

3.1.3 Metamorphic Rocks

Metamorphic rocks are formed when rocks of any class are subjected to heat and pressure at depth. This causes new minerals to form and other minerals to recrystallize. During the process, material from the rock may be added or lost. Marked changes in temperature (T) and pressure (P) occur, which may produce completely new types of rocks. In addition to the formation of new minerals, existing minerals may be realigned into parallel bands and new textures may be formed. At sufficiently high temperatures, the rock may undergo partial melting to form magma, which may then become the source of an igneous rock. For instance, slate is formed from shale that was exposed to high heat and pressure; and marble is a metamorphosed limestone. Metamorphic rocks form during deep burial under Earth's surface or in mountain-building events. A common feature of metamorphic rocks is that minerals rearrange themselves to form plates perpendicular to the force that is applied. This is called **foliation**. Metamorphic rocks include gneiss, schist, slate, quartzite and marble, and Figure 3.3 shows how they form.

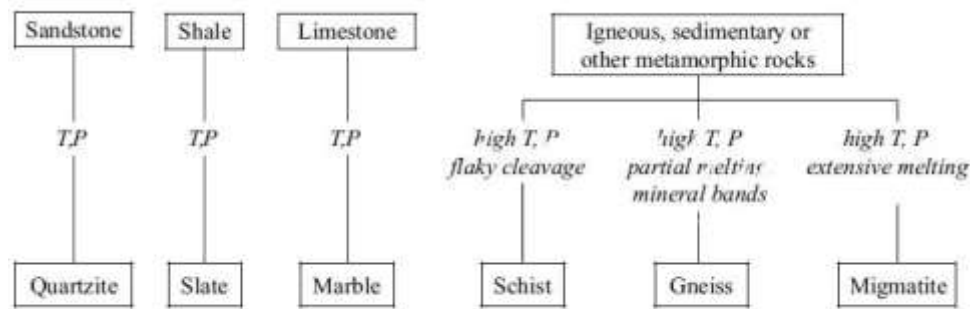


Figure 3.3: Formation of metamorphic rocks

3.2 Minerals

Minerals are the solid constituents of all rocks; igneous, sedimentary and metamorphic and occur as crystals. A mineral can be defined as a natural inorganic substance having a particular chemical composition or range of composition, and a regular atomic structure to which its crystalline form is related.

Minerals are naturally formed crystals that are composed of one or more chemical elements. They are distinguished from other natural solid materials by their crystalline structure. Some natural solid materials formed in rocks are not minerals because they lack a crystalline structure, i.e., they are amorphous, e.g. obsidian or volcanic glass. Most minerals are formed

by inorganic processes; however, a few are formed by organic processes (living organisms), e.g. calcite in coral. Single-element minerals include diamond (from carbon) and the native (i.e., elemental) metals like gold, copper and silver. Other minerals, such as chalcopyrite, sphalerite and mica, are chemical compounds consisting of several elements. Minerals can be divided into their constituent elements. The mineral quartz is composed of two elements, silicon and oxygen. Other minerals may contain many elements. For example, the mineral amphibole is made up of a laundry list of elements including sodium, calcium, magnesium, iron, aluminum, silicon, and oxygen. Elements cannot be further divided into other materials but they can be separated into individual atoms. An atom is the smallest particle of an element that retains the characteristics of the element. All atoms are composed of neutrons, protons, and electrons. The protons and neutrons are present in the atom's nucleus that is surrounded by electrons. The number of protons in an atom is unique for each element and represents the element's atomic number. For example, oxygen has 8 protons, silicon has 14. Protons have a positive charge that is balanced by the negatively charged electrons. Neutrons are neutral, they have no charge.

Table 3.1 list eight elements in their order of abundance in crustal rocks. Thus silicon and oxygen together make up nearly 75 percent of crustal rocks.

Table 3.1: Elements in crustal rocks

Most Common Elements in Continental Crust		
Element	Ion	% by weight
Oxygen (O)	O ²⁻	46.6
Silicon (Si)	Si ⁴⁺	27.7
Aluminum (Al)	Al ³⁺	8.1
Iron (Fe)	Fe ²⁺ , Fe ³⁺	5.0
Calcium (Ca)	Ca ²⁺	3.6
Sodium (Na)	Na ⁺	2.8
Potassium (K)	K ⁺	2.6
Magnesium (Mg)	Mg ²⁺	2.1
Other	-	1.5

3.2.1 Physical characteristics of minerals

These include properties such as colour, lustre, form, hardness, cleavage, fracture, tenacity and specific gravity. Two or three of these properties may be sufficient to identify any one mineral apart from the optical properties. Other characters such as fusibility, fluorescence, magnetism and electrical conductivity are also useful in some cases as means of

identification. A variety of features can be used to identify specific minerals. Some of the most common are listed below.

Colour: Minerals can be identified by noticing the colour. However, it is important to note that colour by itself is not enough to identify a mineral. Chemical impurities often change the colour of a mineral without changing its basic make-up. Some minerals have a distinctive colour, for example, the green colour of chlorite, but most naturally occurring minerals contain traces of substances which modify their colour. Thus quartz, which is colourless when pure, may be white, grey, pink or yellow, when certain chemical impurities or included particles are present. Minerals come in a variety of colours. Examples of common dark-coloured minerals (black, dark brown, dark green) are amphibole, olivine, pyroxene, biotite mica. Light-coloured minerals (white, pink, gray, translucent) are represented by quartz, feldspar (orthoclase, plagioclase), muscovite mica, gypsum, halite, and calcite. However, we must be careful in using colour to identify minerals because some minerals can be found in a wide range of colours. Much more constant is the colour of a mineral in the powdered condition, known as streak. Figure 3.4 shows the colours of Azurite and Malachite.



Figure 3.4: Brightly colored Azurite (blue) and malachite (green).

Streak: When a mineral is rubbed firmly across an unglazed tile of white porcelain (a streak plate), it leaves a line of powder. This is called the streak. The colour of the streak is always the same, whether or not the mineral has impurities. For example, quartz leaves a white streak, whether it is violet (amethyst), pink (rose quartz), or brown (smoky quartz). The streak represents the mineral in powdered form and is often constant even when mineral colour changes. This property is most useful for metallic minerals that leave a dark-coloured streak.

Crystal Form: Minerals form crystals with specific shapes (see Figure 3.5) when they have been able to grow without obstruction. Common shapes are prisms, pyramids, needles, cubes,

and sheets. A number of terms are used to describe various shapes assumed by minerals in groups or clusters

Acicular: in fine needle-like crystals (also described as filiform), e.g. schorl, natrolite.

Botryoidal: consisting of spheroidal aggregations, somewhat resembling a bunch of grapes; e.g. chalcedony.

Concretionary or nodular: terms applied to minerals found in detached masses of spherical, ellipsoidal, or irregular shape; e.g. the flint of nodules chalk

Dendritic: moss-like or tree-like forms, generally produced by deposition of a mineral in thin veneers on joint planes or in crevices; e.g. dendritic deposits of manganese

Reniform: kidney-shaped, the rounded surfaces of the mineral resembling those of kidneys; e.g. kidney iron-ore, a variety of haematite

Tabular: showing broad flat surfaces; e.g. the six-sided crystals of mica

Five commonly occurring mineral relationships are as follows:

Drusy: Closely packed small crystals growing into a cavity, such as a gas bubble preserved in solidified lava.

Radiated: Needle-like crystals radiating from a center: the illustration is of a pyrite (FeS₂) concretion.

Fibrous: Consisting of fine thread-like strands; e.g. asbestos and the satin-spar variety of gypsum.

Granular: In grains, either coarse or fine; the rock marble is an even granular aggregate of calcite crystals.

Reticulated: A mesh of crossing crystals



Figure 3.5: A range of crystal shapes including pyramid (calcite, left) and acicular (needlelike, tourmaline, right).

Lustre: Lustre is the appearance of a mineral surface in reflected light. It may be metallic, as in pyrite or galena; glassy or vitreous, as in quartz; resinous or greasy, as in opal; pearly, as in talc; or silky, as in fibrous minerals such as asbestos and satin-spar (fibrous gypsum). Mineral with no lustre are described as dull. Figure 3.6 shows metallic lustre of galena.

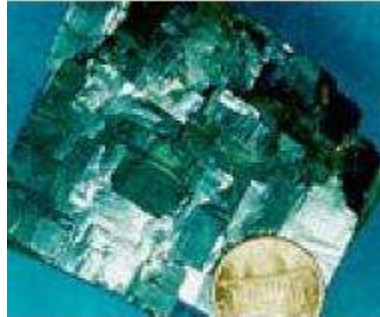


Figure 3.6: Metallic lustre of galena.

Hardness: Hardness or resistance to abrasion is measured relative to a standard scale of ten minerals, known as Moh's Scale of Hardness. These minerals are chosen so that their hardness increases in order of 1 to 10. Hardness is tested by attempting to scratch the minerals of the scale with the specimen under examination. Minerals are ranked from 1 to 10 based upon their relative hardness (Table 3.2). Harder minerals can scratch softer minerals. Ten index minerals make up Moh's scale and other minerals are ranked relative to these. For example, a mineral that could scratch feldspar but not quartz would have a hardness of approximately 6.5.

Table 3.2: Moh's Scale of Hardness

Moh's Hardness Scale	
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

Softest

↓

Hardest

Cleavage: Many minerals possess a tendency to split easily in certain regular directions, and yield smooth plane surfaces called cleavage planes when thus broken. These directions depend on the arrangement of the atoms in a mineral and are parallel to definite crystal faces. Perfect, good, distinct and imperfect are the terms used to describe the quality of mineral

cleavage. Mica has perfect cleavage by means of which it can be split into very thin flakes; feldspar have two sets of good cleavage planes. Calcite has three directions of cleavage. Minerals break along specific planes of weakness related to their atomic structure. Amphibole's cleavage planes intersect at 120 degrees (Figure 3.7); pyroxene has a distinctive 90 degree cleavage intersection. Quartz has no cleavage planes but fractures irregularly.



Figure 3.7: Cleavage planes in amphibole intersect at an angle of 120 degrees.

Fracture: The nature of a broken surface of a mineral is known as fracture, the break being irregular and independent of cleavage. It is sometimes characteristic of a mineral and, also, a fresh fracture shows the true colour of a mineral. Fracture is described as *conchoidal*, when the mineral breaks with a curved surface, e.g. in quartz and flint; as *even*, when it is nearly flat; *uneven*, when it is rough; as *hackly* when the surface carries small sharp irregularities. Most minerals show uneven fracture.

Tenacity: The response of a mineral to hammer blow, to cutting with a knife and to bending is described by its tenacity. Minerals that can be beaten into new shapes are *malleable*; e.g. the native metals of gold, silver and copper. Most minerals are *brittle* and fracture when struck with a hammer. A few brittle minerals can be cut with knife and are described as *sectile*. Flakes of mica can be bent and yet return to their tabular shape when free to do so: they are both *flexible* and *elastic*: cleavage flakes of gypsum are flexible but inelastic.

Specific gravity: Minerals range from 1 to 20 in specific gravity (e.g. native platinum, 21.46), but most lie between 2 and 7. For determining this property a steelyard apparatus such as the Walker Balance can be used, for crystals or fragments which are too small. The specific gravity of small mineral grains is estimated by the use of heavy liquids, of which the chief are bromoform (CHBr_3), $G = 2.80$, and methylene iodide (CH_2I_2), $G = 3.33$, both of which may be diluted with benzene, and Clerici's solution ($G = 4.25$), a mixture of thallium salts which may be diluted with water.

3.3 Rock Forming Minerals

It is convenient to distinguish between minerals, which are *essential* constituents of the rocks in which they occur, their presence being implied by the rock name, and others, which are *accessory*. The latter are commonly found in small amount in a rock but their presence or absence does not affect the naming of it. *Secondary* minerals are those, which result from the decomposition of earlier minerals, often promoted by the action of water in some form, with the addition and subtraction of other material, and with the formation of mineral by-products.

3.3.1 Silicate minerals

Silicates form the largest group of minerals. They contain various elements in combination with silicon and oxygen. Examples are quartz and feldspar.

3.3.1.1 The olivine group

Olivine: Common olivine has the composition $(\text{MgFe})_2\text{SiO}_4$, in which Fe^{2+} replaces part of the Mg^{2+} . Olivine occurs chiefly in basic and ultrabasic rocks. Since it crystallizes at a high temperature, over 1000°C , it is one of the first minerals to form from basic magmas. It has no colour when fresh. Alteration to greenish serpentine is very characteristics, this mineral being often developed along cracks and around the margins of olivine crystals.

3.3.1.2 The pyroxene group

Minerals of this group belong to two systems of crystallization:

- (1) Orthorhombic, e.g. enstatite, hypersthene
- (2) Monoclinic, e.g. augite, dioside

They possess two good cleavage directions parallel to the prism faces of the crystals (prismatic cleavage); the intersection angle of the cleavages is nearly 90° , a characteristic feature of the group. They form 8-sided crystals, and being silicates of Fe and Mg they are dark in colour (except diopside, CaMg).

3.3.1.3 The amphibole group

Minerals of this group are mainly monoclinic. The crystals are elongated in the c-direction and usually bounded by six vertical faces, of which the prism faces intersect at an angle of 124° . This is also the angle between the two cleavage directions, parallel to the prisms. The most common monoclinic amphibole is hornblende.

Hornblende $(\text{CaMgFeNaAl})_3(\text{AlSi})_4\text{O}_{11}(\text{OH})$: An aluminous silicate whose relative proportions of the metal ions vary within the limits shown, giving a range of composition; the (OH)-radicle is found in all amphiboles. Al^{3+} is substituted for Si^{4+} in about one in four positions. The crystals: Monoclinic, dark brown or greenish black: usually 6-sided, of longer habit than augite, with three dome faces at each end.. Common hornblende is found in diorites and some andesites as the dark constituent

Asbestos: The fibrous form of amphibole tremolite, in which crystals grow very long and are flexible. In commerce the term asbestos also includes other fibrous minerals such as chrysolite. These minerals are useful because of their resistance to heat and because of their fibrous nature, which enables them to be woven into fireproof fabrics, cord, and brake linings, and made in to boards, tiles and felt.

3.3.1.4 The mica group

The micas are group of monoclinic minerals whose property of splitting into very thin flakes is characteristic and easily recognized. The commonly occurring micas are muscovite and biotite. Mica crystals are 6-sided, with pseudo-hexagonal symmetry. Their cleavage flakes are flexible, elastic, and transparent.

Muscovite $\text{KAl}_2(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_2$: It is white in colour unless impurities are present to tint the mineral; pearly lustre. Muscovite occurs in granites and other acid rocks as silvery crystals, from which flakes can be readily detached by the point of a penknife; also in some gneisses and mica- schists. It is a very stable mineral, and persists as minute flakes in sedimentary rocks such as micaceous sandstones.

Biotite, $\text{K}(\text{MgFe})_3(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_2$: Crystals are brown to nearly black in hand specimen; single flakes are pale brown and have a sub-metallic or pearly lustre. Biotite occurs in many igneous rocks, e.g. granites, syenites, diorites, and their lavas and dyke rocks, as dark lustrous crystals, distinguished from muscovite by their colour. Also, a common constituent of certain gneisses and schists.

3.3.2 Accessory minerals

Minerals that occur as small crystals and in limited quantities are described as accessory. Occasionally, they may develop to form large crystals and in certain circumstances can be concentrated to become a major rock constituent.

Zircon, ZrSiO_4 : Tetragonal. $H = 7.5$, $G = 4.7$. Zircon occurs in granite and syenites as an original constituent. Crystals are usually very small and in thin section are recognized chiefly by shape.

Andalusite, Al_2OSiO_4 : Orthorhombic, Colour is pink or grey. $H = 7.5$, $G = 3.2$. Andalusite occurs in contact metamorphosed shales and slates. Crystals are prismatic and have a nearly square traverse section.

Sphene, CaTiSO_4 (O, OH, F)

Monoclinic. $H = 4$, $G = 3.5$. Sphene occurs as small wedge-shaped crystals in granite, diorites and syenites

Garnet $(\text{Ca}, \text{Mg}, \text{Fe}^{2+}, \text{Mn})_3 (\text{Al}, \text{Fe}^{3+}, \text{Cr})_2 (\text{SiO}_4)_3$: Cubic. The colour is pale pink. $H = 6.5$ to 7.5 , $G = 3.5$ to 4.0 according to species of mineral Garnet occurs in metamorphic rocks such as mica-schist.

Other accessory minerals are tourmaline and cordierite, $\text{MgAl}_3(\text{AlSi}_5)\text{O}_{18}$

3.3.3 Secondary minerals

These are minerals which result from the alteration of pre-existing minerals. They have little mechanical strength and small angles of friction. Their presence on fractures can significantly reduce the strength of a rock mass. They include chlorite, serpentine, talc, kaolin, epidote and zeolite.

Chlorite $(\text{MgFe})_5\text{Al}(\text{Si}_3\text{Al})\text{O}_{10}(\text{OH})_8$: The chlorites (Greek chloros, green) form a family of green flaky minerals which are hydrous silicates of magnesium and aluminium. Some Fe replaces Mg and gives colour to the chlorite. Like micas they have perfect cleavage, due to the atomic sheet structure. The crystals are frequently 6-sided in shape, with a perfect cleavage parallel to the basal plane. $H = 2$ to $2\frac{1}{2}$ (often soft enough to be scratched by the finger-nail). $G = 2.65$ to 3.0 . Chlorite is found in igneous rocks, and in metamorphic rocks such as chlorite-schist, and in some clay.

Serpentine, $\text{Mg}_6\text{Si}_4\text{O}_{10}(\text{OH})_8$: Serpentine is an alteration product of olivine, of orthorhombic pyroxene, or of hornblende. This reaction takes place in an igneous while it is still moderately hot (hydrothermal action), the source of hot water being magmatic. Serpentine grows as a mass of green fibers or plates, which replace the original mineral as a pseudomorph. A fibrous variety is called chrysotile and is worked in veins for commercial asbestos. $H = 3$ to 4 . Serpentine is found in basic and ultrabasic rocks.

Talc, $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$: A soft, flaky mineral, white or greenish in colour, which occurs as a secondary product in basic and ultrabasic rocks, and in talc-schist. It is often associated with serpentine. Flakes are flexible but not elastic, and are easily scratched by finger-nail. $H = 1$.

Zeolites: These form a group of hydrous aluminous silicates of calcium, sodium, or potassium; they contain molecular water which is readily driven off on heating, a property to which the name refers (Greek zein, to boil). Two commonly occurring natural zeolites are:

Analcite, $\text{Na}_2\text{AlSi}_2\text{O}_6\text{H}_2\text{O}$: Cubic; crystallized as trapezohedra, white in colour. $G = 2.25$. Occurs in the amygdaloids of basalts.

Natrolite, $\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10}2\text{H}_2\text{O}$: Forms white, acicular orthorhombic crystals, generally in radiating clusters. $G = 2.2$.

3.4 Clay minerals

Clays can form as either primary or secondary minerals. Hence they are grouped under one heading because of their economic importance, their presence in most profiles of weathering and their influence upon the mechanical character of rocks and less well consolidated sediments. Being minute they can be seen using only an electron microscope, but their presence may be revealed by placing a few particles that is suspected to be clay, on the teeth. The clay component, if present will feel smooth and the non-clay component will be gritty.

Clay minerals are built up two-dimensional atomic layers or sheets, which are, stacked one upon another in c-direction. The layers are of two kinds:

- (i) Silicon-oxygen sheets (Silica sheet), each formed by linking together of tetrahedral SiO_4 -group. The composition of this layer (tetrahedral layer) is a multiple of Si_2O_5 , or with attached hydrogen, $\text{Si}_2\text{O}_3(\text{OH})_2$.

- (ii) Octahedral layers, in which a metal ion (Al or Mg) lies within a group of six hydroxyls which are arranged at the corners of an octahedron (gibbsite).

The common clay minerals include: Kaolinite, Montmorillonite and Illite

3.4.1 Kaolinite, $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$

This is made up of alternate tetrahedral and octahedral-layers; each pair, $\text{Si}_2\text{O}_3(\text{OH})_2 + \text{Al}_2(\text{OH})_6$, with loss of water becomes $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$. The layers are held together by hydrogen bonding. They are very stable as the hydrogen bond prevents water and ion from penetrating. Kaolinite occurs in hexagonal flakes of minute size, and forms the greater part of kaolin (china clay) deposits. It is also found in soils and sedimentary clays, of which it forms a variable and often small. The mineral dickite has the same composition as kaolinite, but the layers in the structure have a different arrangement relative to one another. Halloysite, $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_2 \cdot 2\text{H}_2\text{O}$, may be included in a group with dickite and kaolinite. It occurs as minute tubes, the rolled-up „sheets“ of silicon-oxygen and Al-hydroxyl composition.

3.4.2 Montmorillonite

This has important base-exchange properties, is built up of 3-layer units comprising two tetrahedral layers separated by an octahedral layer and has the formula $\text{Al}_4\text{Si}_8\text{O}_{20}(\text{OH})_4$. Some aluminium is replaced by magnesium or iron, and small amounts of sodium or layer units or around the edges of the minute crystals. These alkali are exchangeable, and give rise to the high base-exchange capacity of the mineral. In addition, layers of molecular water may occur between the 3-layer units. A typical Ca-montmorillonite would be represented by the formula: $\text{Ca}_{0.5}(\text{MgAl}_3)\text{Si}_8\text{O}_{20}(\text{OH})_4 \cdot x\text{H}_2\text{O}$; the Ca is replaced by sodium in Na-montmorillonite. The proportion of water is variable, and the absorption of water between the 3-layer units gives rise to the considerable swelling properties possessed by clays containing much montmorillonite. The mineral occurs sparsely in soils along with kaolinite.

3.4.3 Illite

It is similar in many respects to white mica, but has less potassium and more water in its composition. It has a much lower base exchange capacity than montmorillonite. Illite is built up of units comprising two tetrahedral layers separated by an octahedral layer, and forms minute flaky crystals in a similar way to montmorillonite. Some of the silicon is replaced by aluminium, and atoms of potassium are attached, giving a general formula of the type: $\text{K}_x\text{Al}_4(\text{Si}_{8-x}\text{Al}_x)\text{O}_{20}(\text{OH})_4$, the value of x varying between 1.0 and 1.5. The OH-content may

exceed 4, out of a total of 24 for O + OH. Sedimentary clays are mostly mixtures of illite and kaolinite, with some montmorillonite, and shales have illite as the most dominant mineral. Illite is probably the most widely distributed clay mineral in marine argillaceous sediments.

3.5 Non-silicate minerals

The more common or economically important non-silicate minerals are:

Native elements: This group consists of chemical elements that occur in nature in an uncombined state. Examples are Sulfur, Copper (Cu), Silver (Ag), Gold (Au), Antimony (Sb), Diamond (C*) Graphite (C*) and sulphur (S).

Sulphides: Included in this group are combinations of various metallic elements with sulfur. These include the following: Chalcocite Cu_2S , Bornite Cu_5FeS_4 , Galena PbS^* , Sphalerite ZnS^* , Pyrite, FeS_2 .

Halides: Halides are naturally occurring chlorides, fluorides, bromides, and iodides. Examples are halite (rock salt) (NaCl^*) and fluorite (CaF_2).

Oxides and Hydroxides: The minerals in this group contain a metal element in combination with oxygen. The iron mineral hematite is an example. A subgroup within the oxides is the hydroxides, which include oxygen in the form of the hydroxyl radical or water. Limonite is an example of a hydroxide. These include Cuprite (Cu_2O), Corundum (Al_2O_3), Haematite (Fe_2O_3^*), Ilmenite (FeTiO_3^*), Magnetite (Fe_3O_4^*), Chromite (FeCr_2O_4) etc.

Carbonates: The carbonate group of minerals contains the carbonate radical. Examples are Calcite (CaCO_3^*), Siderite (Fe_2CO_3^*), Dolomite $\text{CaMg}(\text{CO}_3)_2$, Aargonite (CaCO_3^*), Witherite BaCO_3

Tungstates and Phosphates: These are minerals whose composition includes the phosphate radical. They include Wolframite (FeMnWO_4^*) and Apatite $\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{Cl}, \text{OH})^*$

Sulphates: These minerals include the sulfate radical. Gypsum is an example of a common sulfate mineral. Others include Barytes (BaSO_4^*), Celestine SrSO_4^* , Anglesite PbSO_4 , etc.

3.6 Mineral Identification Procedure

Is it harder than a knife? If YES, what is its overall appearance?

A. Dull and earthy, waxy, or metallic.

(1) Magnetic (small fragments stick to the knife blade) - magnetite.

(2) Nonmagnetic, how does it break (fracture)?

(a) Sharped edges; conchoidal (concave, like the inside of an oyster shell) surface - chert

(b) Rough, uneven surface, red-brown to black - hematite; brown to dark brown - limonite.

NOTE: both hematite and limonite can appear softer than a knife if not tested on a fresh, unweathered surface.

(c) Pale to medium brass colour, often in cubic crystals - pyrite.

(1) No cleavage.

(a) Colourless to white to pale pink - quartz.

(b) Olive green - olivine.

(c) Red-brown - garnet.

(2) Two cleavage planes, intersecting at approximately a 90-degree angle.

(a) Good to perfect cleavage surfaces (feldspar group, one surface with parallel striations) - plagioclase ; no striations present - orthoclase.

(b) Poor to fair cleavage surfaces - pyroxene.

(c) Two cleavage planes, intersecting at 120 and 60 degrees - amphibole (includes hornblende).

Figure 3.8 shows the minerals identification flowchart when the minerals are harder than knife

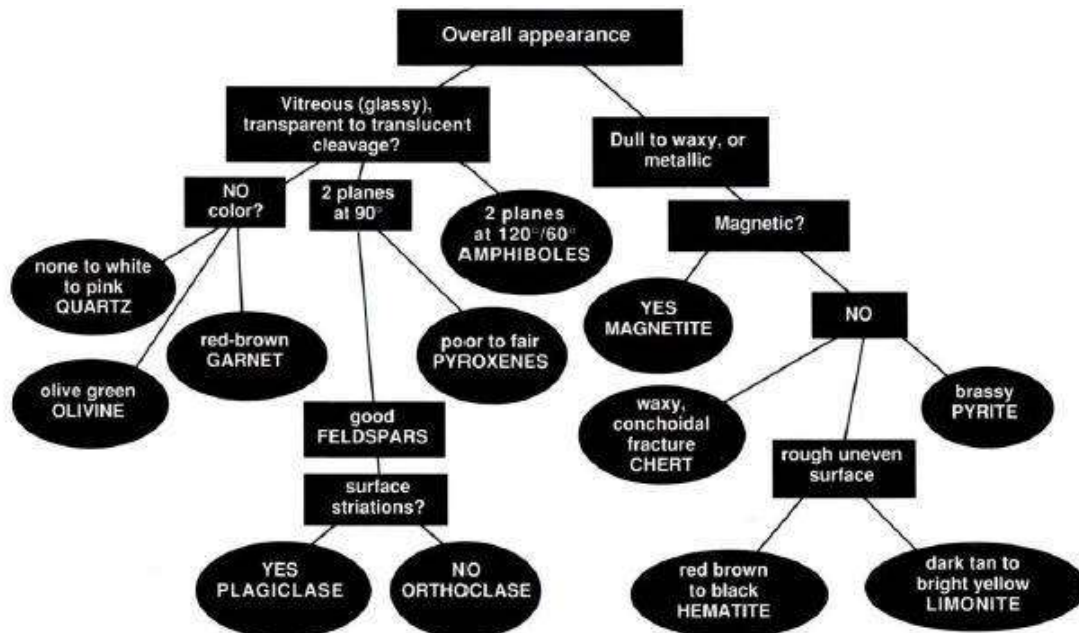


Figure 3.8: Mineral Identification Flowchart – Not scratched by a knife (Harder than knife)

If NO (not harder than knife), will it scratch a copper penny?

A. If yes, will it react with dilute HCl?

- (1) Vigorous reaction - calcite.
- (2) Minor reaction when whole, vigorous when powdered - dolomite.
- (3) No reaction.
- (a) One plane of perfect cleavage - fluorite.
- (b) Plane of poor cleavage - apatite.
- (c) Non-crystalline; waxy to greasy or fibrous appearance - serpentine.

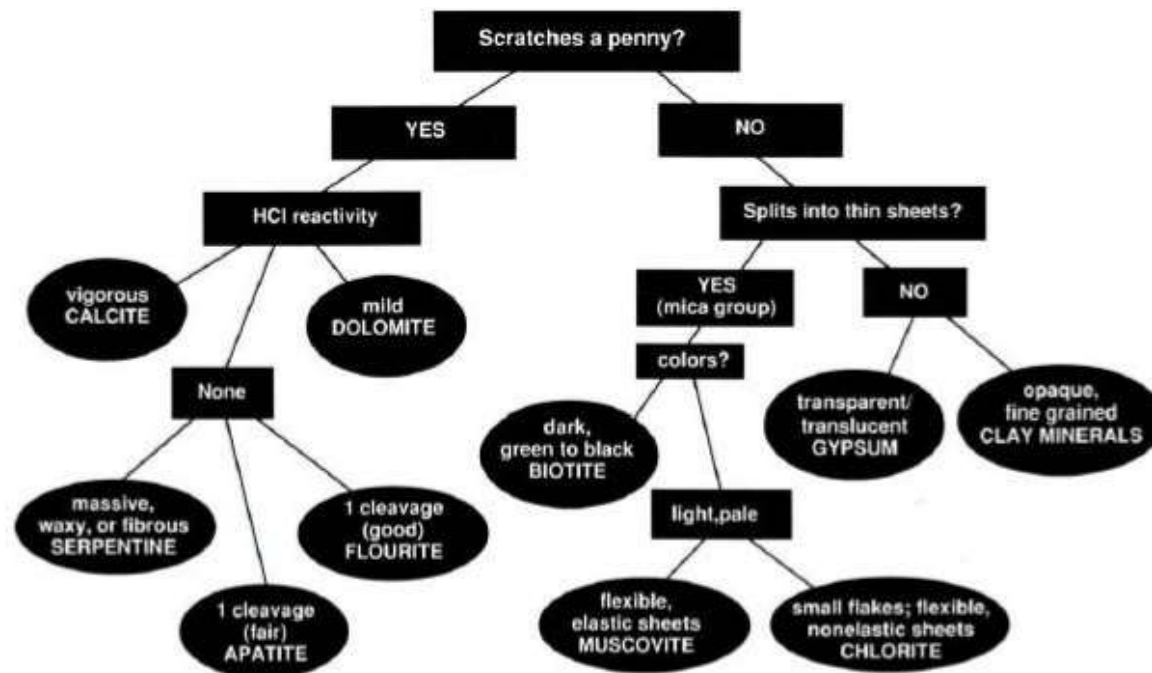
B. If no, does it have perfect cleavage which allows splitting into thin sheets? 1. Yes - mica group.

- (a) Pale, light colours, sheets are flexible and elastic - muscovite. Usually in very small flakes; sheets are flexible but not elastic - chlorite.
- (b) Dark colours, green to brown to black – biotite.

(a) Opaque, very fine grained - clay minerals.

(b) Translucent to transparent - gypsum.

Figure 3.9 shows the minerals identification flowchart when the minerals are softer than knife.



3.7 Identification of Rock Minerals

Identification of rock types involves not only identifying their mineral constituents and their relative amounts, but also a series of characteristics of the rock. Because rocks from different classes can appear quite similar, and rocks within the same class can often appear quite different, separation by class will not be a specific part of the identification process. Two cases are considered: when the mineral grains are easily seen by the naked eye and when they are not visible to the naked eye

Category 1: Distinct mineral grains, easily seen by the naked eye.

A. Entire rock surface easily scratched by a knife. (Make sure that the mineral surfaces are being scratched, and not simply that poorly cemented grains are being dislodged.)

1. Reactivity with dilute HCL.

(a) Vigorously, with much effervescence - limestone or marble.

NOTE: If visibly crystalline with interlocking grains, the rock in question may be a marble or a limestone. Without larger samples to reveal the presence or absence of characteristic irregular banding ("marbled" appearance) and other textural features, distinction between the two may not be possible. The presence of noninterlocking mineral grains and undistorted fossils confirm the rock is a limestone.

(b) Slowly on the rock surface, vigorously if the rock is powdered - dolomite (dolostone) or dolomitic marble.

(c) No reaction, greasy or waxy appearance – serpentinite.

B. Entire rock surface cannot be scratched by a knife, (that is, some or all of the minerals present are harder than the knife blade).

1. The minerals are intergrown (contact surfaces between minerals are irregular and interlocking).

(a) Minerals arranged in layers or bands (foliated).

(i) Irregular, coarse foliation if poorly developed (or lineation), with zones of light minerals (often quartz or feldspar, or both) alternating with zones of dark minerals (often biotite or hornblende). The foliation is not developed to the extent that planes of weakness are present in the rock - gneiss.

(2) Minerals arranged in thinner, more distinct layers which create planes of weakness along which the rock may be split. Mica minerals are plentiful – schist.

NOTE: Some sandstones are color banded. However, examination of the mineral grains will show a lack of intergrowth

b. Minerals not in distinct layers.(massive).

(i) Chief minerals are the feldspars, with orthoclase >plagioclase; five percent or more quartz; mica minerals or hornblende, or both in small amounts are common - granite.

(ii) Like granite, except little or no quartz – syenite.

(iii) Chief minerals are the feldspars, with plagioclase >orthoclase; five percent or more quartz; mica minerals and / or hornblende in small amounts are common - granodiorite.

(iv) Like granodiorite, except little or no quartz - monzonite.

(v) Mainly plagioclase, with hornblende and some biotite; no quartz; medium to dark color - diorite.

(vi) Like diorite, except pyroxene and possibly olivine present instead of hornblende and biotite; color is usually dark - gabbro.

NOTE: Finer grained gabbros are often referred to as diabase (figure 21). The rather ambiguous term traprock is also used for this rock type.

(vii) Chief minerals are pyroxenes and olivine; pyroxenes >olivine; dark color - pyroxenite.

(viii) Chief minerals are pyroxenes and olivine; olivine >pyroxenes; dark color - peridotite.

2. Minerals are in distinct grains that are cemented together rather than intergrown.

(a) Sand-sized particles, cemented by silica, clay, calcite, or hematite; chief minerals are usually quartz and feldspar; breaks around rather than through the sand grains - sandstone.

(b) Similar to sandstone in general appearance; quartz is the chief mineral; grain boundaries range from partial to total intergrowth due to secondary quartz crystallization during metamorphism; due to this intergrowth, the rock breaks through rather than around the mineral grains - quartzite.

NOTE: Under higher levels of metamorphism, quartzite would fall under category B.1 .b., above, due to nearly complete mineral intergrowth. It can easily be separated from the other rocks listed under B.1 .b. because the only mineral present in significant amounts is quartz.

c. Gravel-sized particles of rocks and minerals, cemented by silica, clay, calcite or hematite – conglomerate.

Category 2: Very fine mineral grains, not visible to the naked eye.

A. Glassy.

1. Looks like glass; may have a few inclusions or bubbles; dark brown to black - obsidian.

2. Contains many bubbles, frothy - pumice.

B. Dull, earthy or stony.

1. Can be scratched with a knife.

(a) Reacts vigorously with dilute HCl – limestone.

(b) Reacts slowly when whole or vigorously when powdered with dilute HCl - dolomite.

(c) Reacts slowly or not at all with dilute HCl, whether whole or powdered.

(i) Tends to break into flaky pieces - shale.

(ii) Layered; breaks into thin, flat sheets –

slate. 2. Can't be scratched with a knife.

(a) Very hard; fractured surface is smooth (may be conchoidal) with sharp edges; surface may appear waxy; tan to black color - chert.

(b) Massive; dull-appearing fractured surface; may have small inclusions of glass or crystals.

(i) Light to medium colors - felsite.

NOTE: Felsite includes the extrusive igneous rock types: rhyolite, trachyte, latite, and andesite which usually can't be distinguished by the naked eye. They differ basically only in the relative amounts of the two feldspars (their primary constituents) and the presence or absence of quartz.

(ii) Dark to black color - basalt.

Because this ratio between orthoclase and plagioclase is a continuum, rocks may be found on the borderline between the two groups. If in doubt, classifying a rock as a granite/granodiorite or syenite/ monzonite is sufficient because of their similar performance in construction. As the percentage of plagioclase in this family of rocks increases, the percentage of so-called dark minerals (mainly amphiboles and pyroxenes) also increases, giving the rock a darker overall appearance. This often allows the distinction of diorite from the other members of the group.

The two dark igneous rocks - pyroxenite and peridotite - may be indistinguishable in hand specimen if the mineral crystal size is too small to distinguish cleavage. As was the case above, identifying a rock as being one of the members of this continuum is helpful since they behave similarly in construction uses.

Although often even-textured (mineral grains are all about the same size), all igneous rocks may exhibit what is called porphyritic texture. A porphyritic texture is defined as one in which one or more minerals occur in crystals much larger than the surrounding minerals in the rock. It is the size difference rather than absolute size which defines the texture. Therefore it can exist as 1 mm crystals dispersed through a basalt or 10 mm crystals in granite. The presence of this texture does not affect the rock's classification, although it may affect some

of its engineering properties. Figures 3.10 and 3.11 are two decision tree diagrams for Categories 1 and 2, respectively.

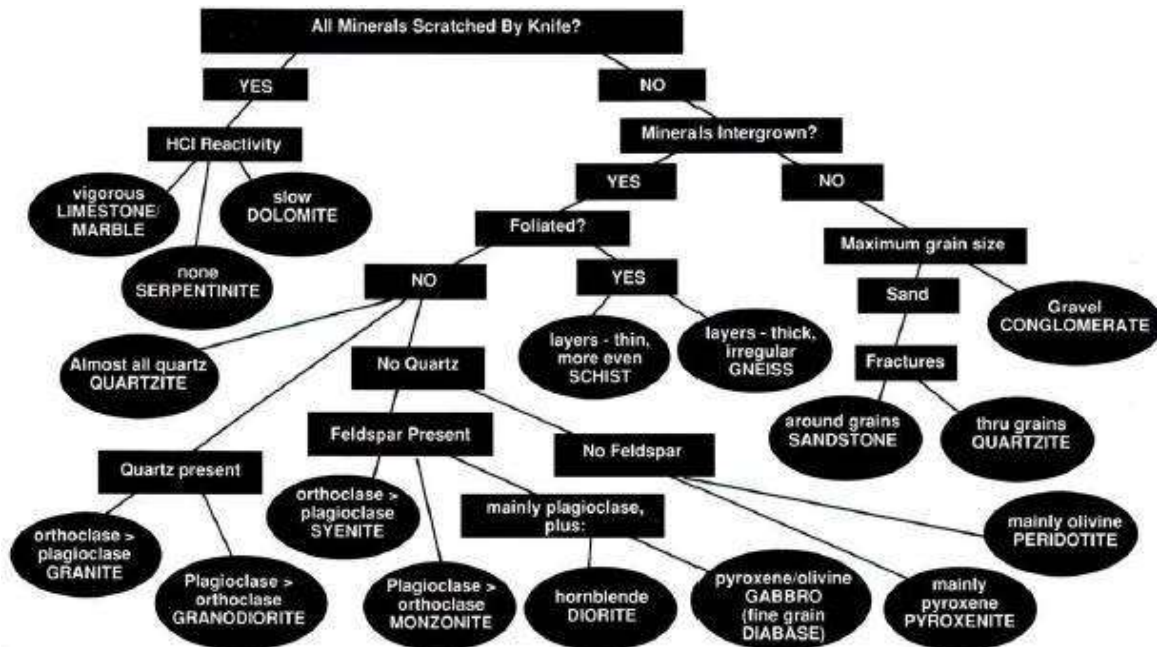


Figure 3.10: Identification flowchart of rocks with mineral grains/crystals easily visible to the naked eye

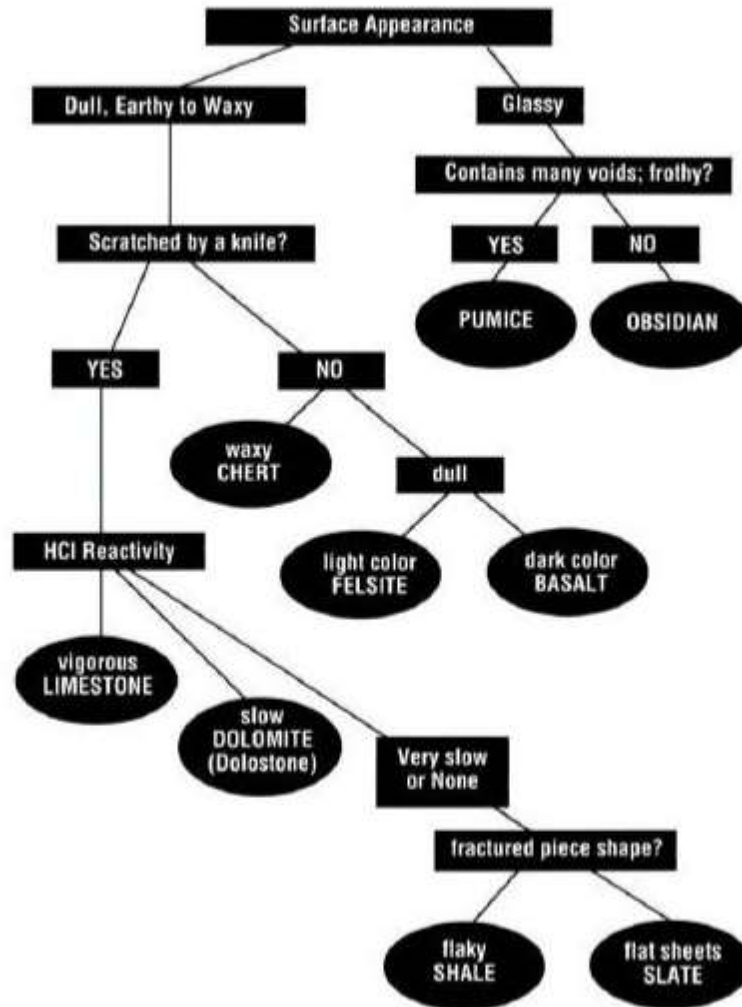


Figure 3.11: Identification flowchart of rocks with very fine mineral grains/crystals not easily visible to the naked eye