Classification of metamorphic rocks

COMMON METAMORPHIC ROCKS

Classification of metamorphic rocks

Metamorphic rocks can be broadly classified by the:

1. **type of foliation exhibited, and**

   to a lesser extent on the

2. **chemical composition of the parent rock.**

Classification of metamorphic rock is difficult unlike in igneous and sedimentary rocks.

Because here the composition of the protolith and P/T conditions widely vary.

The presence and absence of foliated texture thus serves as primary basis for classification.

Foliated metamorphic rocks

They have well defined parallel alignment of minerals. Most rocks have pelitic composition. They are divided into four groups on the basis of metamorphic grades:

Slate
Phyllite
Schist
Gneiss
Migmatites

increases of grade of metamorphism

Non-foliated metamorphic rocks:

Non-foliated metamorphic rocks are generally massive. Four types of such rocks are common:

1. Quartzite
2. Marble
3. Amphibolite
4. Hornfels

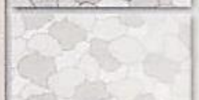
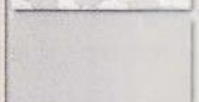
Mineralogy and chemical composition

Metamorphic rocks have diverse mineralogy.

Some minerals are common in igneous and sedimentary rocks also, e.g. quartz, plagiclase, orthoclase, muscovite, biotite, hornblende.

Minerals diagnostic to metamorphic rocks are:

chlorite, garnet, staurolite, kyanite, sillimanite

Rock Name		Texture		Grain Size	Comments	Original Parent Rock
Slate	Increasing Metamorphism	Foliated		Very fine	Excellent rock cleavage, smooth dull surfaces	Shale, mudstone, or siltstone
Phyllite				Fine	Breaks along wavy surfaces, glossy sheen	Shale, mudstone, or siltstone
Schist				Medium to Coarse	Micaceous minerals dominate, scaly foliation	Shale, mudstone, or siltstone
Gneiss				Medium to Coarse	Compositional banding due to segregation of minerals	Shale, granite, or volcanic rocks
Migmatite				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				Coarse-grained	Stretched pebbles with preferred orientation	Quartz-rich conglomerate
Marble		Nonfoliated		Medium to coarse	Interlocking calcite or dolomite grains	Limestone, dolostone
Quartzite				Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone
Hornfels				Fine	Usually, dark massive rock with dull luster	Any rock type
Anthracite				Fine	Shiny black rock that may exhibit conchoidal fracture	Bituminous coal

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Quartzite	Nonfoliated	Medium to coarse	Fused quartz grains, massive, very hard	Quartz sandstone
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Anthracite	Nonfoliated	Fine	Shiny black rock that may exhibit conchoidal fracture	Bituminous coal

Classification of common metamorphic rocks

Mineralogical Classification

Amphibolite: Rock made up essentially of the mineral amphibole

Marble: Rock made up essentially of the mineral calcite

Quartzite: Rock made up essentially of the mineral quartz

1.Foliated Rocks

Slate

Slate is a very fine-grained (< 0.5 mm) foliated rock composed of minute mica flakes that are too small to be visible.

Thus, slate generally appears dull and closely resembles shale.

A noteworthy characteristic of slate is its excellent rock cleavage, or tendency to break into flat slabs.

Phyllite

Phyllite represents a gradation in the degree of metamorphism between slate and schist.

Its constituent platy minerals are larger than those in slate but not yet large enough to be readily identifiable with the unaided eye.

It can be easily distinguished from slate by its glossy sheen (shine) and its sometimes wavy surface.

It is composed mainly of very fine crystals of either Sericite (or muscovite), chlorite, or both.

A B

FIGURE 8.14 Phyllite (A) can be distinguished from slate (B) by its glossy sheen and wavy surface. (Photo by E. J. Tarbuck)

Phyllite

Phyllite

Schist

Schists are medium- to coarse-grained metamorphic rocks in which platy minerals predominate.

These flat components commonly include the micas (muscovite and biotite), which display a planar alignment that gives the rock its foliated texture.

The term schist describes the texture of a rock and as such it is used to describe rocks having a wide variety of chemical compositions.

Some common accessory minerals that occur as porphyroblasts include garnet, staurolite, and sillimanite, in which case the rock is called garnet-mica schist, staurolite-mica schist, and so forth.

Gneiss

Gneiss is medium- to coarse-grained banded metamorphic rock in which granular and elongated (as opposed to platy) minerals predominate.

Most common minerals in gneiss are quartz, K-feldspar, and Na-rich plagioclase feldspar.

It also contain biotite, muscovite, and amphibole that develop a preferred orientation.

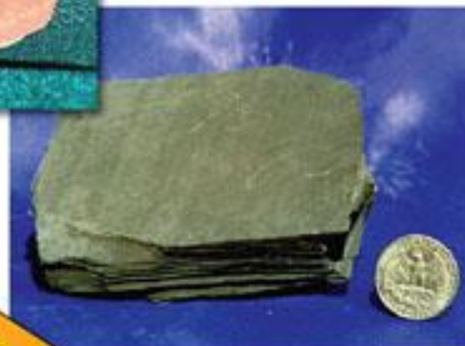
Some gneisses split along layers of platy minerals, but most break in an irregular fashion.

FIGURE 8.12 This rock displays a gneissic texture. Notice that the dark biotite flakes and light silicate minerals are segregated, giving the rock a banded or layered appearance. (Photo by E. J. Tarbuck)

Folded gneiss

With increasing temperature and pressure, metamorphic grade also increases. The higher the metamorphic grade, the more changed the rock will be from its original form. The rocks shown here are (left to right) slate, phyllite, schist and gneiss.

Slate



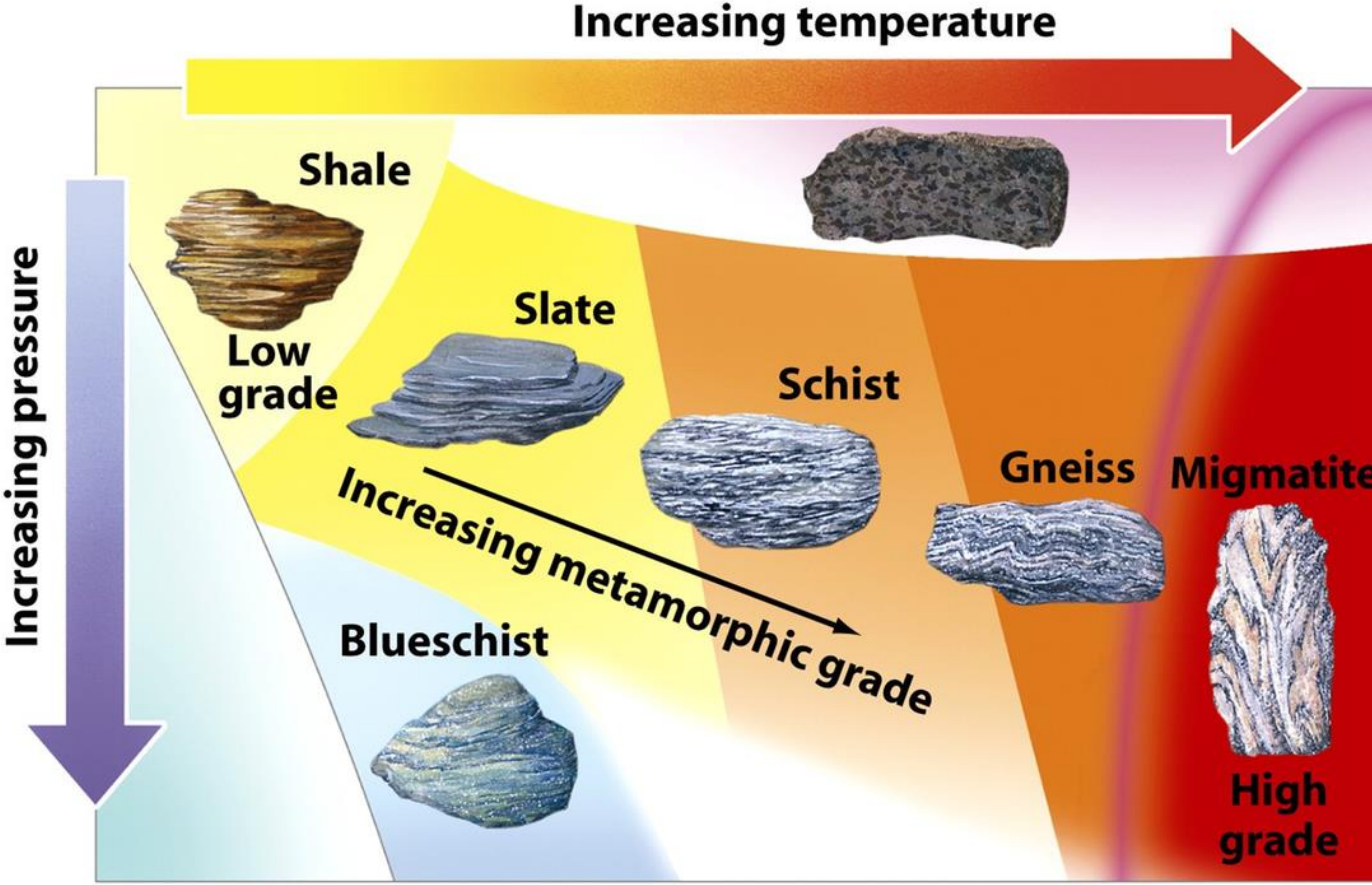
Phyllite

Schist

Gneiss

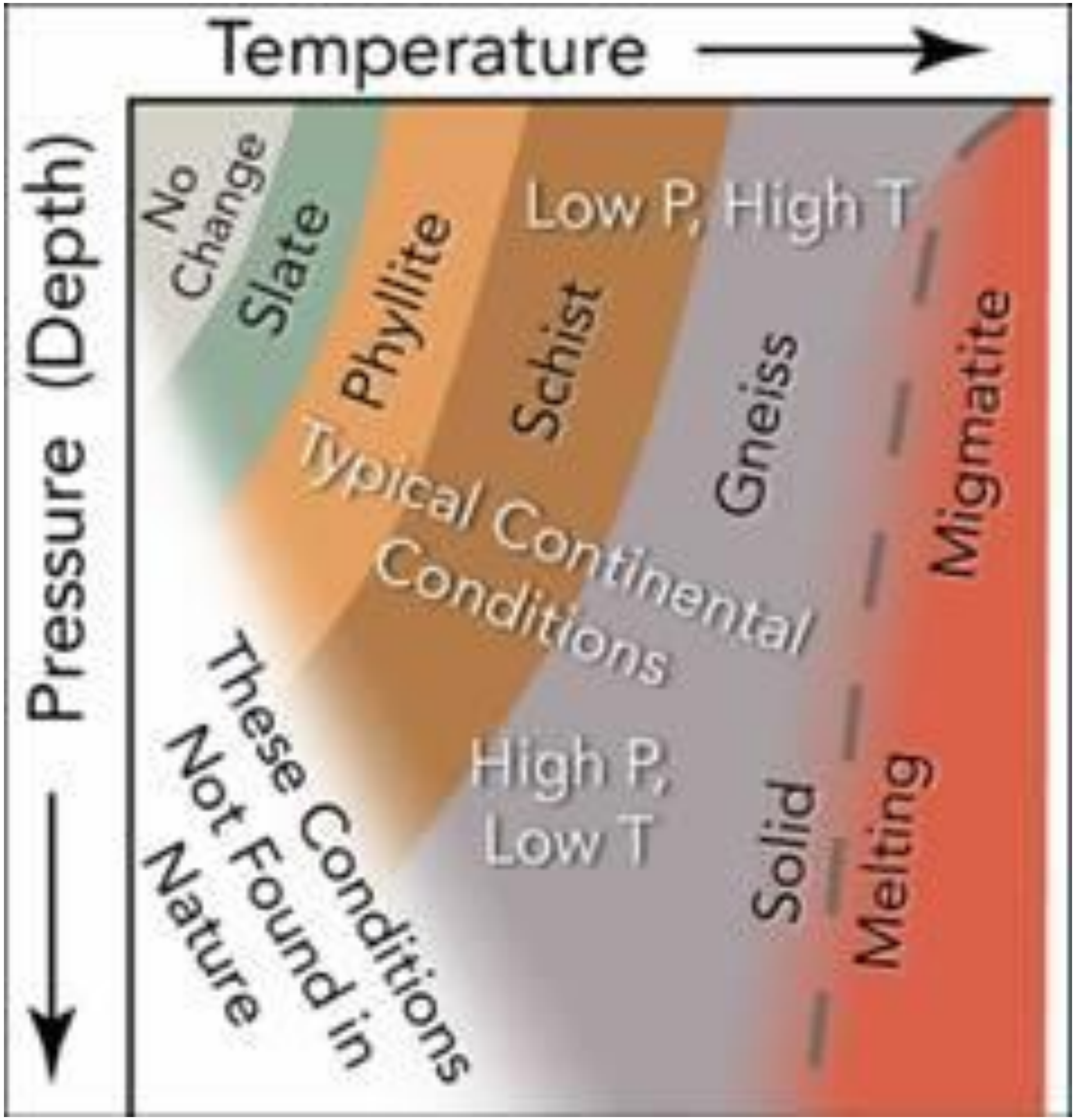
Increasing Metamorphic Grade

(Photographs by Parvinder Sethi)



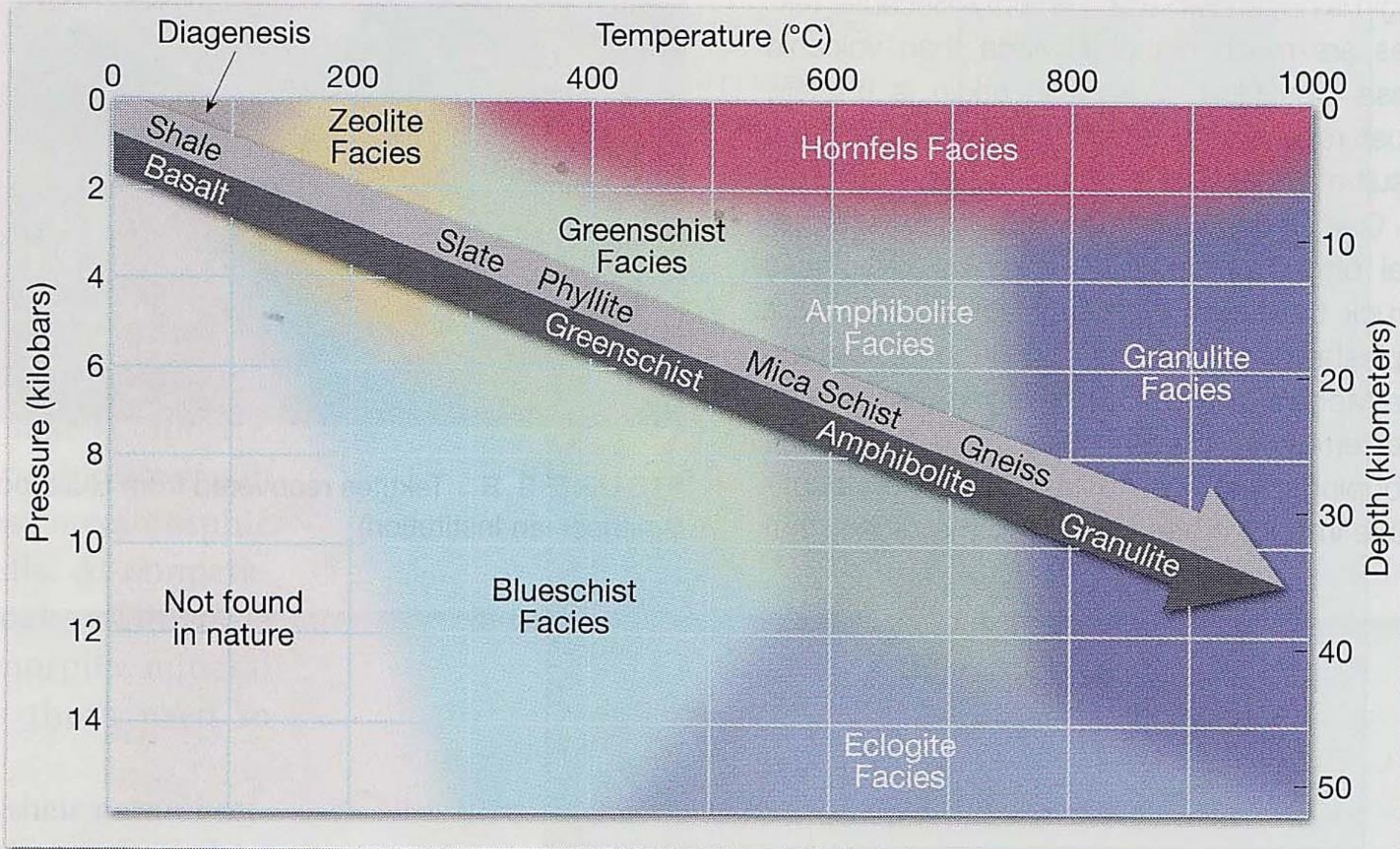
Page 250c Earth: Portrait of a Planet 3/e
Original artwork by Gary Hincks

Regional Metamorphism



- •Increase in temperature is accompanied by an increase in pressure
- •Usually there is directedpressure, so rock deformation increases with metamorphic grade

FIGURE 8.30 Metamorphic facies and corresponding temperature and pressure conditions. Note the equivalent metamorphic rocks produced from regional metamorphism of basalt and shale parent rocks.



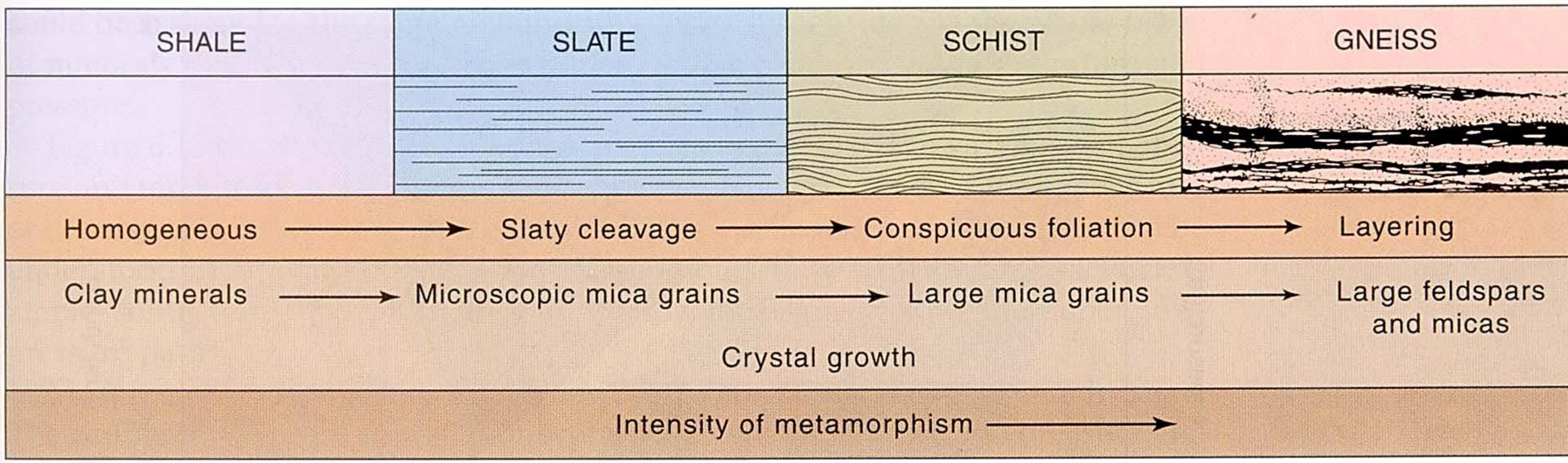
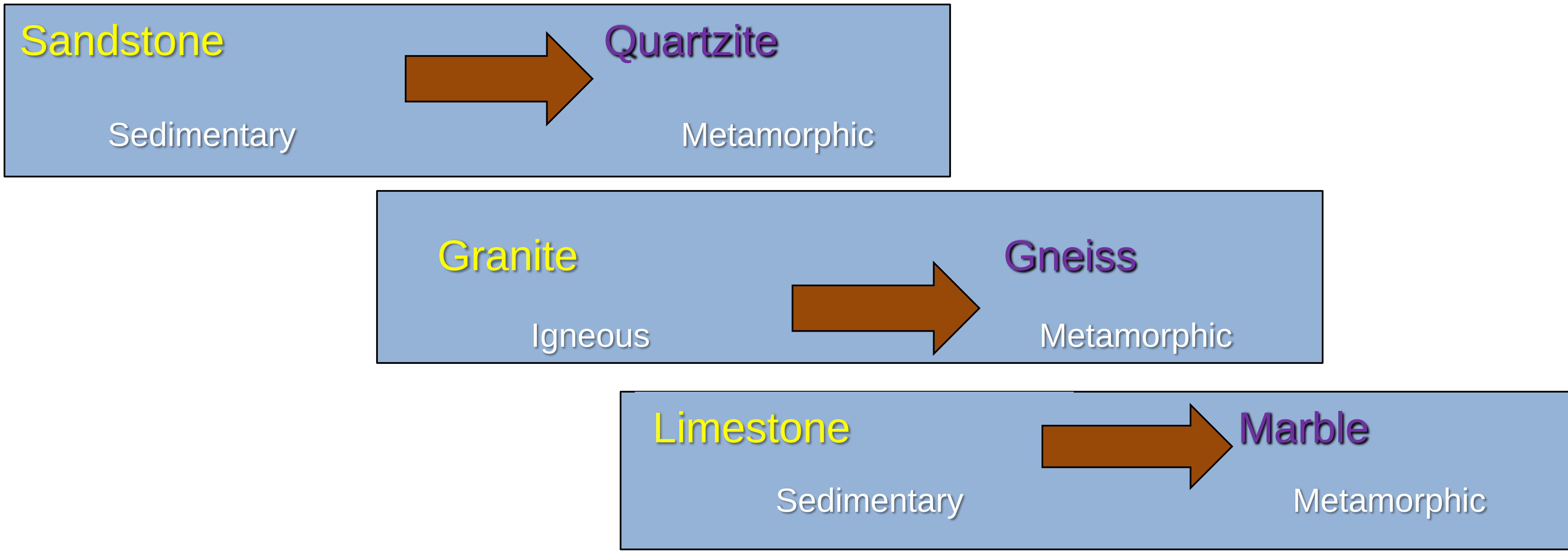


FIGURE 6.11 **The metamorphism of shale** can involve a series of steps, depending on the intensity of temperature and pressure. Shale can change to slate, schist, or even gneiss.

Examples of parent rocks and their metamorphic products



The role of parent rocks. The parent rocks provide the minerals and ion sources that are transformed into new minerals and rocks. In most cases the new metamorphic rock has the same chemical composition as the parent rock that they formed from.

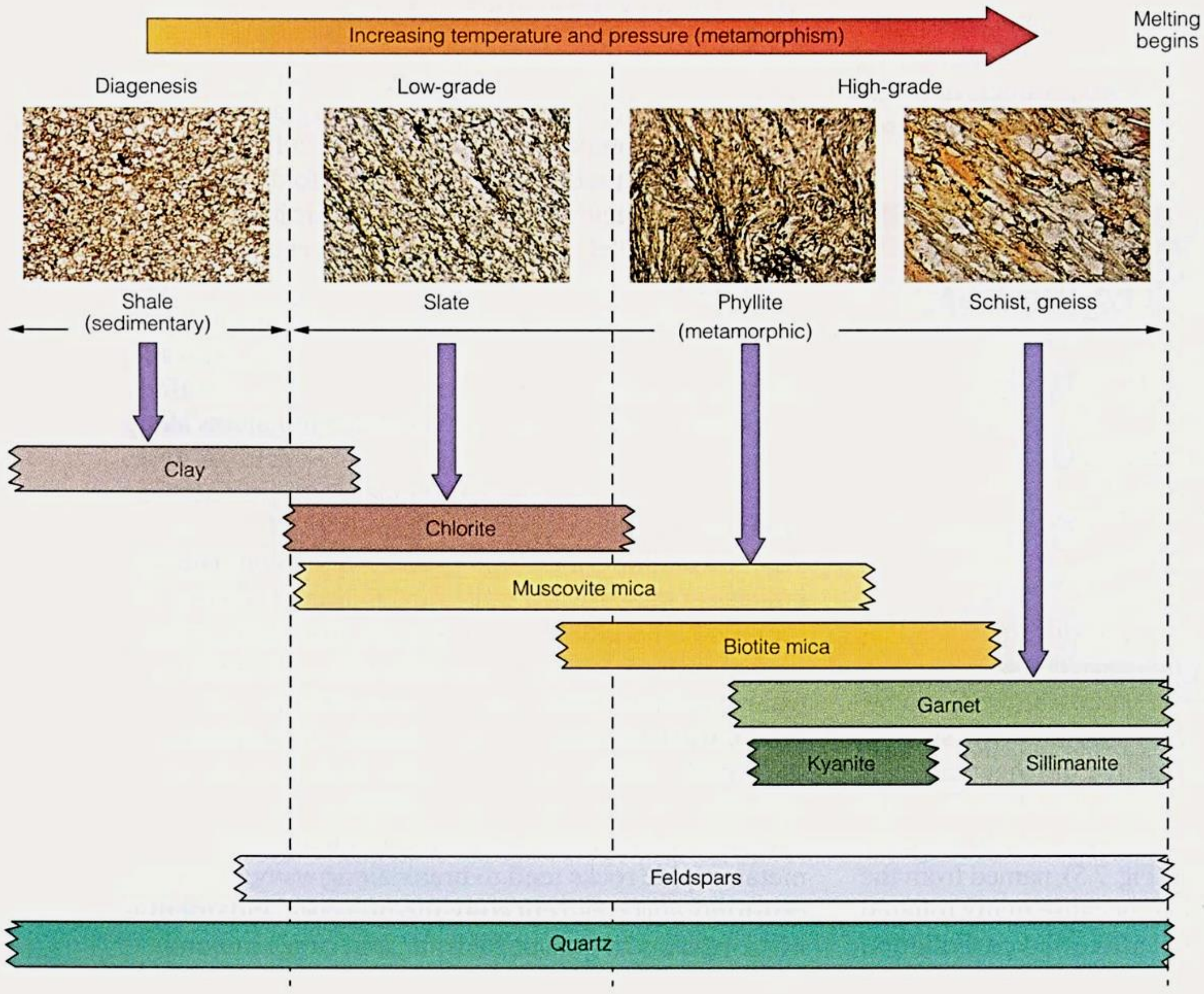


Figure 7.7 From Shale to Schist The bars in this diagram show the changes in mineral assemblage that occur as a shale is metamorphosed from low to high grade. Metamorphism progresses from left to right in the diagram. Before metamorphism occurs, the shale is a sedimentary rock made of clay particles and quartz grains. The first metamorphic rock to develop is a low-grade slate, then a phyllite, and finally a high-grade schist and gneiss. The photographs show the rocks under a microscope; each photo shows a field of view approximately 3 mm (0.12 in.). The minerals kyanite and sillimanite have the same composition (Al_2SiO_5) but different crystal structures—they are found only in metamorphic rocks.

- Gneiss is a medium- to coarse-grained rock formed under high grade-metamorphic conditions.
- Gneiss is primarily composed of quartz, potassium feldspar, and plagioclase feldspar with lesser amounts of biotite, muscovite, and amphibole.
- Granites and sometimes rhyolite provide the parent rock for gneiss.
- Gneisses are generally light colored because they contain a large amount of quartz and feldspar.

2. Nonfoliated Rocks

Marble

It is a coarse, crystalline metamorphic rock whose parent was limestone or dolostone.

It is composed essentially of calcite. Because of its relative softness, marble is easy to cut and shape.

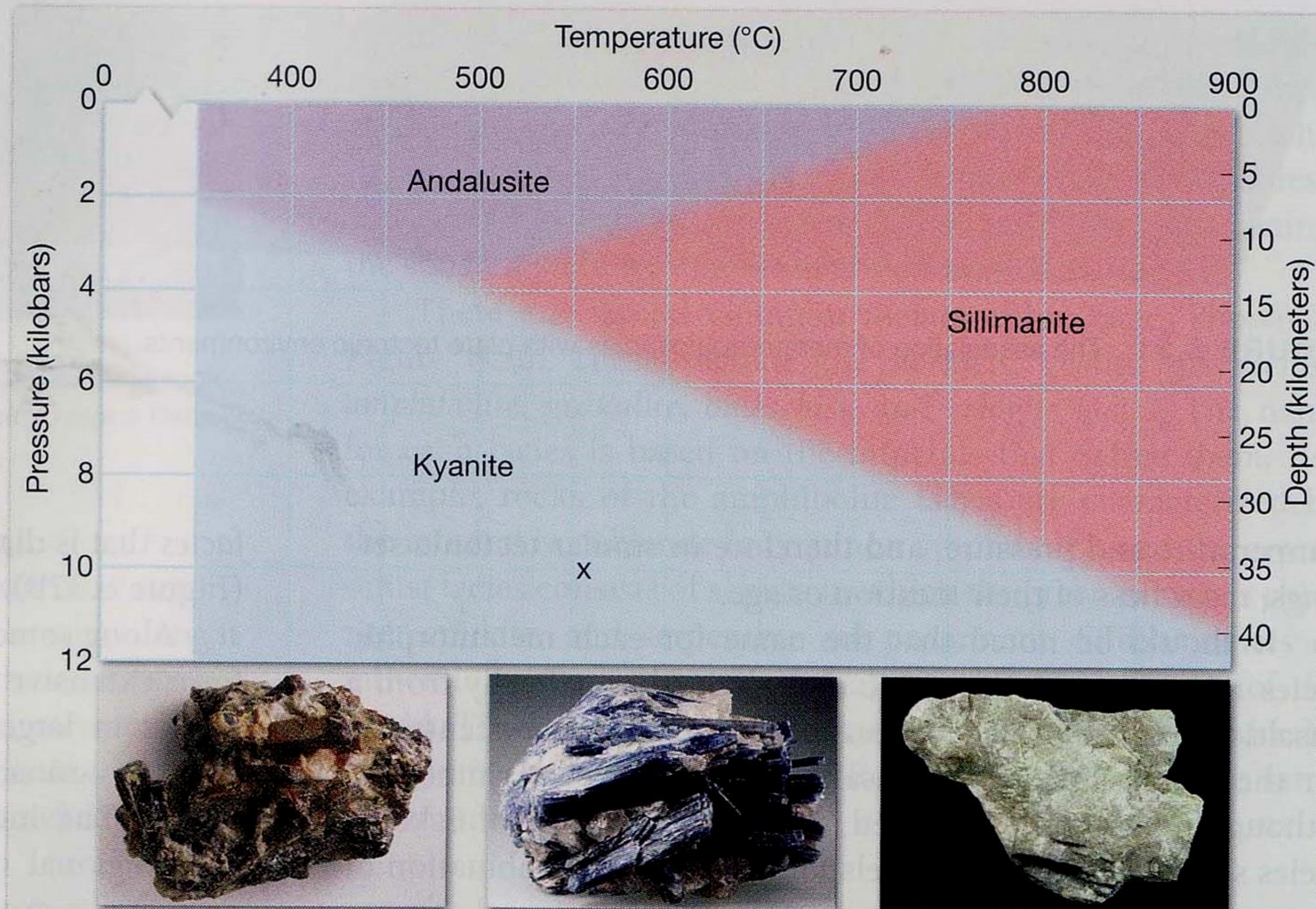
The parent rocks of most marbles contain impurities that color the stone. Thus, marble can be pink, gray, green, or even black .

Quartzite

Quartzite is a very hard metamorphic rock formed from quartz sandstone. Under moderate- to high-grade metamorphism, the quartz grains in sandstone fuse together.

The recrystallization is often so complete that when broken, quartzite will split through the quartz grains rather than along their boundaries.

Sometimes sedimentary features like cross-bedding, ripple, marks are preserved.



A. Andalusite **B.** Kyanite **C.** Sillimanite

FIGURE 8.C Phase diagram illustration of the conditions of pressure and temperature at which the three Al_2SiO_5 minerals are stable. (Photos by **A.** Harry Taylor/Dorling Kindersley Media Library, **B.** Dennis Tasa, and **C.** Biophoto Associates/Photo Researchers, Inc.)

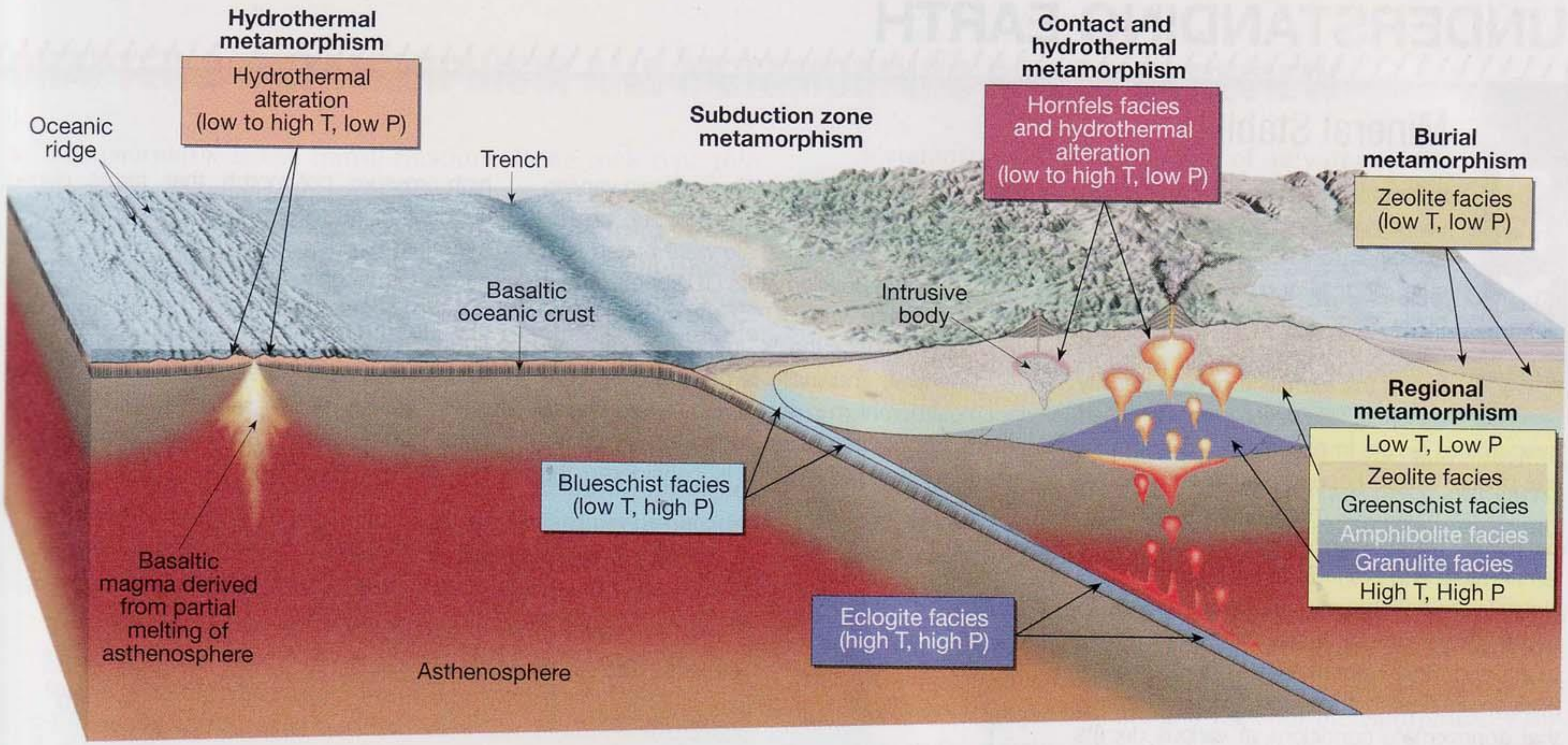


FIGURE 8.31 The association of metamorphic facies with plate tectonic environments.

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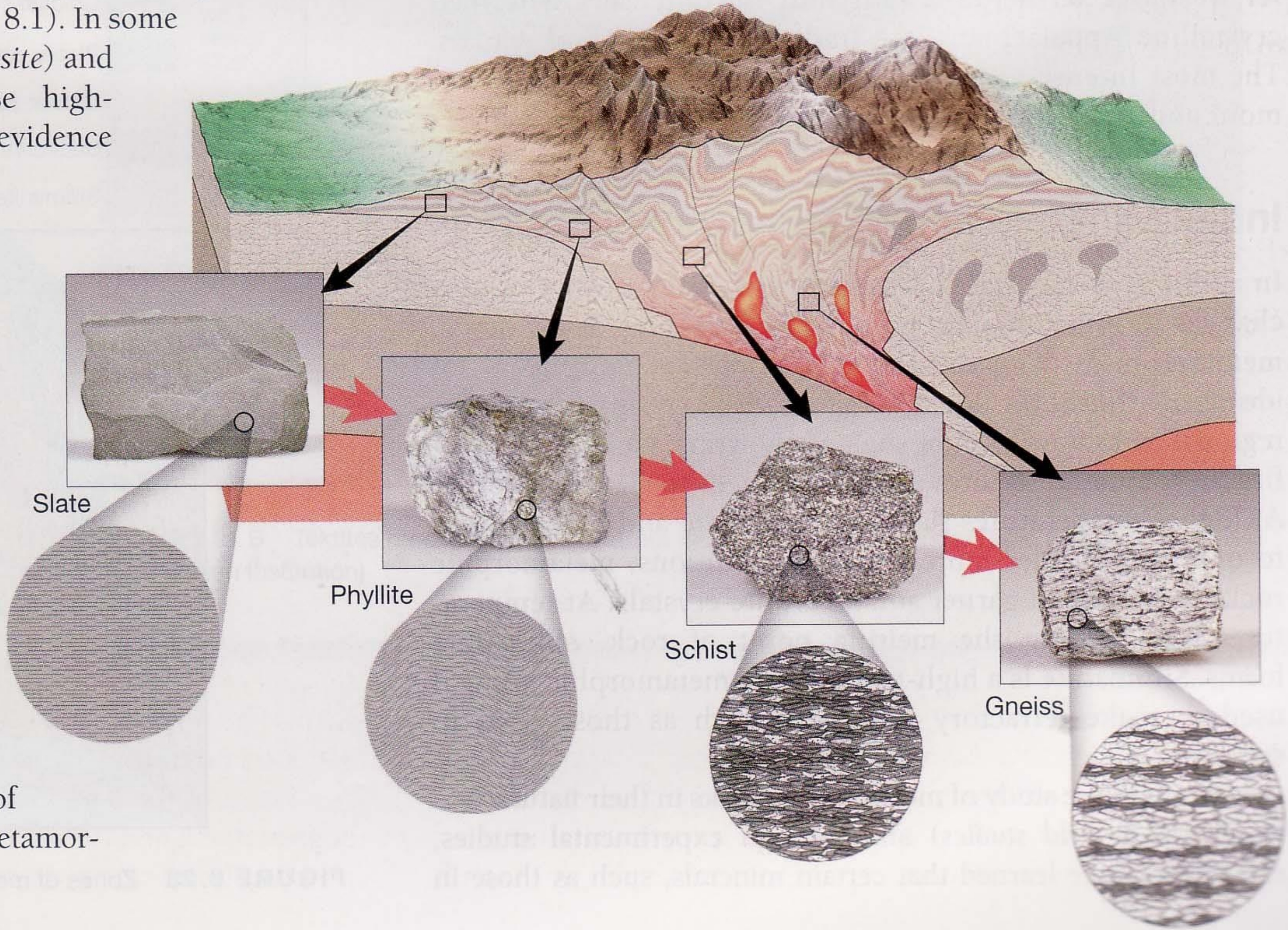
FIGURE 8.26 Idealized illustration of progressive regional metamorphism. From left to right, we progress from low-grade metamorphism (slate) to high-grade metamorphism (gneiss). (Photos by E. J. Tarbuck)



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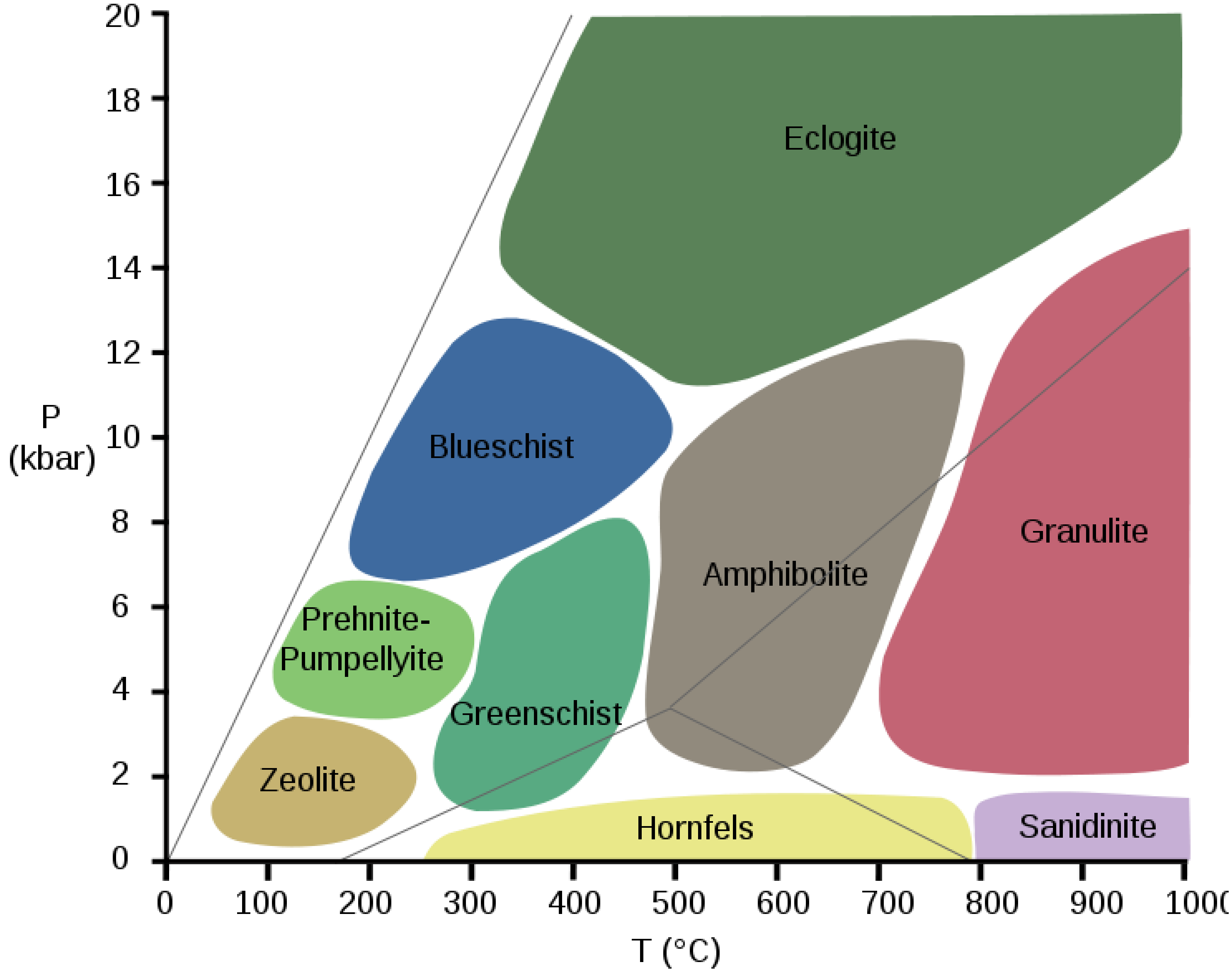

Types of metamorphic facies

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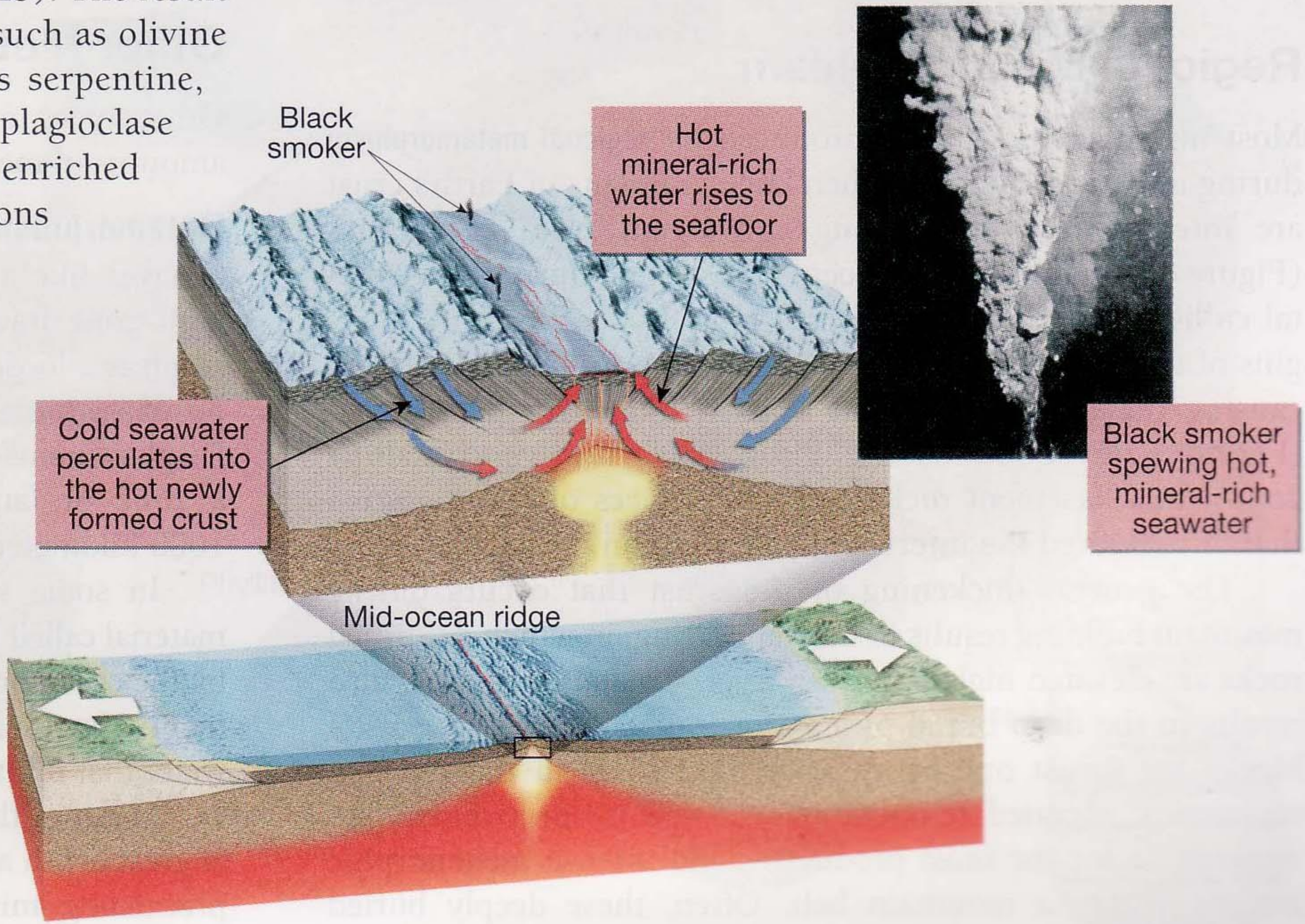
FIGURE 8.23 Hydrothermal metamorphism along a mid-ocean ridge. (Photo by R. Ballard/Woods Hole)



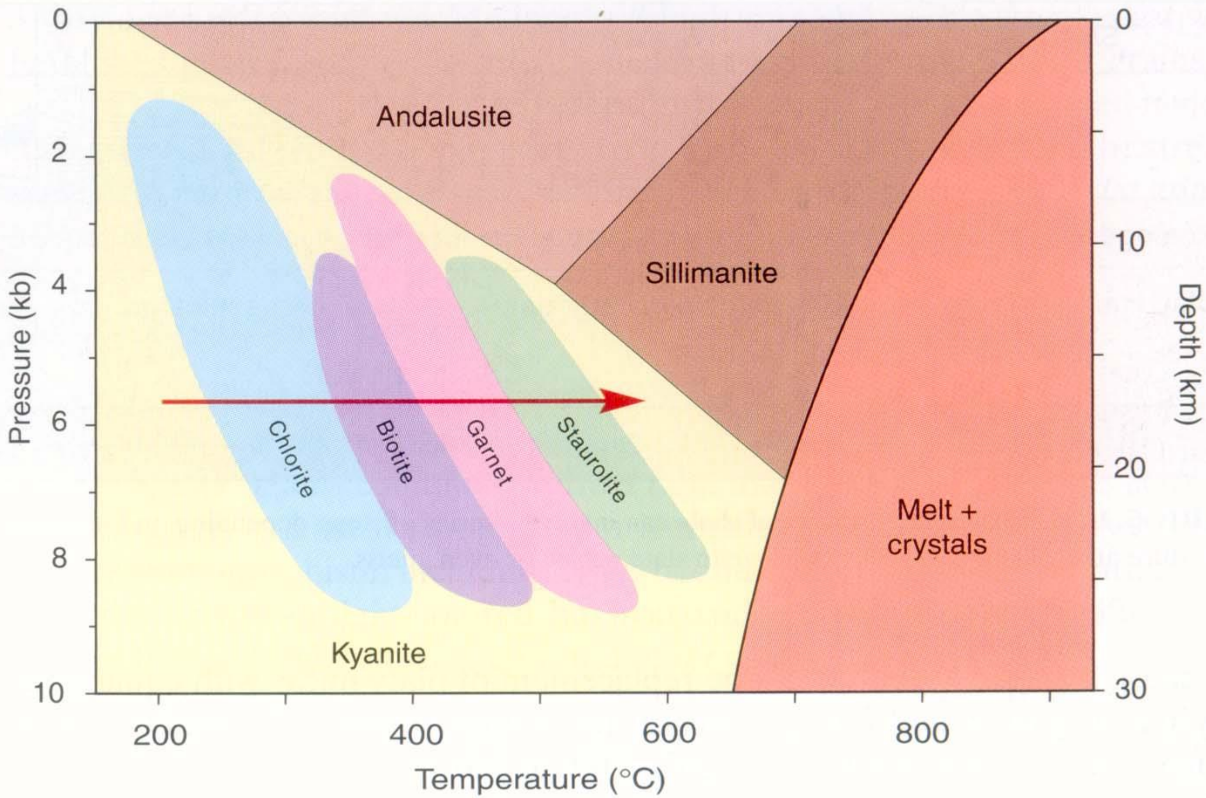


FIGURE 6.13 The grades of regional metamorphism are related to temperature and pressure. The arrow shows a typical change from lower to higher grades at a given depth. The sequence of index minerals will commonly be chlorite, biotite, garnet, staurolite, kyanite, and sillimanite.

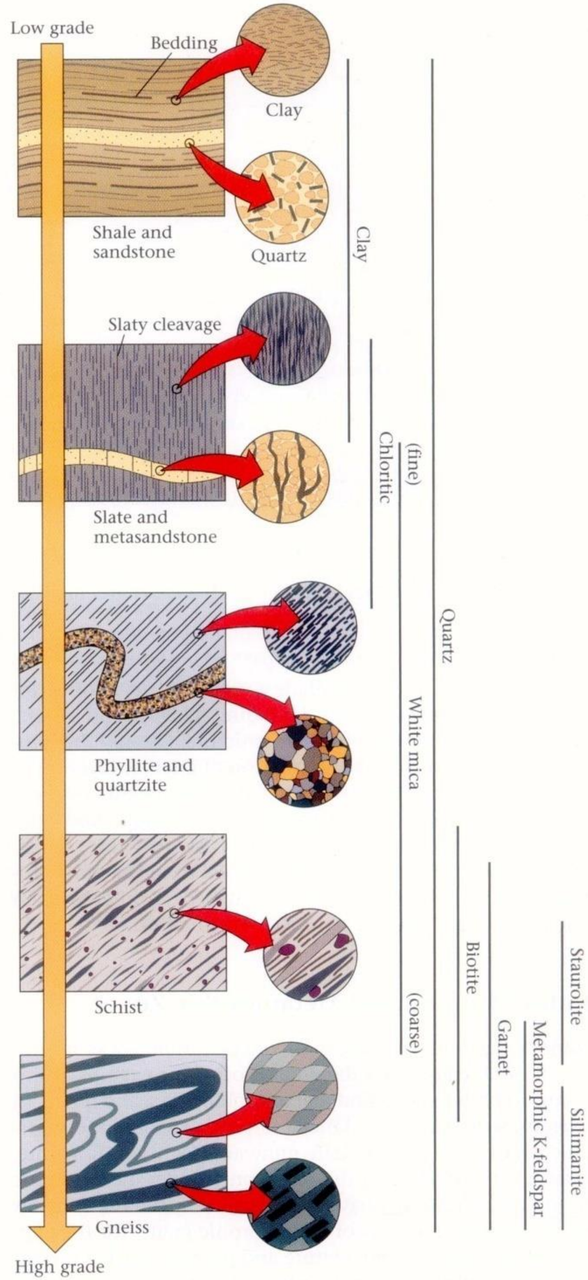


FIGURE 8.19 When shale progressively metamorphoses from low grade to high grade, it first becomes slate, then phyllite, then schist, then gneiss. In many cases, gneiss and schist can form under the same conditions. The side graph shows the stability range of various minerals.

Metamorphism and metamorphic rocks

Compressional forces of unimaginable magnitude and temperatures hundreds of degrees above surface conditions prevailed for perhaps thousands or millions of years produce the deformation and metamorphism displayed by metamorphic rocks.

Under such extreme conditions, solid rocks responds by folding, fracturing, and often by flowing. These conditions change appearance, mineralogy, and sometimes even in over-all chemical composition of the parent rocks.

Unlike some igneous and sedimentary processes that take place in surface or near-surface environments, metamorphism most often occurs deep within Earth, beyond our direct observation.

The study of metamorphic rocks provides important insights into the tectonic processes that operate within Earth's crust and upper mantle.

Metamorphic rocks are found in shield regions such as in eastern Canada, Brazil, Africa, India, Australia, and Greenland.

Moreover, metamorphic rocks are an important component of many mountain belts, including Alps, the Appalachians and the Himalayas.

WHAT DRIVES METAMORPHISM?

Agents of Metamorphism

The agents of metamorphism include

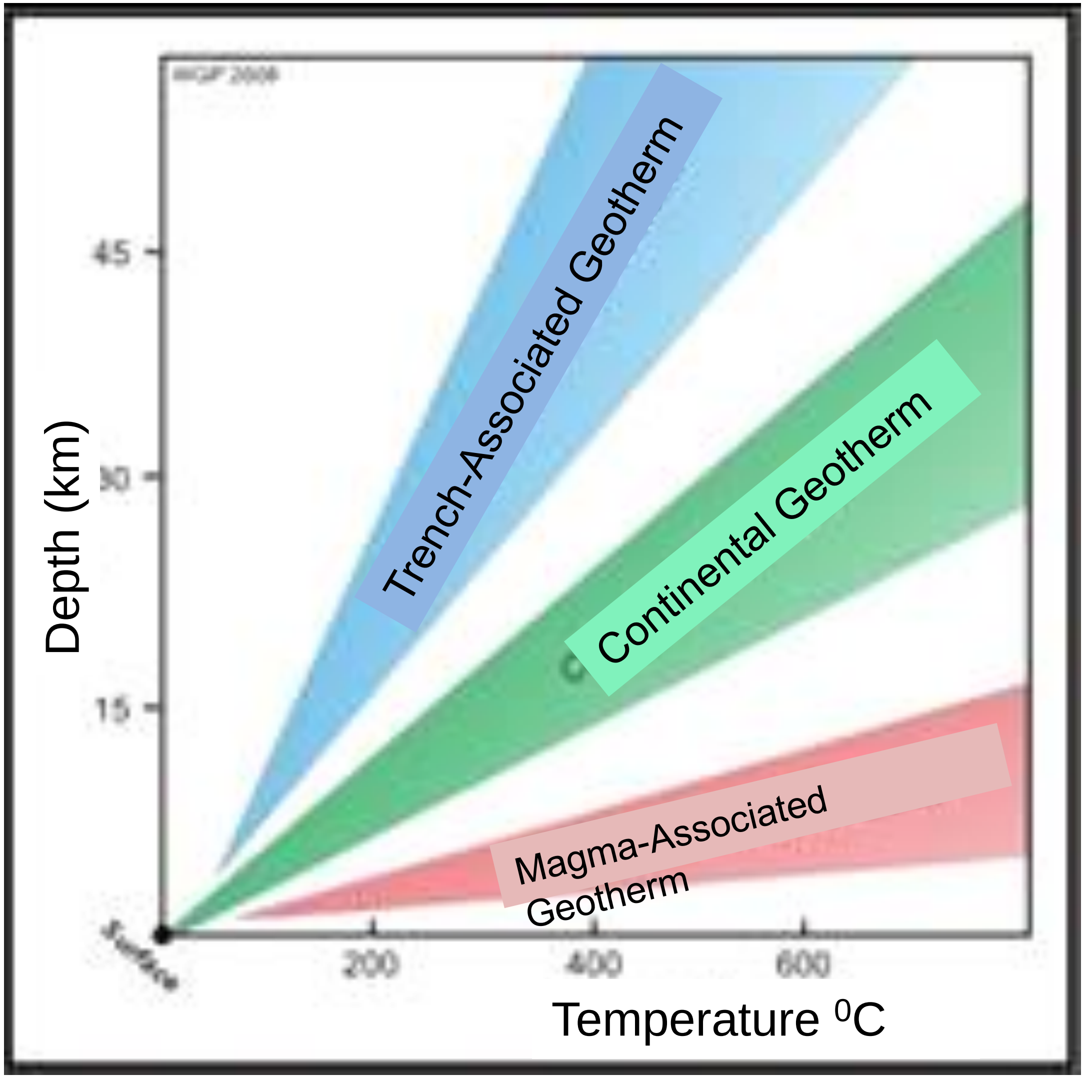
- **Heat,**
- **pressure (stress), and**
- **chemically active fluids.**

During metamorphism, rocks are usually subjected to all three metamorphic agents simultaneously. However, the degree of metamorphism and the contribution of each agent vary from one environment to another.

Heat as a Metamorphic Agent

The most important factor driving metamorphism is heat because it provides the energy needed to drive the chemical reactions that result in the recrystallization of existing minerals and/or the formation of new minerals.

Sources of Heat for Metamorphism



- Heat from Earth's interior
- Geothermal gradient is theincrease in temperature withdepth
  - –Typical continental geothermalgradient is 25-30°C/km
  - –Volcanically active areas havegeothermal gradients of 30-50°C/km
  - –Oceanic trenches havegeothermal gradients as low as 5-10°C/km

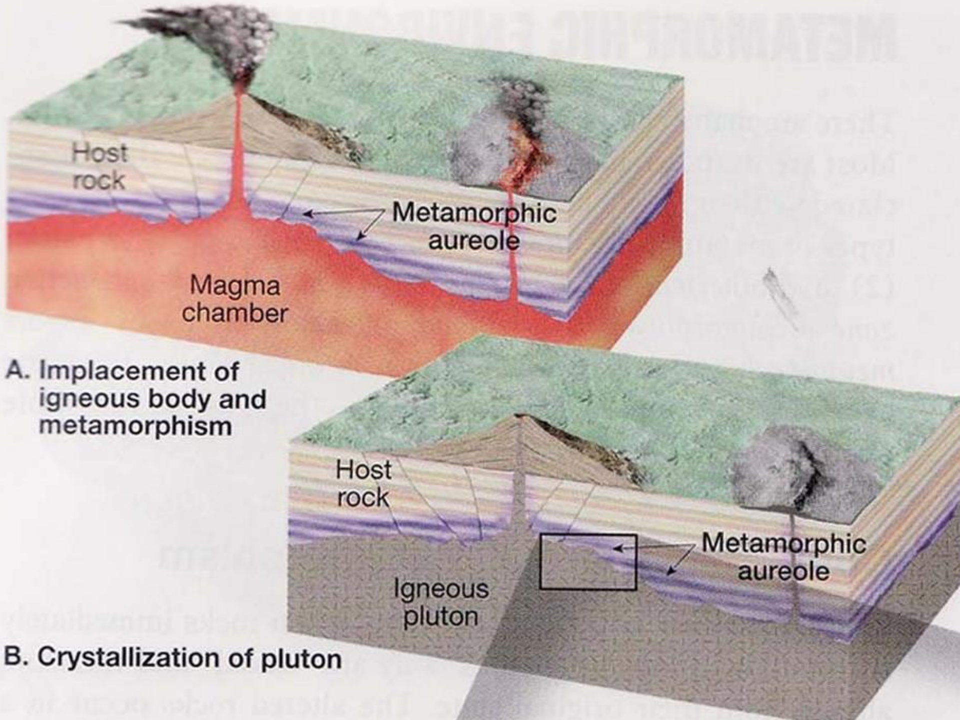
Changes Caused by Heat

When Earth materials arc heated: especially those that form in low-temperature environments, they are affected in two ways.

First, heating promotes recrystallization of mineral grains. This is particularly true of sedimentary and volcanic rocks that are composed of fine-grained clay and silt sized particles. Higher temperatures promote crystal growth where fine particles join together to form larger grains of the same mineralogy.

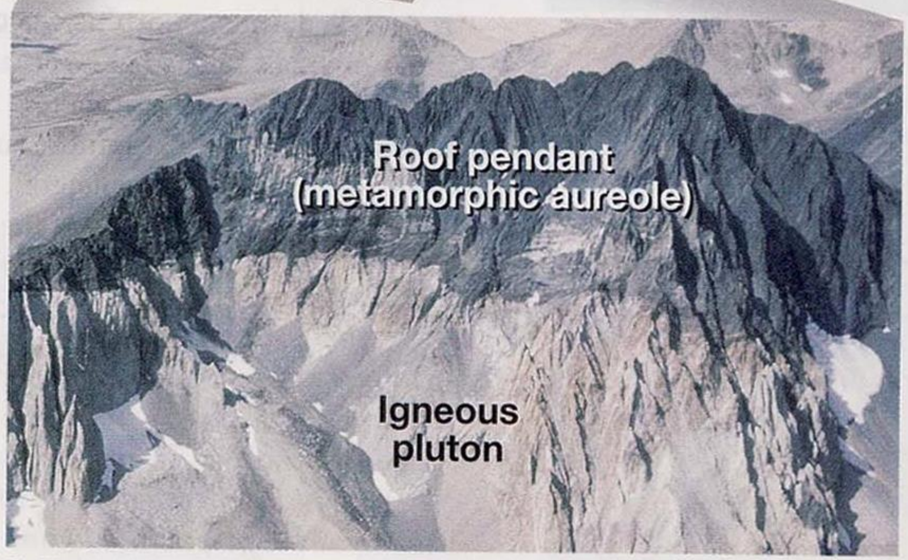
Second, when rocks are heated, they eventually reach a temperature at which one or more minerals become chemically unstable. When this occurs, the constituent atoms begin to arrange themselves into crystalline structures that are more stable in the new high-temperature environment.

These chemical reactions create new minerals with stable configurations that have an overall composition roughly equivalent to that of the original rock.



A. Implacement of igneous body and metamorphism

B. Crystallization of pluton



C. Uplift and erosion expose pluton and metamorphic cap rock

FIGURE 8.20 Contact metamorphism produces a zone of alteration called an *aureole* around an intrusive igneous body. In the photo, the dark layer, called a *roof pendant,* consists of metamorphosed host rock adjacent to the upper part of the light-colored igneous pluton. The term *roof pendant* implies that the rock was once the roof of a magma chamber. Sierra Nevada, near Bishop, California. (Photo by John S. Shelton)

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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

(Slate → Migmatite: Increasing Metamorphism)

FIGURE 8.14 Classification of common metamorphic rocks.

A.

B.

FIGURE 8.15 Phyllite (**A.**) can be distinguished from slate (**B.**) by its glossy sheen and wavy surface. (Photos by E. J. Tarbuck)

FIGURE 8.13 Garnet-mica schist. The dark red garnet crystals (porphyroblasts) are embedded in a matrix of fine-grained micas. (Photo by E. J. Tarbuck)

FIGURE 8.12 This rock displays a gneissic texture. Notice that the dark biotite flakes and light silicate minerals are segregated, giving the rock a banded or layered appearance. (Photo by E. J. Tarbuck)

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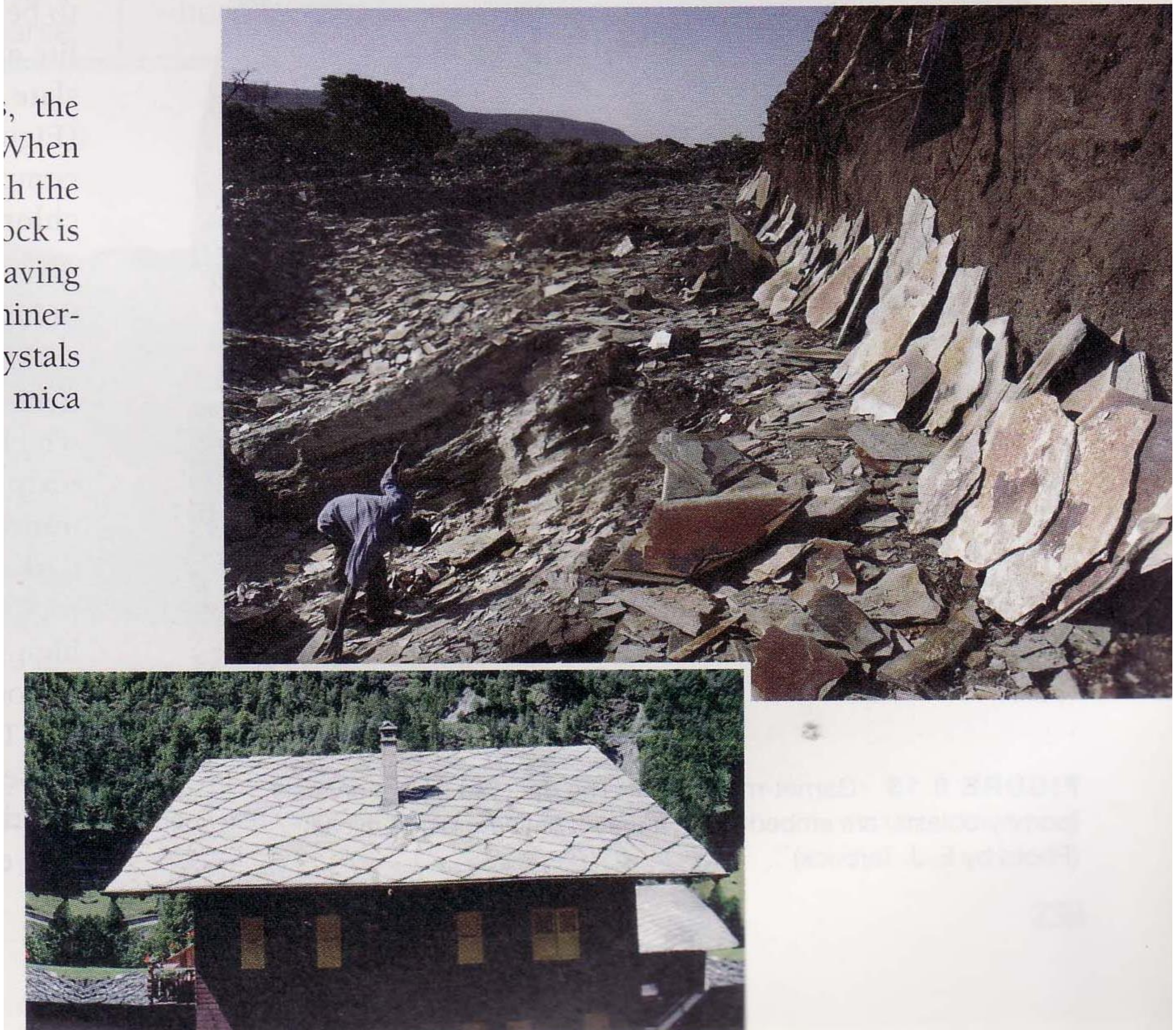
FIGURE 8.11 Excellent slaty cleavage is exhibited by the rock in this slate quarry in Tanzania. Because slate breaks into flat slabs, it has many uses. (Photo by Randy Olson/NGS Image Collection) The inset photo shows the use of slate for the roof of this house in Switzerland. (Photo by E. J. Tarbuck)



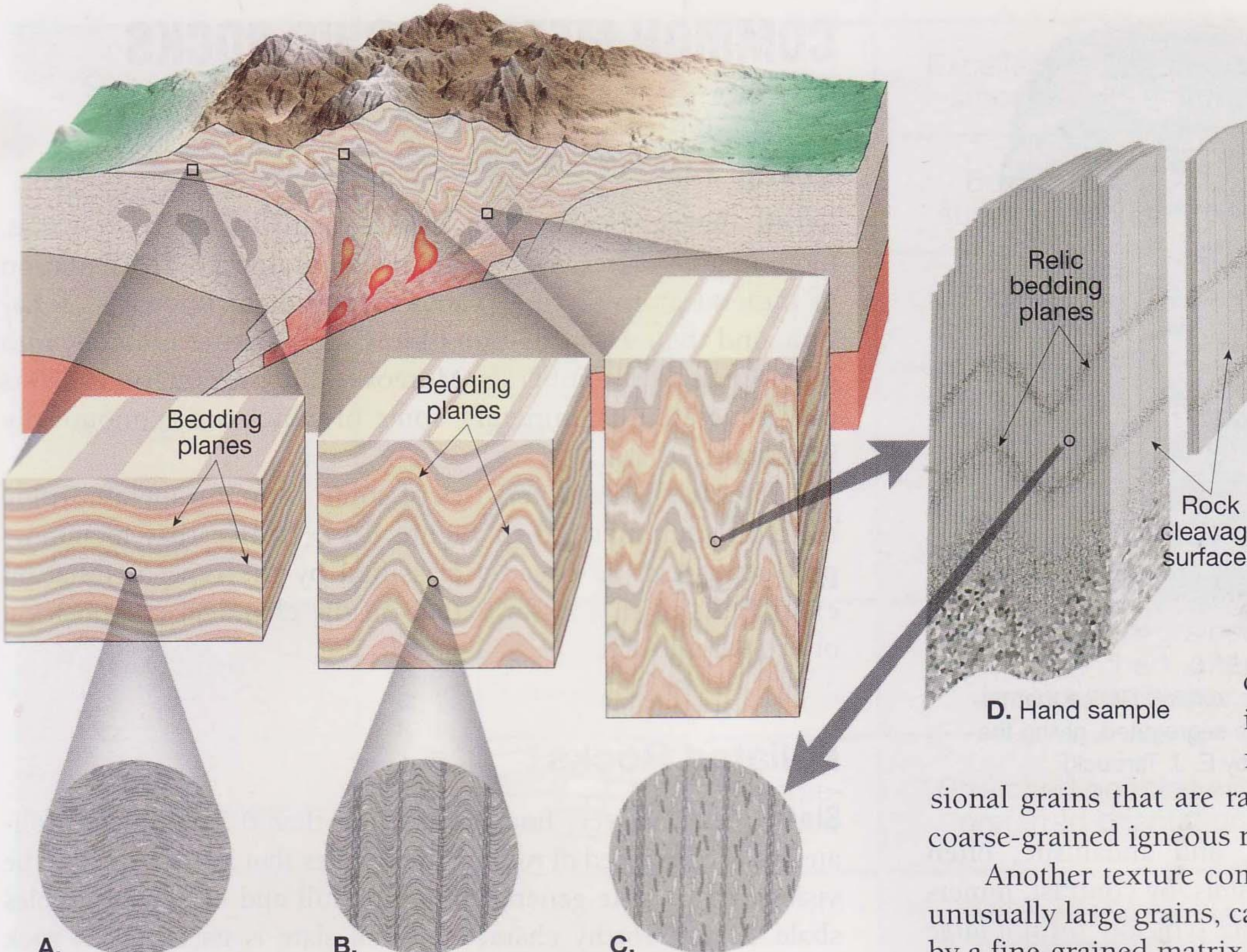


FIGURE 8.10 Development of rock cleavage. As shale is strongly folded (**A, B**) and metamorphosed to form slate, the developing mica flakes are bent into microfolds. **C.** Further metamorphism results in the recrystallization of mica grains along the limbs of these folds to enhance the foliation. **D.** This hand sample of slate illustrates rock cleavage and its orientation to relic bedding surfaces.

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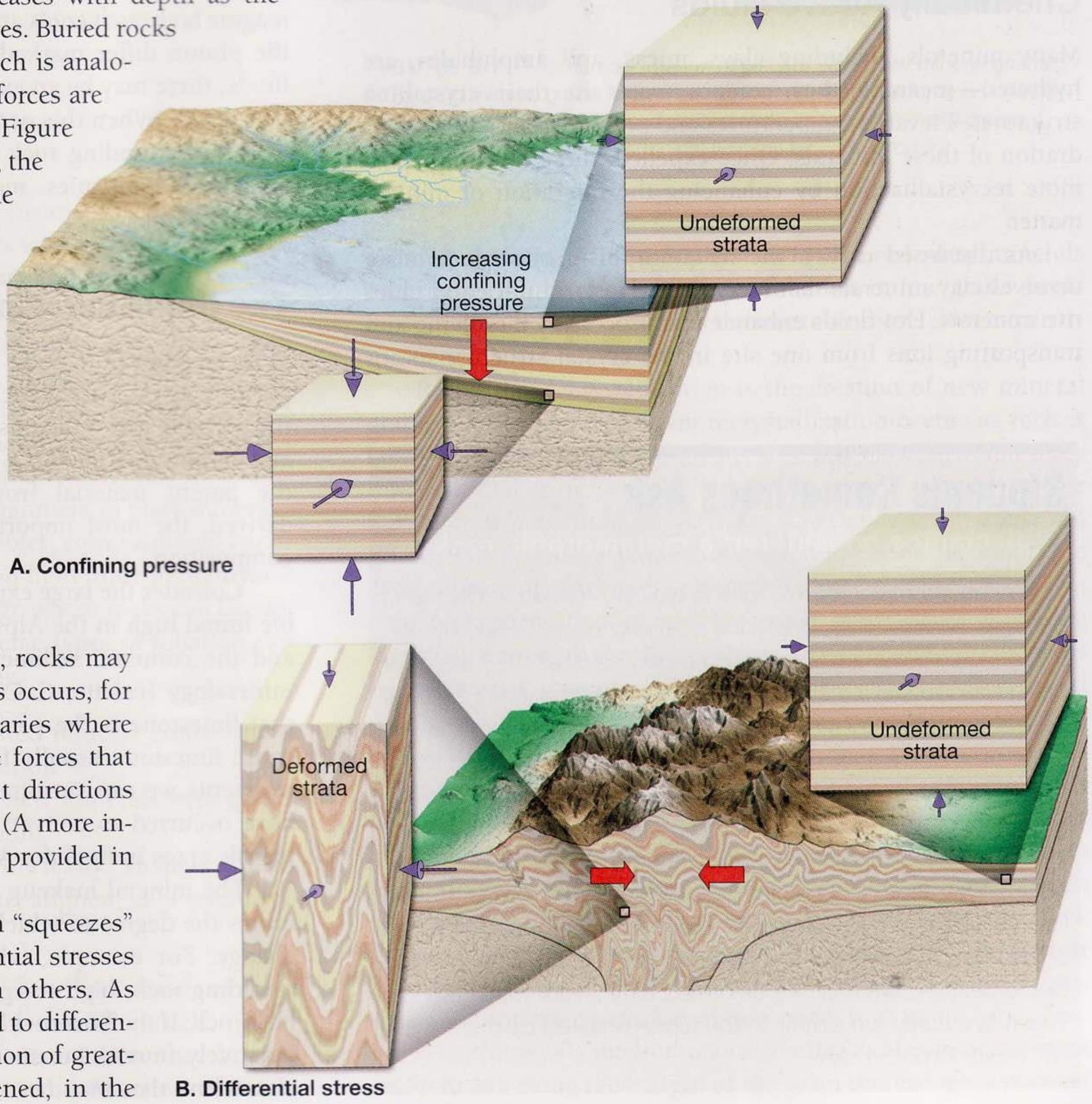
FIGURE 8.5 Confining pressure and differential stress as metamorphic agents. **A.** In a depositional environment, as confining pressure increases, rocks deform by decreasing in volume. **B.** During mountain building, rocks subjected to differential stress are shortened in the direction that pressure is applied, and lengthened in the direction perpendicular to that force.



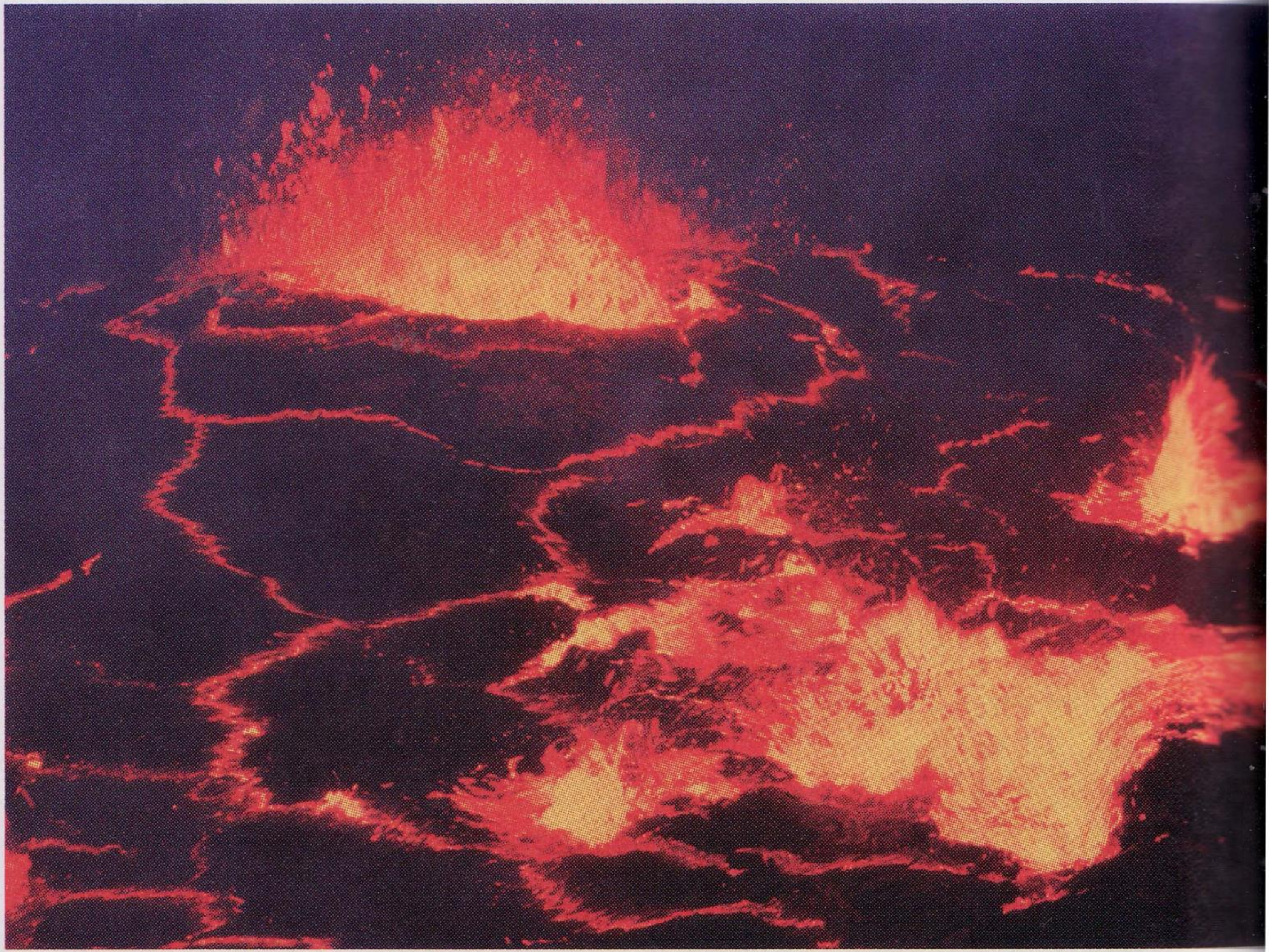


FIGURE 8.4 Earth's interior is the source of heat that drives metamorphism. Lava Lake in Pu'O'o Crater, Hawaii. (Photo by Frans Lanting/CORBIS)

FIGURE 8.1 Deformed metamorphic rocks exposed in a road cut in the Eastern Highland of Connecticut. (Photo by Phil Dombrowski)

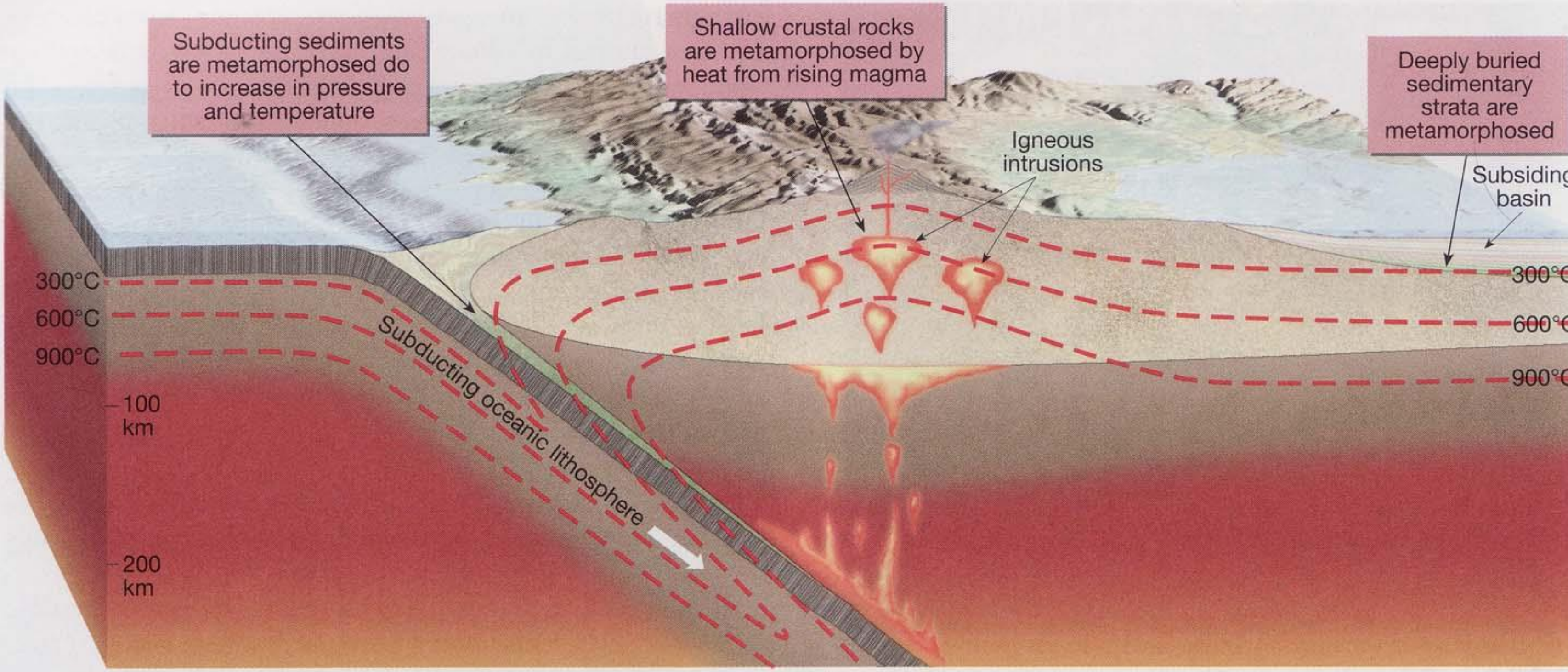


FIGURE 8.3 The geothermal gradient and its role in metamorphism. Notice how the geothermal gradient is lowered by the subduction of relatively cool oceanic lithosphere. By contrast, thermal heating is evident where magma intrudes the upper crust.

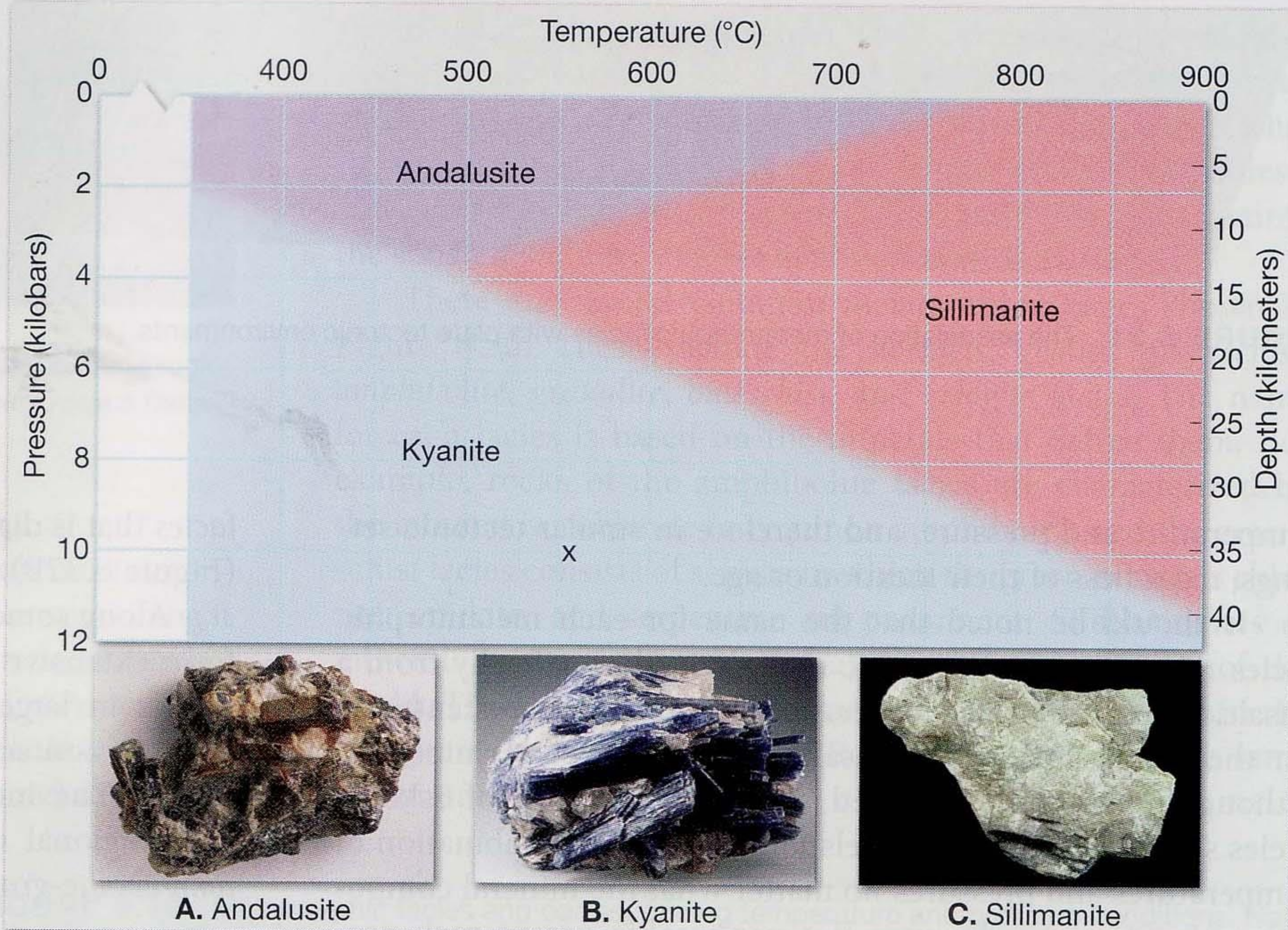
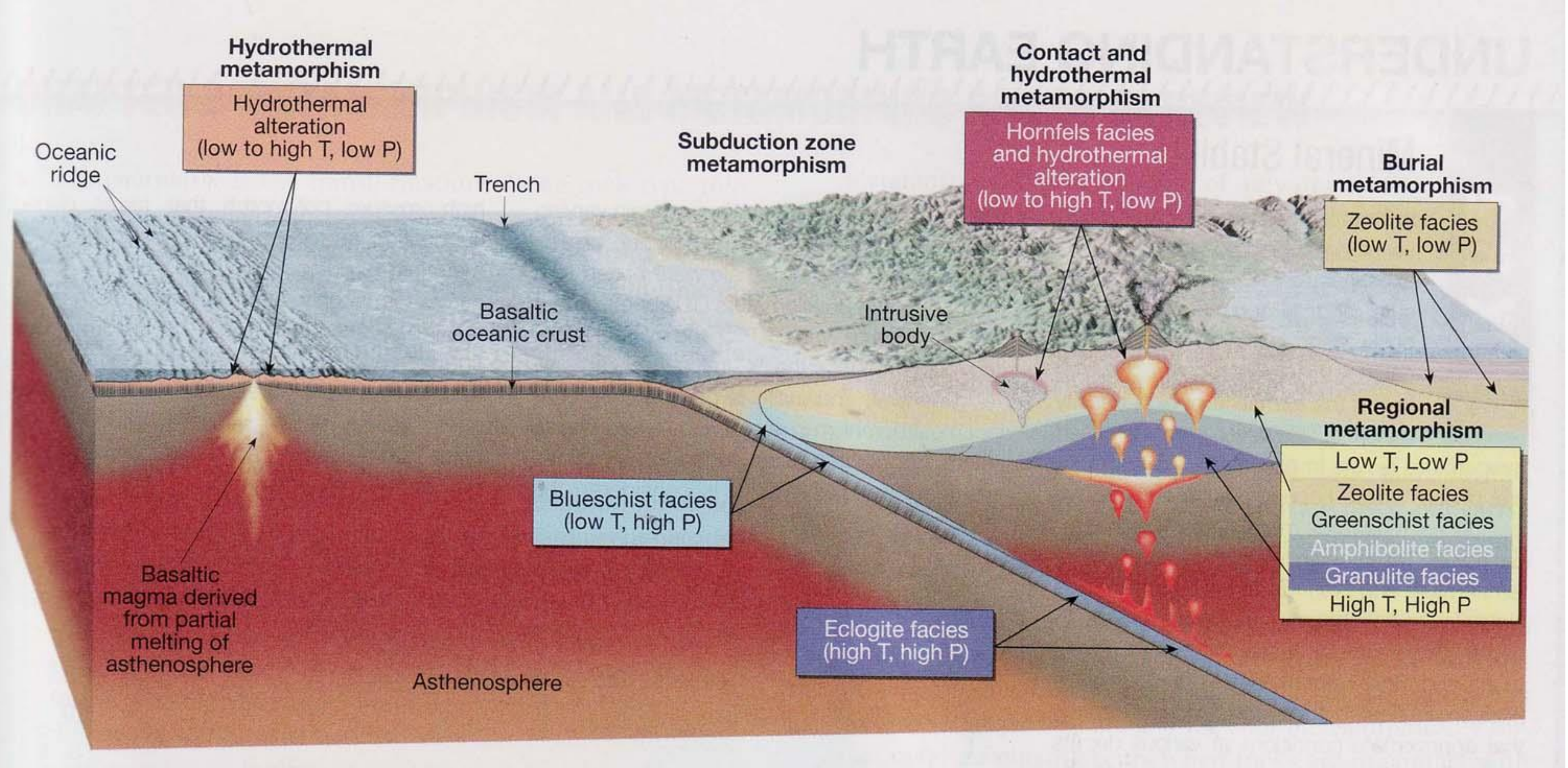


FIGURE 8.C Phase diagram illustration of the conditions of pressure and temperature at which the three Al_2SiO_5 minerals are stable. (Photos by **A.** Harry Taylor/Dorling Kindersley Media Library, **B.** Dennis Tasa, and **C.** Biophoto Associates/Photo Researchers, Inc.)



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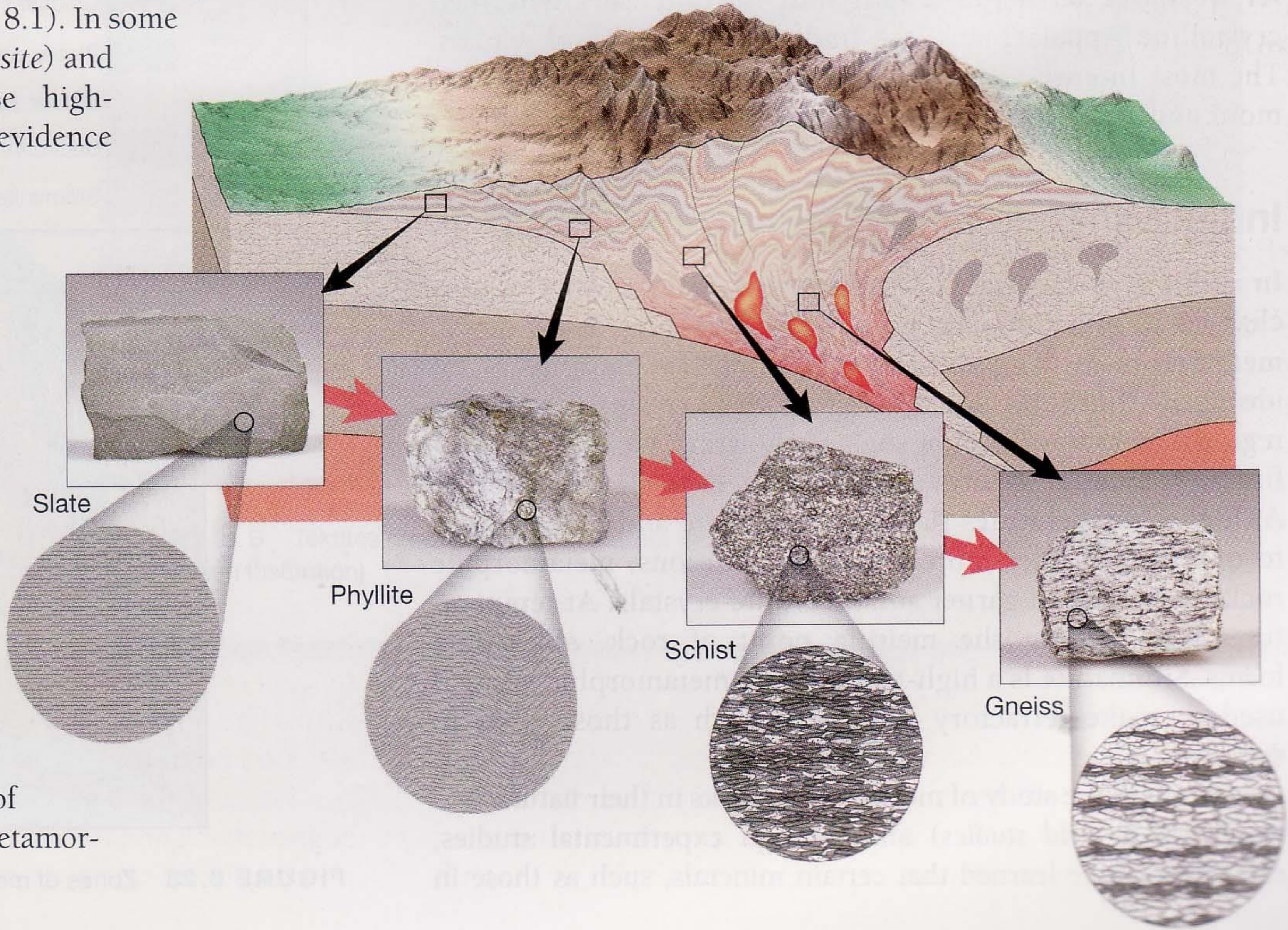

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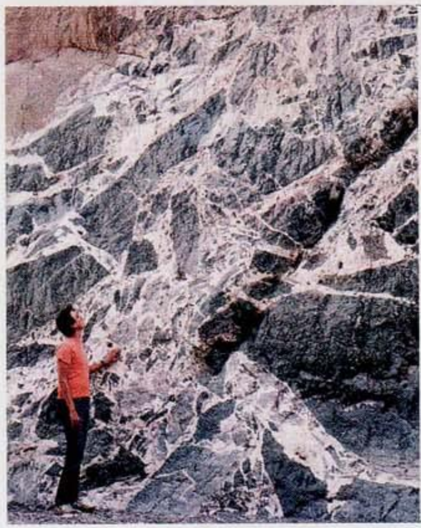
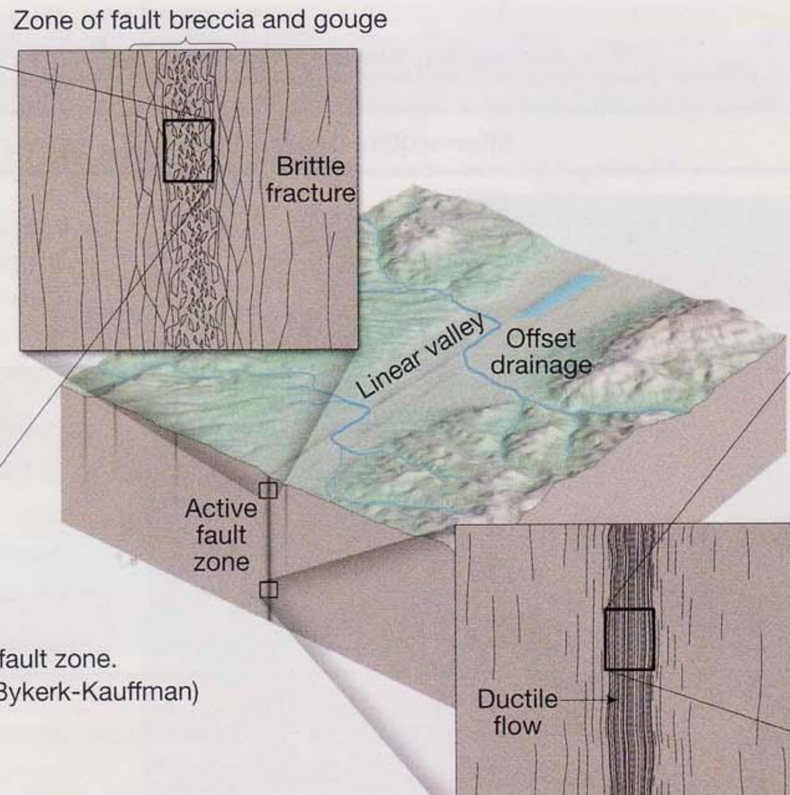


A. Fault breccia, California



B. Mylonite

FIGURE 8.25 Metamorphism along a fault zone. (Photo **A** by A. P. Trujillo, Photo **B** by Ann Bykerk-Kauffman)

As large slabs of rock move in opposite directions, the minerals in the fault zone between them tend to form elongated grains

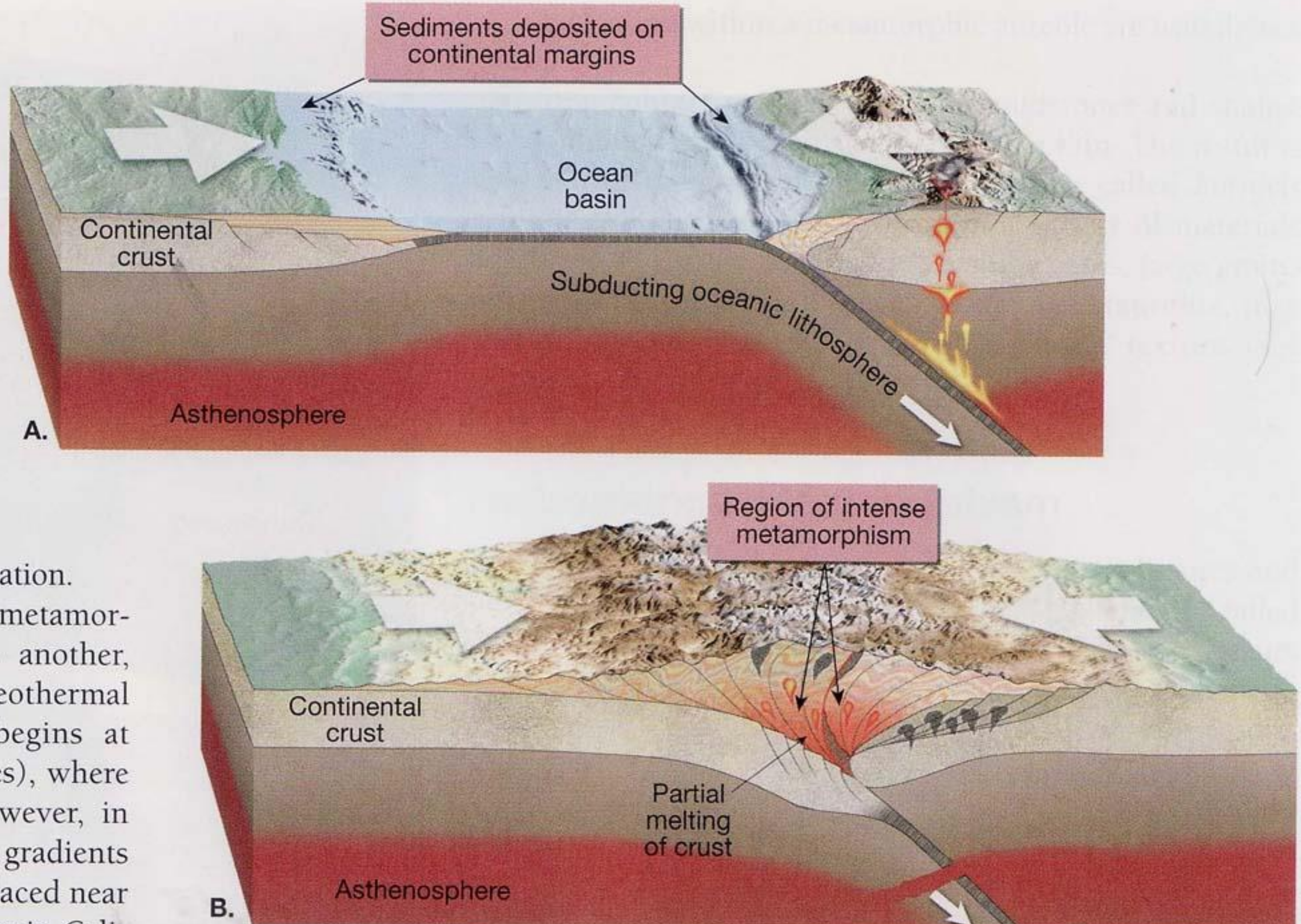


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FIGURE 8.24 Regional metamorphism occurs where rocks are squeezed between two converging lithospheric plates during mountain building.

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FIGURE 8.23 Hydrothermal metamorphism along a mid-ocean ridge. (Photo by R. Ballard/Woods Hole)

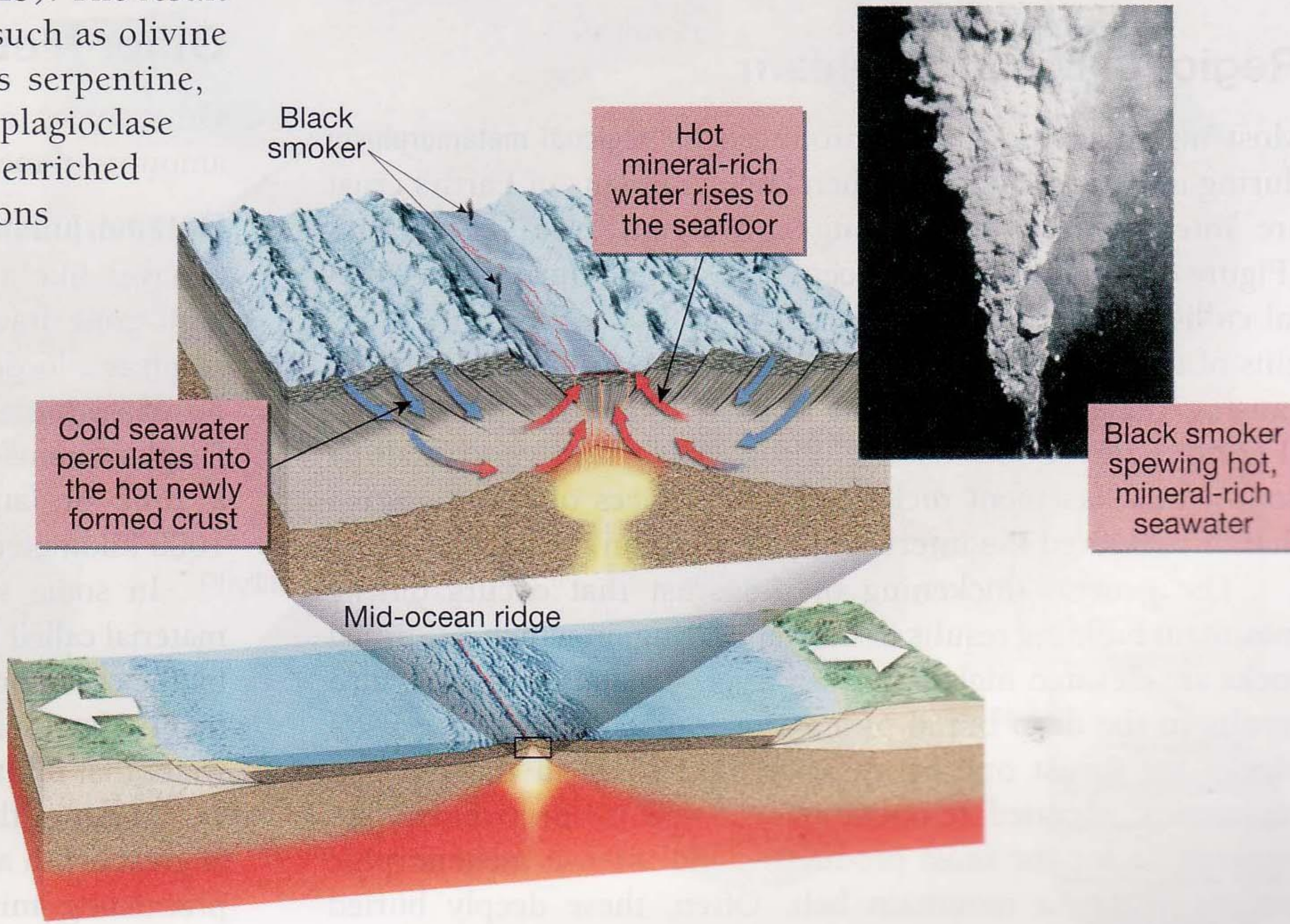
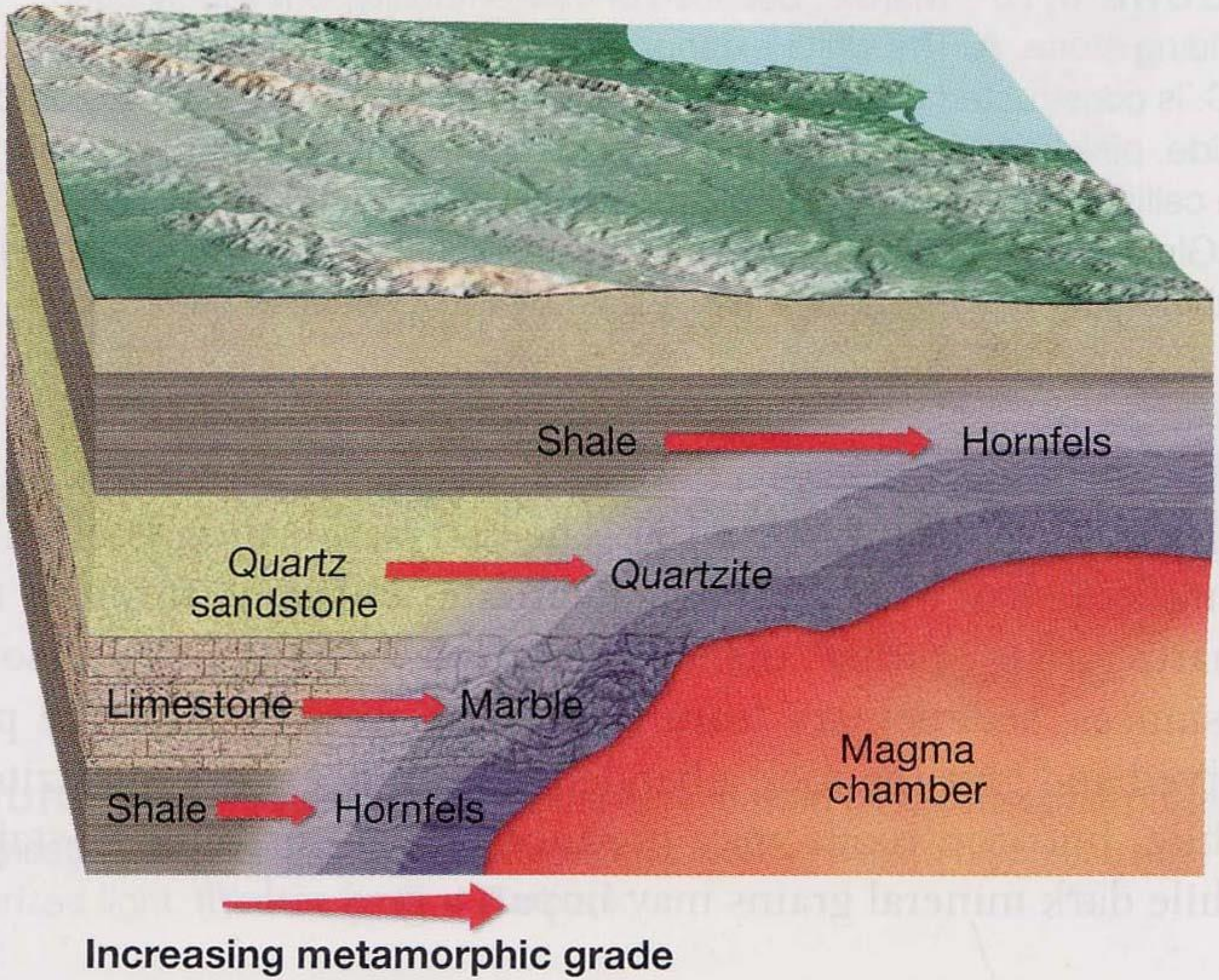
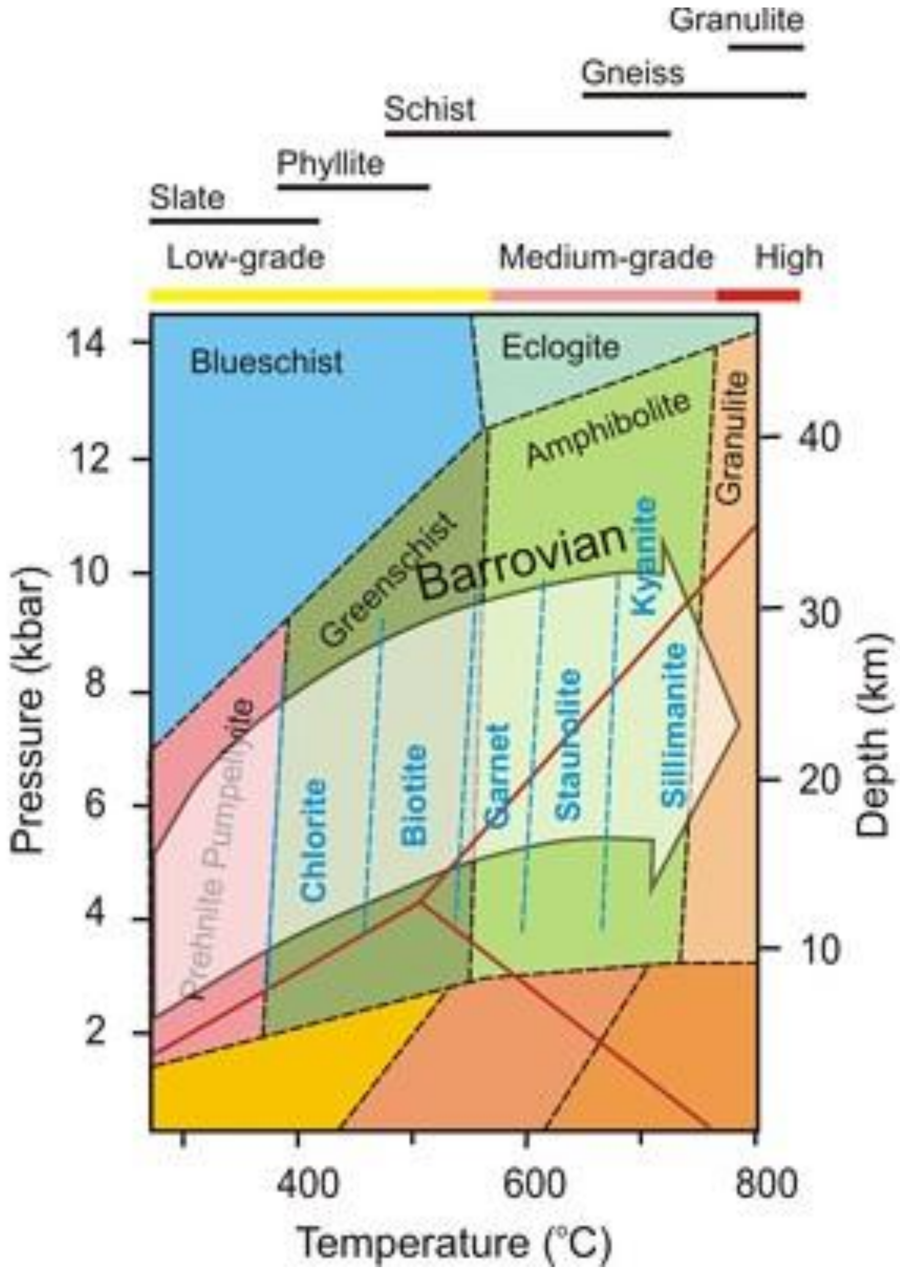


FIGURE 8.21 Contact metamorphism of shale yields hornfels, while contact metamorphism of quartz sandstone and limestone produces quartzite and marble, respectively.





Granulite
Gneiss
Schist
Phyllite
Slate
Low-grade
Medium-grade
High
Blueschist
Eclogite
Amphibolite
Granulite
Greenschist
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Kyanite
Sillimanite
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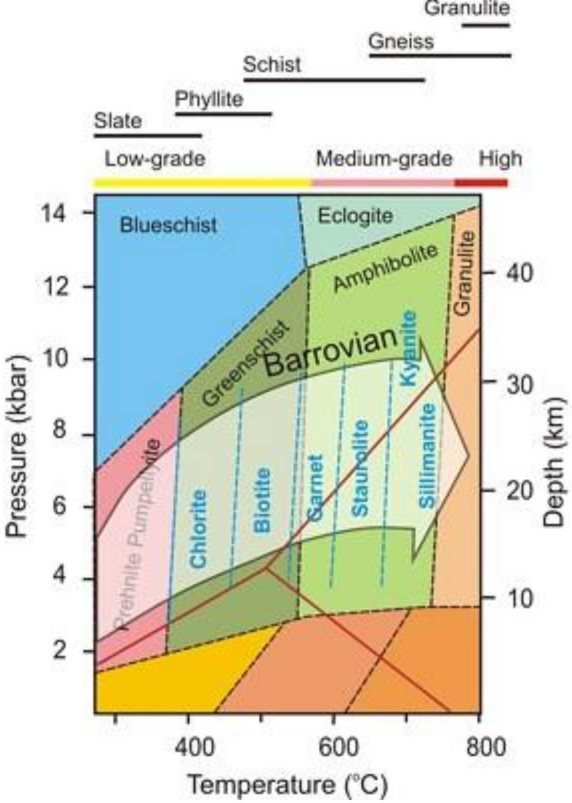

Glossary: Barrovian Zones

Barrovian zones are metamorphic zones that describe the changes in metamorphic mineral assemblages that occur in regionally metamorphosed pelitic rocks characterised by the Highlands of Scotland. Barrovian metamorphism is associated with many orogenic belts. Buchan metamorphism is similar to Barrovian but has elevated temperatures.

Barrovian zones are defined by the first appearance of index minerals that generally persist into higher grade zone (higher temperature). With increasing temperature these minerals are chlorite, biotite, garnet, staurolite, kyanite, and sillimanite. The zones are named after the index mineral. Barrovian zones extend across greenschist; amphibolite and granulite metamorphic facies.

The boundaries between zones form lines at the surface known as isograds. Often one or more of the zones in the Barrovian series may be missing.Related Terms

metamorphic zone, metamorphic grade, metamorphic facies, regional metamorphism, index mineral

Barrovian zones

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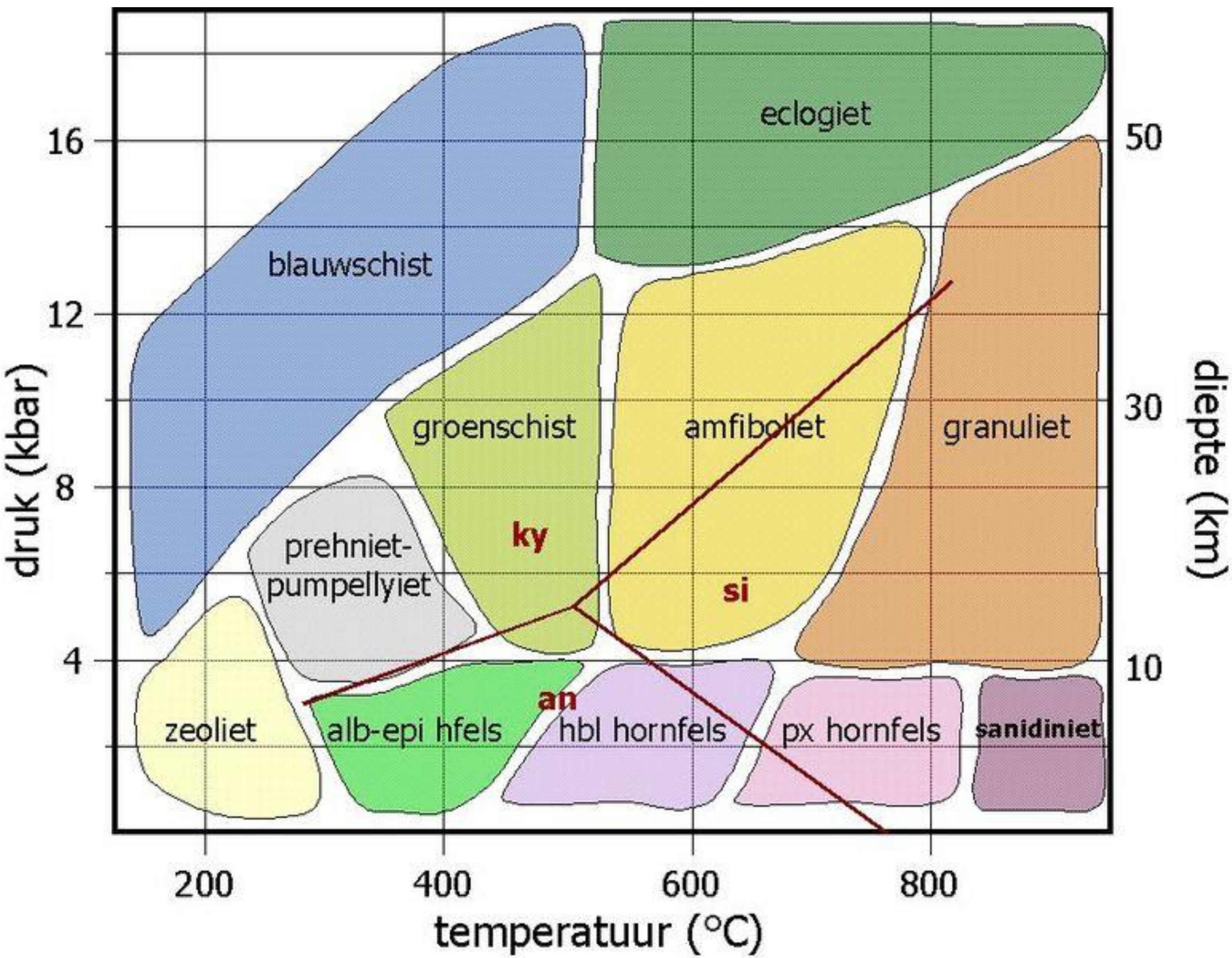
The boundaries between zones form lines at the surface known as isograds. Often one or more of the zones in the Barrovian series may be missing.



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https://commons.wikimedia.org/wiki/File:Metamorfe_facies.jpg

Metamorphic Rocks and the Rock Cycle

Designed to meet South Carolina Department of Education 2005 Science Academic Standards

Department of Natural Resources

South Carolina Geological Survey

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- What are Rocks? (slide 3) (Standard: 3-3.1 (covers slides 3-26))
- Major Rock Types (slide 4)
- The Rock Cycle (slide 5)
  - Metamorphic Rocks (slide 6)
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    - Metamorphic Conditions (slide 8)
    - Causes of Metamorphism (slide 9-11)
      - Heat (slide 9)
      - Pressure (slide 10)
      - Chemically Active Fluids (slide 11)
    - The Role of Parent Rocks in Metamorphism (slide 12)
    - Classifying Metamorphic Rocks by Different Textures (slide 13)
      - Foliated Rock Textures: (slide 14-17)
        - » Slaty Cleavage (15), Schistocity (16), and Gneissic (17)
      - Foliated Metamorphic Rocks: (slide 18-22)
        - » Slate (19), Phyllite (20), Schist (21), and Gneiss (22)
      - Nonfoliated Rock Textures (slide 23)
        - » Marble (slide 24)
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  - Metamorphic Rocks in the Landscape (slide 26)
  - Metamorphic Rocks in South Carolina (slide 27)
- South Carolina Science Academic Standards (slide 28)
- Resources and References (slide 29)

What are Rocks?

- **Most rocks are an aggregate of one or more minerals, and a few rocks are composed of non-mineral matter.**

- **There are three major rock types:**
  - **1. Igneous**
  - **2. Metamorphic**
  - **3. Sedimentary**

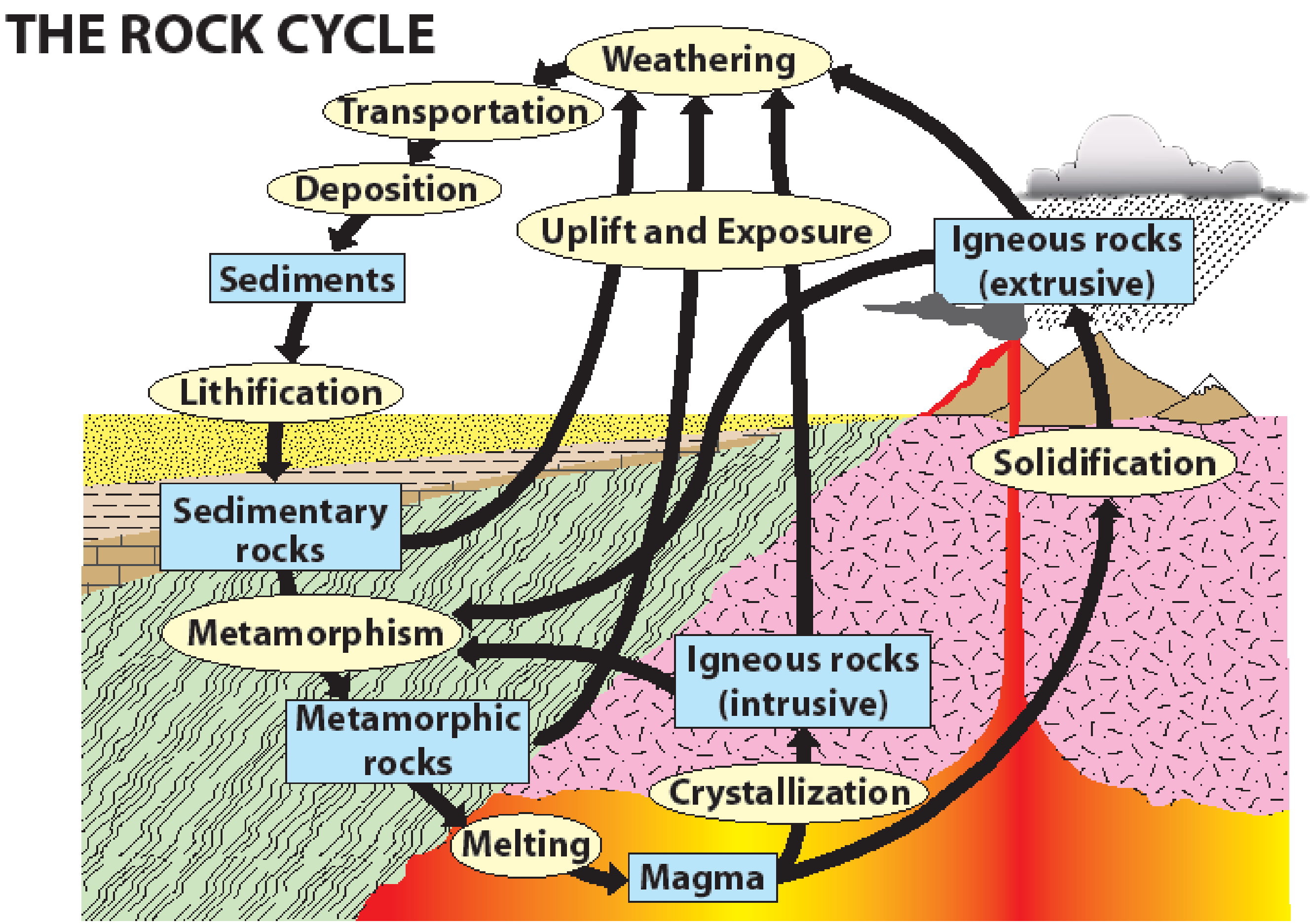
Major Rock Types

- Igneous rocks are formed by the cooling of molten magma or lava near, at, or below the Earth's surface.

- Sedimentary rocks are formed by the lithification of inorganic and organic sediments deposited at or near the Earth's surface.

- Metamorphic rocks are formed when preexisting rocks are transformed into new rocks by heat and pressure below the Earth's surface.

The Rock Cycle



Igneous Rocks -
Rocks that form from the cooling of motlen rock (magma), Example: granite and basalt

Sedimentary Rocks -
Rocks that are fromed from pieces of other rocks, Example: sandstone, or that are deposited from the ocean by chemical processes, Example: limestone

Metamorphic Rocks -
Rocks that are changed by heat and pressure without melting, Example: gneiss

Metamorphic Rocks

- Metamorphic rocks are formed when existing parent rocks are transformed (metamorphosed) by heat and pressure deep below the surface of the earth or along the boundary of tectonic plates.

- The three primary causes of metamorphism include one or more of the following conditions: heat, pressure, and/or chemically active fluids.

- During metamorphism, rocks may fold, fracture, or even partially melt to a viscous state and flow before reforming into a new rock.

- Metamorphic rocks change in appearance, mineralogy, and sometimes even chemical composition from their parent rock source.

- Metamorphism can occur along a range of heat and pressure intensities from low- to high-grade metamorphism.
- Low-grade metamorphism involves lower temperature and compressional forces that result in less overall change to the parent rock. In many cases, after low-grade metamorphic changes the parent rock may still be easily distinguishable.
- High-grade metamorphism results in a total transformation of the parent rock into a new rock whereby its original parent-rock source is difficult to identify.

- 1. Contact or Thermal Metamorphism: occurs when parent rock is intruded by magma (usually an igneous intrusion). Metamorphic changes under these conditions are primarily the result of temperature changes associated with the intruding magma. Additionally, when hot ion-rich water circulates through fractures in a rock, it can also cause chemical changes to the parent rock. These heat-driven, chemical reactions occur with igneous activity and the presence of water.

- 2. Dynamic Metamorphism: occurs when rocks are subjected to extreme pressure very rapidly. Two situations are noted, (a.) fault zones and (b.) impact craters. (a.) In the upper crust, faults are planar zones of crushed rock. The heat generated by friction during faulting can melt and metamorphose portions of the rock. (b.) Impact craters formed by extra-terrestrial objects (meteorites) colliding with the earth are commonly identified by exotic high-pressure minerals formed during the meteorite crash. Stishovite and coesite, both are high-pressure forms of quartz resulting from meteor impacts.

- 3. Regional Metamorphism: occurs when rocks are subjected to both heat and pressure on a regional scale. It is caused by burial deep in the crust and is associated with large scale deformation and mountain building. It is the most widespread form of metamorphism.

Heat

- Heat provides energy for chemical reactions to proceed resulting in new minerals to form from original minerals in the source rock.

- Heat provides the energy that enables individual ions in the rock to mobilize and migrate between other ions recrystallizing and forming into new minerals.

- Heat involved in metamorphism comes from two main sources:

  - 1. Heat transferred during contact metamorphism from magma or igneous intrusions.

  - 2. Progressive temperature increase associated with geothermal gradient as rocks are transported to greater depths below the Earth's surface.

Pressure

- Pressure equals force per unit area: (Pressure = F/A).
- Pressure increases with depth as the weight and thickness of the overlying rocks increases.
- Pressure during metamorphism is manifested by two different forces: body force (confining pressure) and surface force (differential stress).
    - Body force —forces are applied equally in all directions (gravity and weight), as a result individual grains are compressed closer and closer together. Extreme confining pressures that occur at great depths may even cause ions in the minerals to recrystallize and form new minerals.
    - Surface force —operates across a surface and occurs when rocks are compressed or extended along a single plane (push-pull forces). As a result, the rocks are shortened or extended in the direction the pressure is applied. Near the Earth's surface, the cooler temperatures make rocks brittle and more susceptible to fracturing than folding. Deep below the Earth's surface, higher temperature conditions, make the rocks ductile and they flatten and elongate as oppose to breaking along a fracture, the resulting rocks then exhibit intricate folding patterns.

Chemically Active Fluids

- Chemically active fluids that are present between mineral grains during metamorphism act to facilitate ion movement and the re-crystallization of existing and new minerals.
- Higher temperatures increase the reactive capability of ion-rich fluids. When these fluids come in contact with mineral grains, the grains readily dissolve because of differential chemical potentials, and ions migrate to areas of lower potential eventually recrystallizing.
- Chemically active fluids have the ability to move between different rock layers and transport ions from one rock to another before they recrystallize.

- Texture is used to describe the size, shape, and arrangement of grains within a rock.
- The different textures of mineral grains within metamorphic rocks are used to infer information about the conditions which formed them.
- Many of the mineral grains in metamorphic rocks display preferential orientations where the alignment of the minerals is parallel or subparallel to one another.
- Rocks that exhibit parallel or sub-parallel orientation are categorized as foliated, while those that do not exhibit orientations are categorized as nonfoliated.

- Foliation is broadly defined as any planar arrangement of mineral grains or structural features in a rock. Foliation can occur in both igneous and metamorphic rocks (this section will only focus on foliation in metamorphic rocks).

- Foliation in metamorphic rocks occurs when the minerals in the rock align and recrystallize along planes of parallel orientation as a result of heat and compressional forces.

- Minerals recrystallize into platy, elongated, or flattened grains, according to their original crystal habits. They segregate into thin layers that appear as thinly banded slivers of minerals interlayered together.

- Different textures used to describe foliation include: slaty cleavage, schistosity, and gneissic texture.

Foliated Textures: Slaty Cleavage

- Slaty cleavage is used to describe rocks that split into thin, planar slabs when hit with a hammer.
- Rocks with slaty cleavage often contain alternating bands of different minerals where one type of mineral (usually mica formed from recrystallized clay) forms highly aligned platy grains of foliated minerals. The rock will split into thin sections along these bands.
- Slaty cleavage commonly occurs under low-grade metamorphic conditions.

Photo: SCGS

The weathered exterior of this rock and broken fragments show an example of slaty cleavage from the Carolina Slate belt in South Carolina's Piedmont.

Schistosity

- Schistosity describes rocks with foliated mineral grains that are large enough to see without magnification.
- Schistocity occurs under medium-grade metamorphic conditions, and the crystals have a greater opportunity to grow during recrystallization.
- Unlike slaty cleavage, which tends to preferentially affect some minerals more than others, schistosity tends to affect all the different mineral components.
- Rocks with schistosity are generally referred to as schist.

Photo: SCGS

The foliated mineral grains of this schist provide a good example of schistosity. Notice how the rock weathers in flaky sections. Rocks with schistosity can easily crumble or broken into smaller pieces with bare hands.

Gneissic

- Gneissic textures occur when the silicate minerals in the rock separate and recrystallize into alternating bands of light (quartz and feldspar) and dark (biotite, amphibole, or hornblende) grains of silicate minerals.
- The mineral alignment in gneissic rocks is less platy and more granular or elongated than slaty cleavage or schistosity.

Photo: SCGS

The alternating quartz and biotite bands in this rock characterize gneissic texture. This photo also illustrates an example of folding that results from the intense heat and pressure of metamorphic conditions.

- Slate
- Phyllite
- Schist
- Gneiss

Photo: SCGS

South Carolina's Piedmont is composed primarily of foliated metamorphic rocks. In many locations different metamorphic rock types occur in close proximity. Many of the metamorphic rocks in this region are folded and faulted, making for very exciting geology.

Photo: SCGS

Slate

- Slate is a fine-grained rock composed of mica flakes and quartz grains that enable the rock to break into thin slabs of rock, along planes of slaty cleavage.
- Slate forms in low-grade metamorphic environments from a parent rock of either shale, mudstone, or siltstone.
- Slate is commonly thought of as black, but it can also be red when it contains iron oxide minerals, or green when it contains chlorite. Weathered slate may even appear light brown in the example below.

Photo: SCGS

This example of slate is part of the Carolina Slate belt which traverses through the Piedmont of South Carolina. This image also provides a good example of the slaty cleavage that has also been folded.

Schist

- Schist exhibits schistosity, which is formed by the alignment of platy medium- to coarse-grained minerals formed under moderate- to high-grade metamorphic conditions.
- Schists are primarily composed of silicate minerals such as mica (muscovite and biotite), quartz, and feldspar .
- Shale, siltstone, and some sandstones can provide the parent rock for schist.
- Schist may contain accessory minerals such as garnet, tourmaline, and pyrite.

Photo: SCGS

This schist is from the Piedmont region in South Carolina. Notice how the different layers are weathering at slightly different rates, the layers of darker, mica rich schist are weathering more quickly than the tan, feldspar and quartz-rich layers.

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Phyllite

- Phyllite is a low- to moderate-grade metamorphic rock that contains aligned platy mica minerals and has slaty cleavage.
- The individual crystals are fine grained and generally consist of muscovite, white mica, and chlorite (green rocks).
- Phyllite has a satiny appearance and waxy texture.
- Phyllite is a metamorphic form of shale, mudstone, and siltstone.

These samples of phyllite all came from the same quarry in South Carolina. The slaty cleavage of the phyllite is what makes it a foliated rock. As phyllite weathers it parts along the cleavage planes.

- Nonfoliated rock textures form under two basic conditions, metamorphism of monomineralic rocks and metamorphism in the absence of directed stress.
- Nonfoliated textures form during recrystallization of monomineralic rocks where the distribution of mineral growth is approximately equal, i.e. minerals grow at same rate and to same size.
- In the absence of directed stress, minerals with high aspect ratio are randomly oriented and show no preferential alignment.
- Marble is an example of a metamorphic rock with a nonfoliated texture.

Marble

- Marble is a nonfoliated, coarse-grained metamorphic rock formed from the parent rock limestone or dolostone.
- Because it is formed from limestone or dolostone it is predominantly composed of the mineral calcite, which metamorphoses into various carbonate and other minerals. As calcite recrystallizes, all the grains are active at the same time and they grow to the same size and shape, which leads to its nonfoliated texture.
- Different color schemes in marble are the result of impurities or the presence of weathered materials deposited in or near the limestone.

Marble is used as a building material and is popular for sculpture. The word ‘marble’ derives from a Greek word that translates as “shining stone” because it can be polished. Limestone that metamorphoses into marble may contain a lot of fossils; however, the heat and pressure of metamorphism destroys preexisting features primarily through recrystallization.

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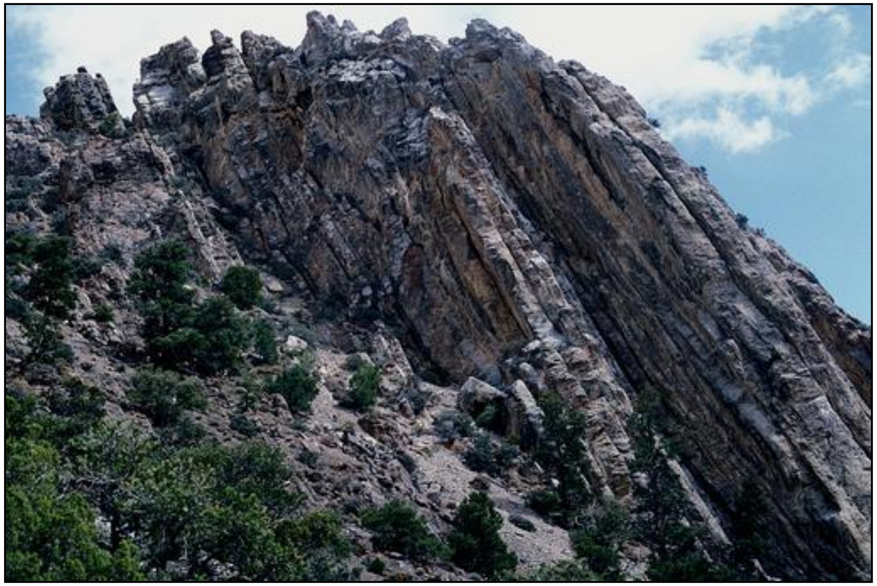
Quartzite

- Quartzite is a metamorphic rock formed under moderate to high-grade metamorphism that exhibits both foliated and nonfoliated structure.
- The parent rock to quartzite is sandstone.
- Quartzite forms from the recrystallization of quartz grains in the sandstone and often the resulting metamorphic rock will preserve vestiges of the original bedding patterns .
- Quartz is predominantly white in color, but can also contain pinkish or grayish shades depending on the presence of iron oxides.

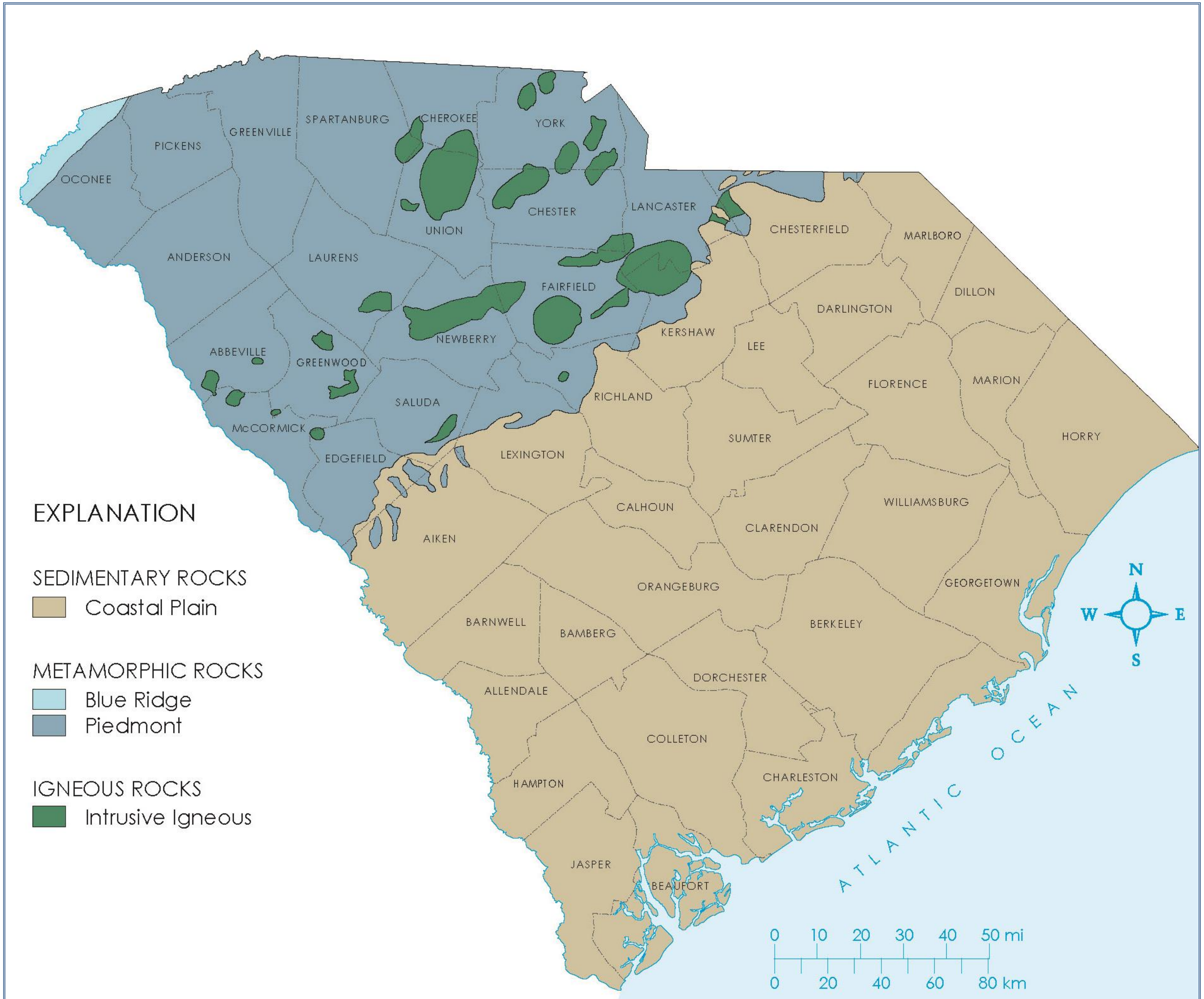
This example of quartzite show a couple of interesting features. First, notice how the different bedding planes have been preserved during the metamorphism. Secondly, there is a fault running though the quartzite that occurred after the formation of the rock. This particular example is of a foliated quartzite (due primarily to the preservation of the bedding planes) however some quartzite rocks are classified as nonfoliated.

Grandfather Mountain, in North Carolina, is part of the Blue Ridge Province of the Appalachian Mountains in the Eastern United States. The rocks in this region began undergoing metamorphism nearly a billion years ago. Million of years later rocks from Africa collided with North America, before rifting apart to eventually form the Atlantic Ocean. Today, weathering and erosion of the surrounding landscape exposes the metamorphosed rocks that make up Grandfather Mountain.

http://www.grandfather.com/



The Snake Range Mountain in Great Basin National Park, Nevada, are metamorphosed sandstone rocks. These vertically oriented bedding planes were once horizontal layers of sediment deposits at the bottom of a sea. Nearly 200 million years ago thrusting, tilting, faulting, and uplifting metamorphosed the sandstone into quartzite. Another major metamorphic event began about 30 million years ago when the earth's crust began stretching in an east to west direction. As a result the rocks faulted into large blocks that tilted, producing the rock orientation we see today.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DARLINGTON
DILLON
NEWBERRY
KERSHAW
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ABBEVILLE
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SEDIMENTARY ROCKS
Coastal Plain
METAMORPHIC ROCKS
Blue Ridge
Piedmont
IGNEOUS ROCKS
Intrusive Igneous

1) Earth's Materials and Changes:

Standard 3-3:

The student will demonstrate an understanding of Earth's composition and the changes that occur to the features of Earth's surface. (Earth Science).

Indicators:

3-3.1: Classify rocks (including sedimentary, igneous, and metamorphic). (slides: 3-26)

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ressure Associated

•***Directed pressure***

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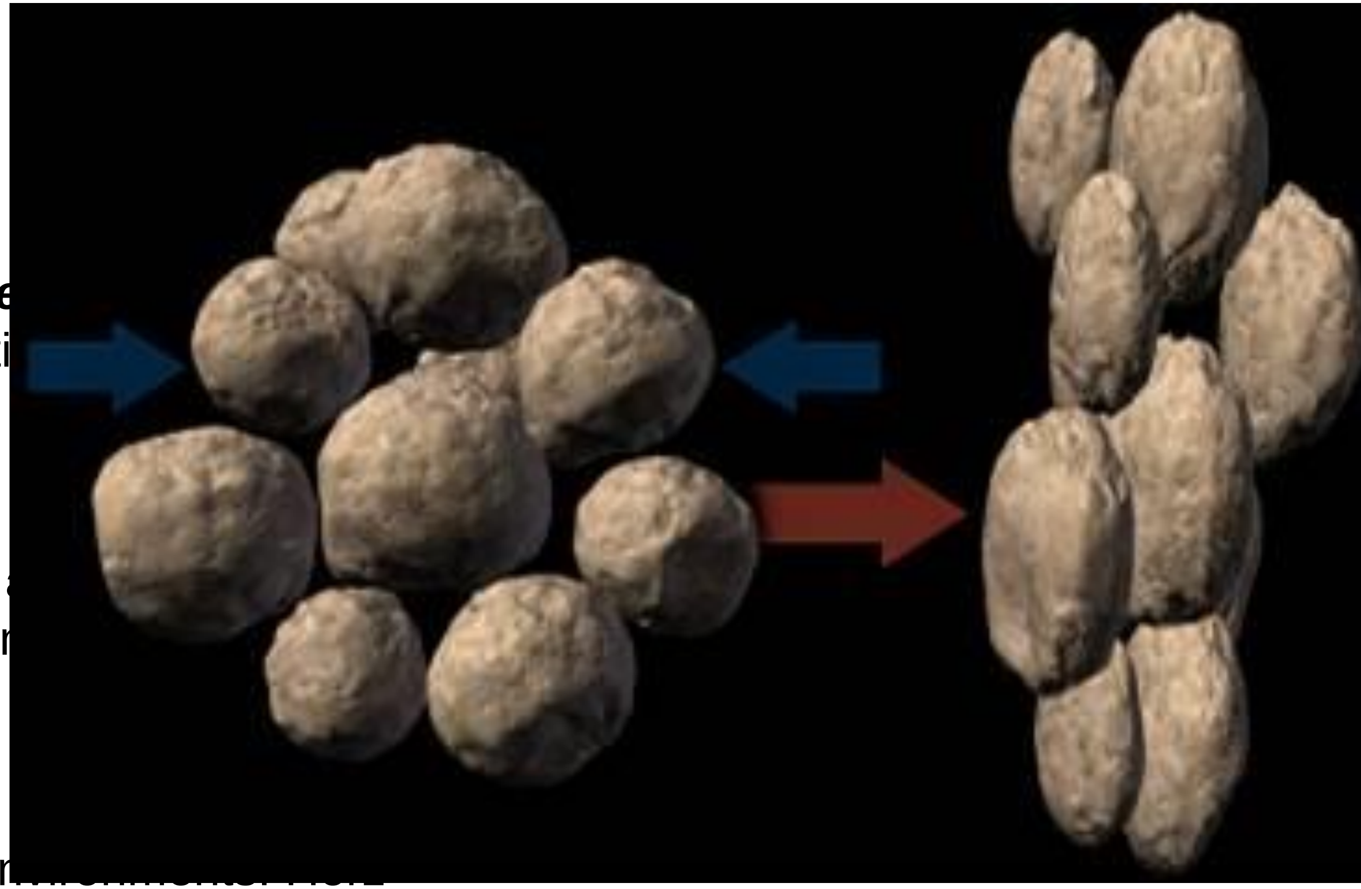

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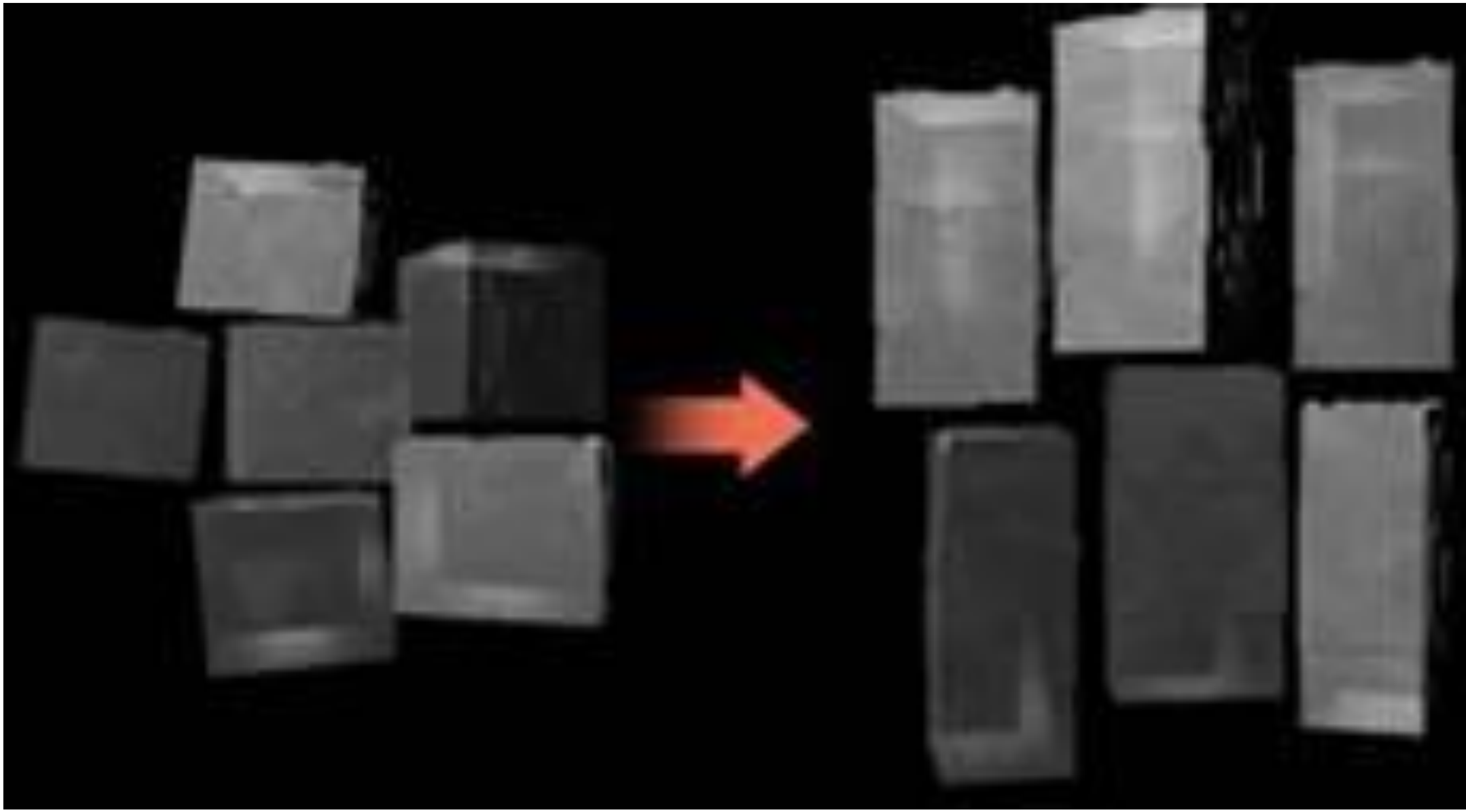
•Directed pressure

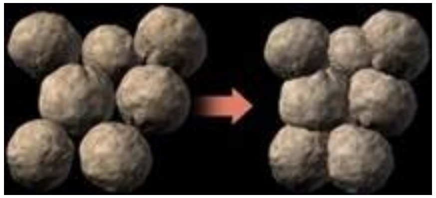
environment

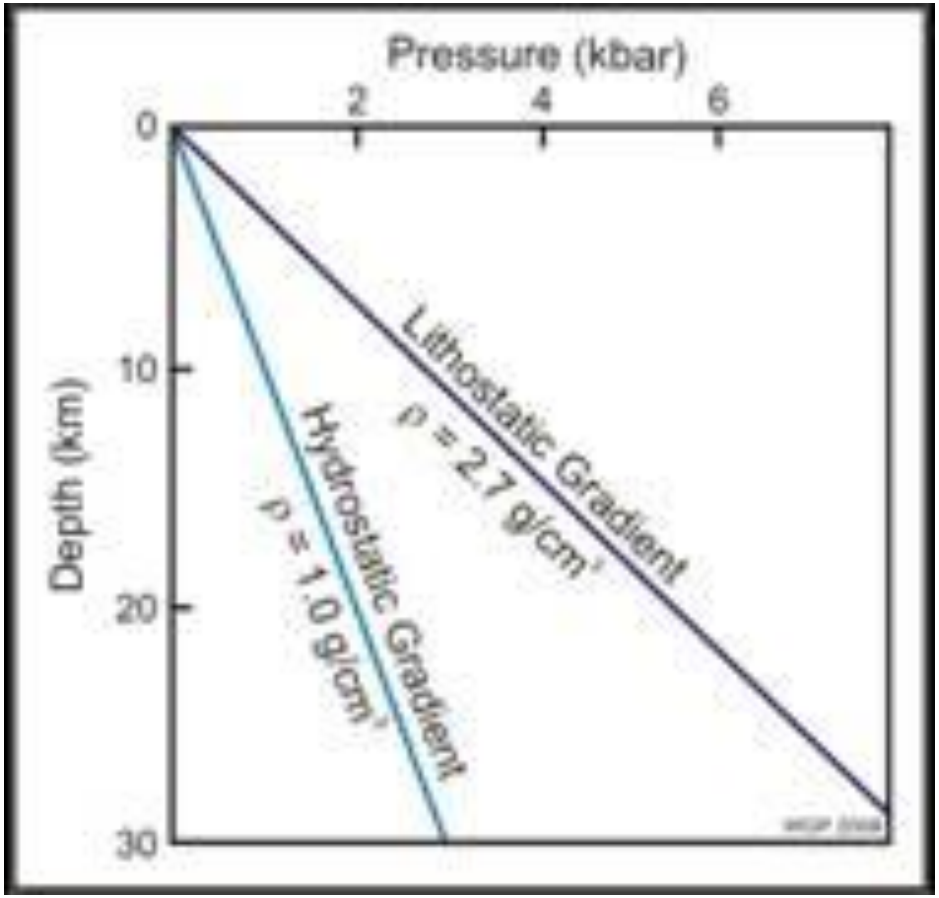
–Compressional en

Vert Pressure

–Extensional environments: Vert > Horz Pressure







Pressure Associated with Metamorphism

•***Lithostatic pressure:*** the confining pressure created bythe material that sits above a particular location.Lithostatic pressure is equal in all directions andcompresses the volume of rock.

–Basalt: 3 g/cm3 (3000 kg/m3)

–Granite: 2.7 g/cm3 (2700 kg/m3)

–The lithostatic pressure at a 10 km depth is ≈ 3 kbar = 0.3 GPa

Essentially Three Environment-Based Variables that Control the Character of Metamorphism

- **Depth of Burial**
- **Temperature (usually a function of depth)**
  - **P and T control mineral stability**
- **Lithostatic versus Directed Pressure**
  - **Controls textures**

Types of Metamorphism
•Contact Metamorphism
–Thermal variation controls processes
•Regional Metamorphism
–Orogenic Metamorphism
•Combination of temperature anddirected pressure
–Burial Metamorphism
•Combination of temperature andlithostatic pressure
•Fault-Zone Metamorphism
–Directed pressure controlsprocesses (GEOL 41.1)

Orogenic Regional Metamorphism

- **High T/Low Pmetamorphismassociated with arccomplex**
  - **–Contact metamorphism atshallow depth**
- **High T/High Pmetamorphismassociated with the foldand thrust belt**

Orogenic Regional Metamorphism

•Low T/High Pmetamorphismassociated with oceanictrench environments

Metamorphism

- Literally translates to “change of form”
- In geology it refers to solid-state changesin mineral assemblages of a rock, and/orthe texture of these minerals
- Due to changes in temperature and/orpressure

Pressure Associated with Metamorphism

- Lithostatic pressure: the confining pressure created bythe material that sits above a particular location.Lithostatic pressure is equal in all directions andcompresses the volume of rock.

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Pressure Associated with Metamorphism

•Directed pressure: pressure is imposed in a particulardirection due to a regional stress field.

•Directed pressure affects the shape and arrangement of the minerals

•Directed pressure varies with tectonic environment

–Compressional environments: Horz > Vert Pressure

–Extensional environments: Vert > Horz Pressure

Classification of Metamorphic rocks

Classification of metamorphic rocks depends on what is visible in the rock and its degree of metamorphism.

Note that classification is generally loose and practical such that names can be adapted to describe the rock in the most satisfactory way that conveys the important characteristics.

Three kinds of criteria are normally employed. These are:

Mineralogical - The most distinguishing minerals are used as a prefix to a textural term. Thus, a schist containing biotite, garnet, quartz, and feldspar, would be called a biotite-garnet schist. A gneiss containing hornblende, pyroxene, quartz, and feldspar would be called a hornblende-pyroxene gneiss.

A schist containing porphyroblasts of K-feldspar would be called a K-spar porphyroblastic schist.

Chemical - If the general chemical composition can be determined from the mineral assemblage, then a chemical name can be employed. For example a schist with a lot of quartz and feldspar and some garnet and muscovite would be called a garnet-muscovite quartzo-feldspathic schist.

A schist consisting mostly of talc would be called a talc-magnesian schist.

Protolithic - If a rock has undergone only slight metamorphism such that its original texture can still be observed then the rock is given a name based on its original name, with the prefix meta- applied. For example: metabasalt, metagraywacke, meta-andesite, metagranite.

In addition to these conventions, certain non-foliated rocks with specific chemical compositions and/or mineral assemblages are given specific names. These are as follows:

***Amphibolites*: These are medium to coarse grained, dark colored rocks whose principal minerals are hornblende and plagioclase.**

They result from metamorphism of basic igneous rocks. Foliation is highly variable, but when present the term schist can be appended to the name (i.e. amphibolite schist).

***Marbles*: These are rocks composed mostly of calcite, and less commonly of dolomite. They result from metamorphism of limestones and dolostones. Some foliation may be present if the marble contains micas.**

***Eclogites*: These are medium to coarse grained consisting mostly of garnet and green clinopyroxene called omphacite, that result from high grade metamorphism of basic igneous rocks. Eclogites usually do not show foliation.**

***Quartzites*: Quartz arenites and chert both are composed mostly of SiO_2. Since quartz is stable over a wide range of pressures and temperatures, metamorphism of quartz arenites and cherts will result only in the recrystallization of quartz forming a hard rock with interlocking crystals of quartz. Such a rock is called a quartzite.**

Serpentinites: **Serpentinites are rocks that consist mostly of serpentine. These form by hydrothermal metamorphism of ultrabasic igneous rocks.**

Soapstones: Soapstones are rocks that contain an abundance of talc, which gives the rock a greasy feel, similar to that of soap.

Talc is an Mg-rich mineral, and thus soapstones from ultrabasic igneous protoliths, like peridotites, dunites, and pyroxenites, usually by hydrothermal alteration.

Skarns: **Skarns are rocks that originate from contact metamorphism of limestones or dolostones, and show evidence of having exchanged constituents with the intruding magma.**

Thus, skarns are generally composed of minerals like calcite and dolomite, from the original carbonate rock, but contain abundant calcium and magnesium silicate minerals like andradite, grossularite, epidote, vesuvianite, diopside, and wollastonite that form by reaction of the original carbonate minerals with silica from the magma.

The chemical exchange is that takes place is called *metasomatism.*

Mylonites: **Mylonites are cataclastic metamorphic rocks that are produced along shear zones deep in the crust. They are usually fine-grained, sometimes glassy, that are streaky or layered, with the layers and streaks having been drawn out by ductile shear.**