GENERAL GEOLOGY

Geology is earth sciences comprising the study of solid earth, the rocks of which it is composed, and the processes by which they change. Geology can also refer generally to the study of the solid features of any celestial body (such as the geology of the Moon or Mars).
Earth, also known as the world, Terra, or Gaia is the third planet from the Sun, the densest planet in the Solar System (5.52) gm/cm^3, and the only celestial body known to accommodate life. It is home to about 8.74 million species and there are over 7.2 billion humans who depend upon its biosphere and minerals.

Historical Notes

About 2300 years ago, the Greeks, led by the philosopher **Aristotle**, were among the first to try to understand the earth. During the 1600s and 1700s, scientists believed the earth had been produced by gigantic, sudden, catastrophic events that built mountains, canyons, and oceans.

In the late 1700s, **James Hutton**, a Scottish doctor, proposed that the physical processes that shape the world today also operated in the geologic past —a principle known as **uniformitarianism** is the assumption that the same natural laws and processes that operate in the universe now have always operated in the universe in the past and apply everywhere in the universe. It has included the concept that "**the present is the key to the past**"**.** Another early concept was **the law of superposition—in an undeformed sequence of sedimentary rocks, each layer is younger than the ones below it and older than those above it**. The **law of faunal succession** is based on the observation that sedimentary rock strata contain fossilized flora and fauna, and that these fossils succeed each other vertically in a specific, reliable order that can be identified over wide horizontal distances, fossils in these rocks occur in the same kind of order, and changes in fossil content represent changes in time. Thus, rocks from different parts of the world containing the same type of fossil formed about the same time.

The Earth's Origin

According to the widely accepted **nebular hypothesis,** the planets and moons in the solar system, including Earth, formed from a **huge cloud** of mostly hydrogen and helium. **Contraction**, **rotation**, and **dropping temperatures** resulted in the formation of small particles, the first being **nickel** and **iron**. These began to stick together, and after tens of millions of years of condensation and accretion, the earth was formed about 5 billion years ago. Although the earth has been cooling ever since and has formed a hard outer crust, part of the interioris still hot and molten.

The Earth's Structure

The earth can be divided into four concentric zones (Figure 1). The innermost is called the **inner core** and is thought to be a **solid**, **spherical mass of iron**. Its radius is about 1,216 kilometers. The next zone, called the **outer core**, is believed to be a layer of molten liquid rich in **nickel and iron** that is about 2,270 kilometers thick. The outer core is overlain by the **mantle,** which is a solid, putty-like rock that can actually flow. The mantle is about 2,900kilometers thick. The **crust,** the outermost zone, is the hardened exterior of the earth and varies in thickness from about 6km under the ocean and 30-50 km on the continents.

The crust is separated from the mantle by the Mohorovičić discontinuity. usually referred to as the Moho, which is the boundary between the Earth's crust and the mantle. Immediately above the Moho, the velocities of primary seismic waves (P-waves) are synonymous with those through basalt (6.7–7.2 km/s), and below they are similar to that of peridotite or dunite (7.6–8.6 km/s). That suggests the Moho marks a change of composition.

The crust and uppermost solid part of mantle is known as the **lithosphere,** Beneath the lithosphere is the **asthenosphere**, a relatively low-viscosity layer on which the lithosphere rides. The asthenosphere, like the lithosphere, is rock, but so hot that 1 to 2 percent of it is melted. As aresult, it is plastic, and weak.

Continental crust is thicker than oceanic crust. The solid lithosphere is composed of the crust and the upper part of the mantle. The softer, more flexible part of the mantle underneath the lithosphere is the asthenosphere.

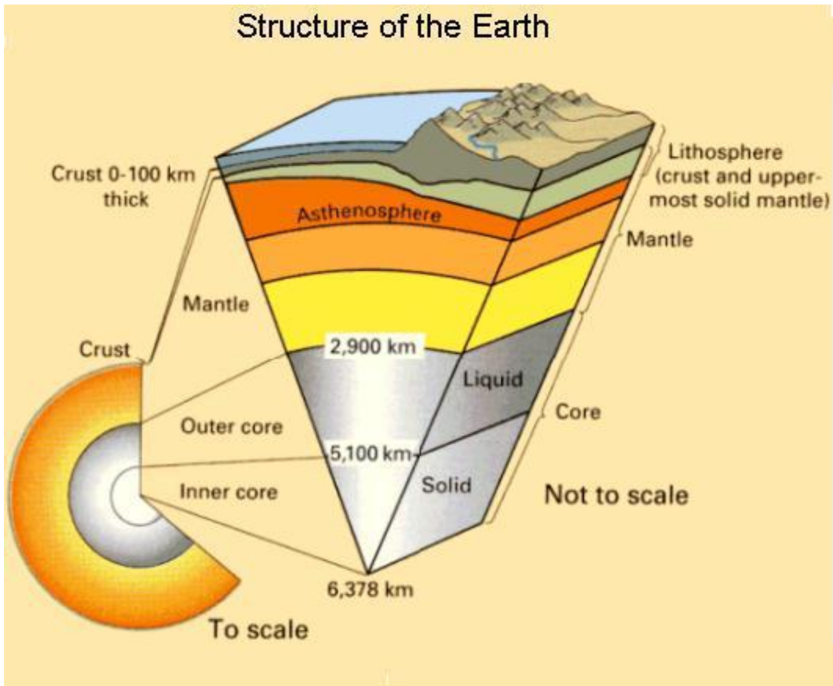


Fig. (1) The Earth structure

The structure of the Earth is summarized in this diagram. Please note, however, that the thickness of the layers is not to scale. For example, the crust is much thinner than shown in this diagram! Also remember that the lithosphere-asthenosphere boundary is really a gradual transition, not a sharp break in material behavior.

As the earth cools, the intense heat being produced in the core creates **convection currents** in the mantle that bring hot mantle material up toward the crust, and colder mantle and crustal rocks sink downward. This heat engine drives **plate tectonics,** or the movements of large segments of the earth's crust (plates) that are separated along deep cracks called **faults.** The plates move over the asthenosphere, which is softer and less resistant. The crust breaks into these segments because of the upward movement of molten material below.

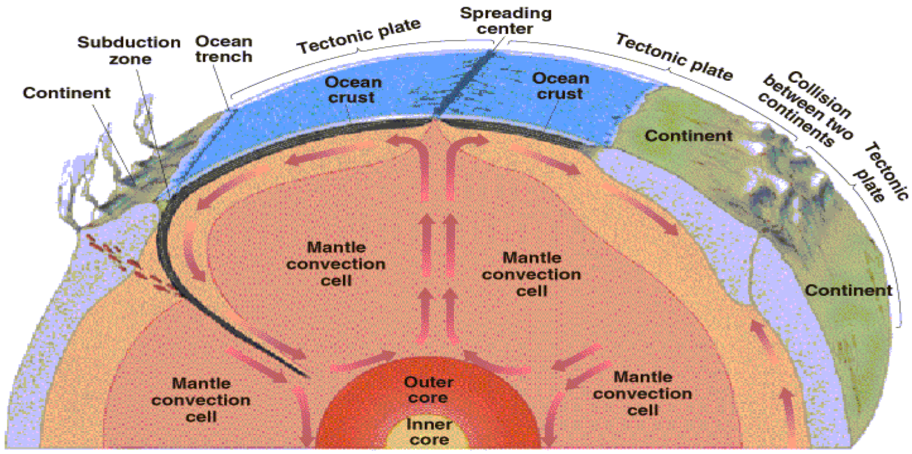


Fig. 2. Show the earth structure and the convection currents.

The powerful internal tectonic forces squeeze and fold solid rock, creating massive changes in the earth's crust, such as rugged mountains and deep submarine canyons.

The fault boundaries between plates are either 1- **divergent**, or 2- **convergent, or 3- transform**. A **divergent boundary** is one marked by plates that move away from each other (Figures 2, 3A, and 4).

A convergent boundary is one at which plates come together (Figures 2, 3B, and 4).

New ocean crust is formed along the deep **mid-oceanic ridges** (divergent boundaries) by the outpouring of mantle lavas on the ocean floor. These ridges are also called **spreading centers.** The new crust pushes to the side the older oceanic crust, which eventually is subducted**,** or forced under another plate at a convergent boundary. The subducted crust moves down a dipping **subduction zone** toward the mantle.

Transform Boundary is one at which plates slide horizontally past each other in opposite directions along a fault plane (Figures, 3C).

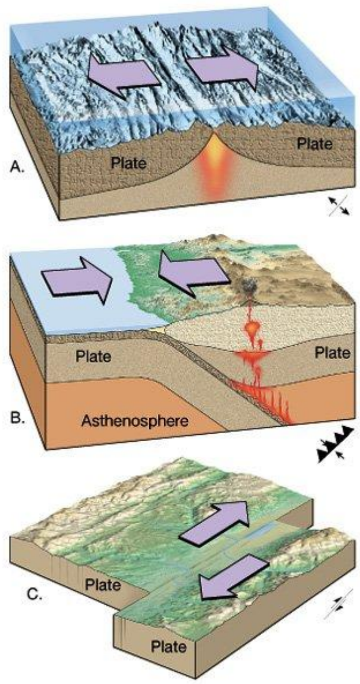


Fig. (3) Plates boundaries, A divergent boundaries, B convergent boundaries, and C transforms boundaries.

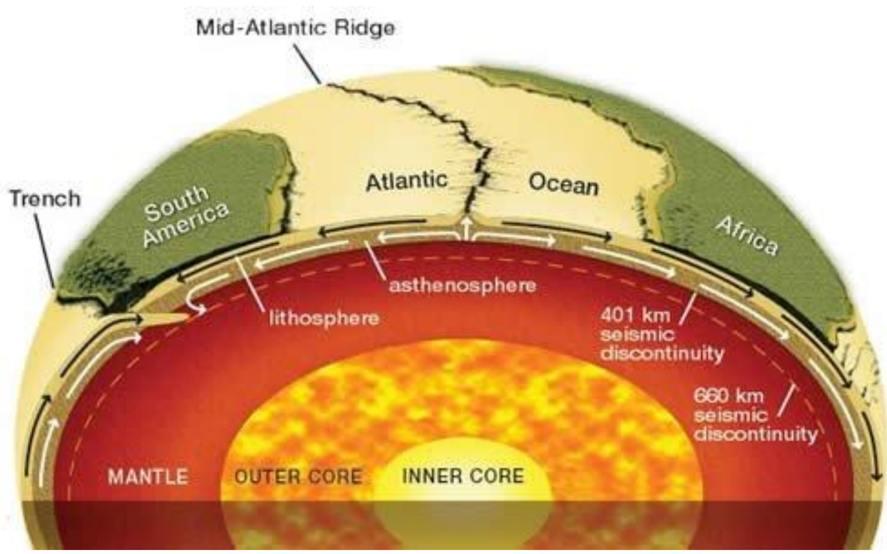


Fig. (4) Three dimension section in the earth from the crust toward the inner core.

The jostling or rubbing of plates results in high heat flows, volcanic activity, deformation, mountain building, and earth quakes, creating ideal places to melt rock into magma. Rocks in subduction zones are subjected to friction and higher geothermal gradients that contribute heat to the melting process.

Geologic Time

Evidence from radiometric dating that the earth is about 4.54 billion years old. As the crust cooled, early geologic processes were largely volcanic, building up continental crust and a primitive atmosphere.
Bacterial forms of life have been found in rocks that are billions of years old. The mud volcanoes at Isua, in south-west Greenland, have been identified as a possible birthplace for life on Earth by an international team headed by researchers from the Laboratoire de Géologie de Lyon. Almost 3.8 billion years ago, these volcanoes released chemical elements indispensable to the formation of the first biomolecules, Complex oceanic organisms such as trilobites began to appear only about 600 million years ago. From about 66 million to 245 million years ago, dinosaurs and other reptiles flourished all over the world. In contrast, human beings have existed in only about the last 3 million years.

Chemical composition

The mass of the Earth is approximately 5.98×10^{24} kg. It is composed mostly of iron (32.1%), oxygen (30.1%), silicon (15.1%), magnesium (13.9%), sulfur (2.9%), nickel (1.8%), calcium (1.5%), and aluminum (1.4%); with the remaining 1.2% consisting of trace amounts of other elements. Due to mass segregation, the core region is believed to be primarily composed of iron (88.8%), with smaller amounts of nickel (5.8%), sulfur (4.5%), and less than 1% trace elements.

The most common elementsin the crust by weight are oxygen (46.6%), silicon (27 .7%), aluminum (8 .1%), iron (5 .0%), calcium (3 .6%), sodium (2 .8%), potassium (2 .6%), and magnesium (2 .1%). These eight elements account for about 98.5 % of the weight of the crust.

The geochemist F. W. Clarke calculated that a little more than 47% of the Earth's crust consists of oxygen. The more common rock constituents of the Earth's crust are nearly all oxides; chlorine, sulfur and fluorine are the important exceptions to this and their total amount in any rock is usually much less than 1%. The principal oxides are silica, alumina, iron oxides, lime, magnesia, potash and soda. The silica functions principally as an acid, forming silicates, and all the commonest minerals of igneous rocks are of this nature. From a computation based on 1,672 analyses of all kinds of rocks, Clarke deduced that 99.22% were composed of 11 oxides (see the table below), with the other constituents occurring in minute quantities.

Chemical composition of the crust

Compound	**Formula**	**Composition**	
		Continental	**Oceanic**
silica	**SiO2**	**60.2%**	**48.6%**
alumina	**Al2O3**	**15.2%**	**16.5%**
lime	**CaO**	**5.5%**	**12.3%**
magnesia	**MgO**	**3.1%**	**6.8%**
iron(II) oxide	**FeO**	**3.8%**	**6.2%**
sodium oxide	**Na2O**	**3.0%**	**2.6%**
potassium oxide	**K2O**	**2.8%**	**0.4%**
iron(III) oxide	**Fe2O3**	**2.5%**	**2.3%**
water	**H2O**	**1.4%**	**1.1%**
carbon dioxide	**CO2**	**1.2%**	**1.4%**
titanium dioxide	**TiO2**	**0.7%**	**1.4%**
phosphorus pentoxide	**P2O5**	**0.2%**	**0.3%**
Total		**99.6%**	**99.9%**

Minerals and Rocks

A **mineral** is a naturally occurring inorganic solid with a characteristic chemical composition and a crystalline structure, a combination of elements that forms an inorganic,. For example, SiO_2 is always the mineral quartz. A **rock** is a solid material that is composed of various minerals. Minerals can have a variety of crystalline shapes. The shape of the crystal is dependent on the: 1- **sizes** of the atoms of the elements, 2- the **chemical bonds** that hold the elements together to form the mineral, and 3-the **pressure** and **temperature** at which the mineral formed.

Most minerals are built around silica **tetrahedrons—four** oxygen atoms connected to a smaller, central silicon atom. Different arrangements of silica tetrahedrons create distinctive atomic structures in minerals, such as **sheet silicates** (the mica and clay mineral **groups), chain silicates** (the pyroxene mineral group), or **framework silicates** (the quartz and feldspar mineral groups).

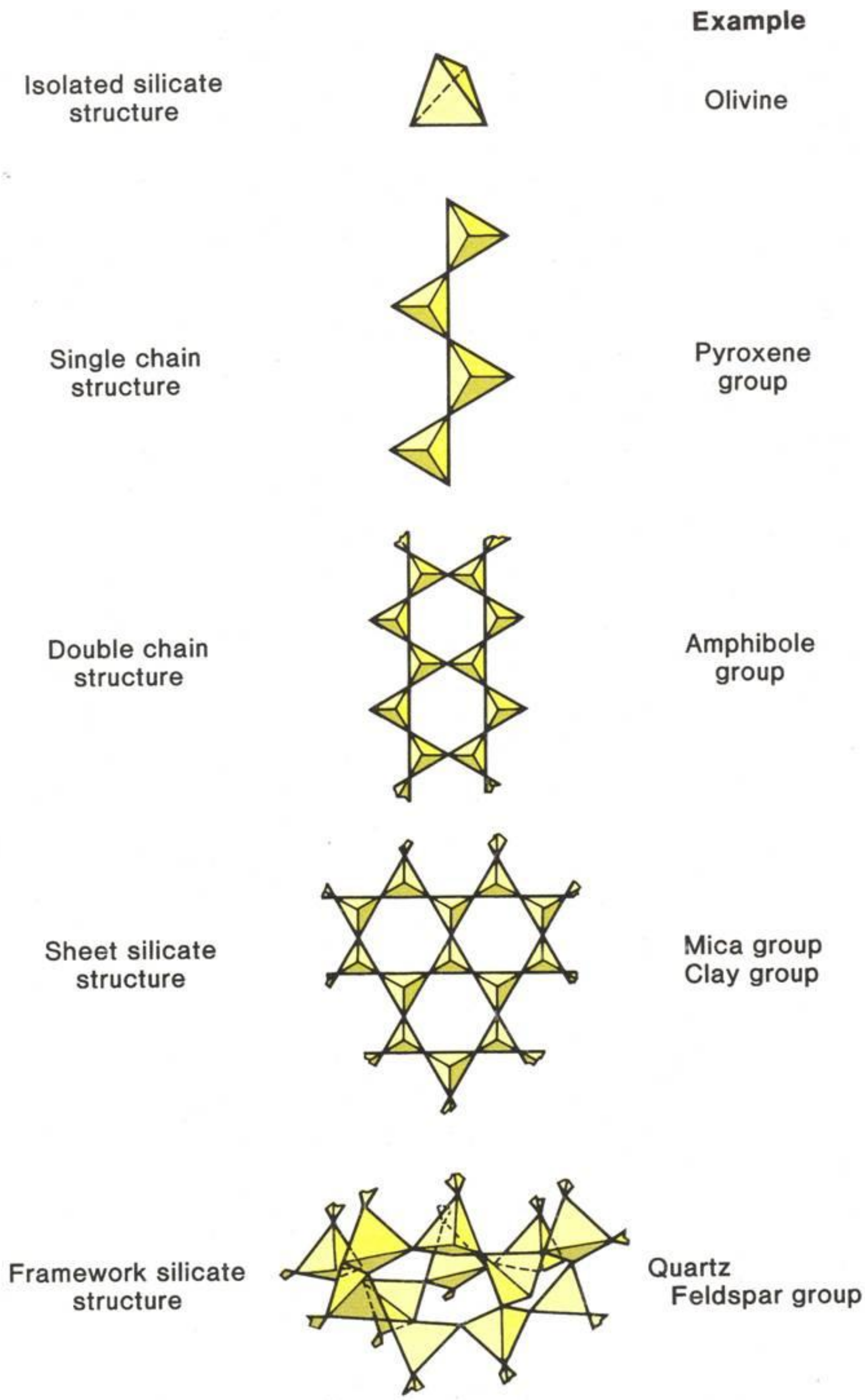


Fig. (5) Silicate structures

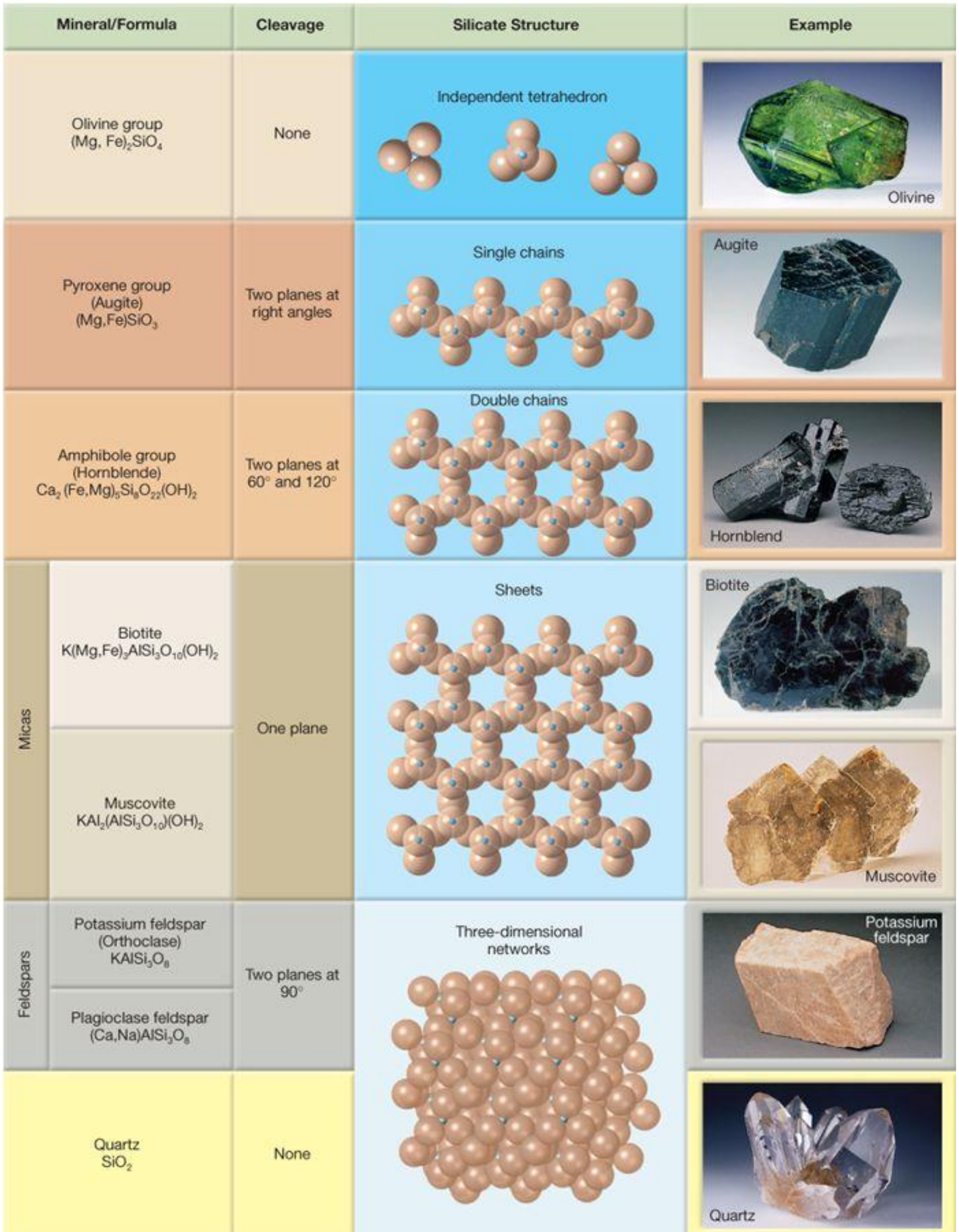


Fig. (6) Chart of silicates minerals

Only several **hundreds** of the **thousands** of **known** minerals are important rock-forming minerals. As one might guess, their chemical compositions contain mostly the eight most common elements in the crust—oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium. The important rock-forming mineral groups are quartz, feldspars, amphiboles, pyroxenes, clays, micas, and carbonates.

A rock's color is determined by its mineral **components** quartz, feldspars, carbonates, and some mica are generally light-colored, tan, or pinkish; pyroxenes, amphiboles, and some mica are dark green to blackish because of their high iron and magnesium content.

PHYSICAL PROPERTIES OF MINERALS

It is often difficult to identify a mineral simply by **looking** at it, but each mineral has a set of distinctive characteristics that are easily tested in the field or laboratory.

How does a geologist identify a mineral in the field?

Chemical composition and crystal structure distinguish each mineral from all others. For example, halite always consists of sodium and chlorine in a one-to-one ratio, with the atoms arranged in a cubic fashion. But if you pick up a crystal of halite, you cannot see the ions.

1-Hardness

Hardness is a distinctive quality of minerals that is determined by the **Mohs' hardness scale. Hardness** is the resistance of a mineral to scratching. It is easily measured and is a fundamental property of each mineral because it is controlled by bond strength between the atoms in the mineral. Talc is the softest mineral on the scale at a value of 1, and diamond is the hardest at avalue of 10 (Table 2). Geologistsoften scratch minerals with aknife blade that has a hardness of about 5. If the mineral scratches the knife, it is harder than 5; if the mineral is scratched, its hardness is less than 5. A thumbnail is about 2.5 on the Mohs' scale. Most geologists can remember the hardness scale only by using a mnemonic device (Table 2) Fig. (7).

Table 2 Mohos scale Minerals

Hardness	Example Materials
1	Talc
2	Gypsum
2.5	Fingernail, pure gold, silver, aluminum
3	Calcite, copper coin (penny)
4	Fluorite
4.5	Platinum, iron
5	Apatite
6	Orthoclase, titanium, spectrolite
6.5	Steel file, iron pyrite, glass, vitreous pure silica
7	Quartz, amethyst, citrine, agate
7.5	Garnet
8	Hardened steel, topaz, beryl, emerald, aquamarine
9	Corundum, ruby, sapphire
9.5	Carborundum
10	Diamond
>10	Aggregated diamond nanorods

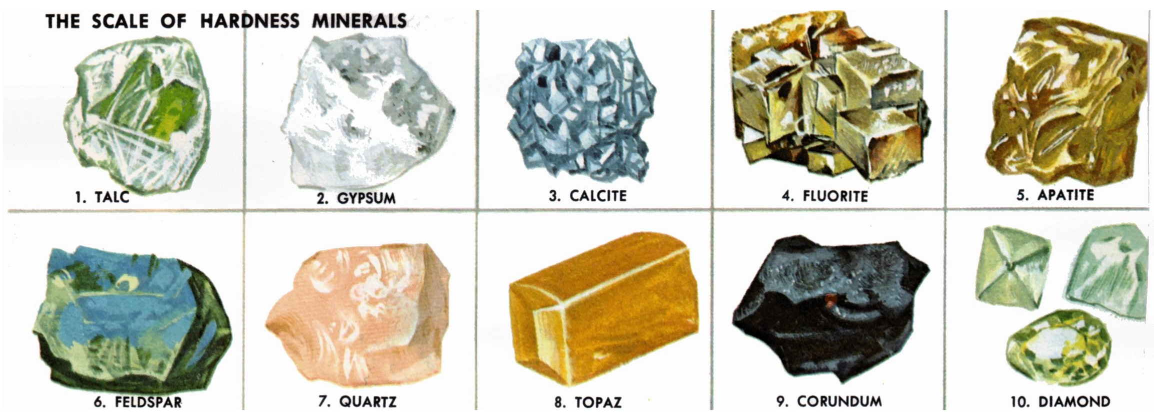


Fig.7 Shows the scale of hardness minerals

Mohs Hardness of Common Objects
Fingernail 2 to 2.5, copper 3, nail 4, glass 5.5, knife blade 5 to 6.5, steel **file** 6.5, streak plate 6.5 to 7

2-Color
Color is the most obvious property of a mineral, but it is commonly unreliable for identification. Color would be a reliable identification tool if

all minerals were pure and had perfect crystal structures. However, both small amounts of chemical impurities and imperfections in crystal structure can dramatically alter color. For example, corundum (Al_2O_3) is normally a cloudy, translucent, brown or blue mineral. Addition of a small amount of chromium can convert corundum to the beautiful, clear, red gem known as ruby. A small quantity of iron or titanium turns corundum into the striking blue gem called sapphire.

3-LUSTER

Luster is the manner in which a mineral reflects light. Amineral with a metallic look, irrespective of color, has ametallic luster. The luster of nonmetallic minerals is usually described by self-explanatory words such as glassy, pearly, earthy, silky, greasy and resinous.

4-CRYSTAL HABIT

Crystal habit is the characteristic shape of a mineral and the manner in which aggregates of crystals grow. If a crystal grows freely, it develops a characteristic shape controlled by the arrangement of its atoms, as in the cubes of halite shown in Figure 8c. Figure 8 showsthree common minerals with different crystal habits.

a

b

C

Figure 8 (a) Garnet crystals have about the same dimensions in all directions. (b) Asbestos is *fibrous*. (c) Kyanite forms *bladed* crystals.

Some minerals occur in more than one habit. For example, Figure 9a shows quartz with a prismatic (pencil shaped) habit, and Figure 9b shows massive quartz. When crystal growth is obstructed by other crystals, a mineral cannot develop its characteristic habit. Figure10 is a photomicrograph (a photo taken through a microscope) of a thin slice of granite in which the crystals fit like pieces of a jigsaw puzzle. This interlocking texture developed because some crystals grew around others as the magma solidified.


(a)


(b)

Figure 9(a) *Prismatic* quartz grows as elongated crystals. (b) *Massive* quartz shows no characteristic shape. (Arkansas Geological Commission, J. M. Howard, Photographer)

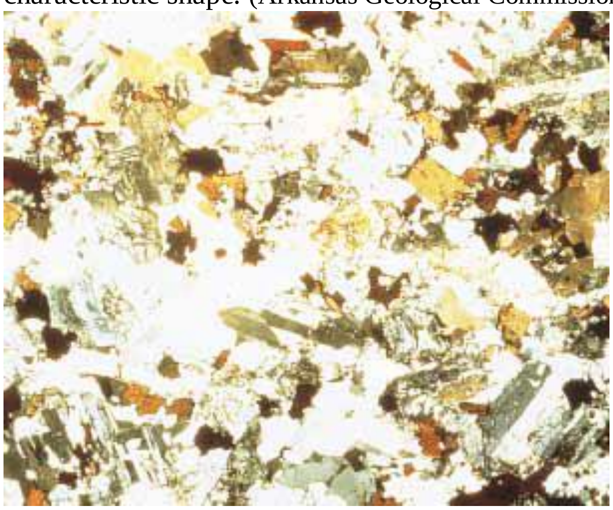


Figure 10A photomicrograph of a thin slice of granite.

5-CLEAVAGE

Cleavage is the tendency of some minerals to break along flat surfaces. The surfaces are planes of weak bonds in the crystal. Some minerals, such as mica and graphite, have one set of parallel cleavage planes (Fig. 11).

Fig.11 shows one set of cleavage in mica mineral.

Others have two, three, or even four different sets, as shown in Figure 12. Some minerals, like the micas, have excellent cleavage. You can peel sheet after sheet from a mica crystal as if you were peeling layers from an onion. Others have poor cleavage. Many minerals have no cleavage at all because they have no planes of weak bonds. The number of cleavage planes, the quality of cleavage, and the angles between cleavages planes all help in mineral identification. A flat surface created by cleavage and a crystal face can appear identical because both are flat, smooth surfaces.

a b c

Figure 12 Some minerals have more than one cleavage plane. (a) Feldspar has two cleavages intersecting at right angles. (b) Calcite has three cleavage planes. (c) Fluorite has four cleavage planes. (Arthur R. Hill, Visuals Unlimited)

6- SPECIFIC GRAVITY

Specific gravity is the weight of a substance relative to that of an equal volume of water. If a mineral weighs 2.5times as much as an equal volume of water, its specific gravity is 2.5. You can estimate a mineral's specific gravity simply by hefting a sample in your hand. If you practice with known minerals, you can develop a feel forspecific gravity. Most common minerals have specificgravities of about 2.7. Metals have much greater specific gravities; for example, gold has the highest specific gravity of all minerals, 19. Lead is 11.3, silver is 10.5, and copper is 8.9.

7-FRACTURE

Fracture is the pattern in which a mineral breaks other than along planes of cleavage. Many minerals fracture into characteristic shapes. **Conchoidal** fracture creates smooth, curved surfaces (Fig. 13). It is characteristic of quartz and olivine. Another type of fracture is **uneven** which is found in anhydrite, and in copper which is uneven jagged, and **Splintery** is a fracture type that occurs in fibrous or finely acicular minerals such as kyanite mineral, **earthy** is a fracture that produces a texture similar to broken children's clay. It is found in limonite mineral.

Figure 13 Quartz typically fractures along smoothly curved surfaces, called conchoidal fractures. This sample is smoky quartz.

8-STREAK

Streak is the color of a fine powder of a mineral. It is observed by rubbing the mineral across a piece of unglazed porcelain known as a streak plate. Many mineral sleave a streak of powder with a diagnostic color on the plate. Streak is commonly more reliable than the color of the mineral itself for identification.Two minerals that have similar outward color may have different colors when powdered. For instance, the minerals **hematite** and **galena** can be confused when both have a gray color. However, hematite's streak is **blood-red**, while galena's streak is **lead gray**. **Pyrite** (known as "Fool's Gold") is always brassy yellow when found in crystals, even broken crystals, of any size; but when powdered, produces a black streak.

OTHER PROPERTIES

Properties such as reaction to acid, magnetism, radioactivity, fluorescence, and phosphorescence can be characteristic of specific minerals. Calcite and some othercarbonate minerals dissolve rapidly in acid, releasing visible bubbles of carbon dioxide gas. Minerals containing radioactive elements such as uranium emit radioactivity that can be detected with a scintillometer. Fluorescent materials emit visible light when they areexposed to ultraviolet light. Phosphorescent minerals continue to emit light after the external stimulus ceases.

ROCK-FORMING MINERALS, ACCESSORY MINERALS, GEMS, ORE MINERALS, AND INDUSTRIALMINERALS:

Although about 3500 minerals are known to exist in the Earth's crust, only a small number—between 50 and100—are important because they are common or valuable.

ROCK-FORMING MINERALS

The rock-forming minerals make up the bulk of most rocks in the Earth's crust. They are important to geologists simply because they are the most common minerals. They are olivine, pyroxene, amphibole, mica, the clay minerals, feldspar, quartz, calcite, and dolomite.
The first six minerals in this list are actually mineral "groups," in which each group contains several varieties with very similar chemical compositions, crystalline structures, and appearances.

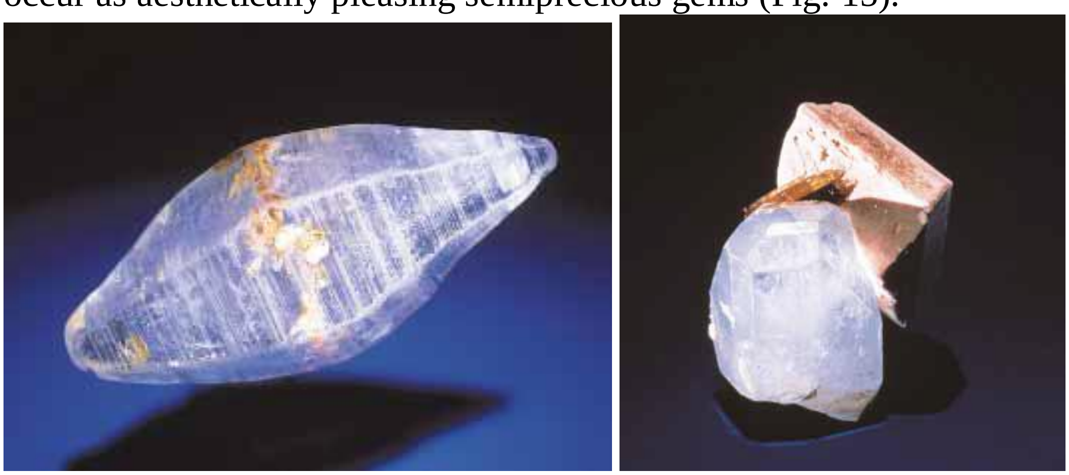
ACCESSORY MINERALS

Accessory minerals are minerals that are common but usually are found only in small amounts. Chlorite, garnet, hematite, limonite, magnetite, and pyrite are common accessory minerals (Fig. 14).

Figure 14 Pyrite is a common accessory mineral.

GEMS

A **gem** is a mineral that is prized primarily for its beauty, although some gems, like diamonds, are also used industrially. Depending on its value, a gem can be either precious or semiprecious. Precious gems include diamond, emerald, ruby, and sapphire (Fig. 3–12). Several varieties of quartz, including amethyst, agate, jasper, and tiger's eye, are semiprecious gems. Garnet, olivine, topaz, turquoise, and many other minerals sometimes occur as aesthetically pleasing semiprecious gems (Fig. 15).



a b

Figure 15(a) Sapphire is one of the most costly precious gem, (b)Topaz is a popular semiprecious gem.

ORE MINERALS

Ore minerals are minerals from which metals or other elements can be profitably recovered. A few, such as native gold and native silver, are composed of a single element. However, most metals are chemically bonded to anions.

Copper, lead, and zinc are commonly bonded to sulfur to form the important ore minerals chalcopyrite, galena (Fig. 16), and sphalerite.

Figure 16 Galena is the most important ore of lead and commonly contains silver.

INDUSTRIAL MINERALS

Several minerals are industrially important, although they are not considered ore because they are mined for purposes other than the extraction of metals. Halite is mined for table salt, and gypsum is mined as the raw material for plaster and sheet rock. Apatite and other phosphorus minerals are sources of the phosphate fertilizers crucial to modern agriculture. Many limestones are made up of nearly pure calcite and are mined as the raw material of cement.

MINERAL CLASSIFICATION

Geologists classify minerals according to their anions (negatively charged ions). Anions can be either simple or complex. A simple anion is a single negatively charged ion, such as O2_. Alternatively, two or more atoms can bond firmly together and acquire a negative charge to form a complex anion. Two common examples are the silicate, (SiO_4)4_, and carbonate, (CO_3)2_, complex anions.

NATIVE ELEMENTS

About 20 elements occur naturally in their native states as minerals. Fewer than ten, however, are common enough to be of economic importance. Gold, silver, platinum, and copper are all mined in their pure forms.

OXIDES

The oxides are a large group of minerals in which oxygen is combined with one or more metals such as hematite (iron oxide, Fe_2O_3), magnetite (Fe_3O_4), a naturally magnetic iron oxide, Spinel ($MgAl_2O_4$), and ice H_2O.

SULFIDES

Sulfide minerals consist of sulfur combined with one or more metals.
Such as pyrite (FeS_2), chalcopyrite ($CuFeS_2$), galena (PbS), and sphalerite (ZnS).

SULFATES

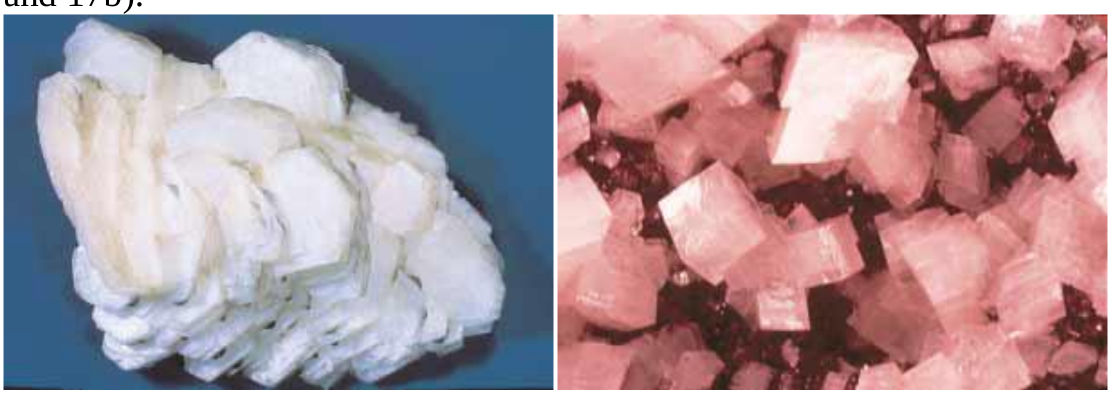
The sulfate minerals contain the sulfate complex anion (SO_4)2_. Gypsum (CaSO4 . 2H2O) and anhydrite ($CaSO_4$).

PHOSPHATES

Phosphate minerals contain the complex anion (PO_4)3_.
Apatite, Ca_5(F,Cl,OH)(PO_4)3.

CARBONATES

The complex carbonate anion (CO_3)2_ is the basis of two common rock-forming minerals, calcite ($CaCO_3$) and dolomite [CaMg(CO_3)2] (Figs. 17a and 17b).



a **b**

Figure 17 Calcite (a) and dolomite (b) are two rock-forming carbonate minerals.

SILICATES

The silicate minerals contain the (SiO_4)4_ complex anion. Silicates make up about 95 percent of the Earth's crust, such as olivine, pyroxene, amphibole and mica.