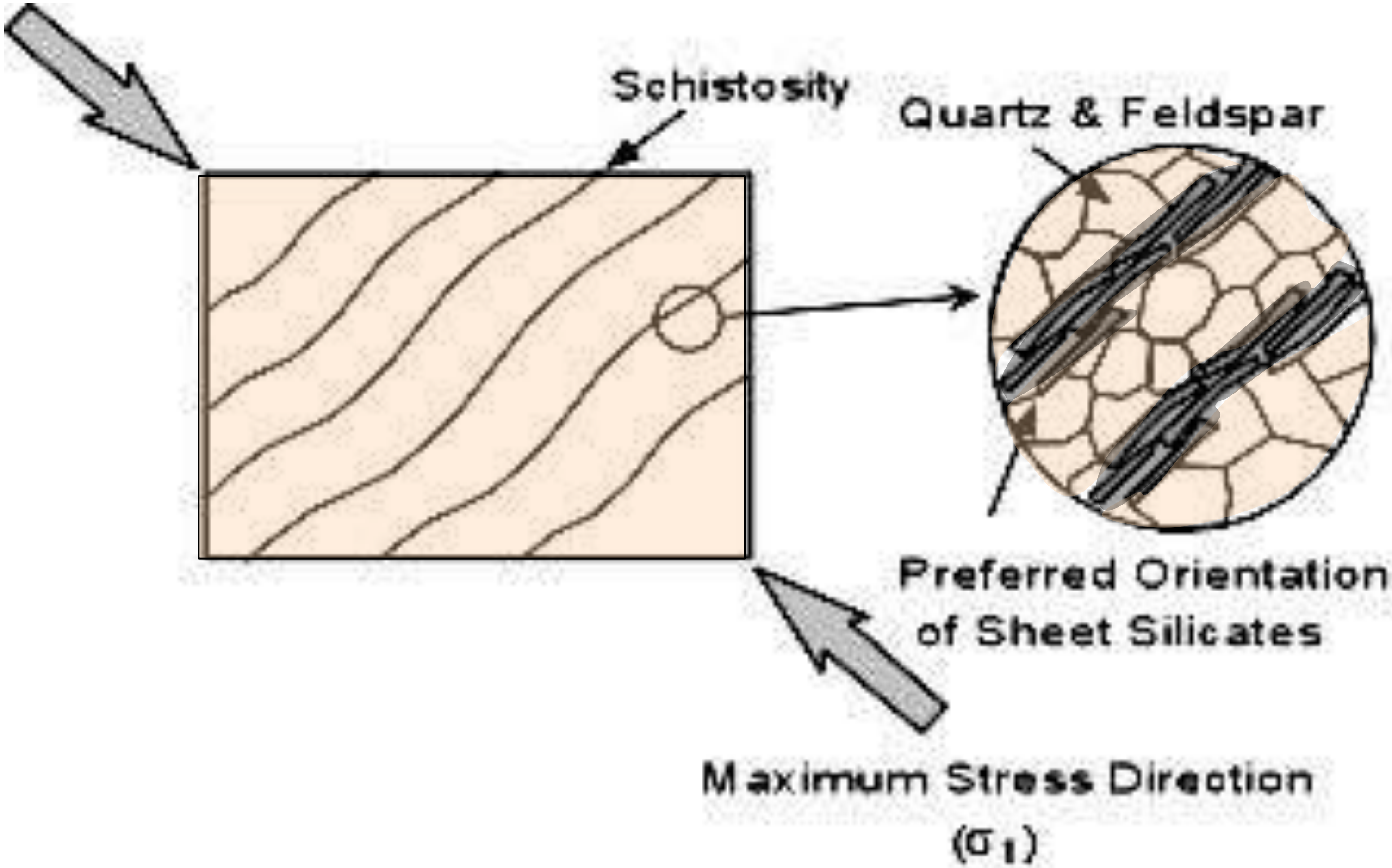
Bedding is perpendicular to cleavage at the top and bottom of the fold

Factors That Control the Characteristics of Metamorphic Rocks

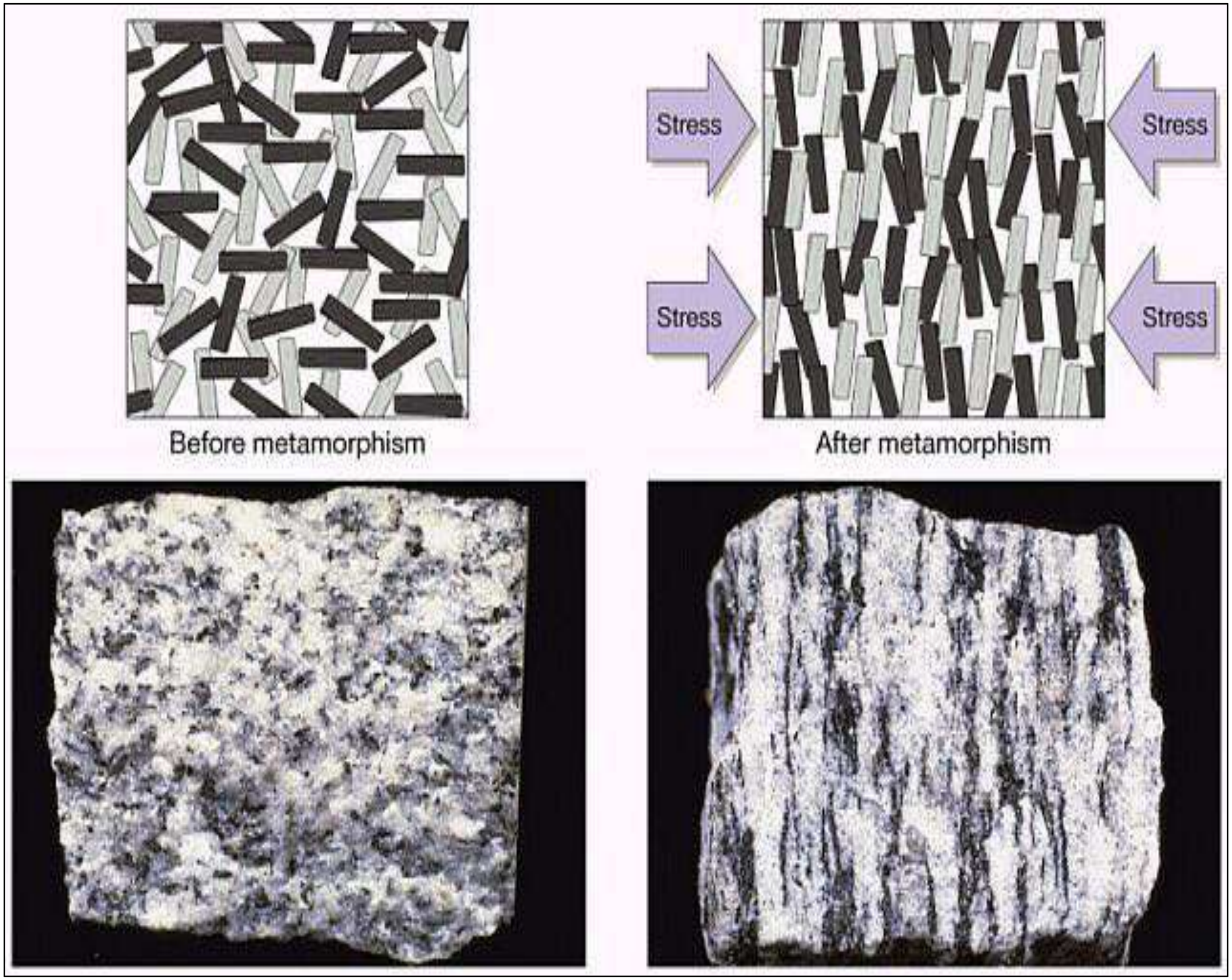
Foliation: Development of Schistosity

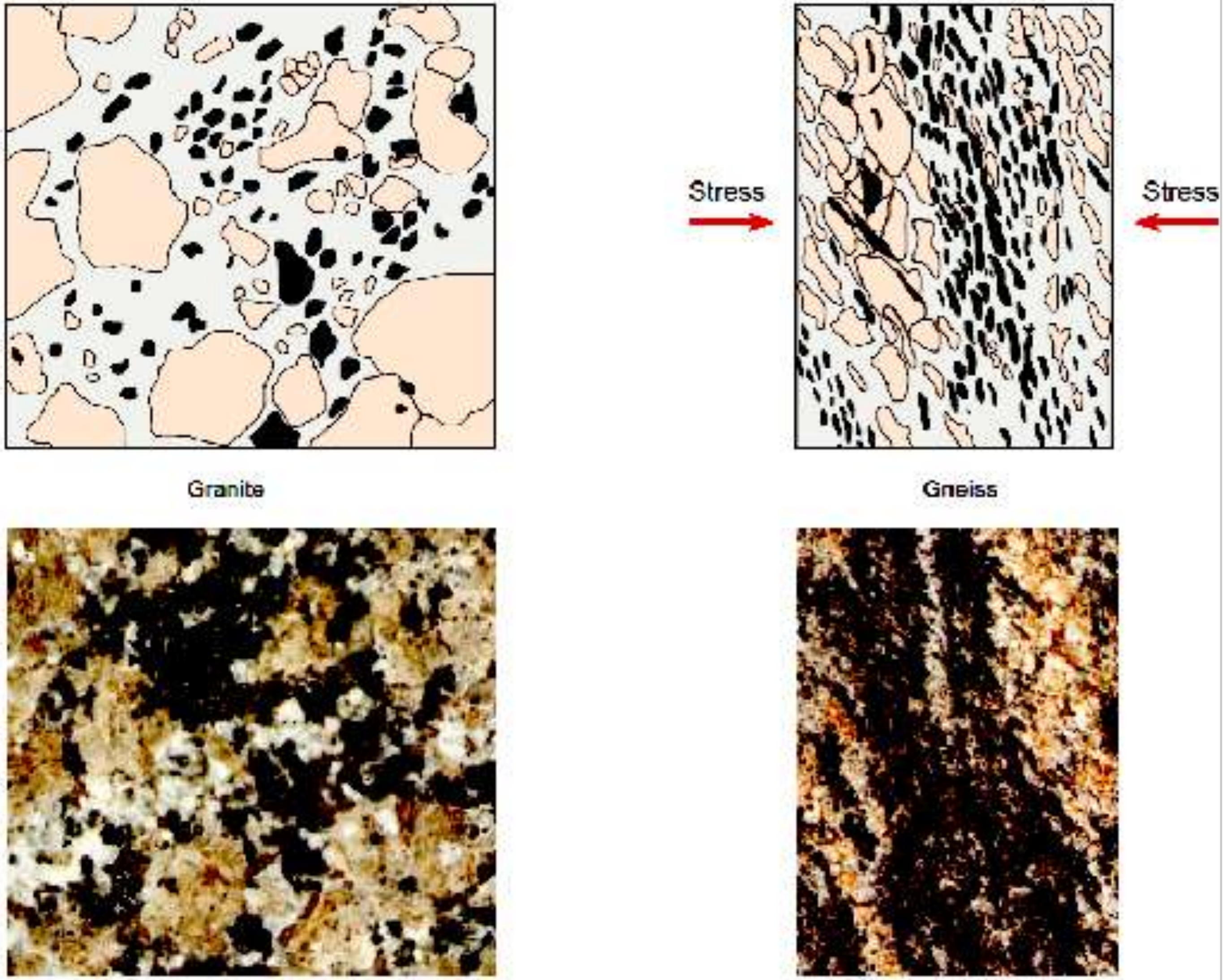


http://www.tulane.edu/~sanelson/geol212/contactmeta.htm

Factors That Control the Characteristics of Metamorphic Rocks

Foliation: Formation of Gneissic Banding





(A) The minerals in this granite crystallized from a melt and in absence of directed stress. Crystals grew freely in all directions.

(B) Micas in this gneiss grew perpendicular to the directed stress. A granite was metamorphosed and developed a foliation to become a gneiss.

FIGURE 6.8 **Foliation develops in metamorphic rocks** when platy minerals grow. Minerals such as mica grow perpendicular to the applied stress. For example, during compression, the foliation will be perpendicular to the directed stress. *(Courtesy of Cold Spring Granite Company)*

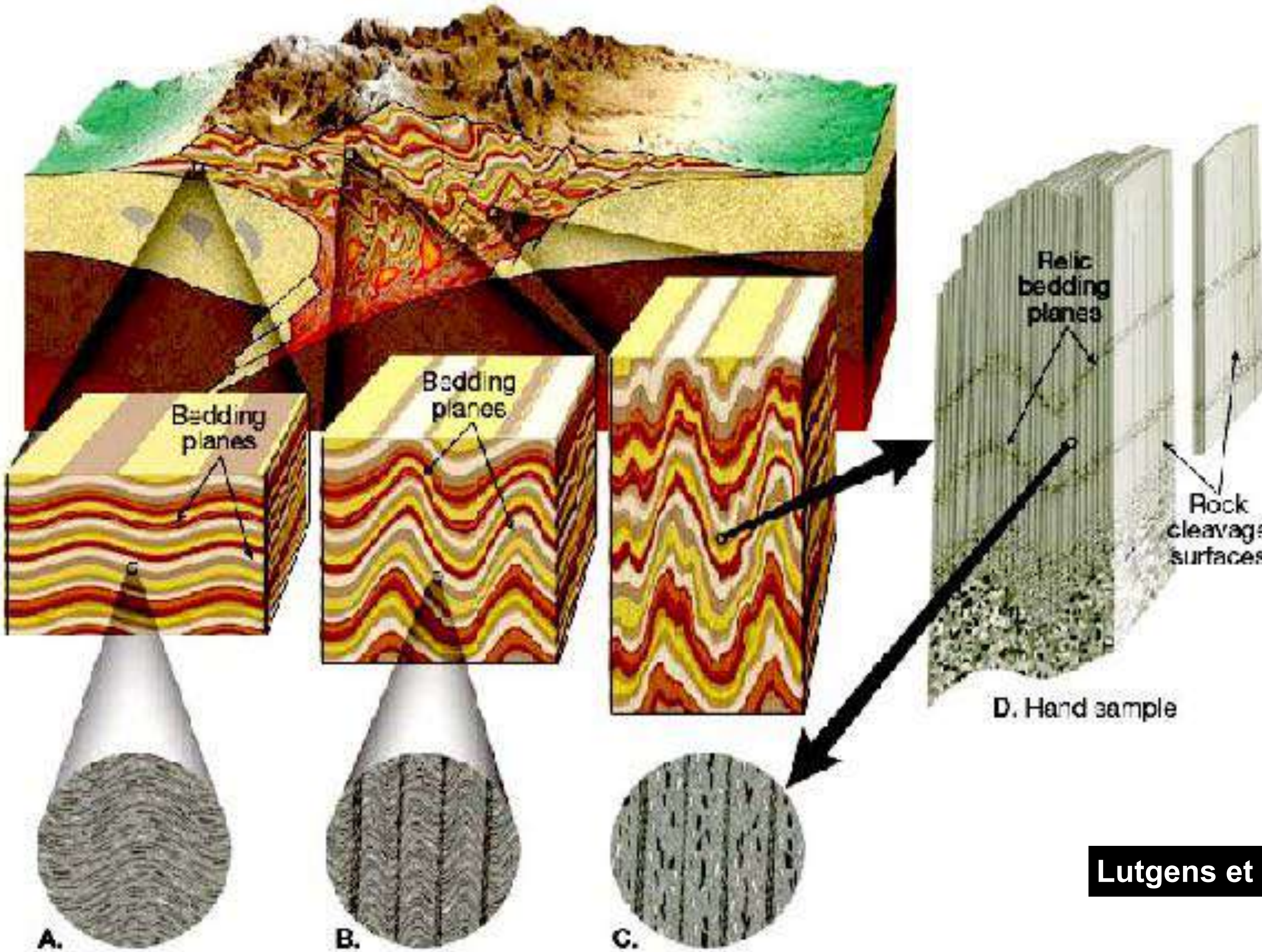


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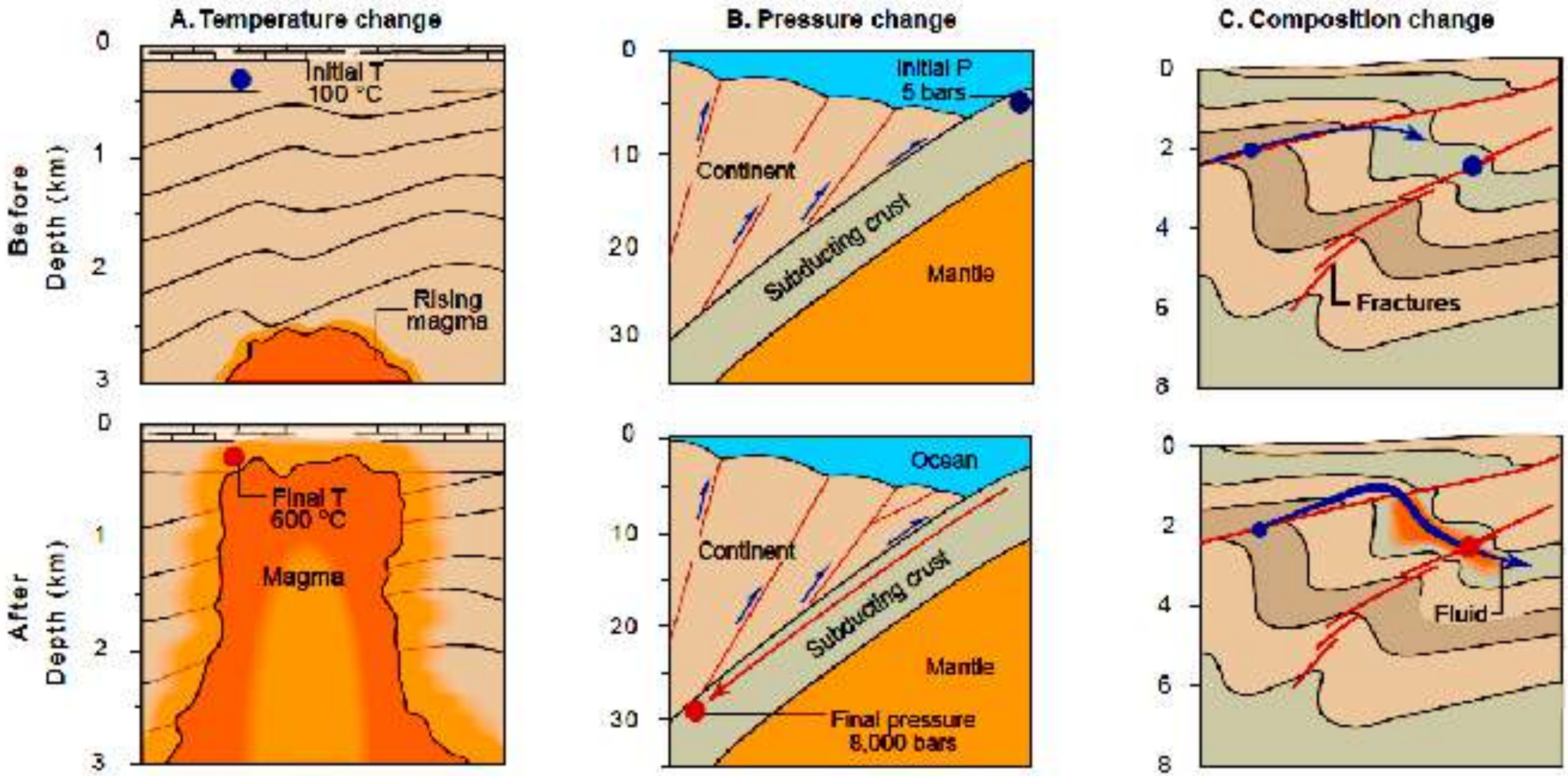
FIGURE 7.7 Development of rock cleavage. As shale is strongly folded (**A.**, **B.**) and metamorphosed to form slate, the developing mica flakes are bent into microfolds. **C.** Further metamorphism results in the recrystallization of mica grains along the limbs of these folds to enhance the foliation. **D.** This hand sample of slate illustrates rock cleavage and its orientation to relic bedding surfaces.

Factors That Control the Characteristics of Metamorphic Rocks

3. **Temperature (or Heat)**
   - ❑ ***Increasing temperature*** **causes increased movement of ions which in turn causes**
     - **Mineral grains to grow larger**
     - **Minerals to recrystallize**
   - ❑ **The upper limit on T for metamorphism is partial melting**

4. **Time**
   - ❑ **Metamorphic reactions and textural changes require millions of years to occur**



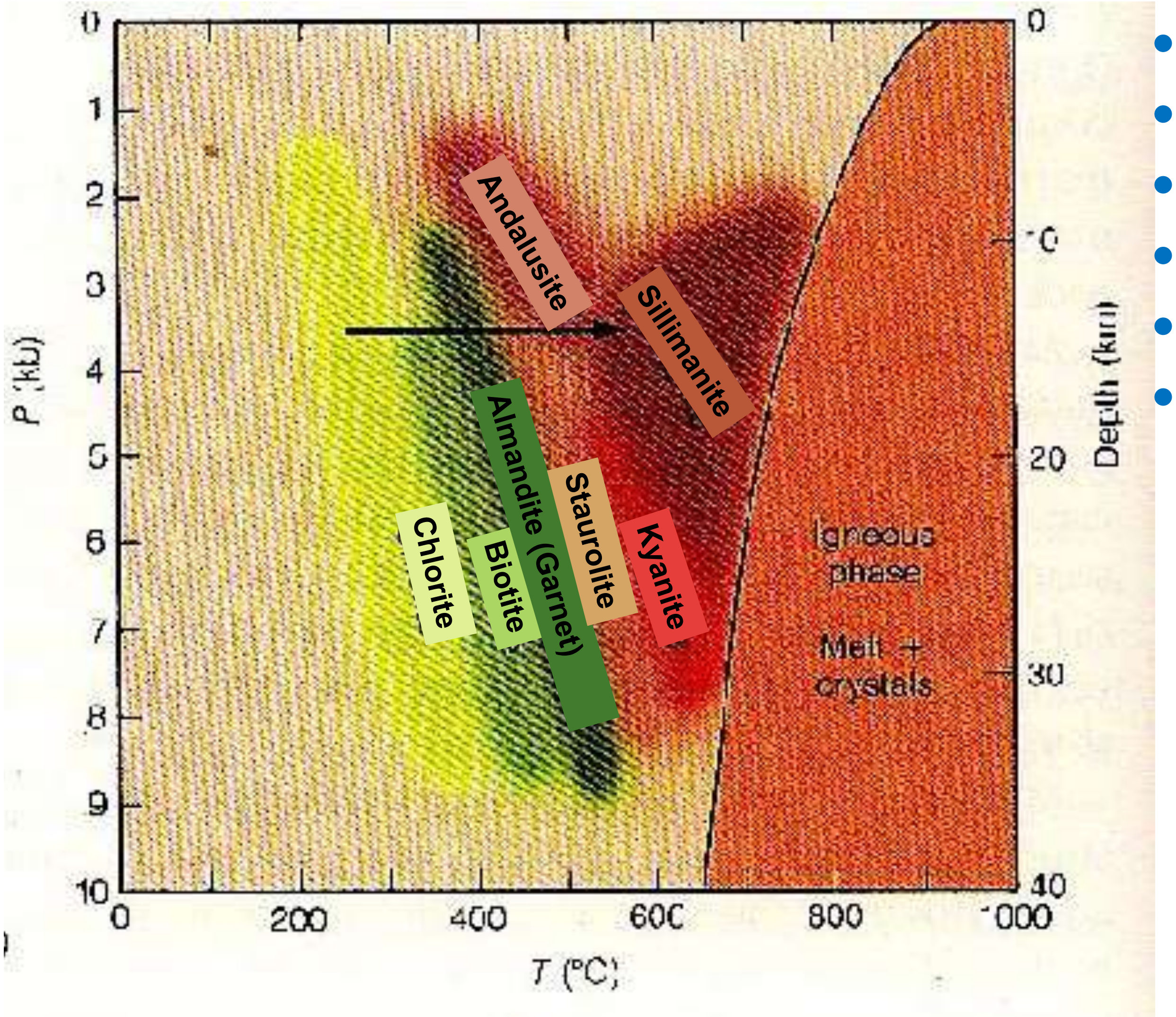
(A) Temperature changes when a magmatic body intrudes the shallow crust and causes recrystallization around the intrusion (region in light orange).

(B) Pressure changes can be caused by the collision of two plates, where minerals at low pressure (blue dot) are dragged to high pressure (red dot) in a subducting plate.

(C) Fluids carrying dissolved ions may flow from one spot (blue dot) to another (red dot), causing minerals along the flow path to recrystallize as they equilibrate with the fluid.

FIGURE 6.4 **Metamorphic changes** can occur as the result of changes in temperature, pressure, and in the composition of pore fluids, as the rocks attempt to reach equilibrium with the new conditions. These cross sections illustrate some of the changes.

Index Minerals of Metamorphic Rocks



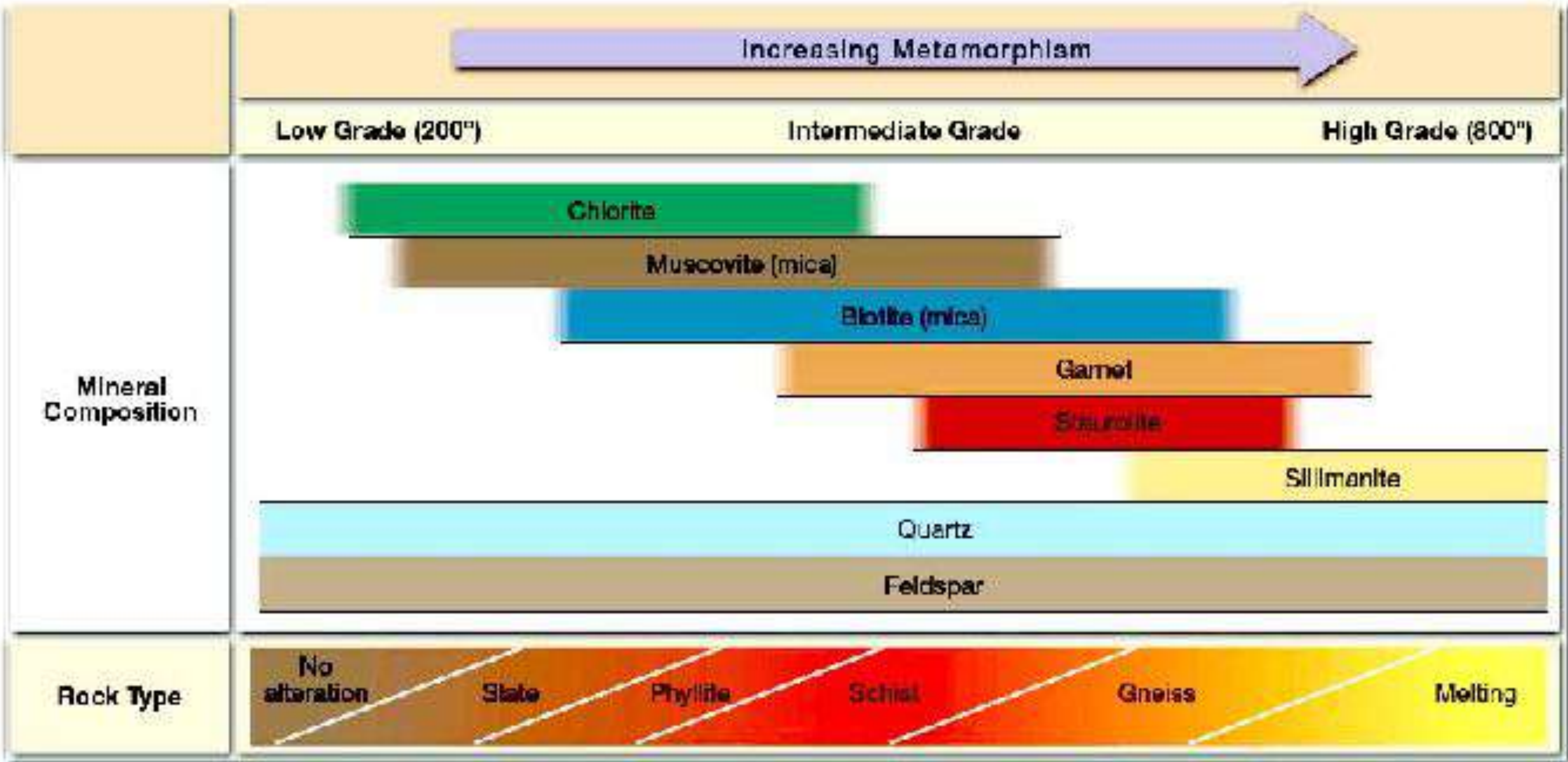
Index Minerals

- Chlorite
- Biotite
- Almandite (garnet)
- Staurolite
- Andalusite
- Kyanite
- Sillimanite

Not specific

- Quartz
- Plagioclase
- Orthoclase
- Biotite
- Muscovite
- Hornblende
- Calcite
- Dolomite

Index Minerals of Metamorphic Rocks



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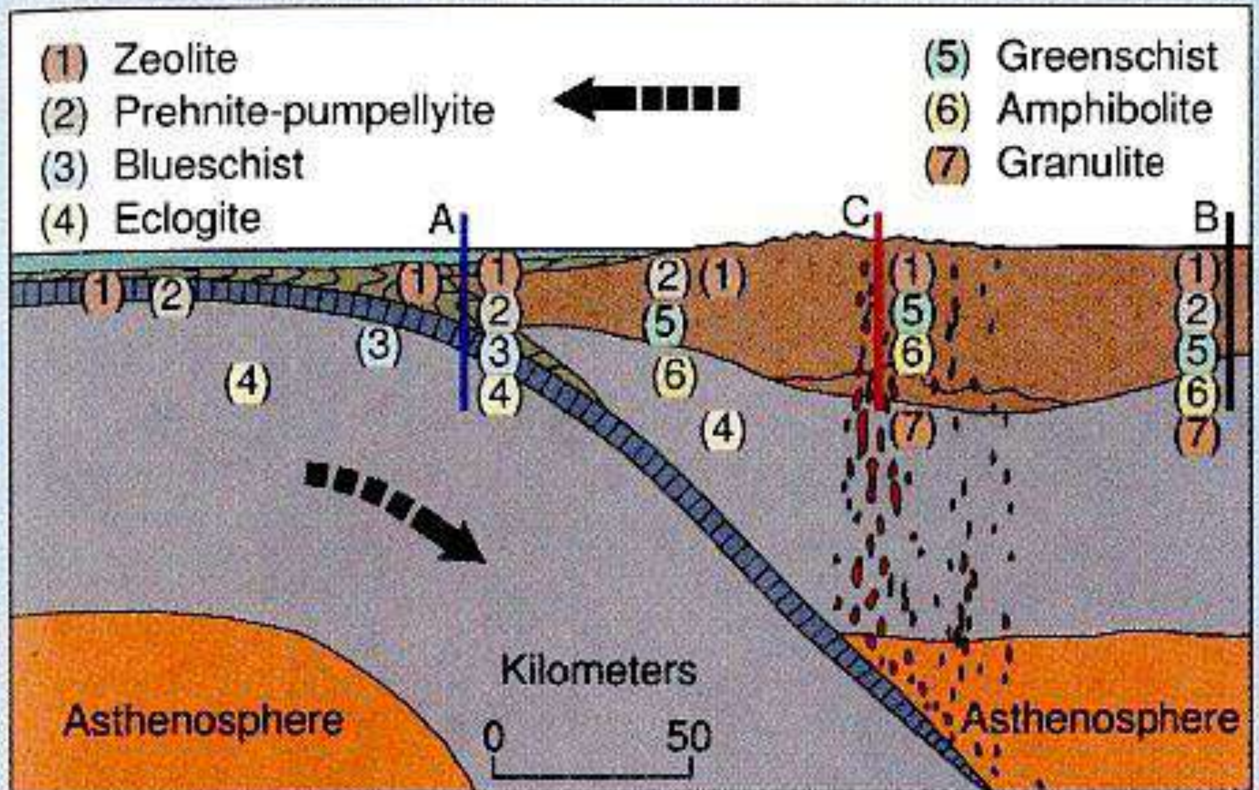
Metamorphic Facies (P & T conditions)

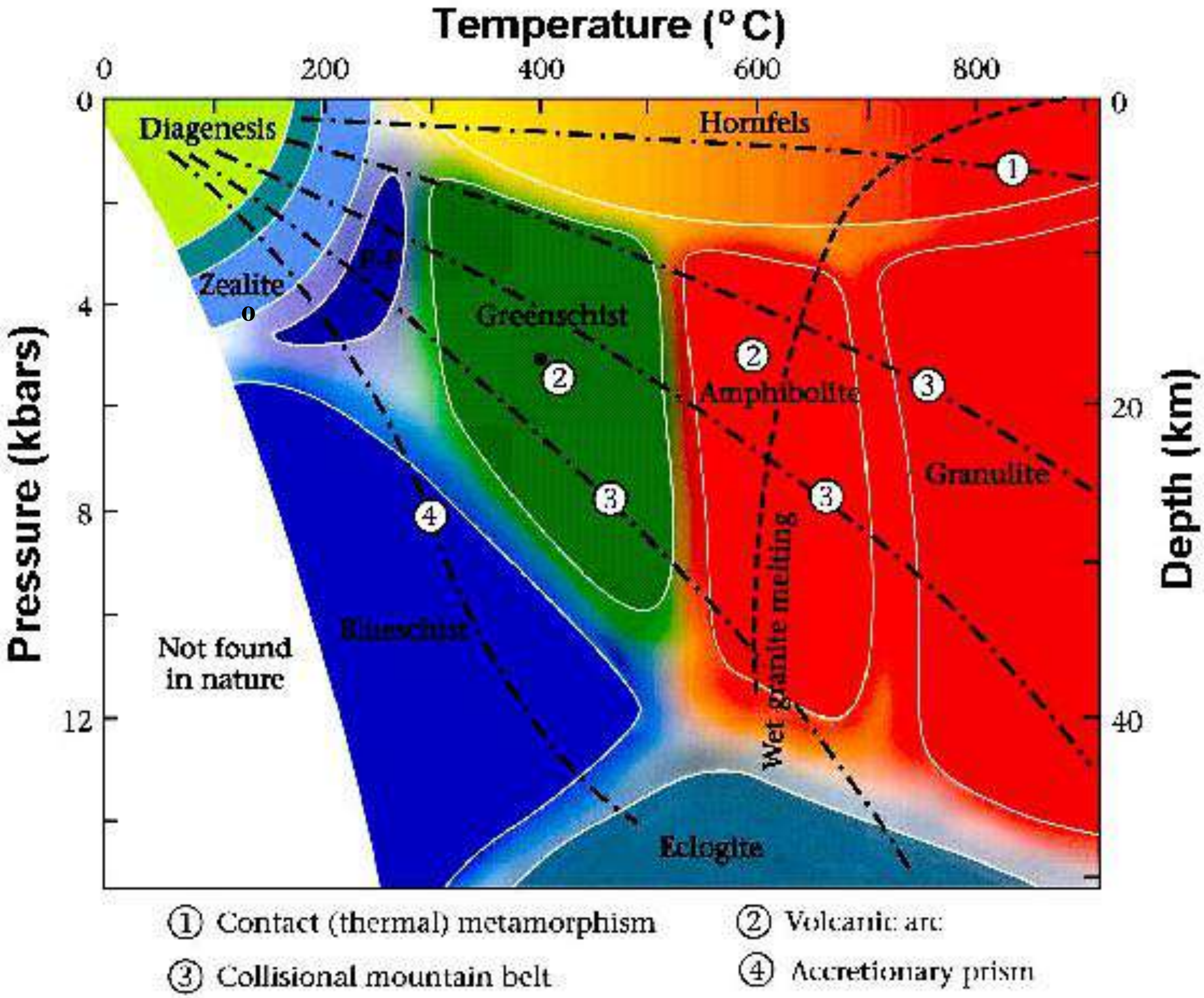


Box 15.3 Figure 2

Schematic representation of the distribution of facies across a convergent plate boundary.

From W. G. Ernst, *Metamorphism and Plate Tectonic Regimes*. Stroudsburg, Pa.: Dowden, Hutchinson, & Ross, 1975; p. 426. Reprinted by permission of the publisher.

Metamorphic Facies (P & T conditions)

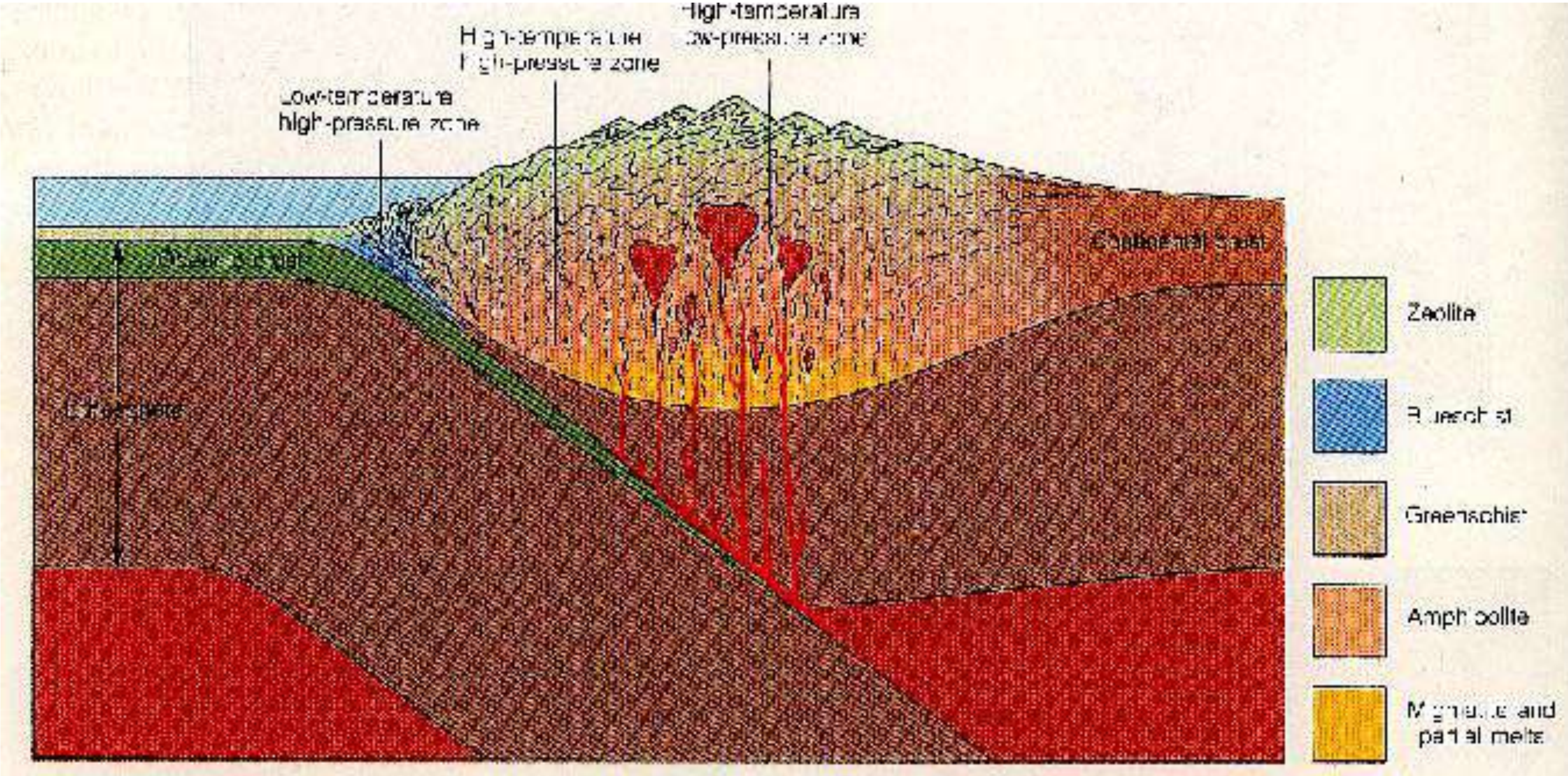


Classification of Metamorphic Rocks

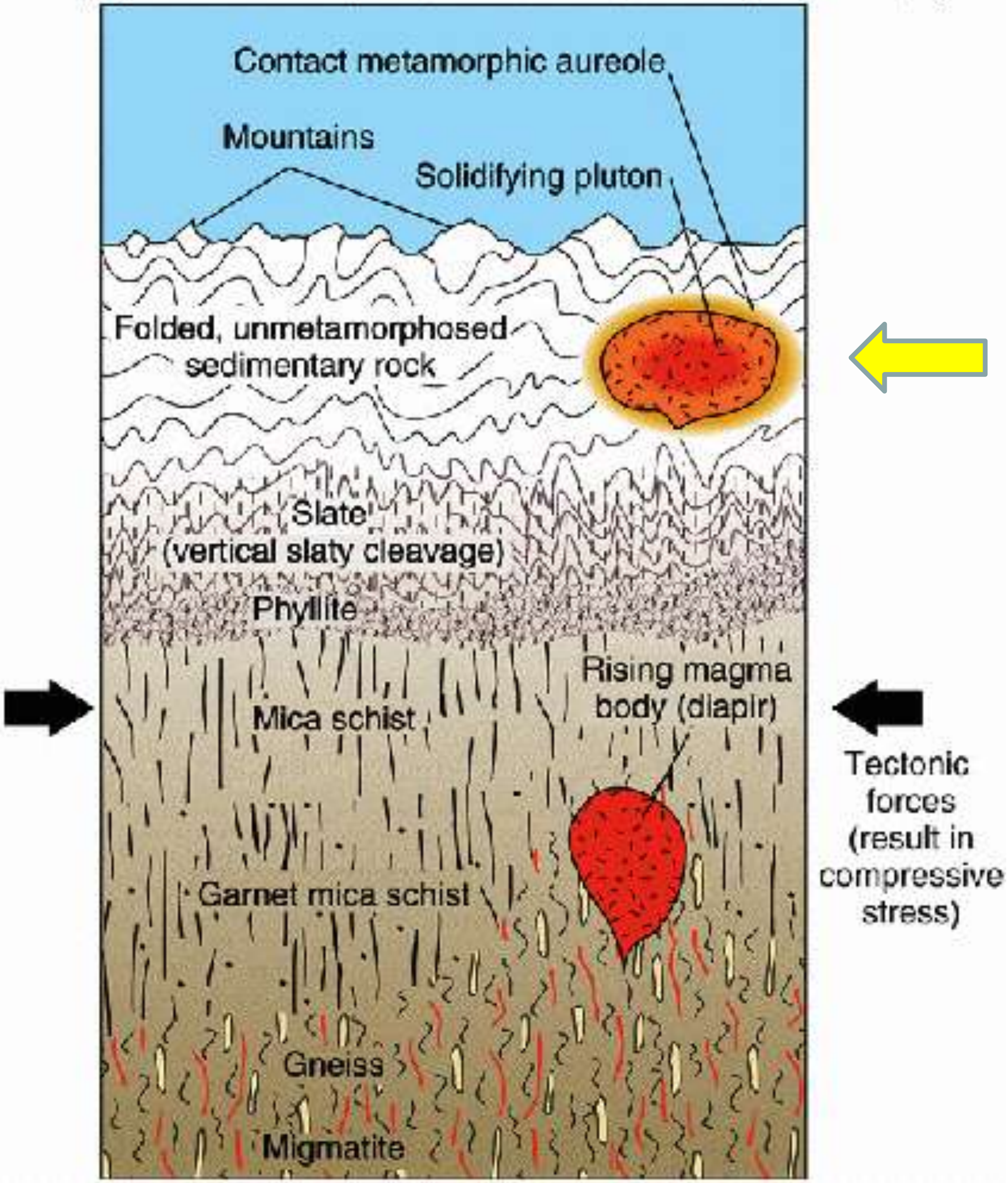
1. <u>Regional metamorphic rocks</u>
   - Form in response to increased temperature and directed pressure along plate boundaries
   - Foliated
   - Sheared by pure shear or simple shear

2. <u>Local (contact) metamorphic rocks</u>
   - Form in response to contact with magma at high T and /or high confining P
   - Found adjacent to igneous intrusions
   - Are usually unfoliated

Where do the metamorphic rocks form?



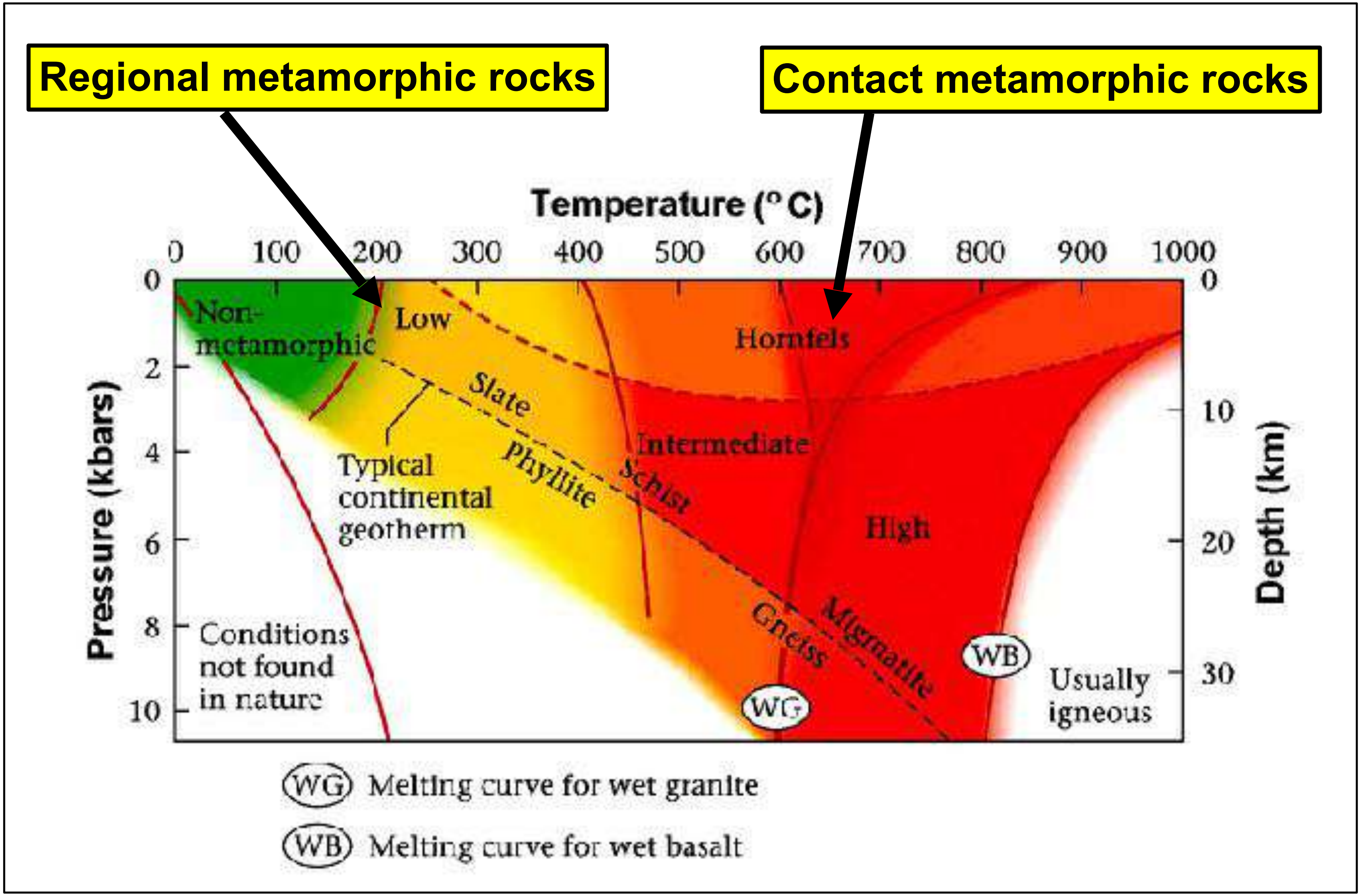
Classification of Metamorphic Rocks



Formation of Contact Metamorphic Rocks

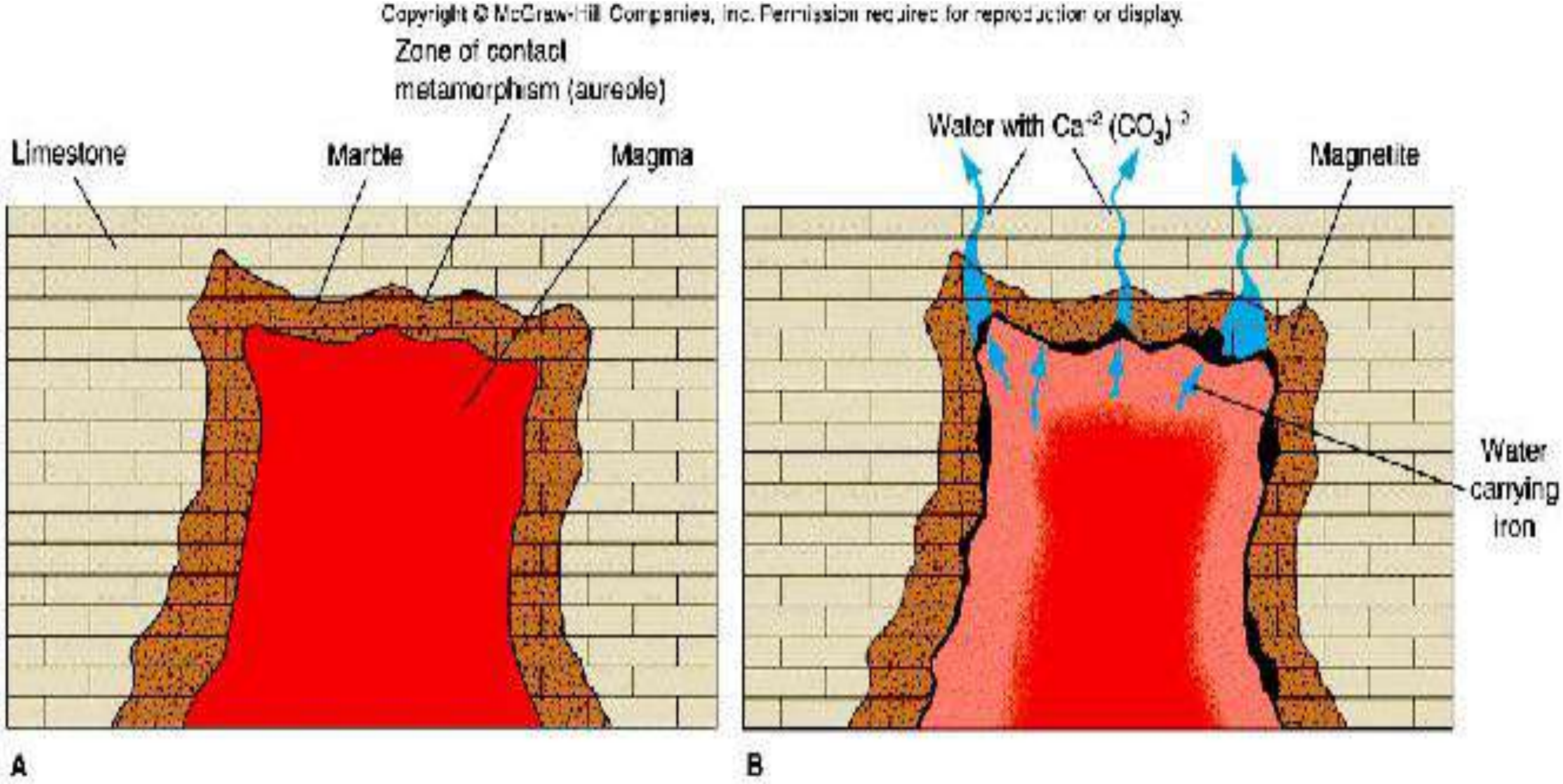
Formation of Regional Metamorphic Rocks

Classification of Metamorphic Rocks



Classification of Metamorphic Rocks

Formation of Contact Metamorphic Rocks



CONTACT METAMORPHISM

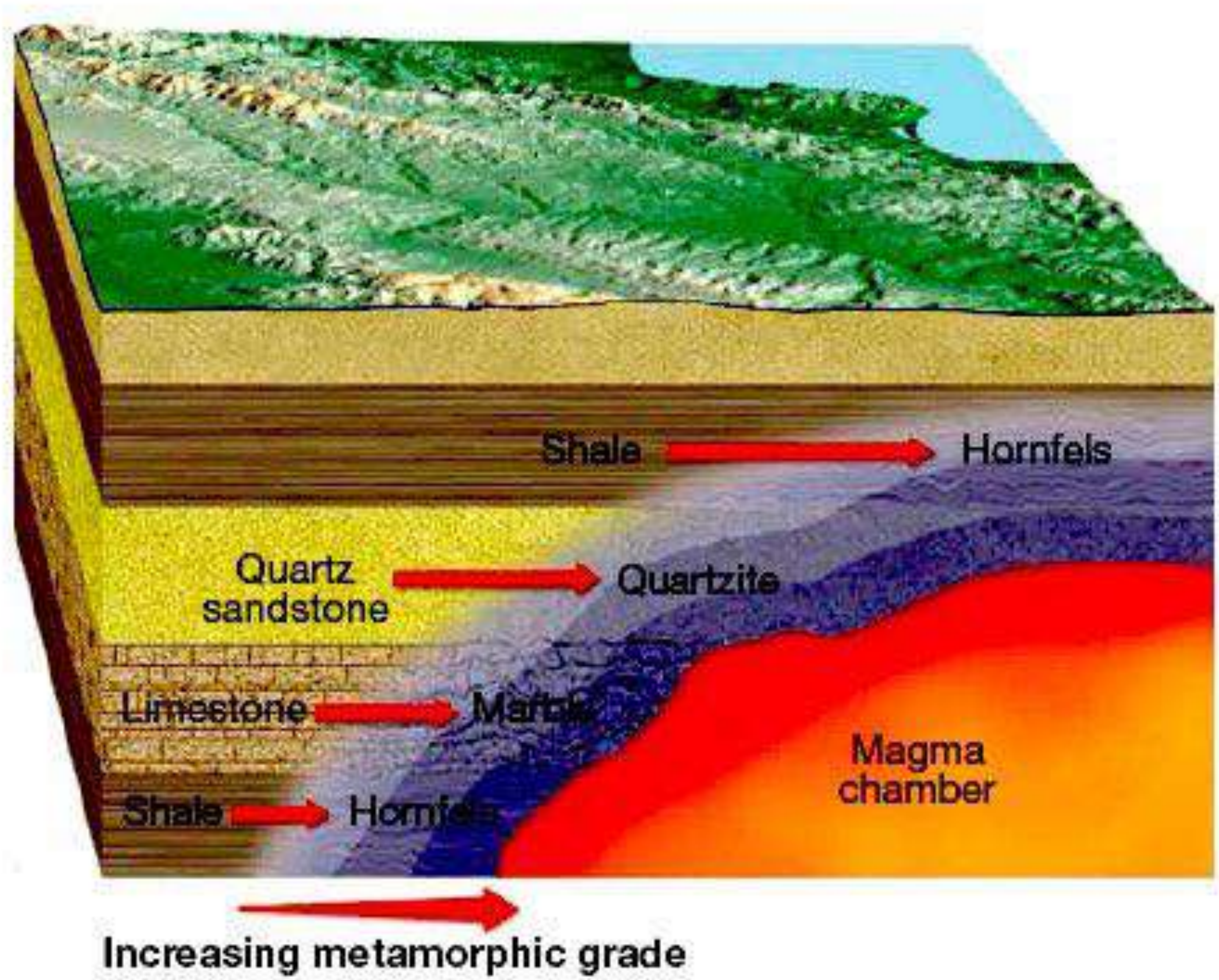


FIGURE 7.15 Contact metamorphism of shale yields hornfels, while contact metamorphism of quartz sandstone and limestone produces quartzite and marble, respectively.

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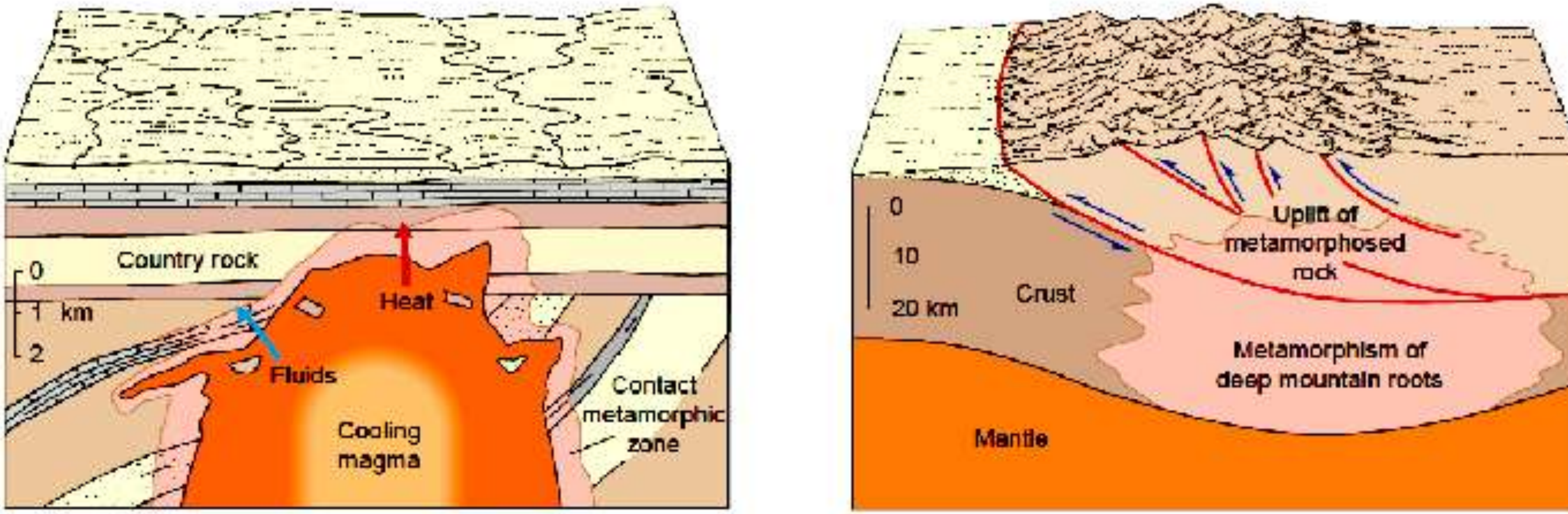
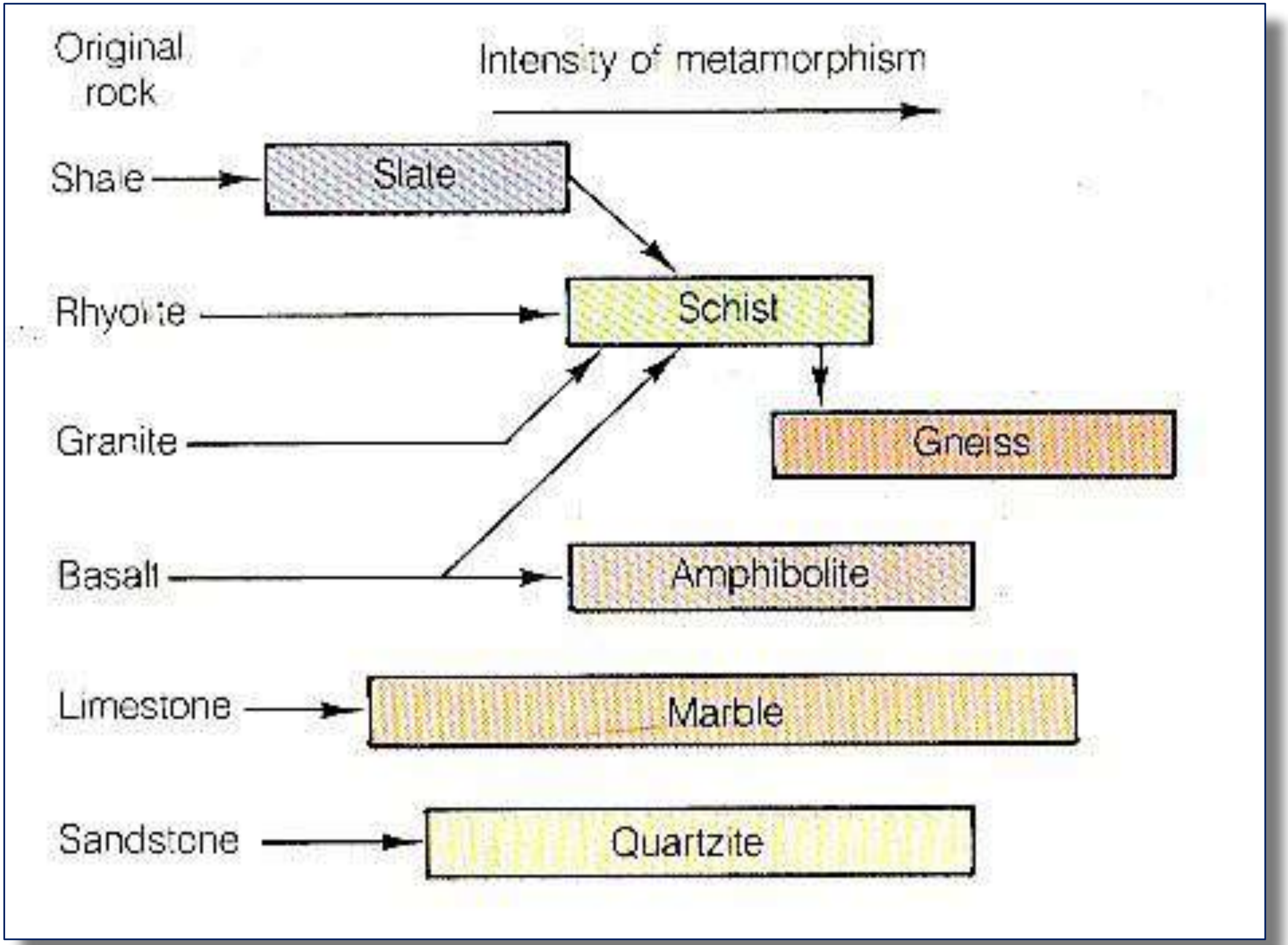


(A) Contact metamorphism occurs around hot igneous intrusions. Changes in temperature and composition of pore fluids cause preexisting minerals to change and reach equilibrium in the new environment. Narrow zones of altered rock extending from a few meters to a few hundred meters from the contact are produced.

(B) Regional metamorphism develops deep in the crust, usually as the result of subduction or continental collision. Wide areas are deformed, subjected to higher pressures, and intruded by igneous rocks. Hot fluids may also cause metamorphic recrystallization.

FIGURE 6.6 **Metamorphic environments** are many and varied. Two major examples are shown here.

Protolith and Metamorphic Rocks



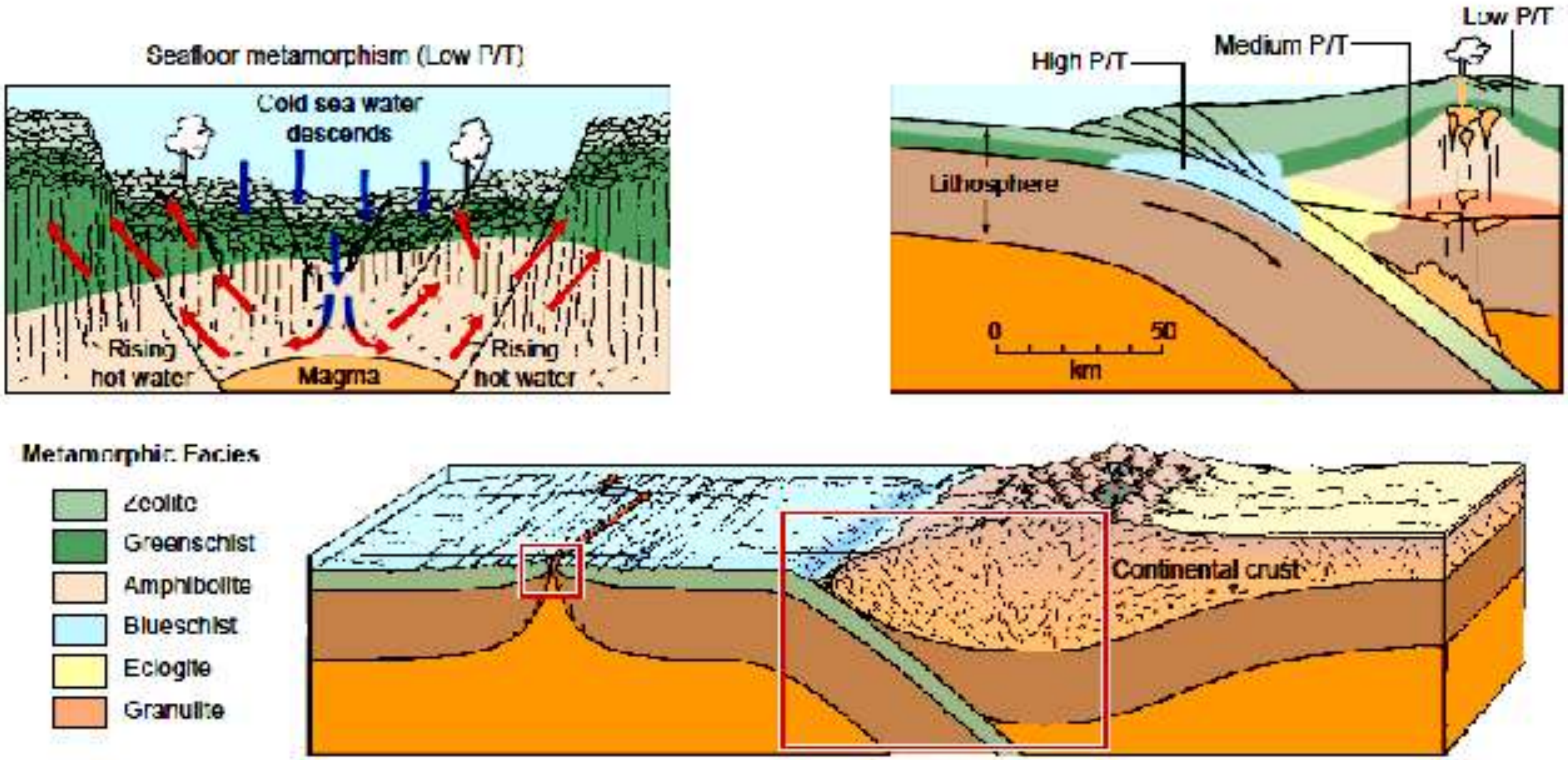


FIGURE 6.19 **The origin of metamorphic rocks** is strongly linked to plate tectonics. Oceanic crust is dragged deep into the mantle along a subduction zone to form blueschists. In the deep mountain roots, high temperatures and high pressures occur and develop schists and gneisses. Contact metamorphism develops around the margins of igneous intrusions. Ocean ridge metamorphism is caused by the circulation of seawater through hot basaltic rocks of the ocean floor.

Types of Metamorphic Rocks

A. Foliated Metamorphic Rocks

Are formed by differential pressure (pure shear, simple shear)

- **Slate**
  Dull, microscopic grains, strong slaty cleavage, any color, mudstone protolith
- **Phyllite**
  Shiny, strongly micaceous with microscopic grains, strong schistosity, cleavage, can be mafic or felsic, any rock-type protolith
- **Schist**
  Shiny, strongly micaceous, fine to medium grained, strong schistosity, cleavage, any color, any rock-type protolith
- **Gneiss**
  Dull, weakly micaceous, fine to coarse grained, banded, weak cleavage, any rock-type protolith, but most often sheared coarse grained protolith such as granite, conglomerate, breccia
- **Migmatite**
  Dull, weakly micaceous, fine to coarse grained, folded banded texture, weak cleavage, almost melted, any rock-type protolith

Types of Metamorphic Rocks

Slate

Protolith: Fine grained rock like shale, mudstone, or siltstone

Appearance: Dull, microscopic grains, strong slaty cleavage, any color

Phyllite

Protolith: **Can be any rock-type**

Appearance: **Shiny, strongly micaceous with *microscopic grains*, has strong schistose cleavage, can be felsic (muscovite-rich, silvery) or Mafic (biotite-rich, shiny medium to dark gray)**

Schist

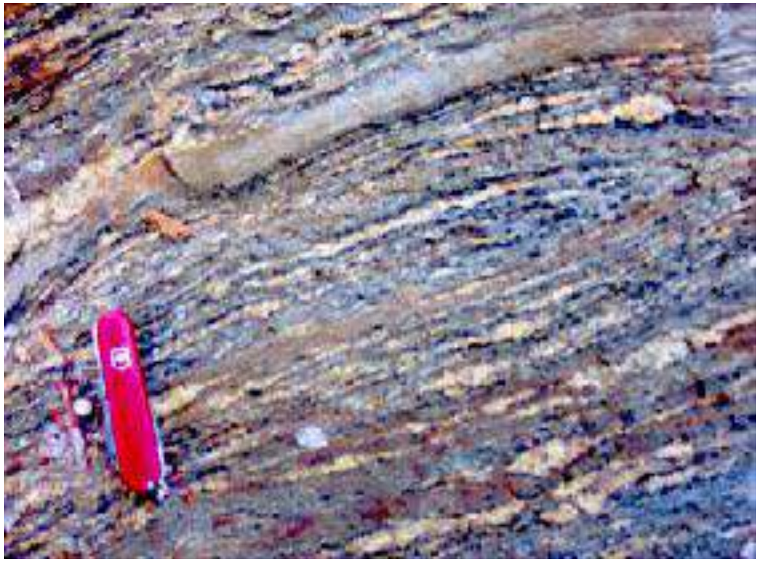
Protolith: **Can be any rock-type**

Appearance: **Shiny, strongly micaceous, fine to medium grained has strong schistose cleavage, can be felsic (muscovite-rich, silvery) or mafic (biotite-rich, shiny medium to dark gray)**

Types of Metamorphic Rocks

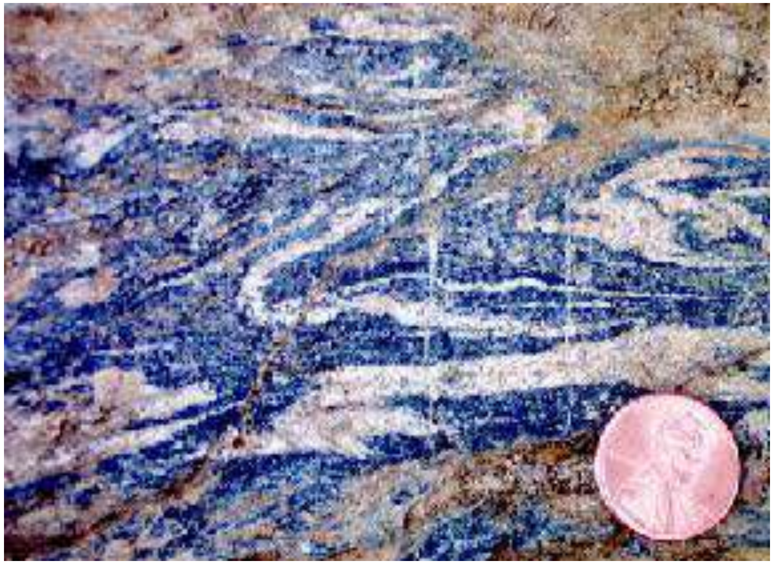
Gneiss

Protolith: **Can be any rock-type, but most often formed from a sheared coarse grained protolith such as granite, conglomerate, breccia**



Appearance: **Dull, weakly micaceous, fine to coarse grained, banded, weak cleavage**

Migmatite



Protolith: Can be any rock-type

Appearance: Dull, weakly micaceous, fine to coarse grained, folded banded texture, weak cleavage, almost melted, a folded gneiss

Types of Metamorphic Rocks

B. Special Types of Metamorphic Rocks

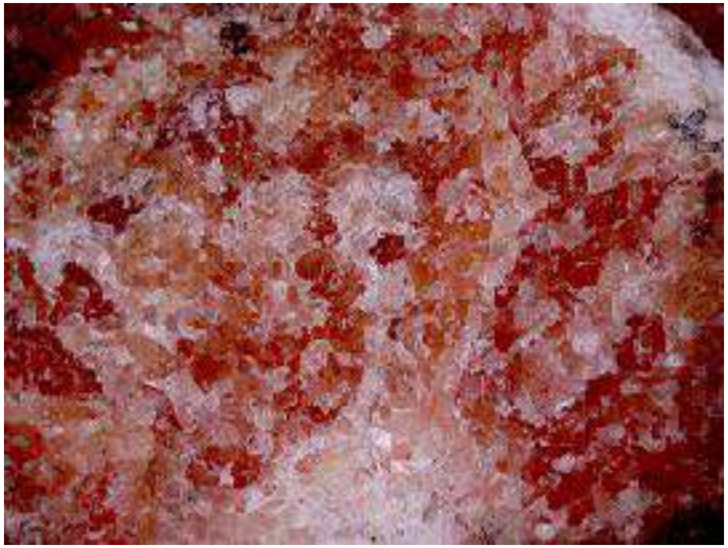
May be foliated or unfoliated

- Quartzite
  - **Metamorphosed sandstone**
  - **Harder than marble**
  - **Will not fizz (release CO_2) in the presence of acid**

B. Special Types of Metamorphic Rocks

May be foliated or unfoliated

- Marble
  - Metamorphosed limestone
  - Contains calcium carbonate
  - Will fizz (release CO_2) in the presence of acid
  - Softer than quartzite



B. Special Types of Metamorphic Rocks

May be foliated or unfoliated

- **Anthracite**
  - **Metamorphosed bituminous coal**
  - **Low density**
  - **Very shiny black**

Types of Metamorphic Rocks

B. Special Types of Metamorphic Rocks

May be foliated or unfoliated

- **Amphibolite**
  - **Dull black, fine to coarse grained, weak cleavage if sheared (gneissic)**
  - **Metamorphosed gabbro, basalt, or diorite**

Dark rock composed mostly of amphibole and Ca-Na plagioclase, may be either foliated or unfoliated, often with large (visible) elongated crystals of amphibole

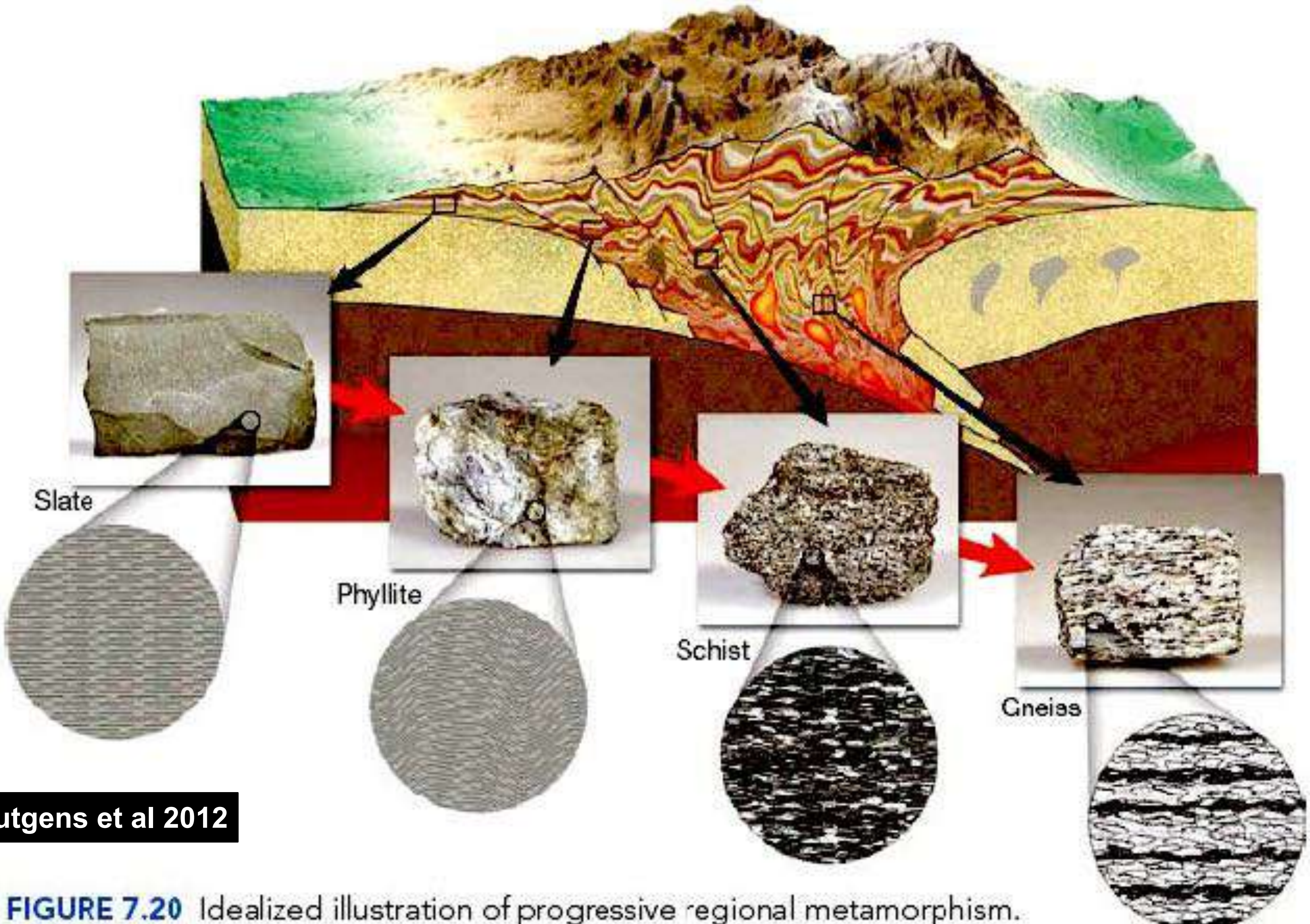


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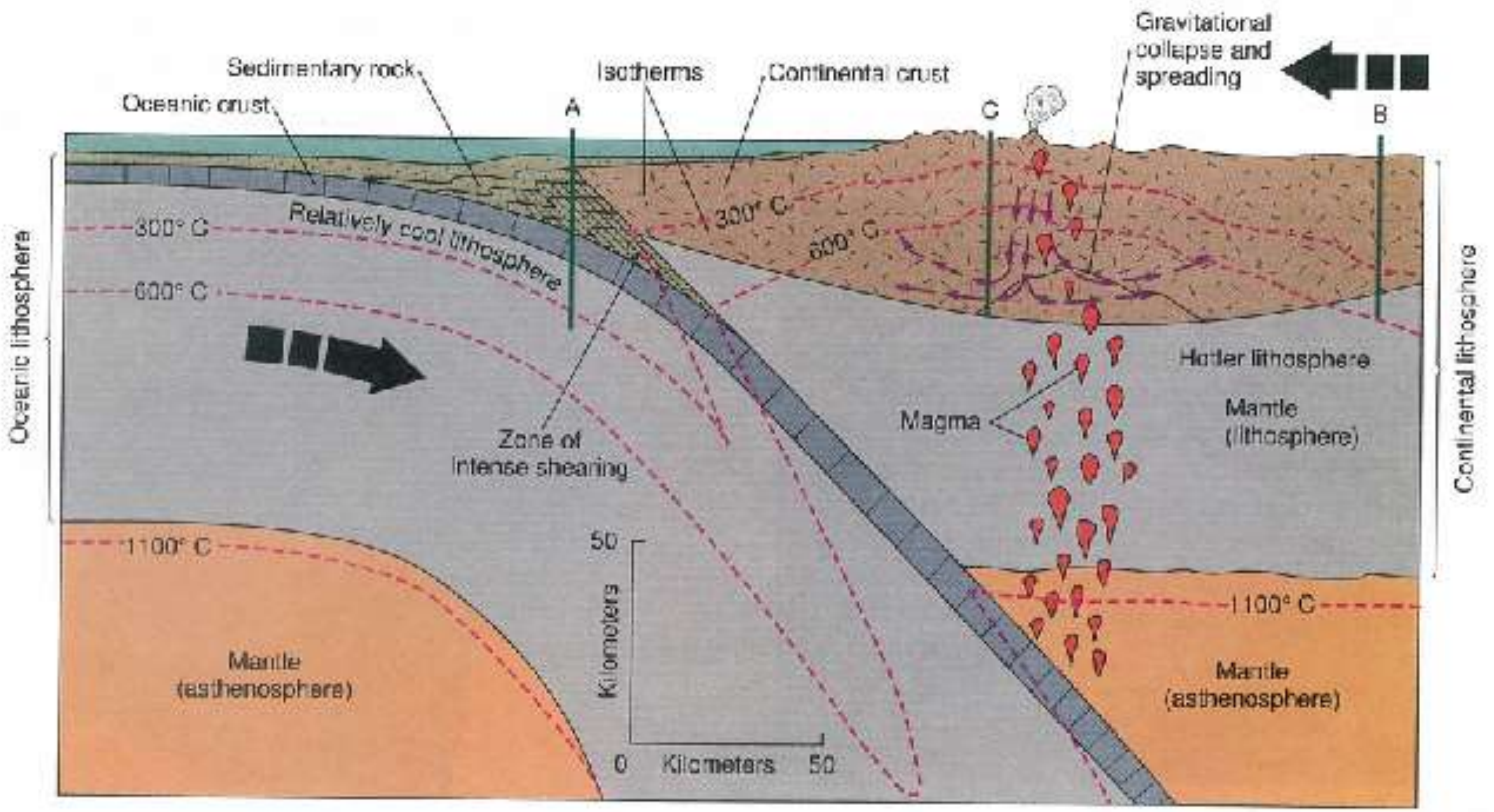
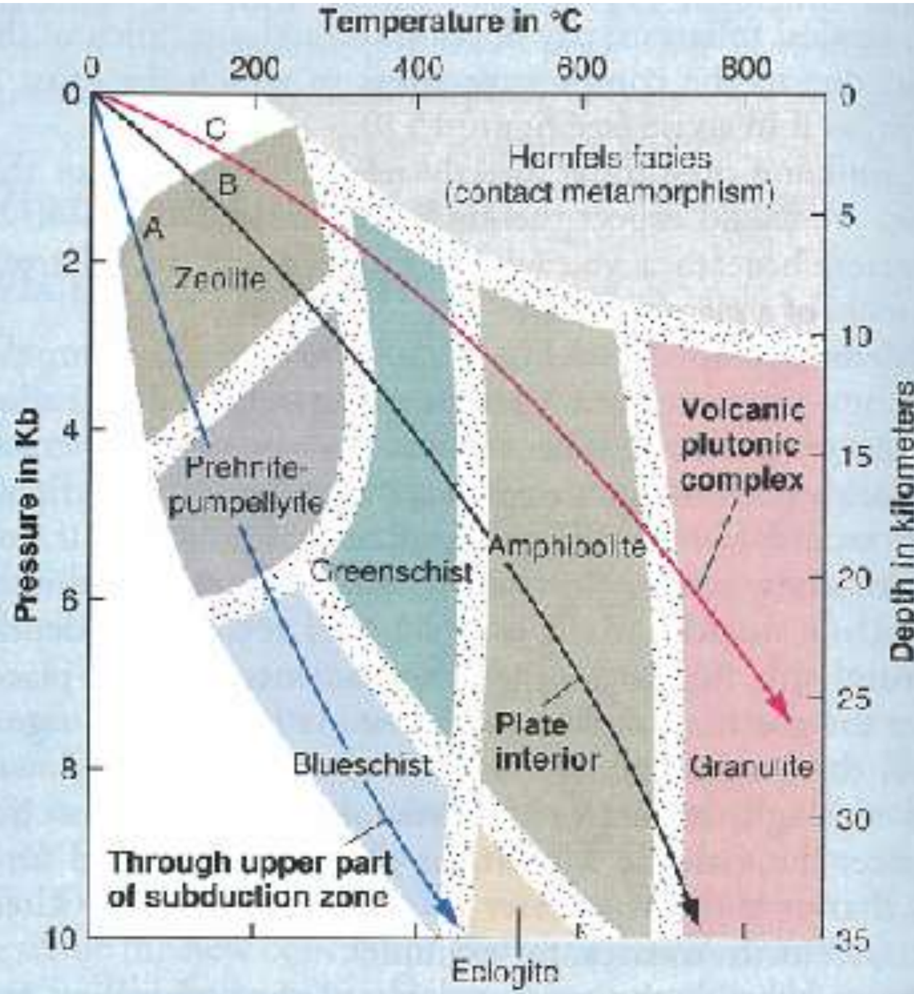
FIGURE 7.20 Idealized illustration of progressive regional metamorphism. From left to right, we progress from low-grade metamorphism (slate) to high-grade metamorphism (gneiss). *(Photos by E. J. Tarbuck)*

THANK YOU

Where do the metamorphic rocks form?

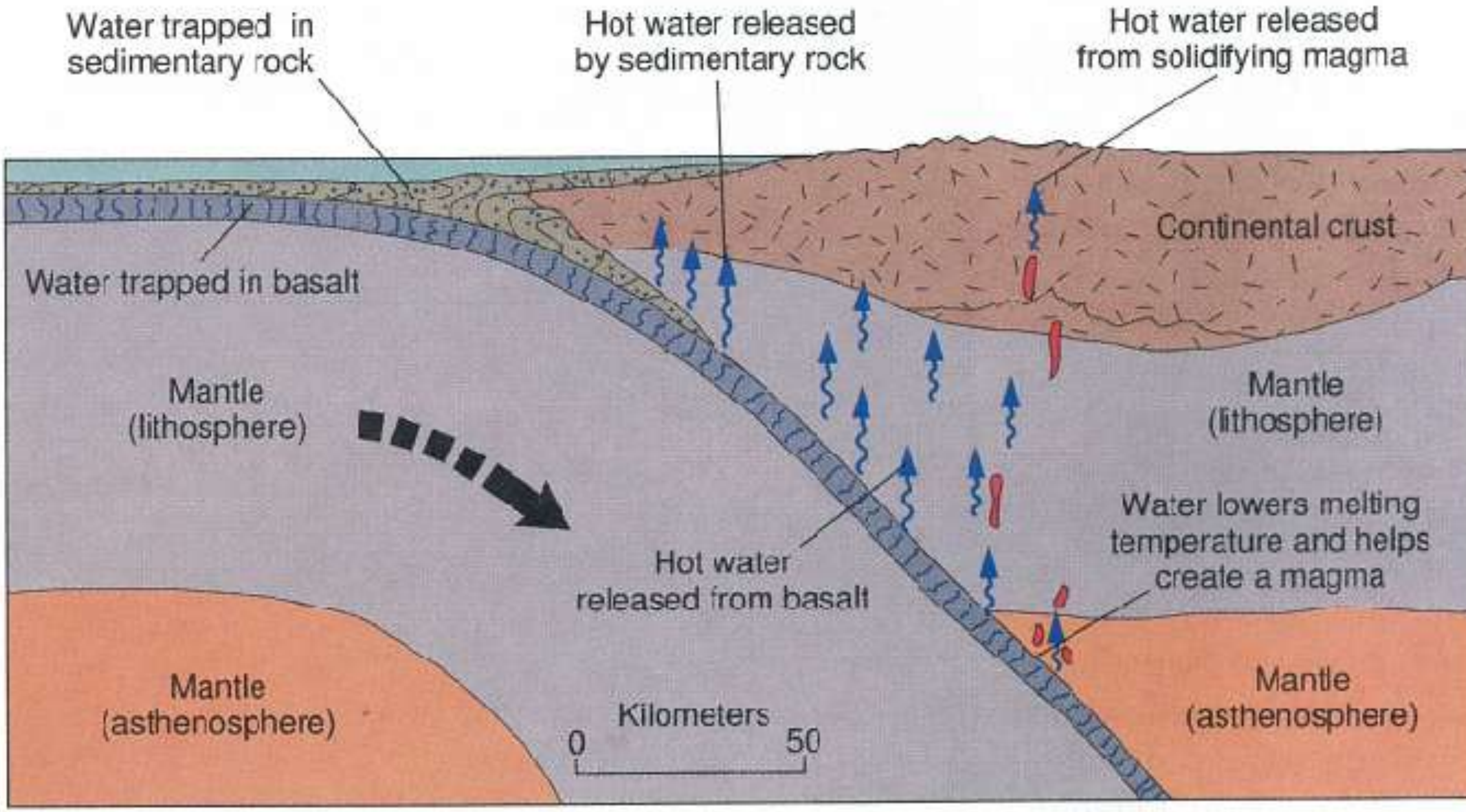




Box 15.3 Figure 1

The metamorphic facies. Facies are named after minerals (prehnite, zeolite, pumpellyite) or rock types (e.g., blueschist, granulite). Boundaries between facies are approximate. The arrows represent increases in temperature with depth for the three lines labeled *A, B, C* in figure 2 and in figure 15.16.

From W. G. Ernst, *Metamorphism and Plate Tectonic Regimes.* Stroudsberg, Pa.: Dowden, Hutchinson, & Ross, 1975, p. 425. Reprinted by permission of the publisher.


Water trapped in
sedimentary rock
Hot water released
by sedimentary rock
Hot water released
from solidifying magma
Continental crust
Water trapped in basalt
Mantle
(lithosphere)
Mantle
(lithosphere)
Water lowers melting
temperature and helps
create a magma
Hot water
released from basalt
Mantle
(asthenosphere)
Kilometers
0
50
Mantle
(asthenosphere)