Welcome

This is

CE181404
Engineering Geology

ROCKS

- **Rocks**: mixtures of minerals: variable properties.
- **Minerals**: compounds of elements: fixed properties.

ROCK CYCLE

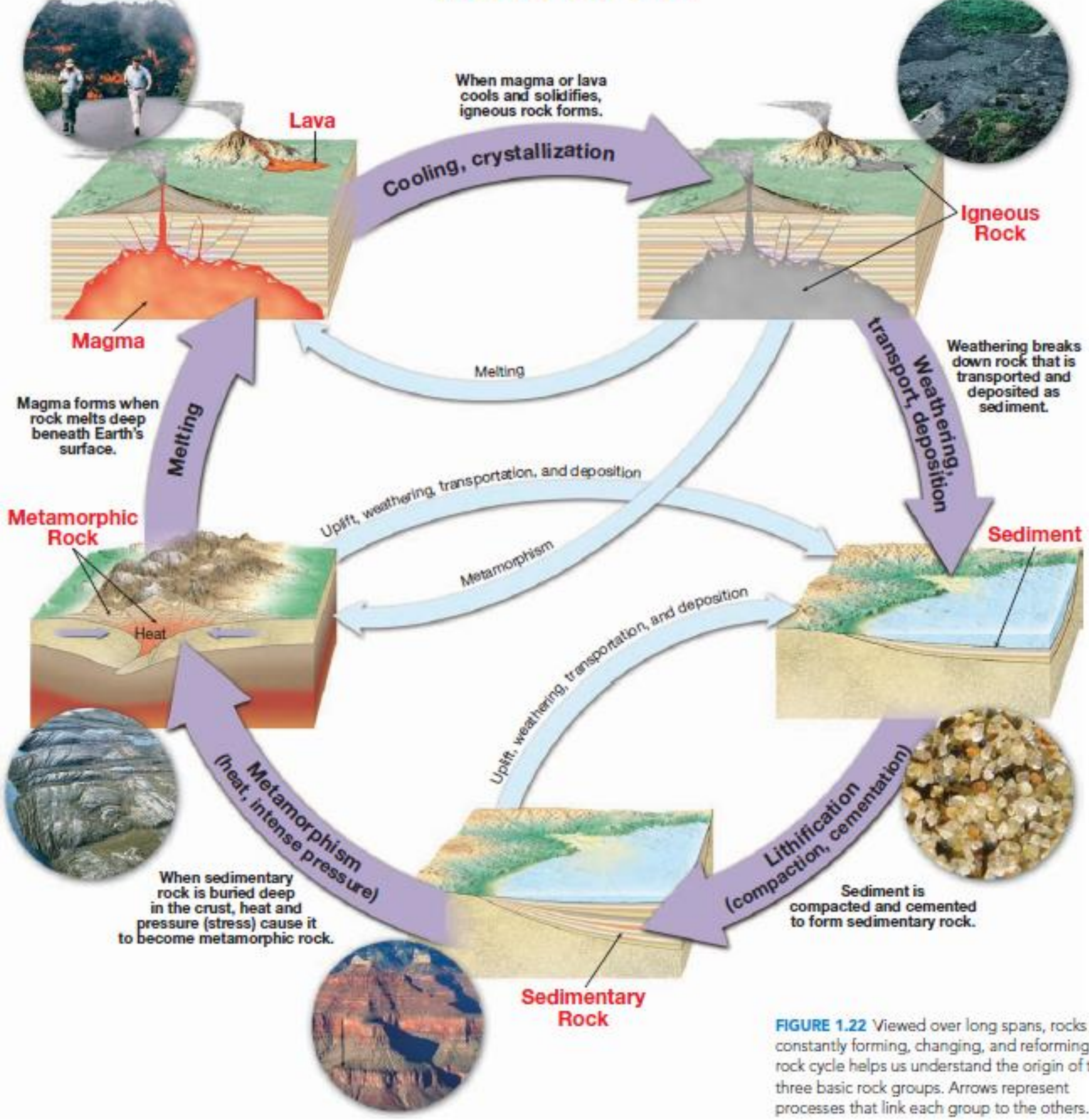


FIGURE 1.22 Viewed over long spans, rocks are constantly forming, changing, and reforming. The rock cycle helps us understand the origin of the three basic rock groups. Arrows represent processes that link each group to the others.

Magma: The Parent Material of Igneous Rock

- The parent material for igneous rocks, called magma**,** is formed by melting that occurs at various levels within Earth’s crust and upper mantle to depths.
- Once formed, a magma body buoyantly rises toward the surface because it is less dense than the surrounding rocks. (When rock melts it takes up more space and, hence, it becomes less dense than the surrounding solid rock.) Occasionally molten rock reaches Earth’s surface where it is called lava.

The Nature of Magma

Magma is completely or partly molten rock, which on cooling solidifies to form an igneous rock composed of silicate minerals. Most magmas consist of three distinct parts—a *liquid component,* a *solid component,* and a *gaseous phase.*

The liquid portion, called melt, is composed mainly of mobile ions of the eight most common elements found in Earth's crust—silicon and oxygen, along with lesser amounts of aluminum, potassium, calcium, sodium, iron, and magnesium.

The solid components (if any) in magma are silicate minerals that have already crystallized from the melt. As a magma body cools, the size and number of crystals increase. During the last stage of cooling, a magma body is like a "crystalline mush" with only small amounts of melt.

The gaseous components of magma, called volatiles**,** are materials that will vaporize (form a gas) at surface pressures. The most common volatiles found in magma are water vapor (H2O), carbon dioxide (CO2), and sulphur dioxide (SO2), which are confined by the immense pressure exerted by the overlying rocks. These gases tend to separate from the melt as it moves toward the surface (low-pressure environment). As the gases build up, they may eventually propel magma from the vent. When deeply buried magma bodies crystallize, the remaining volatiles collect as hot, water-rich fluids that migrate through the surrounding rocks. These hot fluids play an important role in metamorphism.

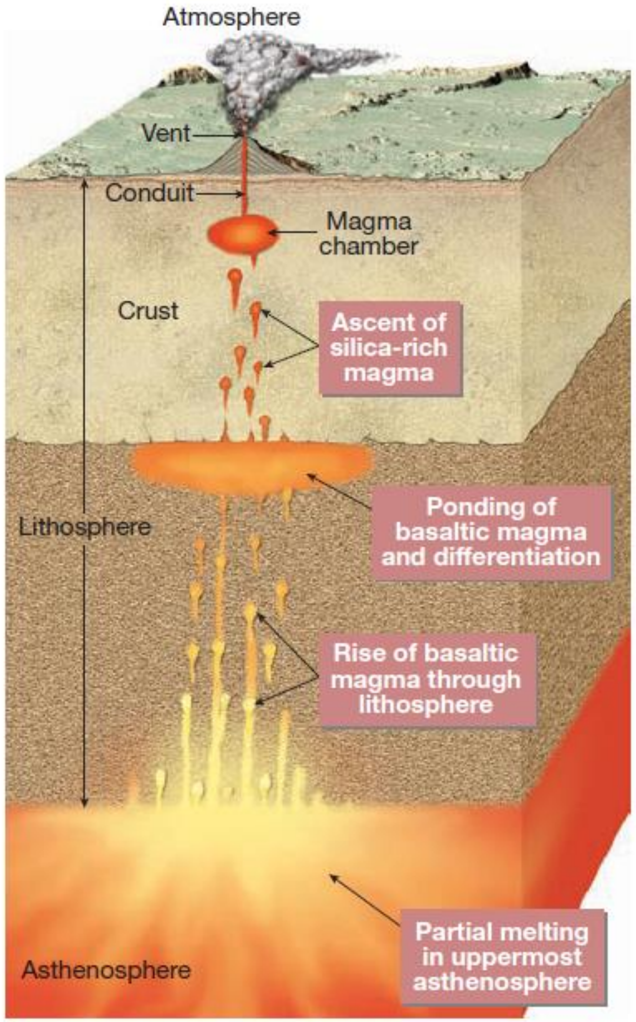


FIGURE 4.3 Schematic drawing showing the movement of magma from its source in the upper asthenosphere through the continental crust. During its ascent, mantle-derived basaltic magmas evolve through the process of magmatic differentiation and by melting and incorporating continental crust. Magmas that feed volcanoes in a continental setting tend to be silica-rich (viscous) and have a high gas content.

FIGURE 3.1 Fluid basaltic lava emitted from Hawaii's Kilauea volcano. *(Photo by U.S. Geological Survey)*

From Magma to Crystalline Rock

In any crystalline solid, the ions are arranged in a closely packed regular pattern. However, they are not without some motion—they exhibit a sort of restricted vibration about fixed points. As temperature rises, ions vibrate more rapidly and consequently collide with ever-increasing vigor with their neighbors. Thus, heating causes the ions to occupy more space, which in turn causes the solid to expand. When the ions are vibrating rapidly enough to overcome the force of their chemical bonds, melting occurs. At this stage the ions are able to slide past one another, and the orderly crystalline structure disintegrates. Thus, melting converts a solid consisting of tight, uniformly packed ions into a liquid composed of unordered ions moving randomly about.

In the process called crystallization, cooling reverses the events of melting. As the temperature of the liquid drops, ions pack more closely together as their rate of movement slows. When cooled sufficiently, the forces of the chemical bonds will again confine the ions to an orderly crystalline arrangement.

From Magma to Crystalline Rock

When magma cools, it is generally the silicon and oxygen atoms that link together first to form silicon–oxygen tetrahedra, the basic building blocks of the silicate minerals. As magma continues to lose heat to its surroundings, the tetrahedra join with each other and with other ions to form embryonic crystal nuclei. Slowly each nucleus grows as ions lose their mobility and join the crystalline network.

The earliest formed minerals have space to grow and tend to have better developed crystal faces than do the later ones that occupy the remaining spaces. Eventually all of the melt is transformed into a solid mass of interlocking silicate minerals that we call an *igneous rock*.

IGNEOUS ROCKS

Igneous rocks (ignis = fire)

Magma is generated by local heating and melting of rocks within the Earth’s crust, mostly at depths between 10 and around 100 km.

Most compositions of rock melt at temperatures of 800–1200°C.

When the magma cools, it solidifies by crystallizing into a mosaic of minerals, to form an igneous rock.

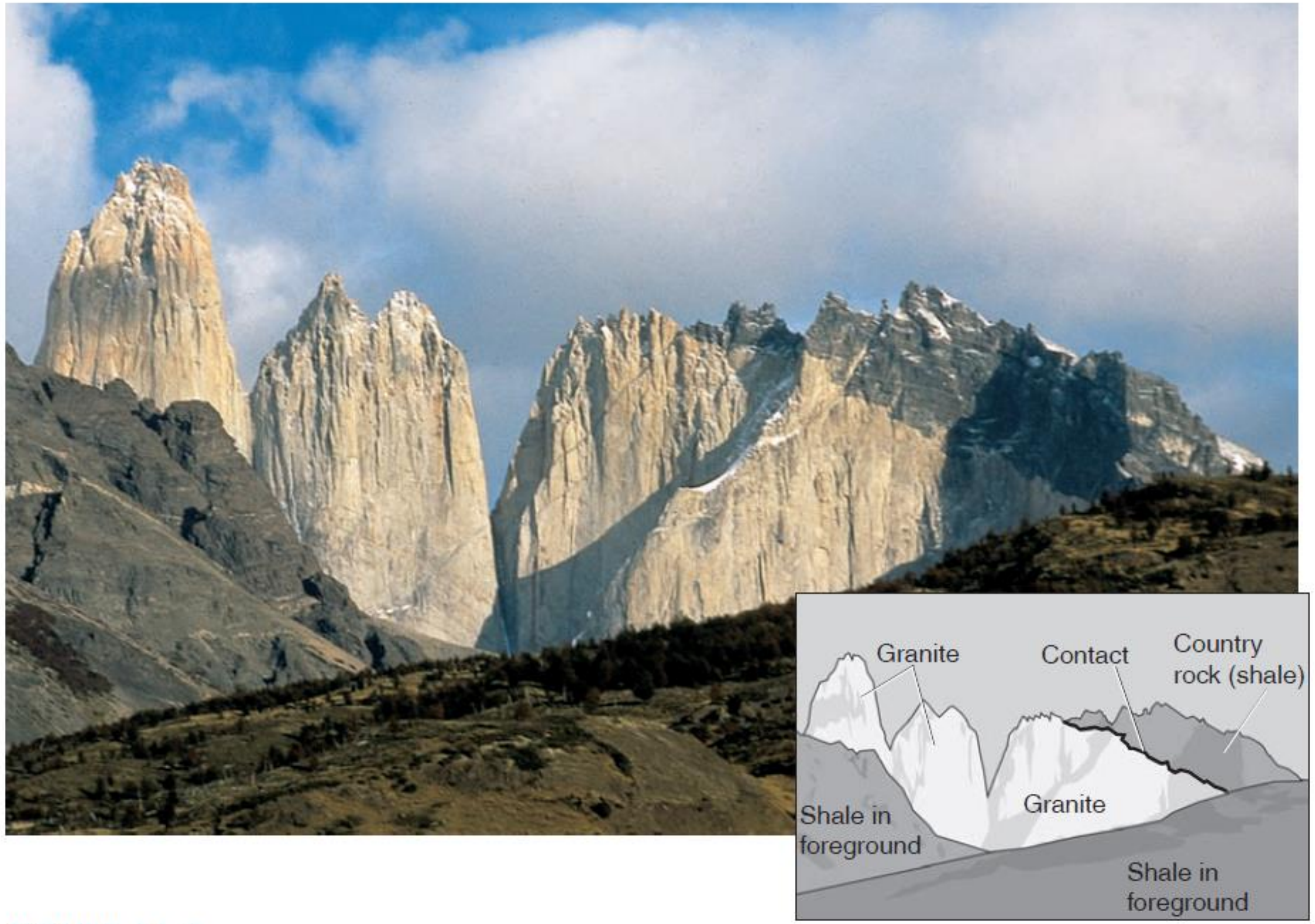


FIGURE 11.3

Granite (light-colored rock) solidified from magma that intruded dark-colored country rock in Torres del Paine, Chile. The dark-colored country rock is shale deposited in a marine environment. The spires are erosional remnants of rock that were once deep underground. *Photo by Kay Kepler*

Geologist’s View

Types of Igneous rocks

- Extrusive Igneous Rocks
- Intrusive Igneous Rocks

Extrusive Igneous Rocks

- These form where magma is extruded onto the Earth's surface to create a volcano. They are also called volcanic rocks.

Intrusive Igneous Rocks

These are formed when magma solidifies below the surface of the Earth. They are also known as plutonic rocks. They may later be exposed at the surface when the cover rocks are eroded away.

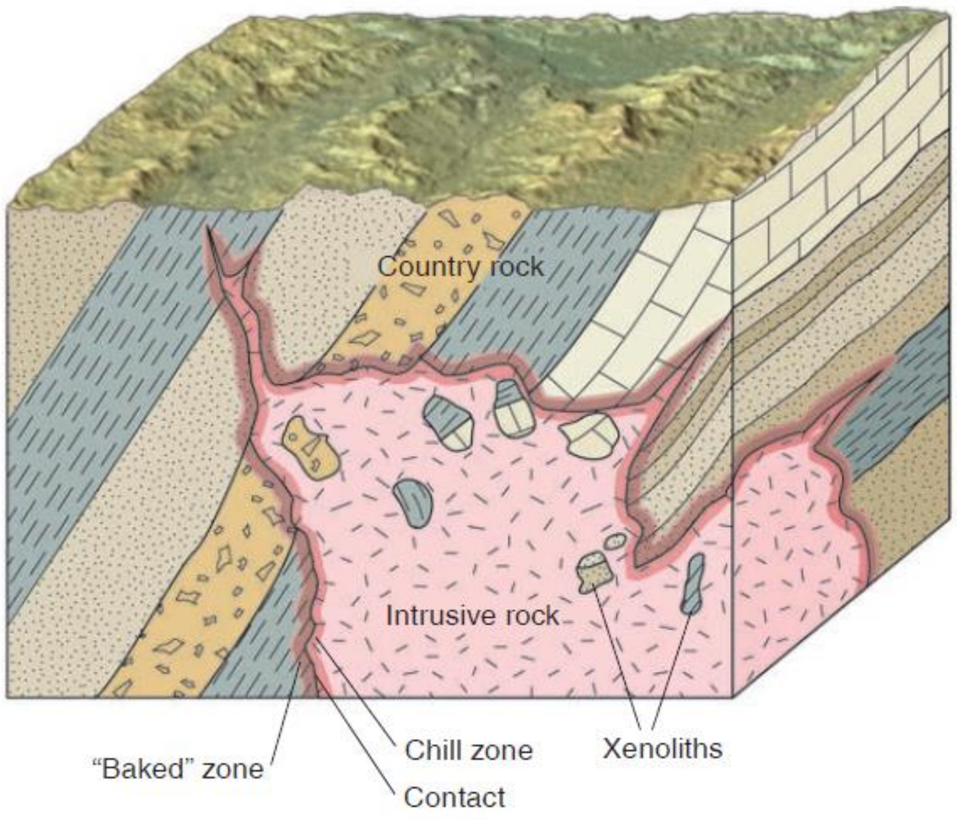


FIGURE 11.4

Igneous rock intruded preexisting rock (country rock) as a liquid. (Xenoliths are usually much smaller than indicated.)

Chemistry of Igneous Rocks

- The chemical composition of the magma determines which minerals and how much of each will crystallize when an igneous rock forms.
- For instance, the presence of quartz in a rock indicates that the magma was enriched in silica (SiO_2).
- For virtually all igneous rocks, SiO_2 (silica) is the most abundant component.
- The amount of SiO_2 varies from about 45% to 75% of the total weight of common igneous rocks.
- The variations between these extremes account for striking differences in the appearance and mineral content of the rocks.

Chemistry of Igneous Rocks

Igneous rocks are composed mainly of silicate minerals. Chemical analyses show that silicon and oxygen are by far the most abundant constituents of igneous rocks. These two elements, plus ions of aluminium (Al), calcium (Ca), sodium (Na), potassium (K), magnesium (Mg), and iron (Fe), make up roughly 98 percent, by weight, of most magmas. In addition, magma contains small mounts of many other elements, including titanium and manganese, and trace amounts of much rarer elements such as gold, silver, and uranium.

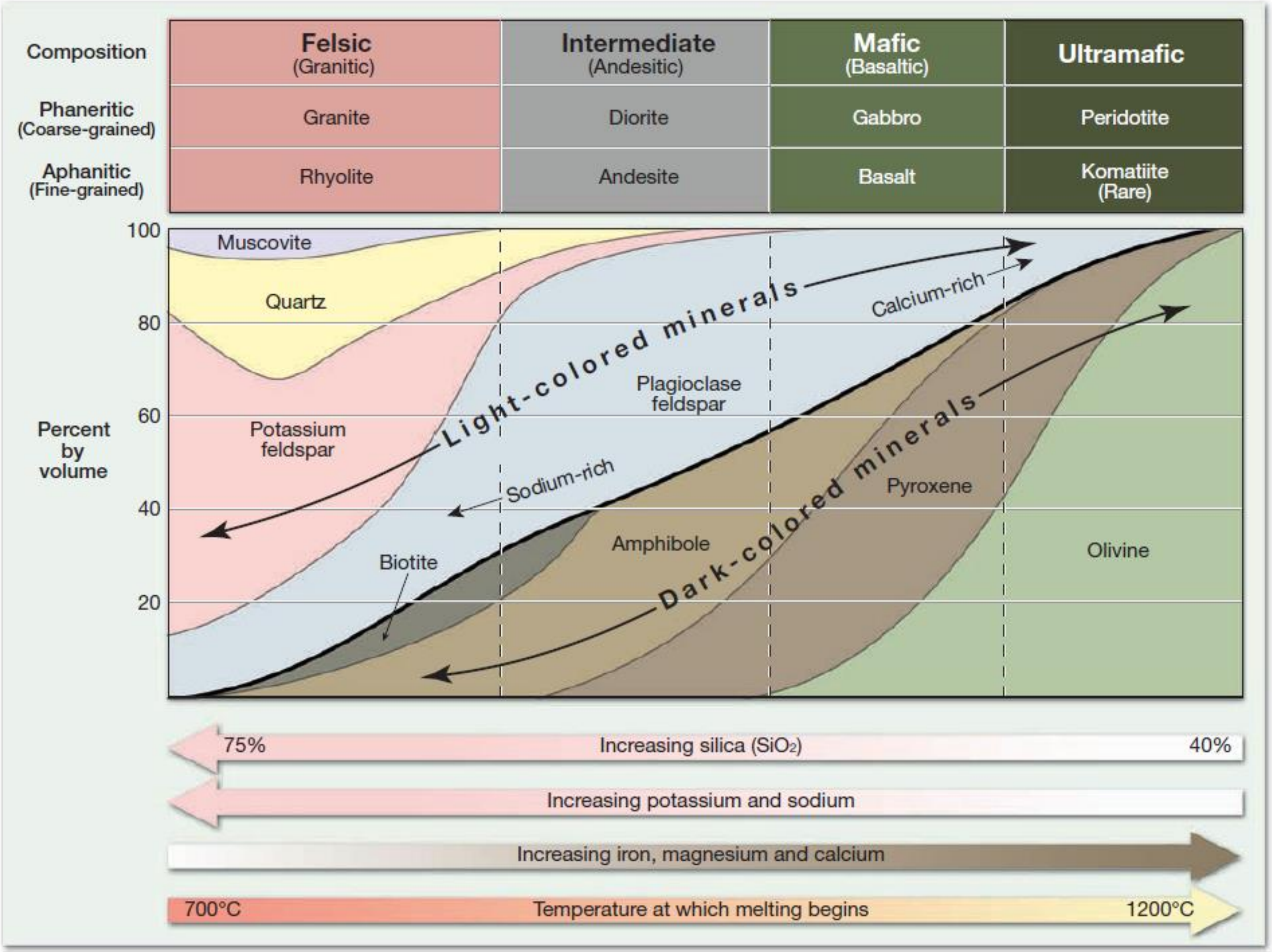
Chemistry of Igneous Rocks

As magma cools and solidifies, these elements combine to form two major groups of silicate minerals.

The *dark (ferromagnesian) silicates* are rich in iron and/or magnesium and comparatively low in silica. *Olivine, pyroxene, amphibole,* and *biotite mica* are the common dark silicate minerals of Earth's crust.

By contrast, the *light (nonferromagnesian) silicates* contain greater amounts of potassium, sodium, and calcium rather than iron and magnesium. As a group, nonferromagnesian minerals are richer in silica than the dark silicates. The light silicates include *quartz, muscovite mica,* and the most abundant mineral group, the *feldspars.* Feldspars make up at least 40 percent of most igneous rocks. Thus, in addition to feldspar, igneous rocks contain some combination of the other light and/or dark silicates listed above.

FIGURE 3.3 Mineralogy of common igneous rocks and the magmas from which they form. (After Dietrich, Daily, and Larsen)



Mafic Rocks(Basaltic)

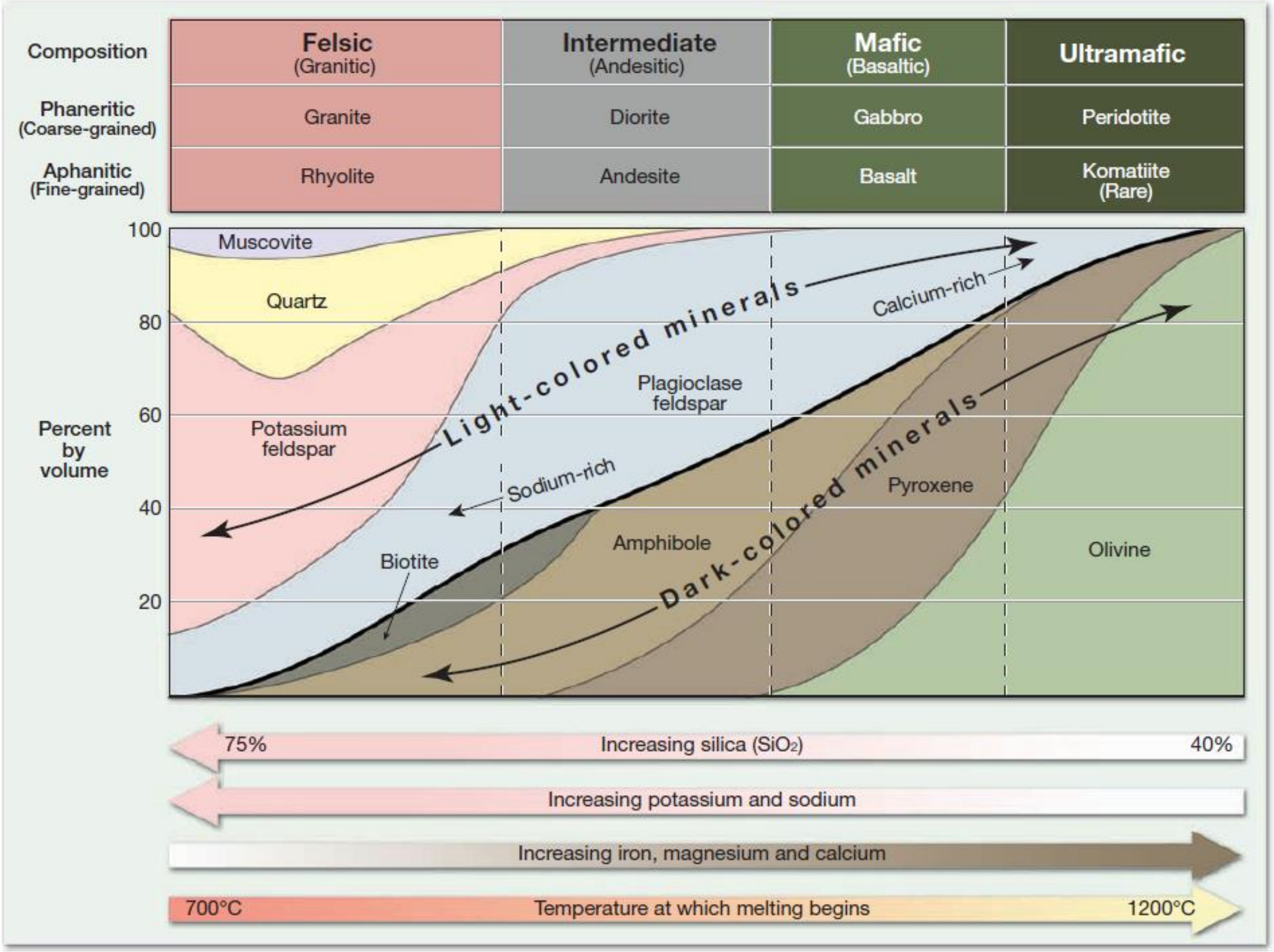
Rocks with a silica content close to 50% (by weight) are considered *silica-poor,* even though SiO2 is, by far, the most abundant constituent.

Rocks in this group are called **mafic**—silica-deficient igneous rocks with a relatively high content of magnesium, iron, and calcium.

The term *mafic* comes from *magnesium* and *ferric.*

Basalt and gabbro are mafic rocks.

FIGURE 3.3 Mineralogy of common igneous rocks and the magmas from which they form. (After Dietrich, Daily, and Larsen)



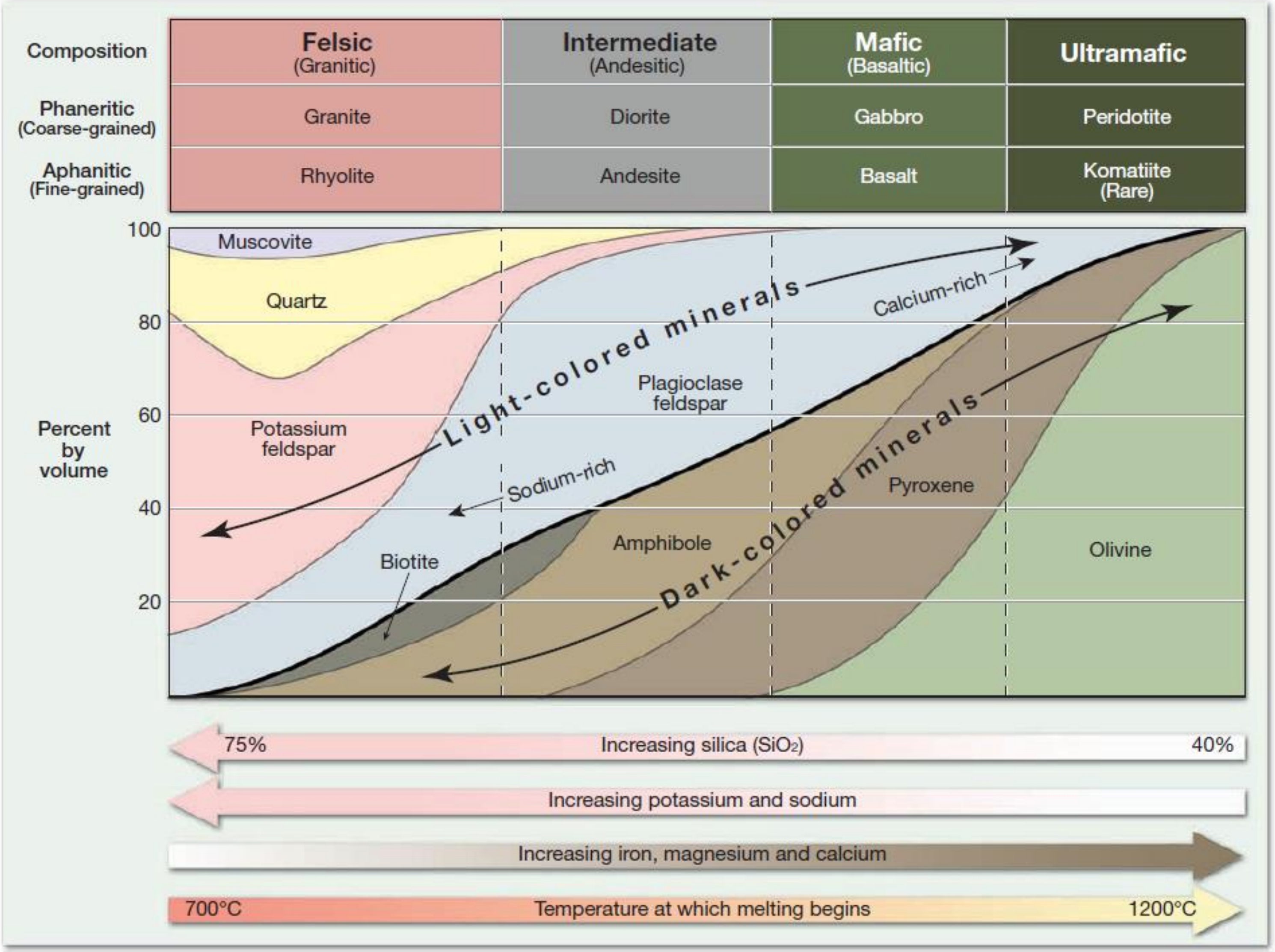
Silicic (Felsic) or Granitic Rocks

The *silica-rich* (65% or more SiO2) rocks tend to have only very small amounts of the oxides of calcium, magnesium, and iron. The remaining 25% to 35% of these rocks is mostly aluminium oxide (Al2O3) and oxides of sodium (Na2O) and potassium (K2O).

These are called **silicic** or **felsic** rocks—silica-rich igneous rocks with a relatively high content of potassium and sodium (the *fel* part of the name comes from *feldspar,* which crystallizes from the potassium, sodium, aluminum, and silicon oxides; *si* in *felsic* is for silica).

Example: rhyolite and granite

FIGURE 3.3 Mineralogy of common igneous rocks and the magmas from which they form. (After Dietrich, Daily, and Larsen)

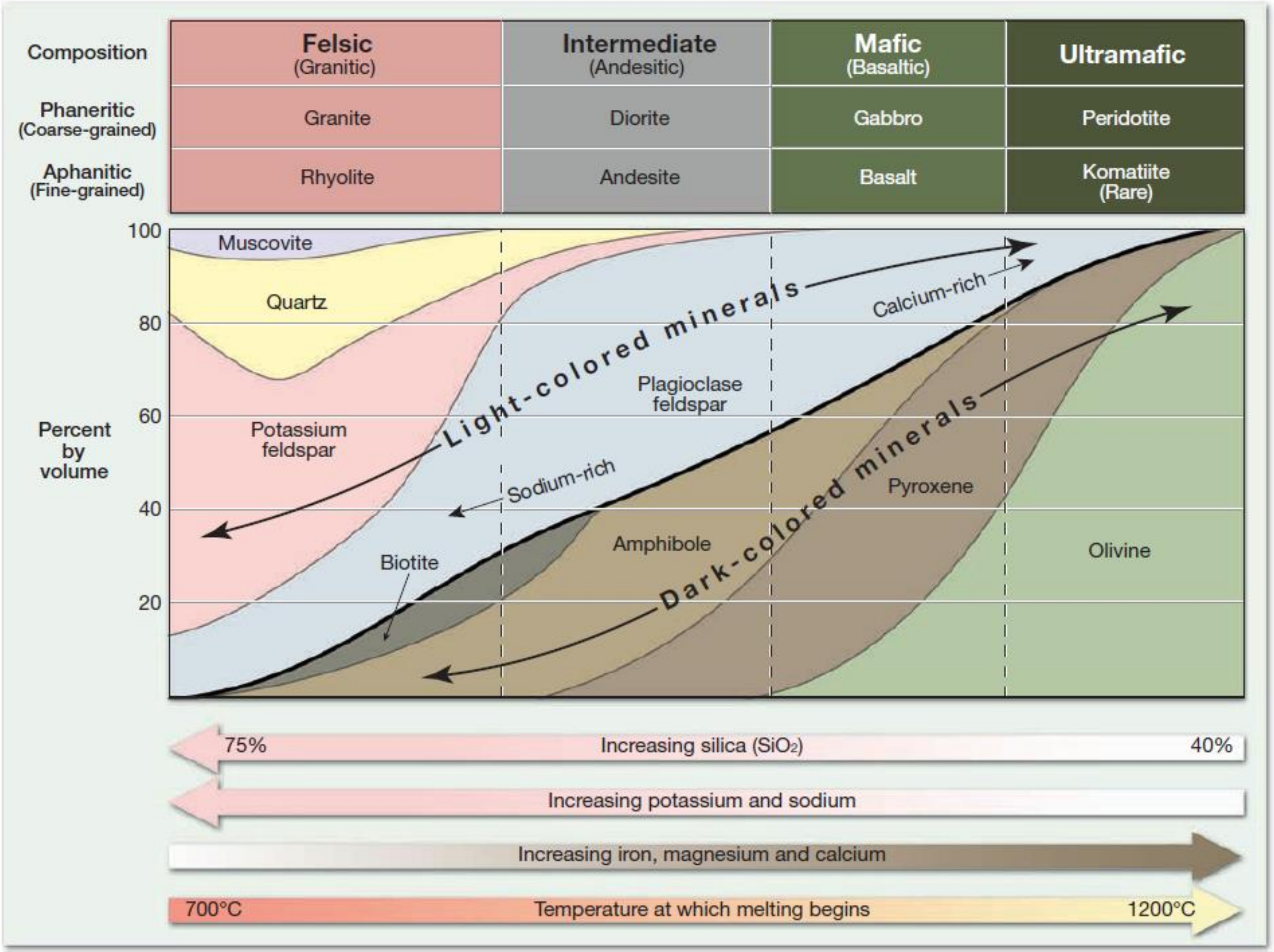


Intermediate (or andesitic) Rocks

Rocks with a chemical content between that of felsic and mafic are classified as **intermediate rocks.**

Andesite, which is usually green or medium gray, is the most common intermediate volcanic rock.

FIGURE 3.3 Mineralogy of common igneous rocks and the magmas from which they form. (After Dietrich, Daily, and Larsen)



Ultramafic Rocks

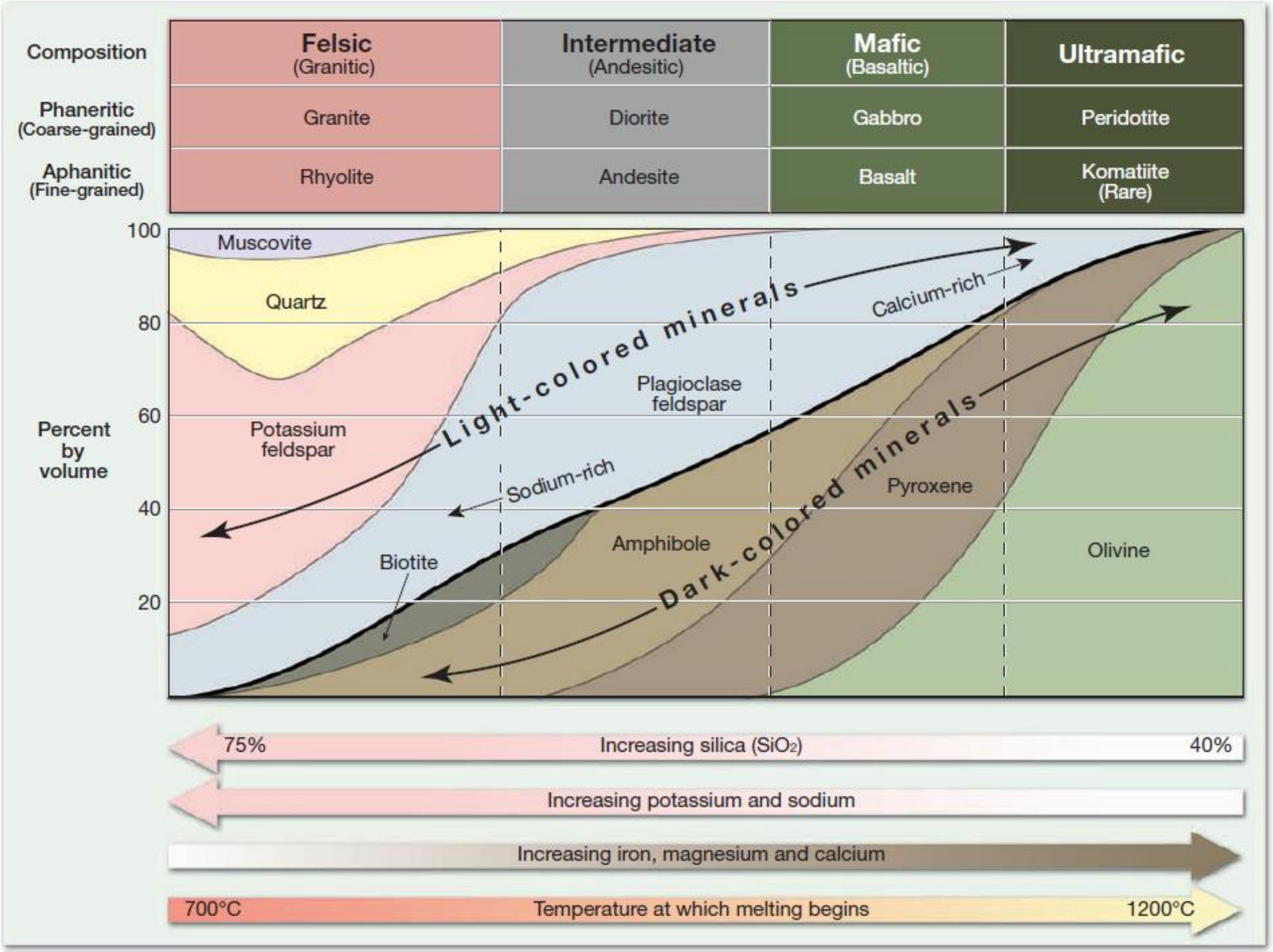
An **ultramafic rock** is composed entirely or almost entirely of ferromagnesian minerals.

No feldspars are present and, of course, no quartz.

Peridotite**,** a coarse-grained rock composed of pyroxene and olivine, is the most abundant ultramafic rock.

Chemically, these rocks contain less than 45% silica.

FIGURE 3.3 Mineralogy of common igneous rocks and the magmas from which they form. (After Dietrich, Daily, and Larsen)



In summary, igneous rocks can be divided into broad groups according to the proportions of light and dark minerals they contain.

Granitic (felsic) rocks, which are composed almost entirely of the lightcolored minerals quartz and feldspar, are at one end of the compositional spectrum (see Figure 3.3).

Basaltic (mafic) rocks, which contain abundant dark silicate minerals in addition to plagioclase feldspar, make up the other major igneous rock group of Earth's crust.

Between these groups are rocks with an *intermediate (andesitic) composition.*

Ultramafic rocks, which lack light-colored minerals, lie at the far end of the compositional spectrum from granitic rocks.

Igneous rock texture

- The term texture is used to describe the overall appearance of a rock based on the size, shape, and arrangement of its mineral grains.
- Texture is an important property because it reveals a great deal about the environment in which the rock formed.
- This fact allows geologists to make inferences about a rock's origin based on careful observations of grain size and other characteristics of the rock.

Factors Affecting Crystal Size

Three factors influence the textures of igneous rocks:

(1) *the rate at which molten rock cools;*

(2) *the amount of silica present;* and

(3) *the amount of dissolved gases in the magma.*

Among these, the rate of cooling tends to be the dominant factor.

Factors Affecting Crystal Size

- A very large magma body located many kilometers beneath Earth's surface will cool over a period of perhaps tens to hundreds of thousands of years. Initially, relatively few crystal nuclei form. Slow cooling permits ions to migrate freely until they eventually join one of the existing crystalline structures. Consequently, slow cooling promotes the growth of fewer but larger crystals.
- On the other hand, when cooling occurs rapidly—for example, in a thin lava flow—the ions quickly lose their mobility and readily combine to form crystals. This results in the development of numerous embryonic nuclei, all of which compete for the available ions. The result is a solid mass of tiny intergrown crystals.
- When molten material is quenched quickly, there may not be sufficient time for the ions to arrange into an ordered crystalline network. Rocks that consist of unordered ions that are "frozen" randomly in place are referred to as *glass*.

Types of Igneous texture

- The effect of cooling on rock textures is fairly straightforward.
- Slow cooling promotes the growth of large crystals,
- Whereas rapid cooling tends to generate small crystals.

Types of Igneous texture

- Aphanitic (Fine-grained) Texture
- Phaneritic (Coarse-grained) Texture
- Porphyritic Texture
- Glassy Texture
- Pyroclastic (Fragmental) Texture
- Pegmatitic Texture

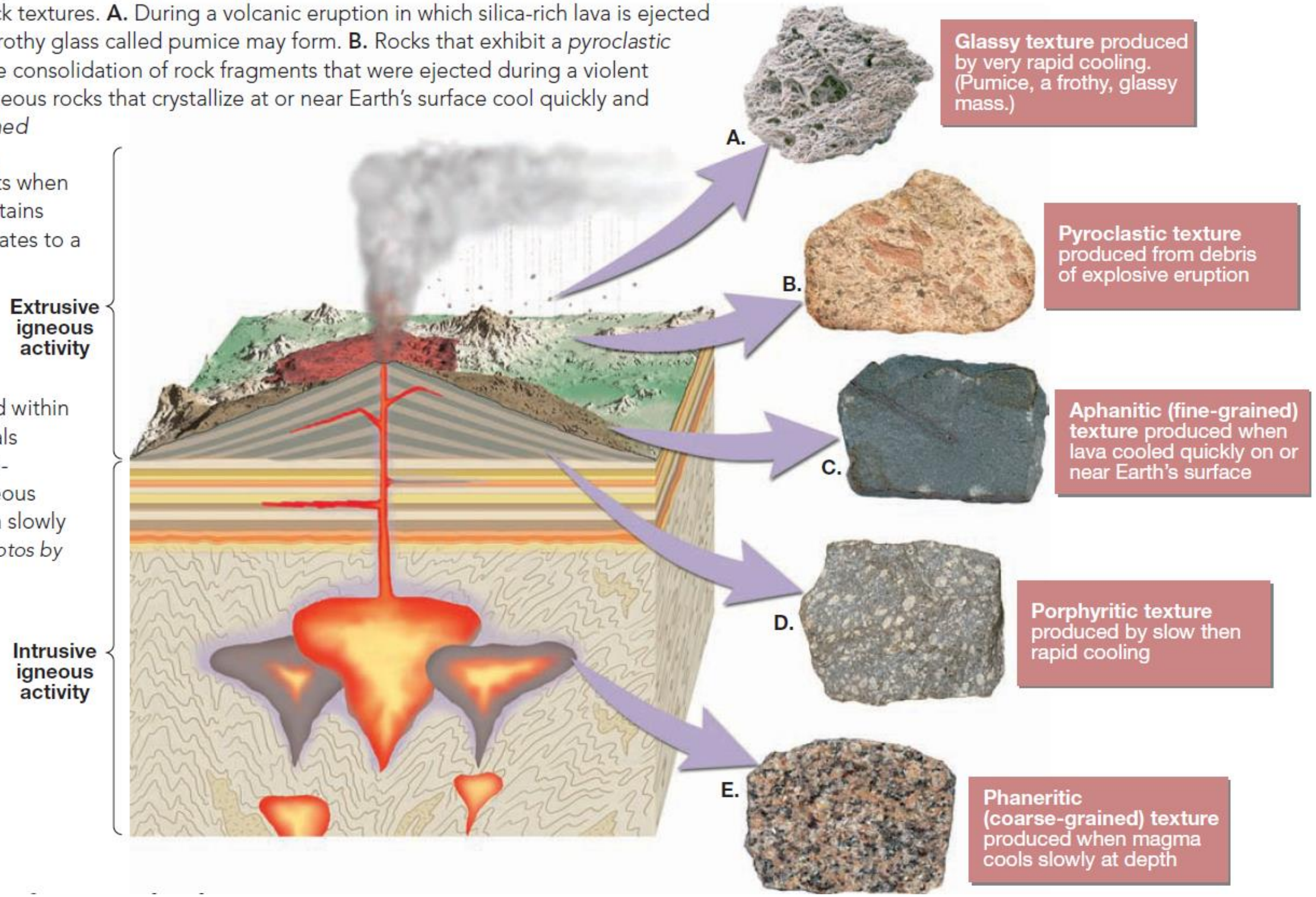


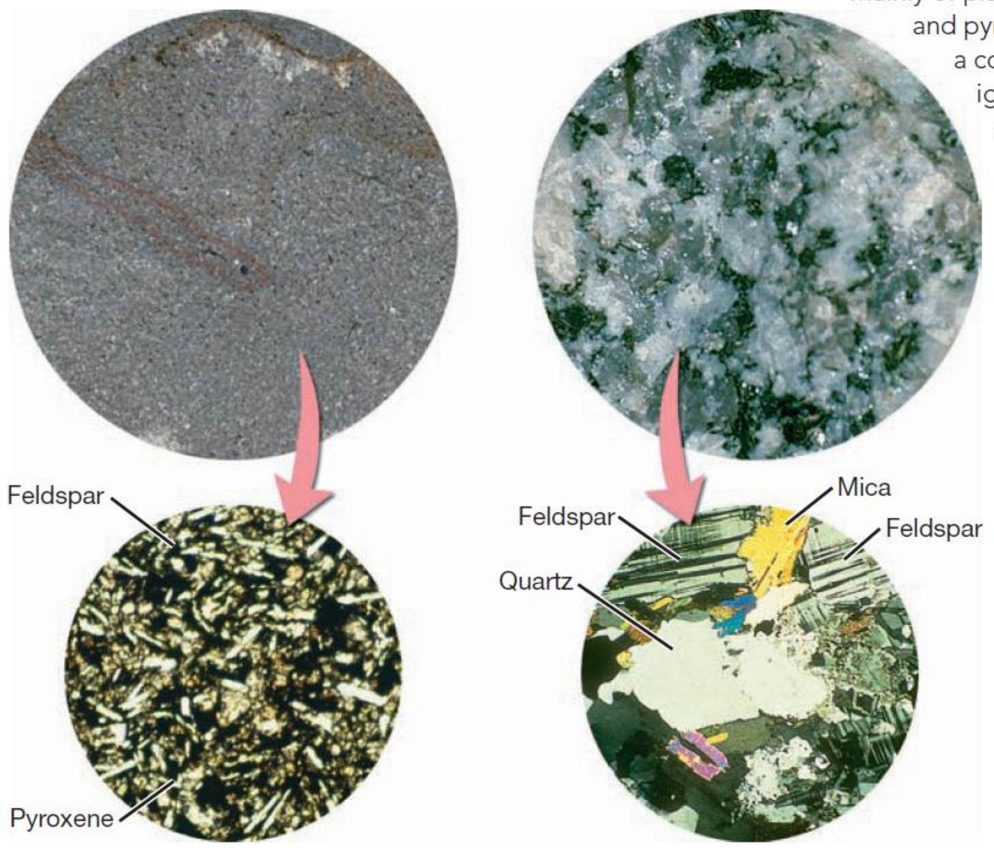
FIGURE 3.4 Igneous rock textures. **A.** During a volcanic eruption in which silica-rich lava is ejected into the atmosphere, a frothy glass called pumice may form. **B.** Rocks that exhibit a *pyroclastic texture* are a result of the consolidation of rock fragments that were ejected during a violent volcanic eruption. **C.** Igneous rocks that crystallize at or near Earth's surface cool quickly and often exhibit a *fine-grained* (*aphanitic*) *texture*. **D.** A *porphyritic texture* results when magma that already contains some large crystals migrates to a new location where the rate of cooling increases. The resulting rock consists of larger crystals (*phenocrysts*) embedded within a matrix of smaller crystals (*groundmass*). **E.** *Coarse-grained* (*phaneritic*) igneous rocks form when magma slowly crystallizes at depth. *(Photos by E. J. Tarbuck)*

Aphanitic (Fine-grained) Texture

Igneous rocks that form at the surface, or as small intrusive masses within the upper crust where cooling is relatively rapid, termed an aphanitic texture(a=not, *phaner* = visible).

The crystals that make up aphanitic rocks are so small that individual minerals can only be distinguished with the aid of a polarizing microscope or other sophisticated techniques.

FIGURE 3.5 Comparison of aphanitic (fine-grained) and phaneritic (coarse-grained) igneous rock textures. The smaller images were generated using a polarizing microscope that produces photomicrographs of thin, transparent rock slices. **A.** Basalt is a fine-grained igneous rock composed mainly of plagioclase feldspar and pyroxene. **B.** Granite is a coarse-grained igneous rock composed mainly of quartz, potassium feldspar, and lesse amounts of mica and dark minerals. *(Photos courtesy of E. J. Tarbuck)*



A. Aphanitic (fine-grained)

B. Phaneritic (coarse-grained)

Aphanitic (Fine-grained) Texture

Common features of many extrusive rocks are the voids left by gas bubbles that escape as lava solidifies. These nearly spherical openings are called *vesicles,* and the rocks that contain them are said to have a vesicular texture**.** Rocks that exhibit a vesicular texture usually form in the upper zone of a lava flow, where cooling occurs rapidly enough to preserve the openings produced by the expanding gas bubbles (FIGURE 3.6).

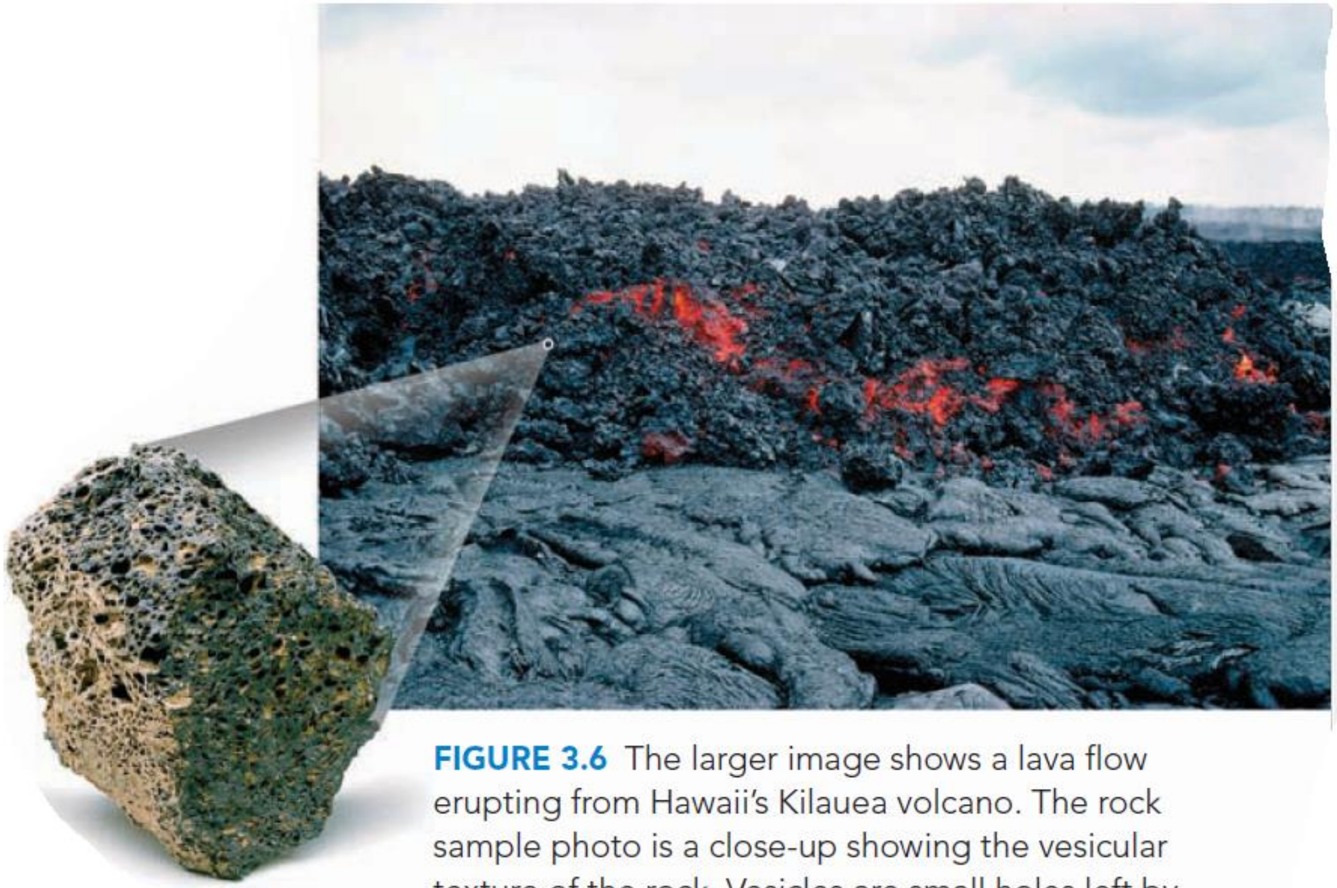


FIGURE 3.6 The larger image shows a lava flow erupting from Hawaii's Kilauea volcano. The rock sample photo is a close-up showing the vesicular texture of the rock. Vesicles are small holes left by escaping gas bubbles. *(Photo by J. D. Griggs, U.S. Geological Survey/rock sample photo courtesy of E. J. Tarbuck)*

Vesicular texure

Rocks with a vesicular texture are very porous. They contain tiny holes called vesicles that formed from gas bubbles in lava or magma.

Examples:

Pumice,

vesicular basalt,

scoria.

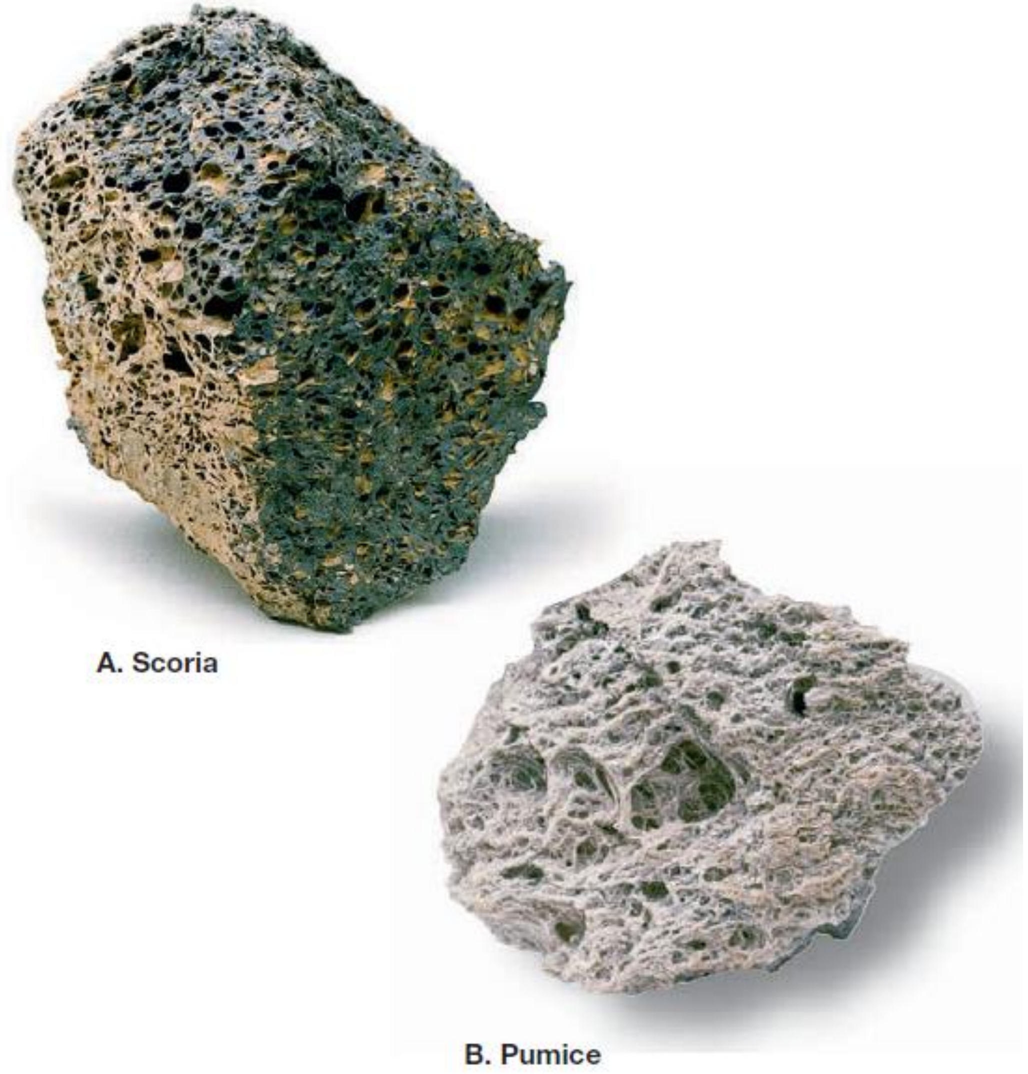


FIGURE 4.10 Scoria and pumice are volcanic rocks that exhibit a vesicular texture. Vesicles are small holes left by escaping gas bubbles. **A.** Scoria is usually a product of mafic (basaltic) magma. **B.** Pumice forms during explosive eruptions of viscous magmas having an intermediate (andesitic) or felsic (rhyolitic) composition. *(Photos by E. J. Tarbuck)*

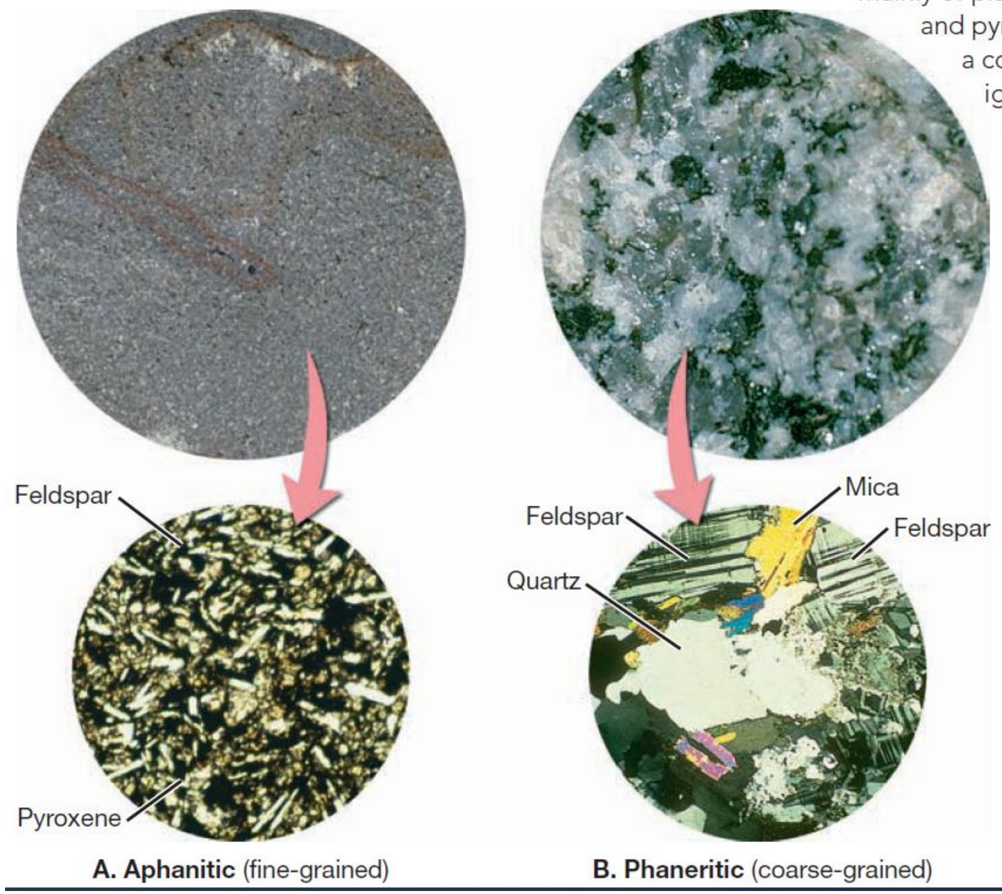
Phaneritic (Coarse-grained)

Phaneritic—a word derived from the Greek word ***phaneros*** or “**visible**.”

When large masses of magma slowly crystallize at great depth, they form igneous rocks that exhibit a coarse-grained texture also referred to as a phaneritic texure (*phaner* = visible).

Coarse-grained rocks consist of a mass of intergrown crystals that are roughly equal in size and large enough so that the individual minerals can be identified without the aid of a microscope.

FIGURE 3.5 Comparison of aphanitic (fine-grained) and phaneritic (coarse-grained) igneous rock textures. The smaller images were generated using a polarizing microscope that produces photomicrographs of thin, transparent rock slices. **A.** Basalt is a fine-grained igneous rock composed mainly of plagioclase feldspar and pyroxene. **B.** Granite is a coarse-grained igneous rock composed mainly of quartz, potassium feldspar, and lesse amounts of mica and dark minerals. *(Photos courtesy of E. J. Tarbuck)*



Porphyritic Texture

Porphyritic texture is produced by slow then rapid cooling.

A large mass of magma may require tens to hundreds of thousands of years to solidify.

Because different minerals crystallize under different environmental conditions (temperatures and pressure), it is possible for crystals of one mineral to become quite large before others even begin to form. Should molten rock containing some large crystals move to a different environment—for example, by erupting at the surface—the remaining liquid portion of the lava would cool more quickly. The resulting rock, which has large crystals embedded in a matrix of smaller crystals, is said to have a porphyritic texture.

The large crystals in such a rock are referred to as **phenocrysts** (pheno=show , cryst= crystal), whereas the matrix of smaller crystals is called **groundmass.**

A rock that has two distinctly different sizes of grains—a groundmass with phenocrysts—is called a **porphyritic** rock. A rock with a *porphyritic* texture is termed a *porphyry.*

Porphyritic granite with large pink phenocrysts of potassium feldspar. (Scale in millimeters.)

Porphyritic Texture

Examples:

Porphyritic granite,

porphyritic andesite,

porphyritic basalt.

Pamela Gore

Porphyritic granite with large pink phenocrysts of potassium feldspar. (Scale in millimeters.)

Glassy Texture

During some volcanic eruptions, molten rock is ejected into the atmosphere, where it is quenched quickly. Rapid cooling of this type may generate rocks having a *glassy texture*.

Glass results when unordered ions are “frozen in place” before they are able to unite into an orderly crystalline structure.

Example:

Obsidian.

PYROCLASTIC (FRAGMENTAL) TEXTURE

It is another group of igneous rocks is formed from the consolidation of individual rock fragments that are ejected during a violent volcanic eruption.

The ejected particles might be very fine ash, molten blobs, or large angular blocks torn from the walls of the vent during the eruption.

Igneous rocks composed of these rock fragments are said to have a pyroclastic texture or a fragmental texture

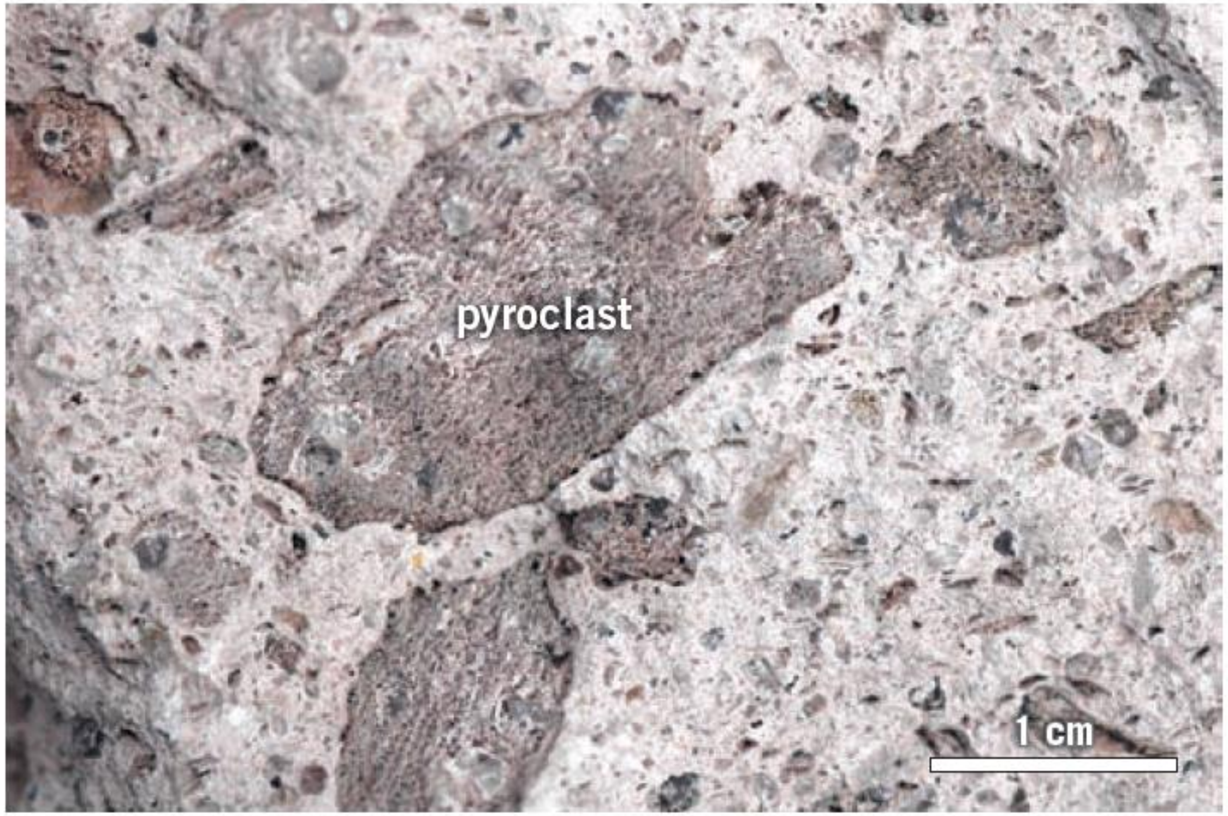


Figure 5.10 Pyroclastic rock. Lapilli-sized pyroclast and coarse ash in a tuff with a rhyolitic composition.

PEGMATITIC TEXTURE.

Under special conditions, exceptionally coarse-grained igneous rocks, called pegmatites**,** may form.

These rocks, which are composed of interlocking crystals all larger than a centimeter in diameter, are said to have a pegmatitic texture. Most pegmatites occur as small masses or thin veins situated around the margins of large intrusive bodies.

Example: Granite pegmatite.

Granite pegmatite vein cutting through granite. (Scale in centimeters.)

Naming Igneous Rocks

Igneous rocks are most often classified, or grouped, on the basis of their texture and mineral composition (FIGURE 3.10).

The various igneous textures result mainly from different cooling histories, whereas the minerology of an igneous rock is the consequence of the chemical makeup of its parent magma.

Chemical Composition		Felsic (Granitic)	Intermediate (Andesitic)	Mafic (Basaltic)	Ultramafic
Dominant Minerals		Quartz Potassium feldspar Sodium-rich plagioclase feldspar	Amphibole Sodium- and calcium-rich plagioclase feldspar	Pyroxene Calcium-rich plagioclase feldspar	Olivine Pyroxene
Accessory Minerals		Amphibole Muscovite Biotite	Pyroxene Biotite	Amphibole Olivine	Calcium-rich plagioclase feldspar
TEXTURE: Phaneritic (coarse-grained)		Granite	Diorite	Gabbro	Peridotite
TEXTURE: Aphanitic (fine-grained)		Rhyolite	Andesite	Basalt	Komatiite (rare)
TEXTURE: Porphyritic		"Porphyritic" precedes any of the above names whenever there are appreciable phenocrysts			Uncommon
TEXTURE: Glassy		**Obsidian** (compact glass) **Pumice** (frothy glass)			
TEXTURE: Pyroclastic (fragmental)		**Tuff** (fragments less than 2 mm) **Volcanic Breccia** (fragments greater than 2 mm)			
Rock Color (based on % of dark minerals)		0% to 25%	25% to 45%	45% to 85%	85% to 100%

FIGURE 3.10 Classification of major igneous rocks based on mineral composition and texture. Coarse-grained rocks are plutonic, solidifying deep underground. Fine-grained rocks are volcanic, or solidify as shallow, thin plutons. Ultramafic rocks are dark, dense rocks, composed almost entirely of minerals containing iron and magnesium. Although relatively rare at or near Earth's surface, these rocks are major constituents of the upper mantle.

FIGURE 3.11 Common igneous rocks. *(Photos by E. J. Tarbuck)*