

Mineralogy:

Study of minerals.

What is a Mineral?

A mineral is a naturally occurring solid chemical substance formed through biogeochemical processes, having characteristic chemical composition, highly ordered atomic structure, and specific physical properties.

To be classified as a true mineral, a substance must be a solid and have a crystalline structure. It must also be a naturally occurring, homogeneous substance with a defined chemical composition.

To meet the definition of "mineral" used by most geologists a substance must meet five requirements:

1. Naturally occurring
2. Inorganic
3. Homogenous
4. Solid
5. Definite chemical composition
6. Ordered internal structure

Requirements of a substance to be designated a mineral:

- It must have been formed by natural processes; i.e. artificial or synthetic or man-made substances are not minerals.
- It must be inorganic substance; i.e. substances of wood or any other organic material can't be mineral.
- It must be homogeneous; i.e. made of same type of molecules and possess the same physical and chemical characters.
- It must be solid; i.e. gaseous, liquid or semisolid (Quasi-solid) substances are not minerals.
- It must have definite chemical composition; i.e. a particular kind of mineral always has the same chemical composition though it may occur in different size, shape, association etc.
- It must be crystalline, i.e. it should possess an orderly atomic structure. No two minerals can possess the same chemical composition and atomic structure.

Exceptions for Definition of Mineral:

Some substances which are traditionally or generally treated as minerals do not have one or any of the above said characters. Few exceptions to the definition of the mineral are:

1. Precious gemstones like diamonds, rubies¹, sapphires² and emeralds³ are synthetically produced under controlled laboratory conditions. They resemble their natural counterparts in all, respects and are treated as minerals.

1,2,3- All are derivatives of corundum. 1- blood red coloured 2- blue coloured 3- green coloured.

2. Coal, amber¹, petroleum, natural gas etc. are typical organic substances which are considered to be minerals.
3. Amethyst², smoky quartz, citrine³, cat's eye⁴, aventurine quartz are some minerals with inhomogeneity. As they possess certain impurities in quartz that give them colour. Similarly bauxite and coal etc. are not homogeneous. Kyanite⁵ mineral usually exhibits blue colours of different intensities.
4. Asphalt (bitumen), copalite¹, petroleum, mercury and natural gas are semisolids, liquids or gases, yet are treated as minerals.
5. Many minerals occur in isomorphic groups; i.e. they do not have a definite chemical composition. Ex. Garnets, olivines, some pyroxenes and amphiboles all are silicate molecules, which are isomorphic.
6. Some minerals like flint, chert, jasper and agate all are silicates with cryptocrystalline character i.e. they do not have a well-developed crystal structures.
7. Although liquid water is not a mineral, it is a mineral when it freezes. Ice is a naturally occurring, inorganic solid with a definite chemical composition and an ordered internal structure.

Physical properties most useful for mineral identification:

1. Color
2. Luster
3. Transparency (or diaphaneity)
4. Crystal Systems
5. Technical Crystal Habits
6. Descriptive Crystal Habits
7. Twinning
8. Cleavage
9. Fracture
10. Hardness
11. Specific Gravity
12. Streak
13. Associated Minerals
14. Notable Localities

1. Color: Color is due to the absorption of certain wavelength of the light by minerals. Generally speaking, color is not a good property to be used in the identification of minerals. It is usually the first property to confuse a novice collector into making an incorrect identification. Many minerals have different colors and some minerals' colors are identical to other minerals' colors. It is important to understand what causes color in minerals in order to understand this mineral property.

1- fossilized resin, 2,3,5 quartz, 2- Purple coloured, 3- pale to brown coloured, 4- Chrysoberyl-BeAl₂O₄

Color in minerals is caused by the absorption, or lack of absorption, of various wavelengths of light. The color of light is determined by its wavelength. When pure white light (containing all wavelengths of visible light) enters a crystal, some of the wavelengths might be absorbed while other wavelengths may be emitted. If this happens then the light that leaves the crystal will no longer be white but will have some color.

Some elements have electrons that absorb certain wavelengths or colors. These wavelengths provide energy to the elements that will often emit another wavelength to get rid of the extra energy. The energy state of the electron is related to the wavelength that it absorbs. The bonding in this element affects the energy state of these electrons. Therefore bonds to different elements produce different colors. Elements that produce colors through absorption and emission of wavelengths are usually transition metals. They can cause a mineral to always be a certain color if they are part of the chemistry of the mineral. However, if there is just a trace of these elements, they still can strongly influence the color of the mineral. Even tiny amounts of these elements can deeply colored minerals.

2. Luster is a description of the way light interacts with the surface of a crystal. This is how one can tell someone how a mineral looks. It has nothing to do with color or shape, but is related to transparency, surface conditions, crystal habit and index of refraction.

Some of the characters regarding luster are:

- Adamantine - very gemmy crystals
- Dull - just a non-reflective surface of any kind
- Earthy - the look of dirt or dried mud
- Fibrous - the look of fibers
- Greasy - the look of grease
- Gumdrop - the look a sucked on hard candy
- Metallic - the look of metals
- Pearly - the look of a pearl
- Pitchy - the look of tar
- Resinous - the look of resins such as dried glue or chewing gum
- Silky - the look of silk, similar to fibrous but more compact
- Submetallic - a poor metallic luster, opaque but reflecting little light
- Vitreous - the most common luster, it simply means the look of glass
- Waxy - the look of wax

3. Transparency, also known technically as diaphaneity, is a function of the way light interacts with the surface of a substance. There are only three possible interactions. If the light enters and exits the surface of the substance in relatively undisturbed fashion, then the substance is referred to as transparent. If the light can enter and exit the surface of the substance, but in a disturbed and distorted fashion, then the substance is referred to as

translucent. If the light cannot even penetrate the surface of the substance, then the substance is referred to as opaque. Many substances that are transparent can easily contain flaws and distortions that will limit a light beam's travels through a substance and make it translucent.

It is rare for an opaque mineral to have any translucent specimens, however, some translucent mineral specimens can become opaque from inclusions or weathering effects. Sphalerite is one example of a normally opaque mineral that often surprises collectors with an occasionally transparent specimen. Although a transparent mineral will always have some samples that are translucent (due to flaws, etc) it may be helpful to know if a mineral is typically transparent or vis-versa. And occasionally, a mineral that is translucent may never be transparent and knowing this can be very helpful to a collector. In listing a mineral's transparency these factors are taken into account to aid the collector as much as possible.

Another consideration is that a transparent mineral may be so strongly colored as to appear opaque. Azurite is an excellent example of this, as the extremely deep transparent blue crystals may appear black and opaque. However, near-surface internal fractures, and sometimes crystal edges when viewed against a bright light, can reveal the true color and transparency.

4. Crystal Structure: Minerals usually form distinct crystals. The shape of the crystals has been found to play an important role in the identification of minerals. The study of crystals is called crystallography and is an important field of study. Not only do scientists in this field study natural crystals but also the crystals formed by metal alloys, chemicals, and other synthetic materials. Often it is the use of crystallographic tools, such as an x-ray spectrometer, that find and distinguish new minerals as well as verify or correct the identification of specimens.

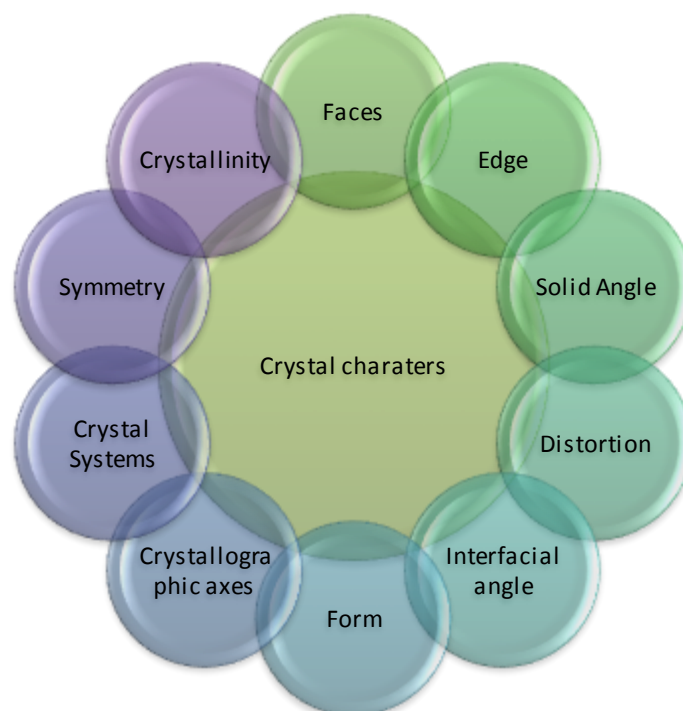
How can crystallography help anyone to identify minerals?

A mineral's crystalline structure, the arrangement of its component atoms and/or ions, is responsible for the outward shape of the crystal.

Defined precisely, *Crystals are solids bounded by smooth, more or less plain surfaces arranged in regular or orderly pattern which is an outward expression of a regular, internal atomic structure.*

Characteristics of Crystals:

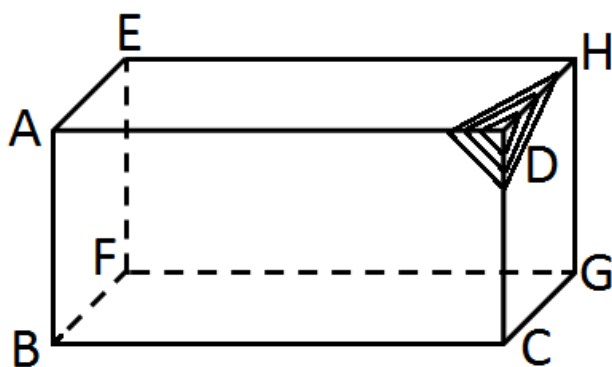
Crystals and minerals can be identified with the uniqueness of the following characters:



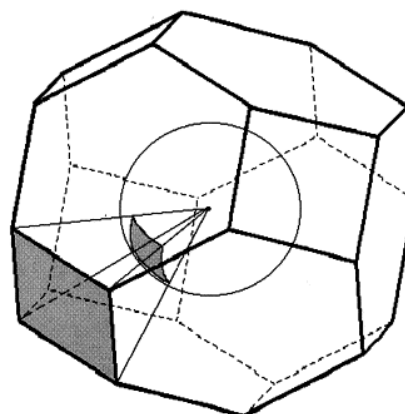
Faces: The crystals are bound by flat surfaces which are known as faces.

Edge: The line of intersection formed by any two adjacent faces in a crystal is called an edge.

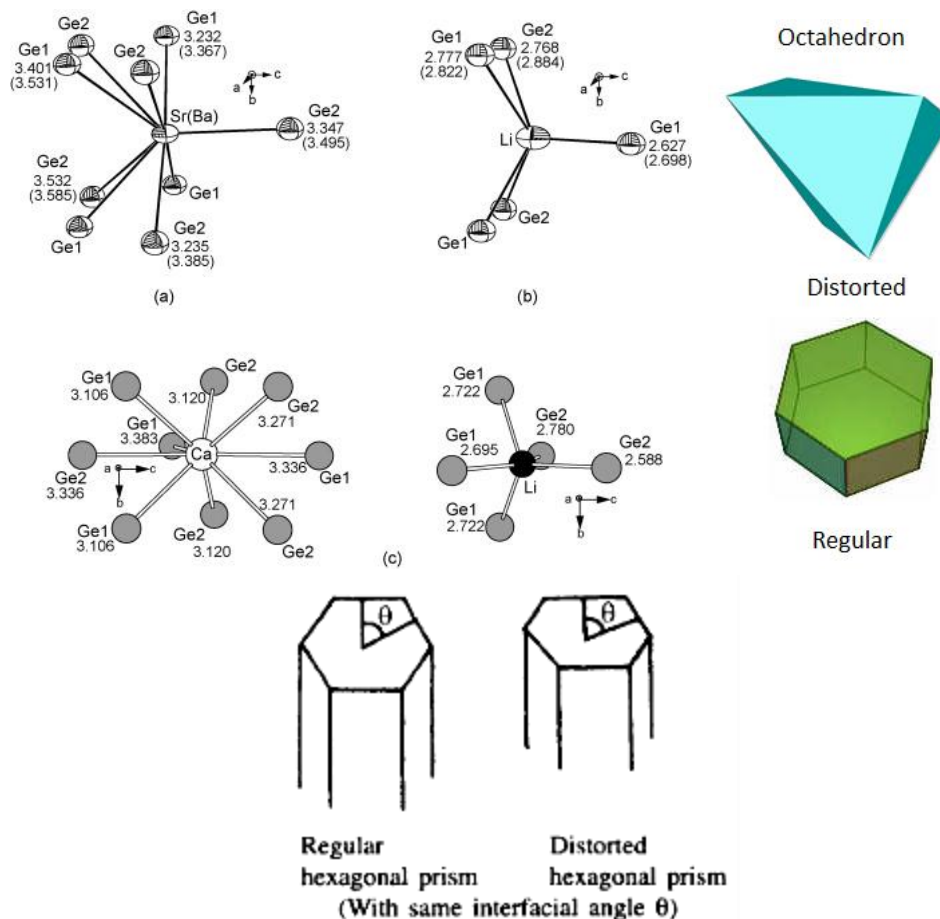
Solid angle: The point of intersection formed by three or more adjacent faces in a crystal is called solid angle.



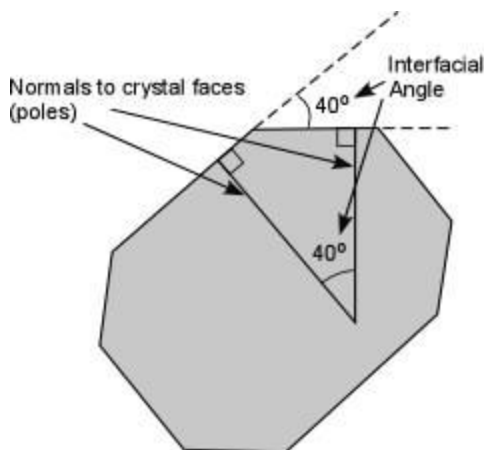
ABCD, AEFB, DHGC, AEHD, BFCG are Faces
 AB, DC, BC, AD, AE, DH, EH, CG etc are Edges
 and D is the Solid Angle



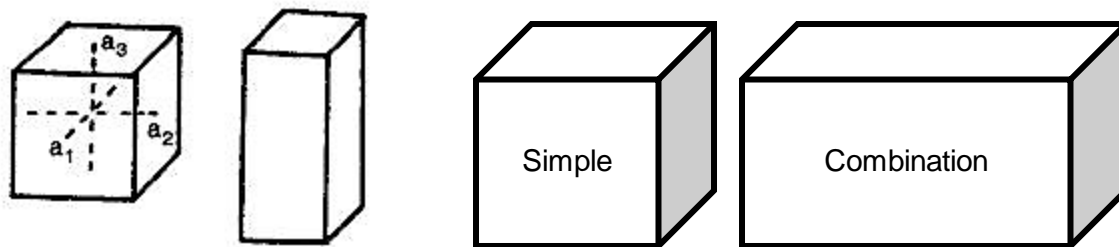
Distortion: In spite of perfect internal atomic arrangement, sometimes crystals develop faces of different sizes and shapes. This kind of geometrical irregularity in the shape of crystals is called distortion. Distortion may be due to some restraint on the growth of the crystal in certain direction or to a greater supply of material being available in one direction as compared with another.



Interfacial angle: It is the angle formed in between the normal of adjacent crystal faces. This is important because both in distorted and proper crystals of the same type, adjacent crystal faces show the same interfacial angles irrespective of the size or shape of the concerned faces. This is the indication of regularity of the internal atomic structure and is measured by goniometer.



Simple form and combination: If a crystal is bounded by all similar or like faces it is a simple form. If a crystal is bounded by dissimilar or unlike faces it is called a combination.



Simple form/Combination
(a_1, a_2, a_3 = crystallographic axes)

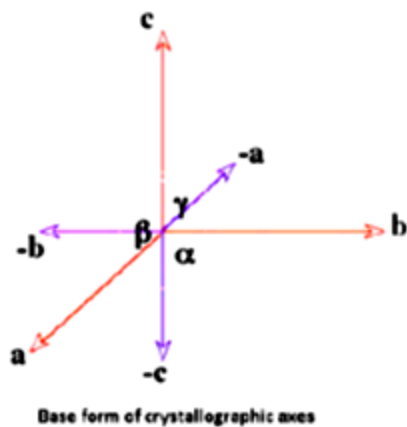
Crystallographic axes: These are the imaginary lines which intersect at the centre of the crystal. The growth or development of the crystal is considered to take place along the axes. Based on the number of such axes, their relative lengths, their interchangeability and their mutual angles, the crystals developed are grouped into six crystal systems. This means any crystalline mineral should belong to one or the other of these six crystal systems only. Yet if any other structure is there it could be amorphous form.

All the Crystal systems can be explained as:

Crystallographic Axes

Crystallographic Axes		
<p>Triclinic System</p> <p>$a \neq b \neq c \quad \alpha \neq \beta \neq \gamma$</p>	<p>Monoclinic System</p> <p>$a \neq b \neq c \quad \alpha = \gamma = 90^\circ, \beta > 90^\circ$</p>	<p>Orthorhombic System</p> <p>$a \neq b \neq c \quad \alpha = \beta = \gamma = 90^\circ$</p>
<p>Tetragonal System</p> <p>$a_1 = a_2 \neq c \quad \alpha = \beta = \gamma = 90^\circ$</p>	<p>Hexagonal System</p> <p>$a_1 = a_2 = a_3 \neq c \quad \alpha = \beta = 90^\circ, \gamma = 120^\circ$</p>	<p>Isometric System</p> <p>$a_1 = a_2 = a_3 \quad \alpha = \beta = \gamma = 90^\circ$</p>

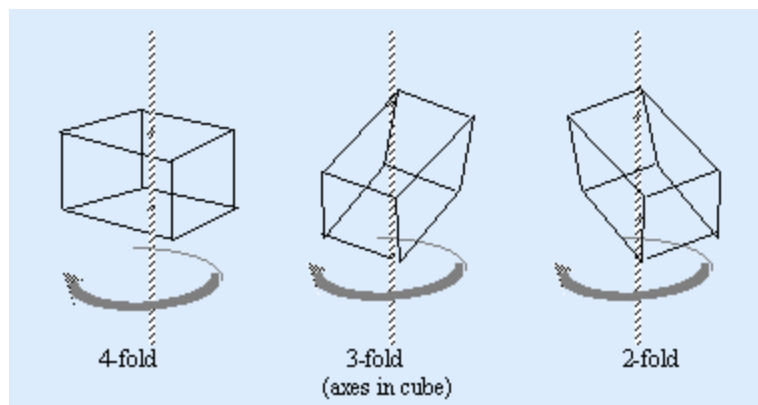
With the above Crystal Systems we may be obtaining one of the following structures of minerals.



Crystal Systems	Crystallographic axes features
Triclinic	$a \neq b \neq c; \alpha \neq \beta \neq \gamma$
Monoclinic	$a \neq b \neq c; \alpha \neq \gamma;$ $\beta > 90^\circ \text{ or } \beta < 90^\circ$
Orthorhombic	$a \neq b \neq c; \alpha = \beta = \gamma = 90^\circ$
Tetragonal	$a = b \neq c; \alpha = \beta = \gamma = 90^\circ$
Hexagonal	$a = b \neq c;$ $\alpha = \beta = \gamma = 120^\circ$
Isometric or cubic	$a = b = c, \alpha = \beta = \gamma = 90^\circ$

Crystal Systems: The six possible crystal systems are cubic system, tetragonal system, hexagonal system, orthorhombic system, monoclinic system and triclinic system. There are other crystals systems also. The main basis for the division is rotational axis.

A rotational axis is a line imaginarily drawn through the crystal that acts as an axis just like the axis for a tire. A face can be repeated on a crystal when the crystal is rotated around this axis and a new face is left at various intervals during the rotation. Consequent to being rotated is that the face must be identical to the original face when the face is viewed head on. In other words, if the face has a right handed slant and is rotated, the rotated faces must keep the right handed slant.



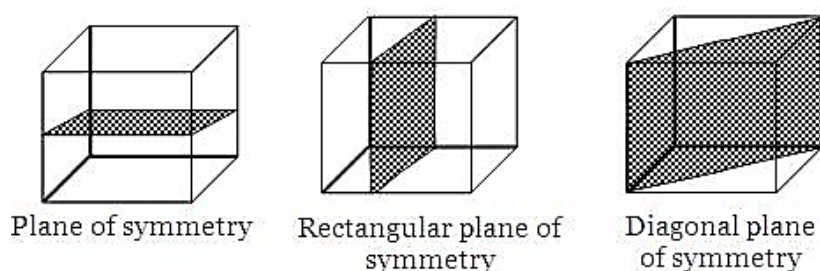
The interval for dropping a face is determined by a division of the full turn into equal segments. For example, to drop four faces on a crystal the rotation requires a stop at every 90 degrees and this type of rotation is called a four fold rotational axis. Rotational axes can have rotations of 1, 2, 3, 4 and 6 fold. Thus the 1 fold axis rotates the crystal in 360 degree intervals, the 2 fold interval is 180 degrees, the 3 fold interval is 120 degrees, the 4 fold interval is 90 degrees and the 6 fold interval is 60 degrees.

THERE ARE THE SEVEN CRYSTALLOGRAPHIC SYSTEMS:

1. CUBIC or ISOMETRIC, requires 4 three fold axis of rotation.
2. TETRAGONAL, requires 1 four fold axis of rotation.

3. HEXAGONAL, requires 1 six fold axis of rotation.
4. TRIGONAL, requires 1 three fold axis of rotation.
5. ORTHORHOMBIC, requires either 3 two fold axis of rotation or 1 two fold axis of rotation and two mirror planes.
6. MONOCLINIC, requires either 1 two fold axis of rotation or 1 mirror plane.
7. TRICLINIC, requires either a center or only translational symmetry.
8. AMORPHOUS; no symmetry is present and it is therefore not a crystallographic system.

Symmetry: The faces, edges and solid angles in crystals occur with some regularity or orderliness. This is known as symmetry. In the study of crystals this symmetry, in a simpler way, is expressed in terms of planes of symmetry, axes of symmetry and centre of symmetry.



Other axes mentioned are crystallographic axes that are used by crystallographers like geometric axes to plot the faces and symmetry elements and their orientations within the crystal. These axes may or may not be part of the symmetry of the crystals. But they usually are since crystallographers will often orient the crystallographic axes along the planes and axes of symmetry.

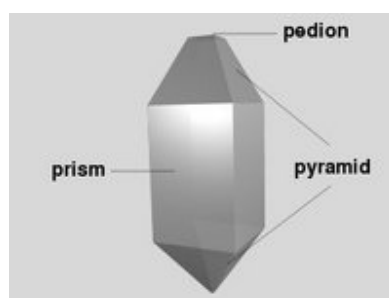
Systems	No. of Planes of symmetry	No. of axes of symmetry present				Centre of symmetry present or absent
		Binary Axes	Trigonal axes	Tetragonal axes	Hexagonal axes	
Cubic or Isometric	9	6	4	3	Nil	Present
Tetragonal system	5	4	Nil	1	Nil	Present
Hexagonal system with hexagonal division	7	6	Nil	Nil	1	Present
Hexagonal system with Trigonal division	3	3	1	Nil	Nil	Present
Orthorhombic System	3	3	Nil	Nil	Nil	Present
Monoclinic system	1	1	Nil	Nil	Nil	Present
Triclinic System	Nil	Nil	Nil	Nil	Nil	Present

5. Crystal Habit: It is a description of the shapes and aggregates that a certain mineral is likely to form. Often this is the most important characteristic to examine when identifying a mineral. Although most minerals do have different forms, they are sometimes quite distinct and common only to one or even just a few minerals. Many collectors strive to collect mineral specimens of certain typical and abnormal habits. There are either open forms or closed forms.

The Open Forms:

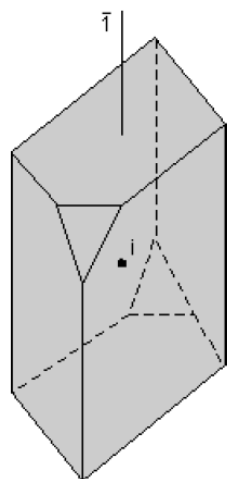
The Pedion:

In this form or class there is no symmetry. In a mineral with low symmetry, a pedion is a possible face. It is a flat face that is not parallel or geometrically linked to any other faces. It can be found on the top of prismatic crystals that lack a perpendicular mirror plane or a two fold rotational axes. Elbaite is a mineral known to form a pedion face. The pedion is possible only on minerals that lack symmetry operations parallel to the pedion face and lack a center.



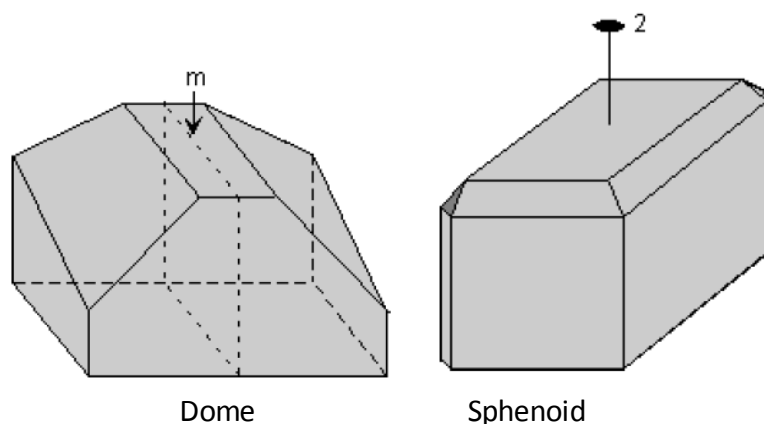
The Pinacoid

Since in this form or class there is only a center of symmetry, pairs of faces are related to each other through the center. Such faces are called *pinacoids*, The pinacoid is composed of only two parallel faces. Prominent pinacoids will form platy or tabular crystals such as in wulfenite, pictured) and can be thought of as the top and bottom of a book. Pinacoids also routinely terminate the top and bottom of prismatic crystals such as apophyllite. It is caused by either a mirror plane reflecting the face from one side of the crystal to the other, a two fold rotational axes rotating the face from one side to the other or simply a center of symmetry (see the triclinic symmetry class) where an inversion of the face takes place through the center of the crystal. It is possible in most every crystal except those lacking the required symmetry of a solitary mirror, two fold axes or a center.



The Dome and Sphenoid

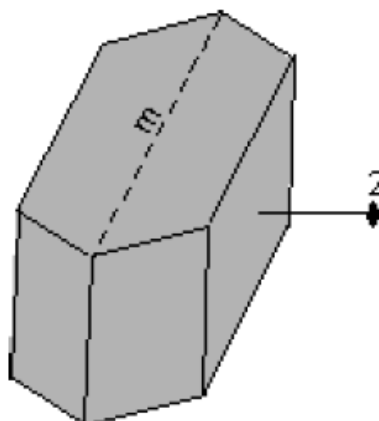
These forms are found in monoclinic and orthorhombic minerals. They consist of only two intersecting faces that are caused by either a mirror (the dome) or a two fold rotational axes (the sphenoid). These two forms could, more graphically, be called "The Tents" because they look like simple pup tents. The rare sulfate mineral pickeringite forms sphenoids and the silicate topaz commonly forms domes (the prominent slanting face pictured below). Domes and sphenoids can also form on the sides of crystals as well as terminations for prismatic crystals. If a dome or sphenoid is on the side of a crystal it might be confused with two of the four faces of a prism (look for similar faces on the other side of the crystal axes).



The Prism

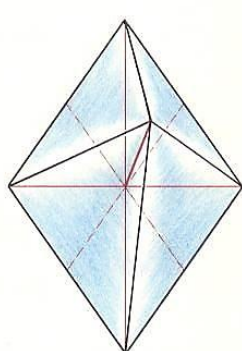
A prism is a set of faces that run parallel (meaning they never converge) to an axis in the crystal. There can be three, four, six, eight or even twelve faces that can form a prism. All the faces of one prism must be separated from each other by a specific amount of degrees or they are not of the same prism. For the three sided prism there must be 120 degrees separating each face, for the four sided prism, 90 degrees, for the six sided prism, 60 degrees, etc, etc. Four sided orthorhombic prism faces are not necessarily separated by 90 degrees and are an exception to the rule, however two adjacent angles must equal 180 degrees. In viewing a prism lengthwise, perfect geometrical shapes should be seen such as a the cube, the hexagon, the octagon or the rhombus (monoclinic crystals). Prisms are not possible in isometric or triclinic minerals. Quartz forms two sets of three sided prisms.

Prismatic habit does not mean that the mineral faces are prism faces for they could be two sets of pinacoids that are parallel to the same axes.

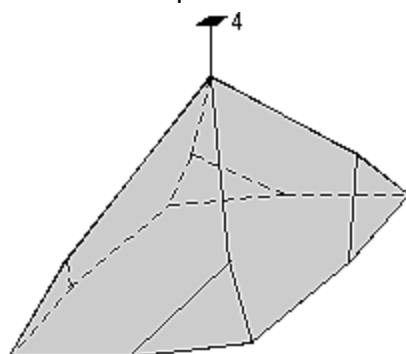


The Pyramid

The pyramids are easy to understand since most people are familiar with the Egyptian and Mexican pyramids. Pyramids, like prisms, are composed of either three, four, six, eight, twelve or even sixteen faces. The faces are separated by a specific amount of degrees as with the prism described above. The faces are not parallel and in fact converge around a crystallographic axes forming a multi-sided tent (compare the dome and sphenoid) with a point unless capped by a pedion or pinacoid. The steepness of the faces of a single pyramid must remain constant. Many minerals may contain a tapering termination of different inclines due to the presence of different pyramids. The mineral uvite can be terminated by a three sided pyramid. Pyramids are not possible on isometric, monoclinic or triclinic minerals.



rhombic pyramid $m\ m\ 2$



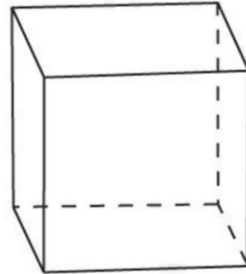
Tetragonal-pyramidal

The Closed Forms:

The Isometric Forms

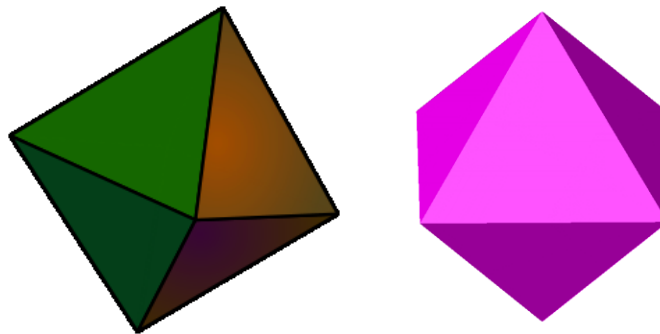
The Cube

The cube is familiar to everyone as a symmetrical six sided box. Although the cube is familiar it is hard to identify its faces on a highly modified crystal that has faces from other forms. Remember it has eight points, six faces and twelve edges that are perpendicular to each other forming 90 degree angles and square cross-sections. The faces are usually square, but if modified can be other geometric shapes. The cube can only be formed by isometric minerals. Galena is a mineral that forms cubes.



The Octahedron

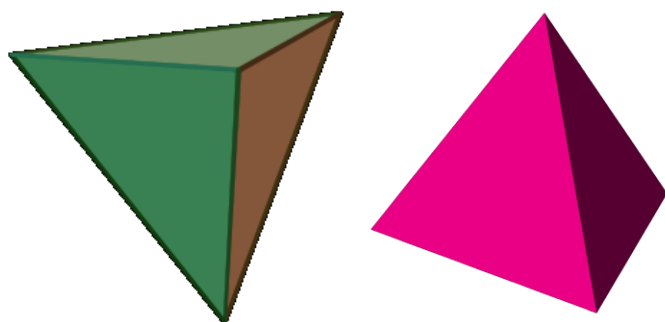
The octahedron is a symmetrical eight sided shape that may look like two four sided pyramids lying base to base. But closer inspection will show that each set of opposing points is exactly the same and could serve equally well as the "top" and "bottom" of the two pyramids. In fact there is no top or bottom on isometric forms. The faces are equilateral triangles unless modified. There are six points, eight faces and twelve edges. Each face is parallel to the opposite face. The octahedron is related to the cube by placing each point of an octahedron at the center of each face of a cube. The mineral diamond commonly forms octahedrons.



The Tetrahedron

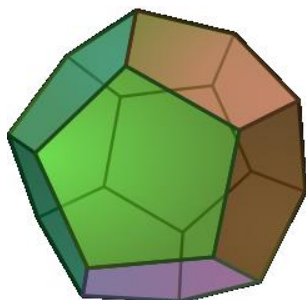
The tetrahedron has only four equilateral triangular faces (unless modified), four points and six edges and when sitting on one face looks like a trigonal pyramid. But every point of the tetrahedron can serve as the top of the pyramid because all four points are identical. The tetrahedron is related to the octahedron by placing the six points of the octahedron in the middle of the six edges of the tetrahedron. In fact the four faces of the tetrahedron would be parallel to four of the eight faces of the octahedron. The tetrahedron can be thought of as having removed every other face from an octahedron and extending the four faces that are left to complete the closed tetrahedron. Tetrahedrons only form in isometric minerals

that have four fold rotoinversion axes. The mineral tetrahedrite as its name infers, forms mostly tetrahedrons.



Dodecahedrons

Another isometric shape the dodecahedron is twelve sided and there are four basic types. The first dodecahedron has symmetrical pentagonal faces (five edged polygons). The second dodecahedron has delta shaped faces (four edged polygons). The third dodecahedron has asymmetrical pentagonal faces. The last dodecahedron has rhombic faces (four edged diamond-shaped polygons).



The pentagonal dodecahedron is termed a pyritohedron because it is most commonly found in the mineral pyrite. The pyritohedron is related to the cube by orienting two of the pyritohedron's faces essentially with each cube face. Two of the pentagonal faces touch bases in a line or edge that is parallel to the cube faces. This edge is responsible for the striations seen on pyrite's cubic faces when the two forms are trying to form together.

The deltoid dodecahedron has four sided delta shaped faces. It is derived from a tetrahedron with each of its four faces replaced by three delta shaped faces. The deltoid dodecahedron is a rare dodecahedron and is usually only seen modifying the tetrahedral crystals of tetrahedrite and tennantite.

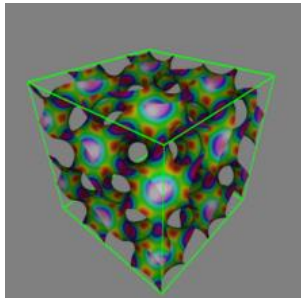
The tetartoid is a 12 sided form that is very rarely seen. The faces are asymmetrical pentagons. The mineral cobaltite has been known to form this type.

The rhombic dodecahedron is found commonly in the garnets as well as other minerals including fluorite (pictured above left on rhodochrosite). Each of the faces of this dodecahedron have a parallel face across from them. The faces are rhombic or diamond-shaped, like the diamonds in a deck of cards. A rhombic dodecahedron has fourteen points,

twelve faces, and twenty four edges. A rhombic dodecahedron is related to the octahedron by placing a dodecahedral face over each of the twelve octahedral edges. The generic use of the word dodecahedron is usually applied to this rhombic form.

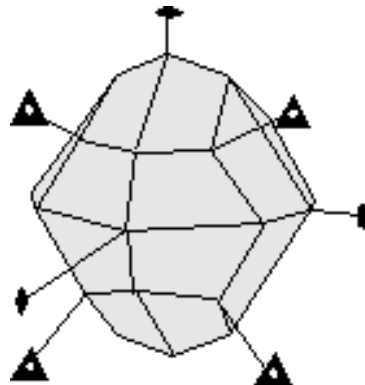
The Gyroid

The gyroid has 24 non-symmetrical pentagonal faces and is a rare form. Cuprite is the only mineral that commonly forms gyroids and usually they are modified by other forms.



The Diploid

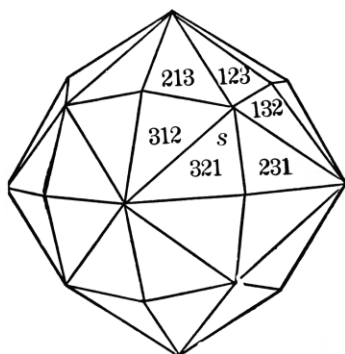
The diploid is also a form that is rarely seen. It has 24 four edged faces that are formed from the splitting of the pentagonal faces on the 12 sided pyritohedron. The split is from the center of the pentagons base edge to the top point of the pentagon. The mineral skutterudite will occasionally form this rare habit.



(Pyrite)

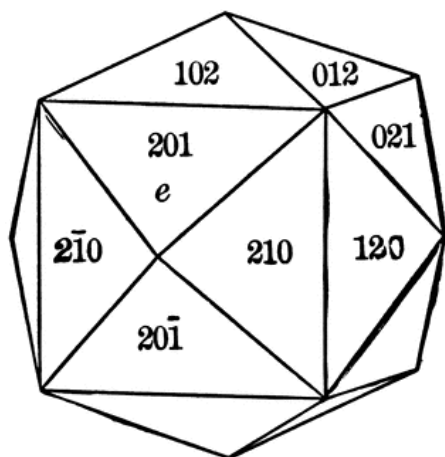
The Hexoctahedron

The hexoctahedron is a richly faceted form with a total, if fully formed, of 48 triangular faces. It is related to the octahedron by the dividing of each of the octahedron's eight faces into six triangular faces. Diamond is found in this form however the crystals tend to appear rounded.



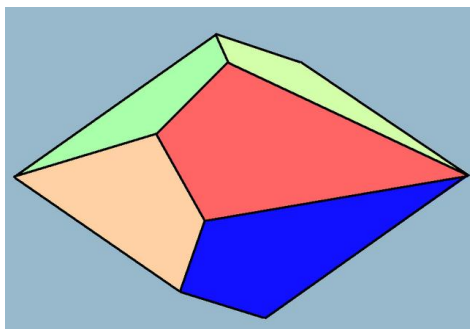
The Tetrahexahedron

This form is composed of 24 triangular faces and is related to the cube by dividing each of the cube's six faces into four faces. The edges of the cube remain in place and form the bottom edge of each isosceles triangle. This form will still give an overall cubic look but with each cube face pushed outward to a four-sided squat pyramid. The mineral fluorite has shown this form but the tetrahexahedral faces are usually just modifying the cubic faces.



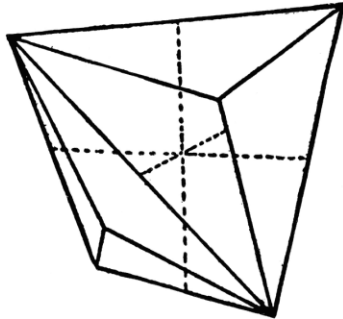
The Trapezohedron

The trapezohedron has 24 trapezium or deltoid shaped faces. They can be thought of in two ways. Either they are dividing each face of an octahedron into three faces or they are dividing each face of a cube into four faces. Either way the result looks a little more like a cube than an octahedron however no edges of the cube or the octahedron remain. The mineral analcime is commonly seen in this form.



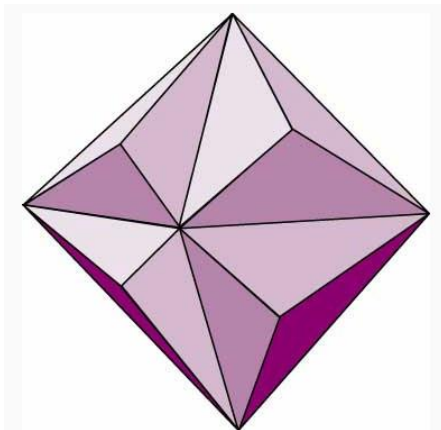
The Tristetrahedron

The tristetrahedron has 12 faces that are shaped like extremely acute isosceles triangles. It is formed by the dividing of a tetrahedral face into three faces. The original edges of the tetrahedron serve as the bases for the triangular faces of the tristetrahedron. The mineral sphalerite can have faces of the tristetrahedron.



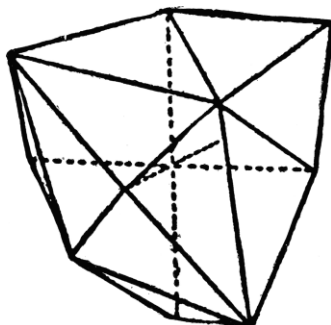
The Trisoctahedron

The trisoctahedron has 24 faces that are shaped like extremely acute isosceles triangles. It is formed by the dividing of an octahedral face into three faces. This is different from the effect created in the trapezohedron in that these faces leave the original edges of the octahedron in place and use them as their base for their squashed triangular shapes. The mineral Diamond can have octahedral crystals modified by the trisoctahedron but rarely is this form fully developed.



The Hextetrahedron

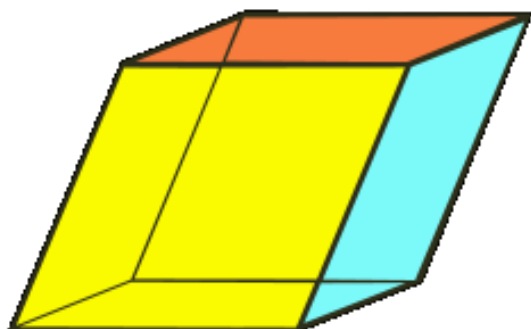
This is also a rare form that almost is never fully developed. It is composed of 24 triangular faces and is formed from the dividing of each face of the tetrahedron into six faces. Its faces are sometimes seen on the highly modified crystals of the mineral sphalerite.



The Non-isometric Closed Forms:

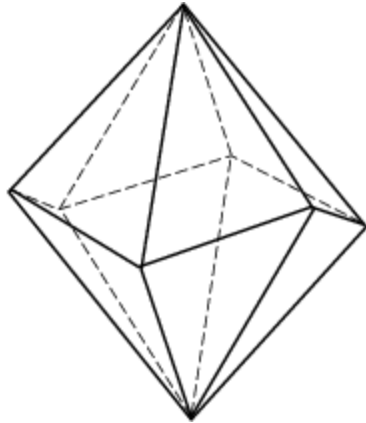
The Rhombohedron

The rhombohedron is difficult to describe. The best way to visualize it is to think of a partially squashed box. In other words a square box that has been sat on and deformed in one direction only. The deformation occurs in the direction of one of the three diagonals that run through the cube from one corner to the other. The steepness of the rhombohedron is variable for different minerals and even within the same mineral a crystal may have several different rhombohedrons of different inclines. The diagonal of "deformation" becomes the prominent axes of symmetry and is trigonal with a three fold rotation about the axes. Six mirror planes protrude through the middle of the faces and edges that converge on the top and bottom points. There are six faces (like a cube) and if the "deformation" is not severe then the crystal can appear to be pseudo-cubic. However careful measurements of angles will differ from 90 degrees and the square-like faces will actually be shown to be rhombic. With severe "deformation" the crystal can appear tabular. The rhombohedron is the only non-isometric closed form with parallel faces. Roto-inversion (discussed below) is the symmetry operation that produces the rhombohedron. The minerals siderite and rhodochrosite are commonly found in rhombohedral crystals.



The Scalahedron

The scalahedron is a general term for three crystal forms differentiated by the symmetry of the prominent axis. The prominent axis can have either a four fold axis of roto-inversion (an eight faced scalahedron) or a three fold axis of roto-inversion (a twelve faced scalahedron). Roto-inversion is the symmetry operation that produces the scalahedron. A scalahedral face (a scalene triangle) if rotated by a fraction of a circle around the crystal and then inverted through the center of the crystal will form a new scalahedral face. If from this new position the face is rotated by the same amount of degrees and again inverted, a third face forms. The entire crystal can be formed in this way. Calcite is famous for forming well shaped trigonal scalahedrons and fine examples of scalahedrons of hematite are actually rare.



6. Descriptive Crystal Habits:

The following terms are more descriptive than the technical crystallographic terms and are therefore easier to understand. There are basically two types: single crystal forms and aggregate forms. The single crystal terms are used to describe individual crystals and so terms like platy or prismatic are used. Aggregate terms are for minerals whose crystals come in groups of at times literally thousands of crystals and form a unique shape. Individual crystals in these aggregates are usually hard to discern. Terms such as dendritic and botryoidal are used to describe these. All these terms are subjective and most minerals form more than one. Some habits differ only in the slightest of ways and differentiation between these is therefore not very diagnostic. However there are some minerals that seem to always be found in one habit. Some examples of habits are pictured and each habit has a link to a mineral that has been known to be found in this habit, but remember few minerals are limited to just one habit.

These are some of the more common descriptive terms used to portray certain crystal habits of both individual and aggregate crystal varieties:

Individual Crystal Terms:

Acicular

Long and needle-like, thinner than prismatic but thicker than fibrous. Natrolite crystals can be good examples of acicular crystals.

Bladed

Elongated and flattened like a blade of grass. More elongated than platy and thinner than tabular. Kyanite forms crystals that are a good example of bladed crystals.

Blocky

Rectangular and box-like, but not necessarily with flat sides. More elongated than equant but less elongated than prismatic and thicker than tabular. Oligoclase forms crystals that are a good example of a blocky habit.

Equant

Any three perpendicular axis through the crystal are more or less equal. Can be used to describe rounded as well as angular crystals. Fluorite forms crystals that are a good example of equant crystals.

Fibrous

Thinner than acicular crystals in either individual crystals or in a tight compact almost cloth-like mass. Okenite forms crystals that are a good example of the fibrous habit.

Platy

Flattened and thin crystals (like plates) but wider than bladed and thinner than tabular. Crystals of wulfenite generally show good examples of the platy crystal habit.

Phantomed

Phantomed crystals occur when a crystal stops growing and then for some reason continues to grow. During the hiatus in growth, small microcrystals of other minerals or even the same mineral may grow on the surface of the crystal. Once the main crystal begins to grow again, it grows out and around these small crystals trapping them as a layer inside. This layer has the shape of the crystal at the time it stopped growing and often has a ghostly look to it, hence the name phantom. Calcite and quartz are two minerals that forms phantomed crystals more often than others.

Prismatic

One of the most common of crystal habits. Prismatic crystals are "pencil-like", elongated crystals that are thicker than needles (see acicular). Indicolite (a variety of elbaite) forms good examples of prismatic crystals.

Pseudomorphs

A pseudomorph (which mean false shape in Latin) is a crystal that has replaced another mineral's chemistry or structure with its own without changing the outward shape of the original mineral. Transformations from one mineral to another are not unusual in nature, but preserving the outward shape of the original mineral is! The end result is that the crystal appears to be one mineral but is actually another. The quartz specimen above was once aegirine.

Sceptered

Sceptered crystals occur when a crystal stops growing and then for some reason continues growth on the upper portion of the crystal but not the lower portion. The result on

prismatic crystals is a shape that appears like a jeweled royal scepter of kings and queens. Scepters are quite popular and rare! Smoky quartz, a variety of quartz, forms sceptered crystals.

Stubby

Slightly more elongated than equant but not as elongated as prismatic and possibly more rounded than blocky. Topaz forms crystals that are a good example of stubby crystals.

Tabular

Book-like (tablets) that are thicker than platy but not as elongated as bladed. Wulfenite forms crystals that are a good example of tabular crystals.

Aggregate Crystal Varieties:

Arborescent

Branching, tree-like clusters similar to dendritic. Some of the best examples of the arborescent crystal form are found in many specimens of native gold.

Botryoidal

Resembling grape bunches with interlocking rounded masses. Formed from acicular or bladed crystals growing from a common site for each rounded mass. The tops of the crystals are smooth and blend so that individual crystal edges are indiscernible except from broken edges. Botryoidal is similar to globular and mammillary; but more of an aggregation of rounded masses. Sub-botryoidal has more discernible crystals. Hematite and smithsonite both form aggregates that are good examples of this form.

Dendritic

A branching growth of crystals usually on a surface or as an inclusion that forms plant-like patterns similar to "Jack Frost" on windows and similar to arborescent, but less tree-like. Sal ammoniac forms aggregates that are a good example of this form.

Druse

Outwardly oriented crystals usually lining the inside of a geode, but is also applied to other outwardly oriented crystal coatings. Amethyst, a variety of quartz, forms aggregates that are a good example of this form.

Encrusting

Thin crust of crystalline material over host rock. Sometimes forms from evaporation, efflorescence or simple precipitation. Uranocircite forms aggregates that are a good example of this form.

Geode

A hollow stone embedded in a layer of rock mineralogically different from the mineral composing the outer shell of the geode (see vugs). Celestite is found in good examples of this form.

Globular

Bubbly, rounded masses, similar to botryoidal or mammillary but less coherent. Gyrolite forms aggregates that are a good example of this form.

Granular

Crystals of a small size, less than 1 cm across, that exhibit no really discernable crystal form. Usually applied to many tiny crystals separated and disseminated throughout a host rock. Franklinite forms crystals that are a good example of this habit.

Hopper Crystals

Crystals where their edges grew faster than their faces forming a "skeletal" like structure. Minerals that form this type of habit usually grow quickly and crystals grown artificially, see bismuth, often show this form. Halite often forms crystals demonstrating this habit.

Lamellar

Layered masses like sheets of paper. Muscovite forms aggregates that are a good example of this form.

Mammillary

Rounded, literally "breast-like" masses, similar to botryoidal and globular but more rounded, larger individual masses. Prehnite and kidwellite forms aggregates that are a good example of this form.

Massive

Indiscernible masses of crystals usually too fine to see. Lazurite forms massive examples.

Micaceous

Flaky to platy crystals compacted together in sparkling masses. Similar to lamellar but with smaller crystals. Muscovite, the most common member of the Mica Group, forms aggregates that are a good example of this form.

Nodular

A stone of concentric growth around a center usually composed of mostly one mineral. Concretions fall under this term. If broken, may show concentric rings. Forms nearly

spherical balls, flat round "suns" to oddly shaped concretions. Pyrite forms good examples of this form.

Oolitic

Rounded pebble to sand sized nodules in a compact mass formed in sedimentary environs. Hematite forms masses that are a good example of this form.

Pisolitic

Rounded marble to pebble sized nodules in a compact mass formed in certain sedimentary environments. Nodules are larger than oolitic forms. Gibbsite forms masses that are a good example of the this form.

Radiating

Distinct crystals arranged in an orientation outward from a common point. Atacamite forms aggregates that are a good example of this form.

Rosette

Petal-like crystals arranged in a flattened radial habit around a central point. Barite roses are good examples of the rosette form.

Stalactitic

A concretionary growth sometimes around a hollow tube, producing long, slowly tapering, rounded masses. Cross-sections usually have circular rings like the rings of a tree. Usually formed in caves or other voids in rocks from the precipitation of a mineral from an evaporating fluid. Rhodochrosite and malachite form aggregates that are attractive examples of this form.

Sub-botryoidal

Similar to botryoidal, but with more crystalline components in the interlocking rounded masses. Adamite typically form aggregates that are a good example of this form.

Vugs

A void in a rock whose "shell" contains the same mineral as the host rock (see geode). A vug can be thought of as a hole created by dissolving the host rock whereas a geode is formed by precipitating a hollow nodule in the host rock. The cavity is sometimes filled with an assortment of minerals, often different than the host rock however. A variety of Quartz known as Herkimer Diamonds are found inside of limestone vugs.

7. Twinned Minerals: Twins can add a fascinating side to otherwise boring minerals or can add yet another dimension to an already complex mineral such as calcite. There are several minerals that form classic twins such as chalcocite, fluorite, sanidine, microcline, harmotome, staurolite, gypsum, cinnabar, spinel and rutile to name a few (more are listed below). Some twins have been given colloquial names such as the "fairy cross", "iron cross" and "cog wheel" twins.

Twins form as a result of an error during crystallization. Instead of a "normal" single crystal, twins will often appear doubled where two crystals appear to be growing out of or into each other, like Siamese twins. Some twins however are not even identifiable outwardly and some minerals in fact have been found to be just a twinned variety of another mineral. Accidental relationships are not considered twins, such as when two distinct crystals grow more or less randomly side-by-side or toward each other, etc. Also epitaxial overgrowths are also not twins. These occur when one mineral of similar structure, but different chemistry, grows onto and "continues" the earlier mineral's crystal. A twin's formation is never random and follows certain defined rules called twin laws. Many types of twin laws are given their own unique names and some are well known, such as the Spinel Law or the Albite Law.

The twin laws are crystallographic in nature and are caused by flaws in the crystal structure that occur during growth or during changes in phases such as from a high temperature phase to a low temperature phase. One example of how twins form is explained by looking at how crystals grow. Most crystals grow by adding layers of atoms, one layer at a time (in a simplistic model). If the first layer is called A and the next layer which is in a different position is called B and the next C followed by another A and so forth, then a structure will be built like so: ABCABCABCABC . . . Many minerals form with such a stacking sequence. But, if an error occurs during growth a twin can be formed. If the next layer of atoms becomes misplaced and assumes the wrong position, then the following sequence will form:

ABCABCABCACBACBACBA

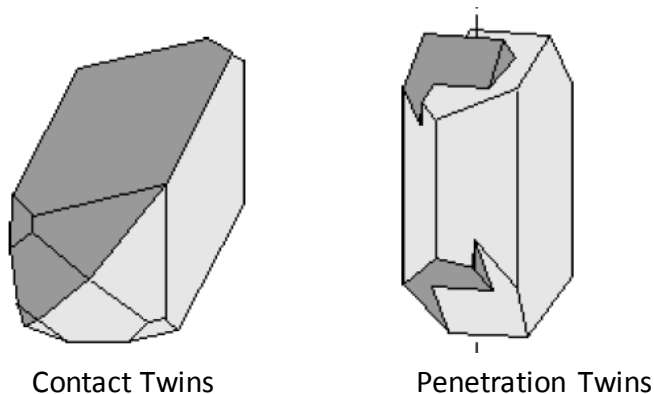
Can you see the flaw? The C layer next to the middle A layer is wrong because there should be a B layer next. The rest of the sequence is then repeated as if nothing happened and the crystal grows outward in both directions until finished growing. Directly through the middle A layer, a mirror plane is produced and the right side of the crystal will be a mirror image of the left side just as a left hand is the mirror image of the right hand. The mirror is easier to see if the A is replaced by a vertical line | which represents a mirror plane as in:

ABCABCABC | CBACBACBA

Not all twins are formed this way, but it gives a good idea of how a twin is possible. Twins are recognized by penetration angles or notches in the crystal, mirror planes that do not normally occur on a specific mineral and crystallographic techniques not normally available to the average collector. Twinning often has a dramatic effect on the outward symmetry of the mineral either by raising or lowering the symmetry. Twinning can make an orthorhombic mineral appear hexagonal or make a trigonal mineral appear monoclinic.

There are two general types of twin styles; contact and penetration. Contact twins have a composition plane (the twin plane) that forms at the boundary between the two twins. The composition plane is a mirror plane where the two twins can look like reflected images of each other (like a Siamese twin). The angle between the twins is critical and in some cases diagnostic. If the angle is 180 degrees then the crystals grow away from each other in opposite directions. If the angle is less than 180 degrees then the twin will have a noticeable bend. These twins form dove-tail, fish-tail and chevron shaped twins.

Many twins form penetration twins which look like two crystals that grew into and out of each other. These twins have portions of their respective twins protruding out of each other on different sides. At times it may look as if half the crystal was twisted in the wrong direction or that whoever made the crystal didn't know how it was supposed to fit together. The effect is really interesting on well formed twins. These twins can form crosses, 3-D star shapes and complex structures.



In some minerals, these two types can be repeated again and again; two, three or nearly an infinite number of times. There are two types of repeat twinning; cyclic and lamellar. Lamellar, which is also called polysynthetic twinning, forms from contact twins repeating continuously one twin after another, even on the microscopic level. Eventually a crystal composed of stacked twin layers is the result. The Feldspar Group minerals are the masters of this type of twinning which for the feldspars is known as the Albite Law.

If a composition twin has an angle of 30, 45, 60 or 90 degrees and it repeats 3, 4, 6 or so times . . . then it could form a complete circle or cyclic twin. Some classic twins form cyclic

twins called "trillings"; where the mineral is composed of three twin components. Other cyclic twins can have 4, 6 or even 8 components, but trillings are the most common.

Among the Elements:

Diamond (Spinel Law and penetration twins)

Among the Sulfides:

Arsenopyrite (cross-shaped twins)

Bourmonite ("Cog Wheel" twins)

Chalcocite (pseudo-hexagonal cyclic twins)

Chalcopyrite (penetration twins)

Cinnabar (penetration twins)

Dyscrasite (penetration twins)

Energite (star shaped cyclic twins)

Galena (Spinel Law twins)

Loellingite (penetration twins)

Marcasite (polysynthetic twinning and "Cockscomb" twins)

Pyrite ("Iron Cross" twins)

Sphalerite (complex; involving penetration and contact twinning)

Stibnite (bent angles on elongated crystals)

Tetrahedrite (penetration twins)

Wurtzite (fourling twins)

Among the Halides:

Boleite (pseudo-cubic twins)

Fluorite (classic penetration twins)

Among the Oxides:

Cassiterite (classic trillings)

Chrysoberyl (hexagonal trillings)

Rutile (classic eightlings and sixlings, "sagenite" lattice twinning and "elbow" twins)

The Spinel Group minerals (Spinel Law twins)

Among the Carbonates:

Aragonite (pseudo-hexagonal trillings)

Calcite (four different contact twins)

Cerussite (pseudo-hexagonal trillings and chevron twins; the very best reticulated twin structures)

Leadhillite (pseudo-hexagonal trillings and Artini Law twins)

Witherite (pseudo-hexagonal pyramidal trillings)

Among the Sulfates:

Gypsum (fishtail and dove-tail twins)
Spangolite ("hatchet" twins)

Among the Phosphates:

Amblygonite (flattened elongated twins)
Herderite (fishtail twins)
Monazite (penetration twins)

Among the Silicates:

Chabazite (simple and complex penetration twins)
Epididymite (six sided tabular trillings and fish-tail twins)
Eudidymite (tabular star shaped twins)

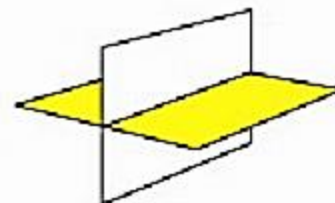
All of The Feldspar Group of Minerals especially:

Albite (Manebach, Carlsbad, Baveno and of course Albite Law lamellar twins)
Andesine (Manebach, Carlsbad and Albite Law lamellar twins)
Labradorite (Albite Law lamellar twins)
Microcline (Manebach, Carlsbad and Albite Law lamellar twins)
Oligoclase (Manebach, Carlsbad and Albite Law lamellar twins)
Orthoclase (Manebach, Carlsbad and Albite Law lamellar twins)
Sanidine (Manebach, Carlsbad and Albite Law lamellar twins)
Harmotome (Stempel, Perier and Marburg Law twins forming complex cross-like penetration twins)
Muscovite ("star" twins)
Neptunite (penetration twins)
Phenakite (penetration twins)
Phillipsite (Harmotome-like twins)
Quartz (Japan Law, Dauphine Law, Brazil Law and others)
Sphene/Titanite (contact twins)
Staurolite (cross-shaped twins gave it its name)
Tridymite (six rayed trillings)

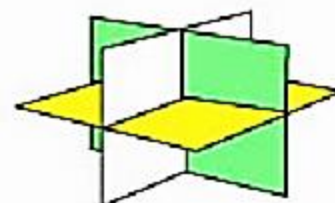
8. Cleavage: When a mineral breaks it does so either by fracturing or by cleaving. Crystal cleavage is a smooth break producing what appears to be a flat crystal face. Here are a few rules about cleavage. First cleavage is reproducible, meaning that a crystal can be broken along the same parallel plane over and over again. All cleavage must parallel a possible crystal face. This means that the crystal could have a crystal face parallel to its cleavage, but these faces are not always formed. All cleavage planes of a mineral must match that mineral's symmetry. And finally, the same mineral will always, always have the same cleavage.



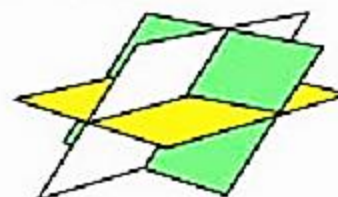
Cleavage in one direction. Example: MUSCOVITE



Cleavage in two directions. Example: FELDSPAR



Cleavage in three directions. Example: HALITE



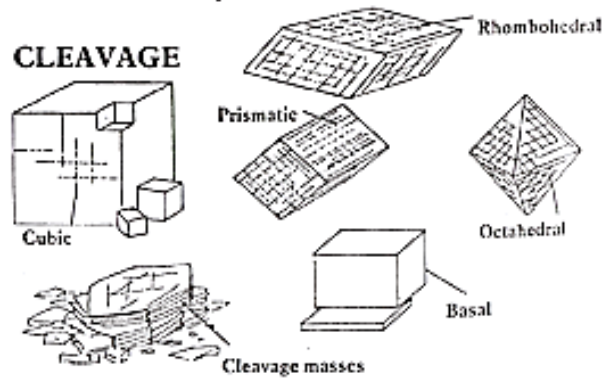
Cleavage in two directions. Example: CALCITE

The tendency for minerals to cleave or not and in which directions is very characteristic and therefore important to the identification of minerals. Cleavage is described in terms of how easy the cleavage is produced. From easiest to hardest to produce the terms are: perfect, imperfect, good, distinct, indistinct, and poor. Cleavage is said to be basal when it occurs perpendicular to the major axis of the mineral and prismatic when it occurs parallel to the major axis. Multiple cleavages that produce geometric polygons are referred to using the name of the geometric polygon, such as octahedral cleavage in the mineral fluorite, cubic cleavage in the mineral halite or rhombohedral cleavage in calcite (pictured). Cleavage occurs in minerals that have specific planes of weakness. These planes or directions are inherent in the structure of the mineral and form a variety of factors.

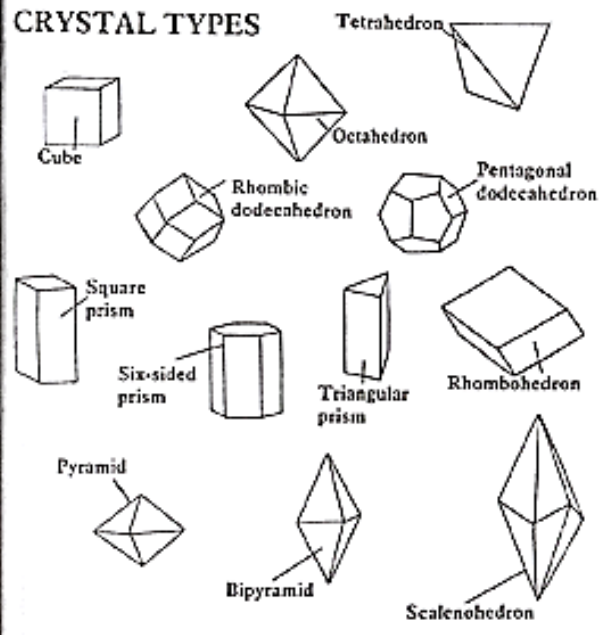
MINERAL HABIT



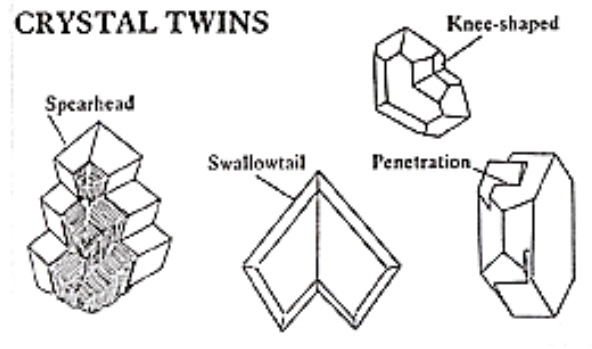
CLEAVAGE



CRYSTAL TYPES



CRYSTAL TWINS



Cleavage, being related to structure, is important at times in the correct identification of a mineral's symmetry. Remember, cleavage must obey the symmetry of the mineral and must be parallel to a possible crystal face. A mineral of the isometric symmetry class can either have no cleavage or at least three directions of identical cleavage that form a closed three dimensional polygon. A mineral of a uniaxial class (trigonal, tetragonal or hexagonal) will potentially have a cleavage perpendicular to the dominant axis and/or prismatic cleavage of either 3, 4 or 6 directions respectively, running parallel to the axis. Other cleavage directions are possible, but will always be controlled by the symmetry of the crystal. A biaxial mineral, those belonging to orthorhombic, monoclinic or triclinic classes, can not have more than two identical cleavage directions.

The angle between cleavages is also important to note and may be diagnostic. The pyroxene and amphibole groups of minerals are distinguished primarily by cleavage angle with the pyroxenes having a more acute angle. The angle may also help identify the type of cleavage. Three identical directions of cleavage in one mineral can only be either cubic cleavage, rhombic cleavage or prismatic (forming six sided prisms). If the angle between cleavage faces is 90 degrees, then the cleavage is cubic. If the angle is 60 degrees, then the cleavage

is prismatic. Also, if the angle is something else and there are three identical cleavages, then the cleavage is rhombic.

The phyllosilicates are a group of minerals whose structure is based upon stacked layers. A natural cleavage plane is produced between these layers. Other minerals may have cleavage planes that are more related to bond strength. Weak bonds that all lie in a plane will produce a cleavage direction.

To identify cleavage in a mineral remember that it is always parallel to a possible crystal face, it is reproducible over and over again and that it may be seen as internal reflection planes. Cleavage can be observed without the specimen being cleaved all the way through as pictured above. Minerals with perfect cleavage will sometimes have a stairstep look around a broken section. Twinning may break a mineral's cleavage at the twin plane and this should be kept in mind. Knowledge of a mineral's cleavage can be important in determining if a given specimen has been broken or not (a key characteristic in a mineral specimen's value). The related property of parting is thought by many to just be an example of poor cleavage. Many minerals lack any cleavage at all and will only show fractures.

9. Fracture: Fracture is a description of the way a mineral tends to break. It is different from cleavage and parting which are generally clean flat breaks along specific directions. Fracture occurs in all minerals even ones with cleavage, although a lot of cleavage directions can diminish the appearance of fracture surfaces. Different minerals will break in different ways and leave a surface that can be described in a recognizable way. Is the broken area smooth? Irregular? Jagged? Splintery? These are some of the ways of describing fracture.

Although many minerals break in similar ways, some have a unique fracture and this can be diagnostic.

The most common fracture type is conchoidal. This is a smoothly curved fracture that is familiar to people who have examined broken glass. Sometimes described as a clam-shell fracture. Quartz has this fracture type and almost all specimens that have been broken, demonstrate this fracture type very well.

Another common type is subconchoidal. Similar to conchoidal, just not as curved, but still smooth. Andalusite can show this type.

Uneven is a type that is basically self explanatory. It is a common type that is found in anhydrite.

Unlike uneven, jagged has sharp points or edges that catch on a finger that's rubbed across the surface. Usually this indicates a metal such as copper, a metal alloy or some sulfides or oxides.

Splintery is a fracture type that occurs in fibrous or finely acicular minerals and in minerals that have a relatively stronger structure in one direction than the other two. Chrysotile serpentine is a typical mineral with splintery fracture and kyanite is an example of a non-fibrous mineral that has this fracture.

Earthy is a fracture that produces a texture similar to broken children's clay. It is found in minerals that are generally massive and loosely consolidated such as limonite.

10. Hardness: In terms of reliability, hardness is one of the better physical properties for minerals. Specimens of the same mineral may vary slightly from one to another, but generally they are quite consistent. Inconsistencies occur when the specimen is impure, poorly crystallized, or actually an aggregate and not an individual crystal.

Hardness is one measure of the strength of the structure of the mineral relative to the strength of its chemical bonds. It is not the same as brittleness, which is another measure of strength, that is purely related to the structure of the mineral. Minerals with small atoms, packed tightly together with strong covalent bonds throughout tend to be the hardest minerals. The softest minerals have metallic bonds or even weaker van der Waals bonds as important components of their structure. Hardness is generally consistent because the chemistry of minerals is generally consistent.

Hardness can be tested through scratching. A scratch on a mineral is actually a groove produced by microfractures on the surface of the mineral. It requires either the breaking of bonds or the displacement of atoms (as in the metallic bonded minerals). A mineral can only be scratched by a harder substance. A hard mineral can scratch a softer mineral, but a soft mineral can not scratch a harder mineral (no matter how hard you try). Therefore, a relative scale can be established to account for the differences in hardness simply by seeing which mineral scratches another. That is exactly what French mineralogist Friedrich Mohs proposed almost one hundred and seventy years ago. The Mohs Hardness Scale starting with talc at 1 and ending with diamond at 10, is universally used around the world as a way of distinguishing minerals. Simply put; the higher the number, the harder the mineral.

Below is the Mohs Hardness Scale:

In order to use this scale, it is necessary to have on hand some of the minerals in the scale. If you wish to test an unknown mineral for hardness you might want to start with an ordinary specimen of apatite to see if the unknown mineral can scratch it. If the unknown mineral

scratches the apatite, then you can conclude that it has a hardness of 5 or more. If the apatite can scratch the unknown mineral, then the unknown mineral has a hardness of 5 or less. If they can scratch each other, then the unknown mineral has a hardness of 5. You will need to perform other tests to narrow down the hardness. If it is softer than apatite, try calcite, etc., etc until you have narrowed down the approximate hardness. Remember, this is a relative scale and a mineral that can scratch a mineral that has a hardness of 4.5 may be given a hardness of 5, but it still might be softer than apatite.

One word of caution for inexperienced collectors: do not SCRATCH NICE CRYSTAL FACES! A fractured, cleaved or inconspicuous part of the mineral should still give a good hardness test and not damage a potentially wonderful specimen.

What if you do not have the minerals listed in the Mohs Hardness Scale? Well, a collector might keep a few items of known hardness in a "hardness kit"; just in case they are needed.

Below is a revised Mohs Hardness Scale with some everyday items listed:

Talc

Gypsum

--fingernail at 2.5

Calcite

--copper (old penny) at 3.5

Fluorite

Apatite

--window glass or typical knife blade at under 5.5

Orthoclase

--streak plate or good steel file at over 6.5

Quartz

Topaz

Corundum

Diamond

Again, the Mohs Hardness Scale is only relative. Meaning that fluorite at 4 is not twice as hard as gypsum at 2; nor is the difference between calcite and fluorite similar to the difference between corundum and diamond. An absolute hardness scale looks a little different than the relative scale. Using sensitive equipment, a comparison of the absolute hardness of minerals can be measured. It turns out that most minerals are close in hardness. But as hardness increases, the difference in hardness greatly increases as seen in the scale below.

Below is an absolute hardness scale:

- 1 Talc
- 3 Gypsum
- 9 Calcite
- 21 Fluorite
- 48 Apatite
- 72 Orthoclase
- 100 Quartz
- 200 Topaz
- 400 Corundum
- 1600 Diamond

The simpler, relative Mohs hardness scale is much easier to remember and use. It is easy to see why diamond gets so much respect as the hardest natural substance known to man. The next hardest mineral, corundum, is four times softer! There are many substances that are currently being created and studied to beat diamond in hardness. But diamonds' all carbon, extremely dense, structurally sound and tightly bonded structure is hard to beat. At present only diamonds created with isotopes of carbon have exceeded the mark of 10 on the hardness scale.

Hardness is particularly important for gemstones. Very few soft minerals are cut as gems and when they are, they generally are cut only for collectors and not for wearable jewelry. Apatite is one of the softest of gemstones. Mostly gemstones have a hardness of 7 or more. Hardness also plays a major part in the minerals that are used for grinding, polishing and other abrasive purposes. Soft minerals can be used as high temperature lubricants, pencil lead, talcum powder, paper gloss, etc.

Here are a few hints on how to use hardness to identify minerals:

Keep in mind that most minerals have small differences in hardness according to the direction of the scratch and the orientation of the scratch and that some minerals such as kyanite and diamond, have a marked difference in hardness with respect to these factors. A massive specimen will probably be softer than a single crystal and ideally hardness should only be used on individual crystals.

Some minerals will have a range of hardness due mostly to impurities or substitution of certain ions.

Don't be fooled by a dust trail on a mineral after being "scratched" by a softer mineral. It may look as if the softer mineral scratched the harder mineral but in actuality the softer mineral just left a dust trail across the resistant surface of the harder mineral (always blow air over the scratch or rub across the scratch to be sure it's a scratch).

Another clue to relative hardness is ease of scratching (both diamond and quartz scratch glass, but diamond scratches glass ". . . like a knife through butter").

Final Tip to remember the Mohs scale try remembering this phrase:

The Geologist Can Find An Ordinary Quartz, (that) Tourists Call Diamond!

11. Specific Gravity: It is a measure of the density of a mineral. At times it is such a useful property that it is the only way to distinguish some minerals without laboratory or optical techniques. Gold can easily be distinguished from "fool's gold" by specific gravity alone, although there are many other ways. Specific gravity is a unit less measure, because it is derived from the density of the mineral divided by the density of water and thus all units cancel. However, since water's density equals 1 gram per cubic centimeter (at specific conditions), then a mineral's specific gravity would also correspond to a mineral's density as expressed in grams per cubic centimeter.

Specific gravity, or SG, as already stated compares the density of a mineral to the density of water. If a mineral has a SG of 2, then it is twice as dense as water. If a mineral has a SG of 3 then it is three times as dense as water and so forth. However, comparing a mineral to water is not practical and is not really helpful. It is easier to consider what is the SG of a typical mineral and compare minerals that way.

The Earth's crust, where we are most likely to collect minerals from, is composed mostly of the minerals quartz, calcite and feldspar. These minerals have SG's around 2.75 and that is close to the average SG of the rocks on the outer surface of the Earth's crust. Therefore, the SG of most rocks that people would pick up and be familiar with, will have a specific gravity of approximately 2.75. To use specific gravity, hold a mineral of unknown SG in one hand and in the other hand a mineral of known SG preferably one near the average of 2.75 and of the same size as the unknown mineral; then compare. How does the unknown mineral compare? By convention, comparisons of SG are split between luster categories: non-metallic and metallic. Non-metallic minerals tend to be of a low density and we naturally expect them to be so. So, when one is surprisingly heavy, it becomes very diagnostic.

The following unscientific scale is used for specific gravity comparisons with average crustal non-metallic minerals (such as quartz, calcite and feldspar).

- 1 -- 2 very light
- 2 -- 2.5 light
- 2.5 -- 3 average
- 3 -- 3.5 slightly above average
- 3.5 -- 4 above average
- 4 -- 5 heavy
- 5 -- 7 very heavy
- 7 -- 10 extremely heavy
- 10+ beyond being extremely heavy

Metallic minerals, which are usually composed of heavy elements such as iron, lead or silver, have a higher SG than their translucent cousins. Therefore it is helpful to have a scale comparing metallic minerals with an average specific gravity of around 4.5. The following scale is intended as a comparison of only metallic minerals.

- 1 -- 3 very light
- 3 -- 4 light
- 4 -- 5 average
- 5 -- 6 slightly above average
- 6 -- 7 above average
- 7 -- 10 heavy
- 10 -- 20 very heavy even for metallic minerals
- 20+ must be platinum

In some minerals a solid solution series exists in which substitution of one element occurs with another element in the chemistry of the mineral. Such a situation is found in the mineral olivine, $(\text{Mg, Fe})_2\text{SiO}_4$. When near pure Mg_2SiO_4 , olivine has a SG of approximately 3.3 and when near pure Fe_2SiO_4 , olivine has a SG of approximately 4.2. Most olivine is a mixture and the percentage of iron can be determined with some certainty by using the SG.

Specific gravity can be measured accurately by use of sensitive laboratory equipment. For the average person a good estimate of SG can be obtained by use of a rigged balance system. If the mineral can be weighed first dry, D , and then weighed, W , while immersed in a liquid, usually water, then the SG can be obtained by the following formula:

$$\text{SG} = \frac{D}{(D-W)L}$$

where L is the density of the liquid,

if water is used, $L=1$, so that the formula is simply $\frac{D}{(D-W)}$.

The mineral being tested must be homogenous and not contain other minerals. It is best to test single small crystals that are not attached to a host rock.

12. Streak: Streak is closely related to color, but is a different property because the color of the mineral may be different than the color of the streak. Streak is actually the color of the powder of a mineral. It is called streak because the proper way to test for streak is to rub a mineral across a tile of white unglazed porcelain and to examine the color of the "streak" left behind. It has proven to be a powerful property because it is generally very consistent from specimen to specimen for a given mineral.

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. Hematite

is probably the most well-known example of streak with its completely surprising streak color.

Unfortunately, translucent minerals have, usually, a rather undiagnostic white streak. Many opaque minerals similarly have a rather unhelpful black streak. However, there are about 20% of minerals that have unique shades of red, orange, yellow, blue, green, gray and even purple streaks and in many cases these streaks are very diagnostic.

There are many reasons why a mineral might have a different streak color than its outward color. First, there are translucent minerals that are colored by trace elements. These minerals require a large amount of travel time for light to pick up the coloring effects of these trace elements. As a result, small crystals are typically paler than large crystals and extrapolating down to a speck of powder will remove all coloring effects of a trace element and result in a white streak. A translucent mineral that has variable colors will almost certainly have a white streak.

Secondly, a mineral's structure and/or coatings can affect the outward color of a mineral and the streak in many ways is the true color of the mineral. 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. It is the structure and chemistry of pyrite that produces the brassy yellow color, but only when enough structure is there. Gold's streak by the way is yellow! One note of caution, a streak plate is only about 6.5 in hardness and a mineral harder than 6.5 will not leave a streak on a streak plate but might scratch the plate leaving a white powder of porcelain, not the mineral! Fortunately most minerals harder than 6.5 have a white streak.

13. Mineral Associations: Minerals will often form in specific environments and be associated with specific minerals. Sometimes a mineral is only associated with a certain suite of minerals. Identification of these associated minerals can help in the identification of an unknown mineral. For instance, the phyllosilicate mineral apophyllite is typically associated with Zeolite Group minerals. It becomes diagnostic to find zeolites with a mineral that is suspected of being apophyllite and vice versa.

Not all possible associations can be mentioned for most minerals. But, in some cases a mineral may only be found with a few key minerals. Benitoite is one such example. It is found associated with only natrolite, neptunite and serpentine and a few other very rare minerals. In these cases, the associations can be one of the most important characteristics. Keep in mind that in most mineral descriptions only important or common associations are listed and the fact that a mineral is found in association with a mineral that was not mentioned should not be considered an error and don't discount the possible identity of the

unknown mineral based on this alone. Remember these are only an aid to identification and not the only possible associations.

Mineral associations can be quite fun for the collector. In addition to a collection containing all the possible forms, colors, varieties, etc. of a mineral, it could also contain all the possible associations! Some mineral associations are quite interesting, beautiful and full of character. Often mineral collectors strive for certain classic mineral combinations. At times the attractiveness of an association is in its contrasting or complementary colors and at others it is just the unique character difference in the crystal forms and habits such as a dendritic gold specimen emerging from a marble-like quartz base. And hey! You often get more for your money when you can get two, three or four minerals in one specimen!

14. Notable localities: There exists, in certain places around the world, areas that for one reason or another produce the most amazing assortment of minerals. These sites are well known to mineral collectors everywhere. The ones mentioned here are just some of those fabulous localities.

These sites are special for a number of reasons. They may be the type locality for a number of rare minerals. A 'type locality' is a site where the first specimens of a mineral were discovered and identified as a new mineral species. The sites mentioned here are type localities for several hundred mineral species. They also could each be a place where literally hundreds of different mineral species are found. Such a site is very scarce since most mineral sites rarely have a dozen different minerals. They also may be a site that produces the very best crystals or unique crystals, such as twins or exquisite gemstones. And finally, these sites may have just produced specimens at such amazing quantities that they are to be commended just for providing the average collector with an opportunity to possess such lovely collection pieces at affordable prices.

They are not, however, just mines that produce thousands of tons of ore. While these sites may be special to miners and of economic significance, they are not so special to mineral collectors unless they have produced numerous, new, special, rare and/or well crystallized mineral specimens. They are also not "one mineral" wonders. Such sites may have made a name for themselves with spectacular and numerous specimens of one mineral or another, such as Mt. Ida, Arkansas' wonderful examples of quartz clusters or Dundas, Tasmania's colorful and exotic crocoite specimens, but these sites lack the diversity of species that is required to make this list. The following list is large enough as it is.

There are hundreds of wonderful mineral locations that deserve adulation and all cannot be mentioned. Nor is there any attempt to signify an order of importance. Both active and inactive sites are listed because even inactive sites may still have specimens on the mineral

market and these sites are not forgotten so easily. Links to some of the sites give more detailed information and at least a partial list of the significant minerals that have been found there. If a site is not mentioned and you feel it deserves mentioning, please fill out a feedback form with the information of the site and why it should be included.

The locality from where a mineral is found is not so much a physical property as it is a condition of the environment of formation for a particular mineral. However, this can be an important asset in correctly identifying a mineral. Especially if the site is known to produce a very unique mineral. It is very important to keep accurate records for all specimens even if identification is considered conclusive and always try and obtain the exact locality from dealers when you purchase specimens.

COMPOSITION OF CRUST AND DOMINANT MINERALS

Over 7000 minerals or more used each day. Fortunately, we don't need to be concerned with most of these (about 20-30 will do). These geologically important minerals are primarily silicate minerals. The dominance of silicate minerals can be understood if we examine the composition of the bulk earth and of the continental crust.

Oxide	Percent
SiO ₂	60.6
Al ₂ O ₃	15.9
CaO	6.4
MgO	4.7
Na ₂ O	3.1
Fe as FeO	6.7
K ₂ O	1.8
TiO ₂	0.7
P ₂ O ₅	0.1

Minerals may be classified according to chemical composition. They are here categorized by anion group. The list below is in approximate order of their abundance in the Earth's crust.

The list follows the Dana classification system which closely parallels the Nickel-Strunz¹ classification.

1. Silicates' (compounds contain SO₄⁴⁻)
2. Carbonates' (compounds contain CO₃²⁻)
3. Sulfates' (compounds contain SO₄²⁻)
4. Halides' (compounds contain F⁻, Cl⁻, Br⁻, I⁻, etc.)
5. Oxides' (compounds contain O²⁻)
6. Sulfides' (compounds contain S²⁻)
7. Phosphates' (compounds contain PO₄³⁻)
8. Native minerals (compound that occur in un-combined state like Fe, Pb, Ag, etc.)

1- Nickel-Strunz classification is a scheme for categorizing minerals based upon their chemical composition, introduced by German mineralogist Karl Hugo Strunz in his 1941 *Mineralogische Tabellen*.

Silicates

It is the largest group of minerals (most rocks are $\geq 95\%$ silicates). Silicates are composed largely of silicon and oxygen, with the addition of ions such as aluminium, magnesium, iron, and calcium. Some important rock-forming silicates include the feldspars, quartz, olivines, pyroxenes, amphiboles, garnets, and micas.

Element	Wt%	Atomic%	Volume%
O	46.60	62.55	~94
Si	27.72	21.22	~6
Al	8.13	6.47	
Fe	5.00	1.92	
Ca	3.63	1.94	
Na	2.83	2.34	
K	2.59	1.42	
Mg	2.09	1.84	
Total	98.59	100.00	100

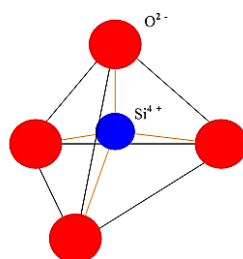
In order to discuss the silicates and their structures it is first necessary to remember that the way atoms are packed together or coordinated by larger anions, like oxygen depends on the radius ratio of the cation to the anion, R_x/R_z .

R_x/R_z	C.N.	Type
1.0	12	Hexagonal or Cubic Closest Packing
1.0 - 0.732	8	Cubic
0.732 - 0.414	6	Octahedral
0.414 - 0.225	4	Tetrahedral
0.225 - 0.155	3	Triangular
<0.155	2	Linear

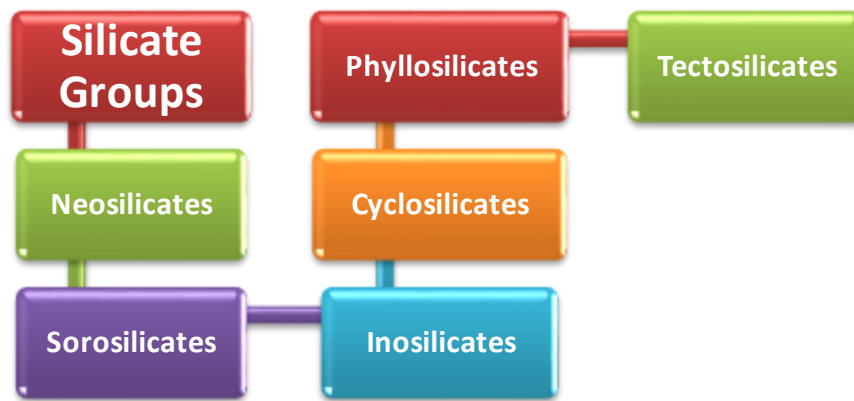
C.N - Coordination Number

The tetrahedron SiO_4 structure of silicate minerals is the secret of silicates occurring in many forms.

Structure of Silicate Block (SiO_4^{4-})



Silicate Types:



Nesosilicates or orthosilicates or Islandsilicates:

Nesosilicates, have isolated $[\text{SiO}_4]^{4-}$ tetrahedra that are connected only by interstitial cations. If the corner oxygens are not shared with other SiO_4^{4-} tetrahedrons, each tetrahedron will be isolated. Thus, this group is often referred to as the island silicate group. In this group the oxygen's are shared with octahedral groups that contain other cations like Mg^{+2} , Fe^{+2} , or Ca^{+2} . Nickel-Strunz classification: 0.9A Olivine is a good example: $(\text{Mg,Fe})_2\text{SiO}_4$.



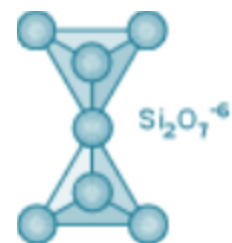
Widely occurring neosilicates can be sub grouped as

- Phenakite group
- Olivine group
- Garnet group
- Zircon group
- Al_2SiO_5 group
- Humite group

Sorosilicates:

Sorosilicates have isolated double tetrahedra groups with $(\text{Si}_2\text{O}_7)^{6-}$ or a ratio of 2:7.

If one of the corner oxygens is shared with another tetrahedron, this gives rise to the sorosilicate group. It is often referred to as the double island group because there are two linked tetrahedrons isolated from all other tetrahedrons. In this case, the basic structural unit is $\text{Si}_2\text{O}_7^{6-}$.

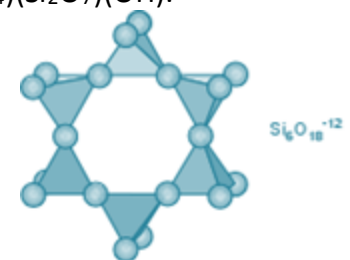


Nickel-Strunz classification: 09.B

A good example of a sorosilicate is the mineral hemimorphite - $\text{Zn}_4\text{Si}_2\text{O}_7(\text{OH})\cdot\text{H}_2\text{O}$. Some sorosilicates are a combination of single and double islands, like in epidote (has both $(\text{SiO}_4)^{4-}$ and $(\text{Si}_2\text{O}_7)^{6-}$ groups) - $\text{Ca}_2(\text{Fe}^{+3},\text{Al})\text{Al}_2(\text{SiO}_4)(\text{Si}_2\text{O}_7)(\text{OH})$.

Cyclosilicates:

Cyclosilicates, or ring silicates, have linked tetrahedra with $(\text{Si}_x\text{O}_{3x})^{2x-}$ or a ratio of 1:3. These exist as 3-member $(\text{Si}_3\text{O}_9)^{6-}$, 4-member $(\text{Si}_4\text{O}_{12})^{8-}$ and 6-member $(\text{Si}_6\text{O}_{18})^{12-}$ rings. If two of the oxygens are shared and the structure is arranged in a ring, such as that shown here (a six membered ring forming the structural group $\text{Si}_6\text{O}_{18}^{12-}$), we



get the basic structural unit of the cyclosilicates or ring silicates. Three membered rings, $\text{Si}_3\text{O}_9^{-6}$, four membered rings, $\text{Si}_4\text{O}_{12}^{-8}$, and five membered rings $\text{Si}_5\text{O}_{15}^{-10}$ are also possible. Nickel-Strunz classification: 09.C

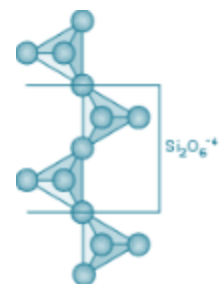
A good example of a cyclosilicate is the mineral Beryl - $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$, the other Tourmaline - $(\text{Na,Ca})(\text{Al,Li,Mg})_3(\text{Al,Fe,Mn})_6(\text{Si}_6\text{O}_{18})(\text{BO}_3)_3(\text{OH})_4$

Inosilicates:

Inosilicates, or chain silicates, have interlocking chains of silicate tetrahedra with either SiO_3 , 1:3 ratio, for single chains or Si_4O_{11} , 4:11 ratio, for double chains. Nickel-Strunz classification: 09.D

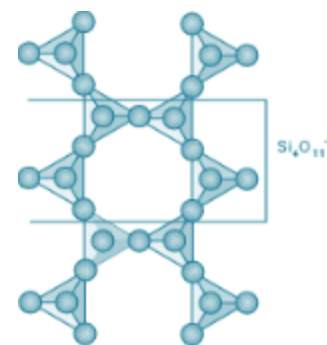
Inosilicates (Single Chain):

If two of the oxygens are shared in a way to make long single chains of linked SiO_4 tetrahedra, we get the single chain silicates or inosilicates. In this case the basic structural unit is $\text{Si}_2\text{O}_6^{-4}$ or SiO_3^{-2} . This group is the basis for the pyroxene group of minerals, like the orthopyroxenes $(\text{Mg,Fe})\text{SiO}_3$ or the clinopyroxenes $\text{Ca}(\text{Mg,Fe})\text{Si}_2\text{O}_6$.



Inosilicates (Double Chain):

If two chains are linked together so that each tetrahedral group shares 3 of its oxygens, we can form double chains, with the basic structural group being $\text{Si}_4\text{O}_{11}^{-6}$. The amphibole group of minerals are double chain silicates, for example the tremolite - ferroactinolite series - $\text{Ca}_2(\text{Mg,Fe})_5\text{Si}_8\text{O}_{22}(\text{OH})_2$.



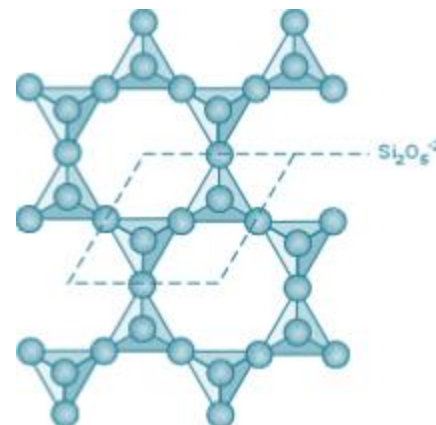
Phyllosilicates:

Phyllosilicates or sheet silicates, form parallel sheets of silicate tetrahedra with Si_2O_5 or a 2:5 ratio.

If 3 of the oxygens from each tetrahedral group are shared such that an infinite sheet of SiO_4 tetrahedra are shared we get the basis for the phyllosilicates or sheet silicates. In this case the basic structural group is $\text{Si}_2\text{O}_5^{-2}$. The micas, clay minerals, chlorite, talc, and serpentine minerals are all based on this structure.

Nickel-Strunz classification: 0.9E

A good example is biotite - $\text{K}(\text{Mg,Fe})_3(\text{AlSi}_3)\text{O}_{10}(\text{OH})_2$.



Tectosilicates:

Tectosilicates, or "framework silicates," have a three-dimensional framework of silicate tetrahedra with SiO_2 or a 1:2 ratio. This group comprises nearly 75% of the crust of the Earth. Tectosilicates, with the exception of the quartz group, are aluminosilicates.

If all of the corner oxygens are shared with another SiO_4 tetrahedron, then a 3D framework structure develops. The basic structural group then becomes SiO_2 . The minerals quartz, cristobalite, and tridymite all are based on this structure. If some of the Si^{+4} ions are replaced by Al^{+3} then this produces a charge imbalance and allows for other ions to be found coordinated in different arrangements within the framework structure.



Nickel-Strunz classification: 09.F without H_2O , 09.G with H_2O (Zeolites, Quartz-Aluminium Group).

Carbonates:

The carbonate minerals consist of those minerals containing the anion $(\text{CO}_3)^{2-}$. They are calcite and aragonite (both calcium carbonate), dolomite (magnesium/calcium carbonate) and siderite (iron carbonate). Carbonates are also found in evaporitic settings (e.g. the Great Salt Lake, Utah) and also in karst regions, where the dissolution and re-precipitation of carbonates leads to the formation of caves, stalactites and stalagmites.

Carbonate minerals make up the bulk of limestones and dolostones. Are found as cementing agents in clastic sedimentary rocks, and make up the shells of many organisms. The carbonates are based on the CO_3^{2-} structural unit, which has carbon surrounded by 3 oxygens in triangular coordination. Thus each Oxygen has a residual charge of $-2/3$. In the carbonate structure, no two triangles share the corner oxygens and the C-O bonds are highly covalent.

There are three structural types of carbonates:

Calcite Group	Aragonite Group	Dolomite Group
Calcite CaCO_3	Aragonite CaCO_3	Dolomite $\text{CaMg}(\text{CO}_3)_2$
Magnesite MgCO_3	Witherite BaCO_3	Ankerite $\text{CaFe}(\text{CO}_3)_2$
Siderite FeCO_3	Strontianite SrCO_3	
Rhodochrosite MnCO_3	Cerussite PbCO_3	
Smithsonite ZnCO_3		

In addition, there are the hydroxyl Cu carbonates - Malachite, $\text{Cu}_2\text{CO}_3(\text{OH})_2$ and Azurite $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$.

The Calcite Group:

The calcite group minerals are all hexagonal. They have Ca, Mg, Fe, Mn, or Zn divalent cations in 6-fold coordination with the CO_3^{2-} groups, in a structure that is similar to that of NaCl. All members of this group show rhombohedral cleavage, thus breaking into rhomb-shaped cleavage blocks.

Calcite CaCO_3 : The most common carbonate mineral is calcite. It is the principal constituent of limestone and its metamorphic equivalent - marble. Deposits of fine grained calcite in

powder form are referred to as chalk. It forms the cementing agent in many types of sandstone, and is one of the more common minerals precipitated by living organisms to form their skeletal structures.

Calcite is also precipitated from groundwater where it forms veins, or in open cavities like caves and caverns can form the cave decorations - like stalactites and stalagmites, and encrustations. It is also precipitated from hot springs where it is called travertine. Calcite does occur in rare igneous rocks called carbonatites. These form from carbonate magmas. Calcite is also precipitated from hydrothermal fluids to form veins associated with sulfide bearing ores.

Properties

In hand specimen, calcite is distinguished by its rhombohedral cleavage, its hardness of 3, and by its effervescence in dilute HCl. It can range in color from white, to slightly pink, to clear, but dark colored crystals can also occur. In thin section it is most readily distinguished by its high birefringence, showing high order white interference colors, by its rhombohedral cleavage and its uniaxial negative character. Because of its high birefringence, it shows a large change in relief on rotation of the stage. Furthermore, its refractive index direction (low RI direction) when parallel to the polarizer shows a negative relief when compared to the mounting medium of the thin section. Calcite can be distinguished from Aragonite by the lack of rhombohedral cleavage and biaxial nature of Aragonite.

Magnesite $MgCO_3$:

Magnesite is a common alteration product of Mg-rich minerals on altered igneous and metamorphic rocks. Like calcite, it shows perfect rhombohedral cleavage, but unlike calcite, it does not readily effervesce in dilute HCl. It does, however, effervesce in hot HCl. These properties and its association with Mg-rich minerals and rocks make it distinguishable from Calcite.

Siderite $FeCO_3$:

Siderite forms complete solid solution series with Magnesite, although the environment in which the two minerals occur usually determines that either Mg-rich Magnesite or Fe-rich Siderite will form, and one rarely sees intermediate end members. In hand specimen, siderite is usually brown colored and effervesces only in hot HCl. In thin section it resembles Calcite, but has a much higher refractive index than Calcite and is commonly pale yellow to yellow brown in color without the analyzer inserted.

Rhodochrosite $MnCO_3$:

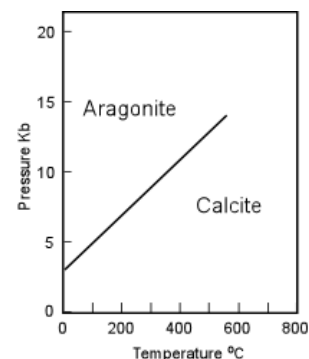
Rhodochrosite is the Mn bearing carbonate, and is thus found only in environments where there is an abundance of Manganese. It is relatively rare and occurs as hydrothermal veins¹ and as an alteration product of Mn rich deposits. In hand specimen it shows a distinctive pink color along with the rhombohedral cleavage common to the Calcite group minerals. Hot HCl is required to make the mineral effervesce.

1- Hydrothermal Veins: Distinct sheet like body of crystallised minerals with in a rock.

The Aragonite Group

The Aragonite group of minerals are all orthorhombic, and can thus be distinguished from minerals of the calcite group by their lack of rhombohedral cleavage. Aragonite (CaCO_3) is the most common mineral in this group.

Aragonite is the higher pressure form of CaCO_3 but, nevertheless occurs and forms at surface temperatures and pressures. When found in metamorphic rocks it is a good indicator of the low temperature, high pressure conditions of metamorphism, and is thus commonly found in Blueschist Facies metamorphic rocks along with Glaucophane. Water containing high concentrations of Ca and carbonate can precipitate Aragonite. Warm water favors Aragonite, while cold water favors calcite, thus Aragonite is commonly found as a deposit of hot springs. Aragonite can also form by biological precipitation, and the pearly shells of many organisms are composed of Aragonite. Fine needle-like crystals of Aragonite are produced by carbonate secreting algae.



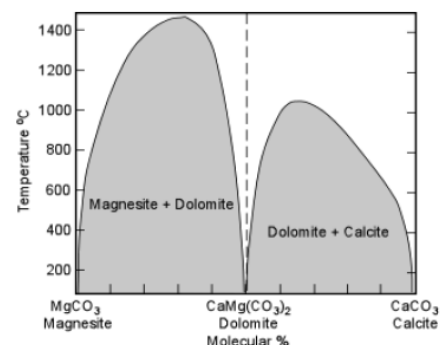
Properties

In hand specimen, Aragonite, like calcite effervesces in cold HCl. But, unlike Calcite, Aragonite does not show a rhombohedral cleavage. Instead it has single good cleavage. It is usually transparent to white in color and forms in long bladed crystals. Twinning is common and this can produce both cyclical twins, which, when present, make it look pseudo-hexagonal, and single twins. In thin section Aragonite is distinguished by its high birefringence, showing high order white interference colors, its biaxial character with a $2V$ of about 18° , and extinction parallel to the cleavage.

The Dolomite Group

Dolomite - $\text{CaMg}(\text{CO}_3)_2$ and Ankerite - $\text{CaFe}(\text{CO}_3)_2$ form a complete solid solution series, although because Mg-rich environments are much more common than Fe-rich environments, Mg-rich dolomites are much more common than Ankerites. Ankerite is common mineral in Pre-Cambrian iron formations. Dolomite is a common constituent of older limestones, probably the result of secondary replacement of original calcite. It is also found as dolomitic marbles, and in hydrothermal veins.

Dolomite is a unique chemical composition, as can be seen in the Magnesite - Calcite phase diagram shown here. Two solvi exist at low temperatures. Thus, any high Mg-calcite - dolomite solid solutions that might exist at high temperatures would form nearly pure calcite and pure dolomite at surface temperatures, and similarly, any Magnesite - Dolomite solid solutions that might exist at high temperatures would form nearly pure Magnesite and pure Dolomite at low temperatures. Thus, Magnesite and Dolomite commonly occur together, as do Calcite and Dolomite.



Properties

Dolomite, and therefore rocks containing large amounts of dolomite, like dolostones, is easily distinguished by the fact that dolomite only fizzes¹ in cold dilute HCl if broken down to a fine powder. Also, dolostones tend to weather to a brownish color rock, whereas limestones tend to weather to a white or gray colored rock. The brown color of dolostones is due to the fact that Fe occurs in small amounts replacing some of the Mg in dolomite.

Apatite $\text{Ca}_5(\text{PO}_4)_3(\text{OH},\text{F})$

Apatite is another very common and almost ubiquitous (always present) accessory mineral in igneous rocks and many metamorphic rocks. If the rock contains any phosphorous it is usually found in apatite. Apatite is hexagonal, hence uniaxial with a negative optic sign. Its refractive indices $\omega = 1.624$ to 1.666 and $\epsilon = 1.629$ to 1.667 are higher than both quartz and nepheline, giving apatite a higher relief than these minerals. Its birefringence, expressed as 1° gray interference colors is similar to that of quartz and nepheline. Quartz, however, is optically positive. Nepheline, while optically negative, shows much lower relief than does apatite. The crystal form of apatite is usually distinctive. If cut parallel, it usually has a hexagonal outline. If cut parallel to the C axis, it appears as doubly terminated prisms.

1 – CO₂ gas effervescences in solution as Aerated water (Soda Water))

Sulfates:

Sulfate minerals all contain the sulfate anion, SO_4^{2-} . Sulfates commonly form in evaporitic settings where highly saline waters slowly evaporate, allowing the formation of both sulfates and halides at the water-sediment interface. Sulfates also occur in hydrothermal vein systems as gangue minerals along with sulfide ore minerals. Another occurrence is as secondary oxidation products of original sulfide minerals. Common sulfates include anhydrite (calcium sulfate), celestine (strontium sulfate), barite (barium sulfate), and gypsum (hydrated calcium sulfate).

Halides:

The halide minerals are the group of minerals forming the natural salts and include fluorite (calcium fluoride), halite (sodium chloride), and sal ammoniac (ammonium chloride). Halides, like sulfates, are commonly found in evaporite settings such as salt lakes and landlocked seas such as the Dead Sea and Great Salt Lake. The halide class includes the fluoride, chloride, bromide and iodide minerals.

Oxides

They commonly occur as precipitates close to the Earth's surface, oxidation products of other minerals in the near surface weathering zone, and as accessory minerals in igneous rocks of the crust and mantle. Common oxides include hematite (iron oxide), magnetite (iron oxide), chromite (iron chromium oxide), spinel (magnesium aluminium oxide – a common component of the mantle), ilmenite (iron titanium oxide), rutile (titanium dioxide), and ice (hydrogen oxide). The oxide class includes the oxide and the hydroxide minerals.

Sulfides:

Many sulfide minerals are economically important as metal ores. Common sulphides include pyrite (iron sulfide – commonly known as fools' gold), chalcopyrite (copper iron sulfide), pentlandite (nickel iron sulfide), and galena (lead sulfide). The sulfide class also includes the selenides, the tellurides, the arsenides, the antimonides, the bismuthinides, and the sulfosalts (sulfur and a second anion such as arsenic).

Phosphates

The phosphate mineral group actually includes any mineral with a tetrahedral unit AO_4 where A can be phosphorus, antimony, arsenic or vanadium. By far the most common phosphate is apatite which is an important biological mineral found in teeth and bones of many animals. The phosphate class includes the phosphate, arsenate, vanadate, and antimonate minerals.

Native minerals

The elemental group includes native metals and inter-metallic elements (gold, silver, copper), semi-metals and non-metals (antimony, bismuth, graphite, sulfur). This group also includes natural alloys, such as electrum (a natural alloy of gold and silver), phosphides, silicides, nitrides and carbides (which are usually only found naturally in a few rare meteorites).

FELDSPARS GROUP:

Feldspars ($KAlSi_3O_8$ – $NaAlSi_3O_8$ – $CaAl_2Si_2O_8$) are a group of rock forming tecto-silicate minerals which make up as much as 60% of the Earth's crust. Feldspar is derived from the German Feld, "field", and Spath, "a rock that does not contain ore".

"Feldspathic" refers to materials that contain feldspar.

Feldspars crystallize from magma in both intrusive and extrusive igneous rocks, as veins, and are also present in many types of metamorphic rock. Rock formed almost entirely of calcic plagioclase feldspar (see below) is known as anorthosite. Feldspars are also found in many types of sedimentary rock.

Compositions

This group of minerals consists of framework tectosilicates. Compositions of major elements in common feldspars can be expressed in terms of three end members:

The alkali feldspars are as follows:

- Orthoclase (monoclinic), — $KAlSi_3O_8$
- Sanidine (monoclinic) — $(K,Na)AlSi_3O_8$
- Microcline (triclinic) — $KAlSi_3O_8$
- Anorthoclase (triclinic) — $(Na,K)AlSi_3O_8$

Plagioclase feldspars

The plagioclase feldspars are triclinic. The plagioclase series follows (with percent anorthite in parentheses):

- Albite (0 to 10) — $NaAlSi_3O_8$

- Oligoclase (10 to 30) — $(\text{Na,Ca})(\text{Al,Si})\text{AlSi}_2\text{O}_8$
- Andesine (30 to 50) — $\text{NaAlSi}_3\text{O}_8$ — $\text{CaAl}_2\text{Si}_2\text{O}_8$
- Labradorite (50 to 70) — $(\text{Ca,Na})\text{Al}(\text{Al,Si})\text{Si}_2\text{O}_8$
- Bytownite (70 to 90) — $(\text{NaSi,CaAl})\text{AlSi}_2\text{O}_8$
- Anorthite (90 to 100) — $\text{CaAl}_2\text{Si}_2\text{O}_8$

Barium feldspars

The barium feldspars are monoclinic and comprise the following:

- Celsian — $\text{BaAl}_2\text{Si}_2\text{O}_8$
- Hyalophane — $(\text{K,Na,Ba})(\text{Al,Si})_4\text{O}_8$

Feldspar is a common raw material used in glassmaking, ceramics, and to some extent as a filler and extender in paint, plastics, and rubber. In glassmaking, alumina from feldspar improves product hardness, durability, and resistance to chemical corrosion. In earth sciences and archaeology, feldspars are used for K-Ar dating, argon-argon dating, thermoluminescence dating and optical dating.

Physical properties of feldspar as whole

Structure	tectosilicate
Chemical formula	KAlSi_3O_8 — $\text{NaAlSi}_3\text{O}_8$ — $\text{CaAl}_2\text{Si}_2\text{O}_8$
Color	pink, white, gray, brown
Crystal system	triclinic or monoclinic
Twinning	tartan, carlsbad, etc
Cleavage	two or three
Fracture	along cleavage planes
hardness	6
Luster	vitreous
Diaphaneity	opaque
Birefringence	first order
Pleochroism	none
Other characteristics	exsolution lamellae common

Quartz:

Quartz is the second most abundant mineral in the Earth's continental crust, after feldspar. It is made up of a continuous framework of SiO_4 silicon–oxygen tetrahedra, with each Oxygen being shared between two tetrahedra, giving an overall formula SiO_2 .

Crystal habit and structure:

Quartz belongs to the trigonal crystal system. The ideal crystal shape is a six sided prism terminating with six-sided pyramids at each end.

Quartz Varieties

1. Citrine
2. Rose quartz
3. Smoky quartz
4. Amethyst
5. Milky quartz
6. Jasper
7. Agate
8. chalcedony

Occurrence

Quartz is an essential constituent of granite and other felsic igneous rocks. It is very common in sedimentary rocks such as sandstone and shale and is also present in variable amounts as an accessory mineral in most carbonate rocks. It is also a common constituent of schist, gneiss, quartzite and other metamorphic rocks.

Category	Silicate mineral	Mohs scale hardness	7 – lower in impure varieties (defining mineral)
Chemical formula	Silica (silicon dioxide, SiO ₂)	Luster	Vitreous – waxy to dull when massive
Crystal habit	6-sided prism ending in 6-sided pyramid (typical), drusy, fine-grained to microcrystalline, massive	Streak	White
Crystal system	α-quartz: trigonaltrapezohedral	Diaphaneity	Transparent to nearly opaque
	class 3 2; β-quartz: hexagonal 622 ^[1]	Specific gravity	2.65; variable 2.59–2.63 in impure varieties
Twinning	Common Dauphine law, Brazil law and Japan law	Pleochroism	None
Cleavage	{0110} Indistinct	Melting point	1670 °C (β tridymite) 1713 °C (β cristobalite) ^[1]
Fracture	Conchoidal	Other characteristics	Piezoelectric, may be triboluminescent, chiral (hence optically active if not racemic)
Tenacity	Brittle		

MICA GROUP:

The mica group of sheet silicate (phyllosilicate) minerals includes several closely related materials having highly perfect basal cleavage. All are monoclinic with a tendency towards pseudo-hexagonal crystals and are similar in chemical composition. The highly perfect cleavage, which is the most prominent characteristic of mica, is explained by the hexagonal sheet-like arrangement of its atoms.

Mica classification

Chemically, micas can be given the general formula

$X_2Y_{4-6}Z_8O_{20}(OH,F)_4$ in which X is K, Na, or Ca or less commonly Ba, Rb, or Cs;

Y is Al, Mg, or Fe or less commonly Mn, Cr, Ti, Li, etc.;

Z is chiefly Si or Al but also may include Fe^{3+} or Ti.

Structurally, micas can be classed as di-octahedral ($Y = 4$) and tri-octahedral ($Y = 6$). If the X ion is K or Na the mica is common mica whereas if the X ion is Ca the mica is classed as brittle mica.

Tri-octahedral MICAS

Common MICAS:

Brittle micas:

Occurrence

Mica is widely distributed and occurs in igneous, metamorphic and sedimentary regimes. Large crystals of mica used for various applications are typically mined from granitic pegmatites.

Uses

1. Thin transparent sheets of mica called "isinglass" were used for peepholes in boilers, lanterns, stoves, and kerosene heaters because they were less likely to shatter compared to glass when exposed to extreme temperature gradients.
2. Another use of mica is in the production of ultra-flat thin film surfaces (e.g. gold surfaces) using mica as substrate.
3. Sheet mica is used principally in the electronic and electrical industries. Its usefulness in these applications is derived from its unique electrical and thermal insulating properties and its mechanical properties, which allow it to be cut, punched, stamped, and machined to close tolerances.
4. Sheet mica is used in electrical components, electronics, isinglass, and atomic force microscopy. Other uses include diaphragms for oxygen-breathing equipment, marker dials for navigation compasses, optical filters, pyrometers, thermal regulators, stove and kerosene heater windows, and mica-thermic heater elements.

Category	Phyllo Silicate mineral
Chemical formula	$X_2Y_{4-6}Z_8O_{20}(OH,F)_4$
Crystal habit	flaky
Crystal system	pseudo-hexagonal
Twinning	Common Dauphine law, Brazil law and Japan law
Cleavage	Perfect basal
Fracture	Flaky
Tenacity	Brittle
Mohs scale hardness	1
Luster	Vitreous – waxy to dull when massive
Streak	White
Diaphaneity	Transparent
Specific gravity	Light

OLIVINE GROUP

The mineral olivine (when gem-quality also called peridot) is a magnesium iron silicate with the formula $(Mg,Fe)_2SiO_4$. It is a common mineral in the Earth's subsurface but weathers quickly on the surface.

Olivine gives its name to the group of minerals with a related structure (the olivine group) which includes tephroite (Mn_2SiO_4), monticellite ($CaMgSiO_4$) and kirschsteinite ($CaFeSiO_4$).

Identification and paragenesis:

Olivine is named for its typically olive-green color (thought to be a result of traces of nickel), though it may alter to a reddish color from the oxidation of iron.

Translucent olivine is sometimes used as a gemstone called peridot, the French word for olivine. It is also called chrysolite, from the Greek words for gold and stone. Some of the finest gem-quality olivine has been obtained from a body of mantle rocks on Zabargad island in the Red Sea. Olivine/peridot occurs in both mafic and ultramafic igneous rocks and

as a primary mineral in certain metamorphic rocks. Mg-rich olivine crystallizes from magma that is rich in magnesium and low in silica.

Extra-terrestrial occurrences:

Olivine has also been identified in meteorites, the Moon, Mars, in the dust of comet Wild 2, within the core of comet Crystal structure. Minerals in the olivine group crystallize in the orthorhombic system (space group Pbnm) with isolated silicate tetrahedra, meaning that olivine is a nesosilicate. In an alternative view, the atomic structure can be described as a hexagonal, close-packed array of oxygen ions with half of the octahedral sites occupied with magnesium or iron ions and one-eighth of the tetrahedral sites occupied by silicon ions.

Uses

The aluminium foundry industry uses olivine sand to cast objects in aluminium. Olivine sand requires less water than silicon based sand while providing the necessary strength to hold the mold together during handling and pouring of the metal. Less water means less gas (steam) to vent from the mold as metal is poured into the mold.

Category	Mineral Group
Chemical formula	(Mg, Fe) ₂ SiO ₄
Color	Yellow to yellow-green
Crystal habit	Massive to granular
Crystal system	Orthorhombic
Cleavage	Poor
Fracture	Conchoidal – brittle
Mohs scale hardness	6.5–7
Luster	Vitreous
Streak	White
Diaphaneity	Transparent to translucent
Specific gravity	3.27–3.37

PYROXENES GROUP

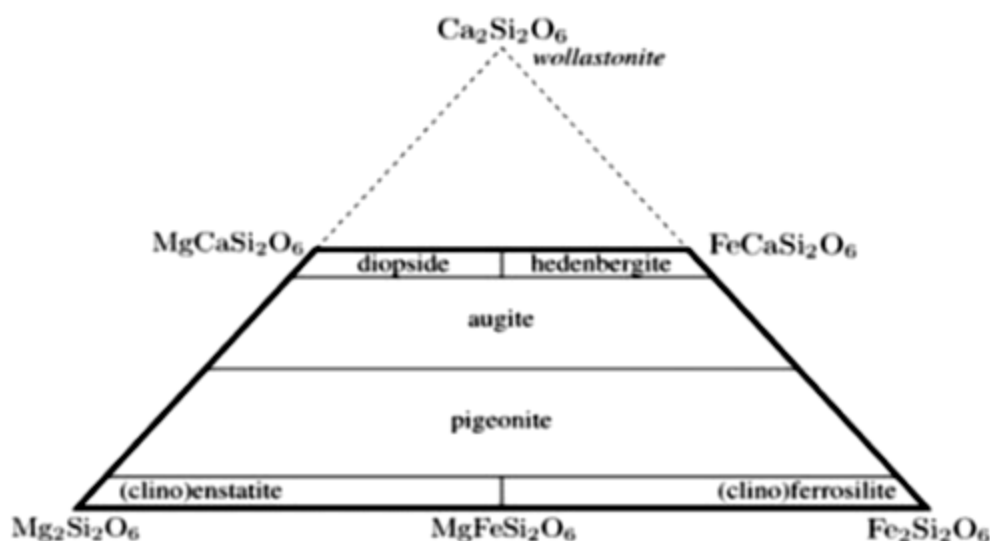
The pyroxenes are a group of important rock-forming inosilicate minerals found in many igneous and metamorphic rocks. They share a common structure consisting of single chains of silica tetrahedra and they crystallize in the monoclinic and orthorhombic systems.

Pyroxenes have the general formula $XY(\text{Si,Al})_2\text{O}_6$ (where X represents calcium, sodium, iron⁺² and magnesium and more rarely zinc, manganese and lithium and Y represents ions of

smaller size, such as chromium, aluminium, iron⁺³, magnesium, manganese, scandium, titanium, vanadium and even iron⁺²).

Pyroxene structure

The chain silicate structure of the pyroxenes offers much flexibility in the incorporation of various cations and the names of the pyroxene minerals are primarily defined by their chemical composition. Pyroxene minerals are named according to the chemical species occupying the X (or M2) site, the Y (or M1) site, and the tetrahedral T site. Cations in Y (M1) site are closely bound to 6 oxygens in octahedral coordination. Cations in the X (M2) site can be coordinated with 6 to 8 oxygen atoms, depending on the cation size.



Pyroxene minerals

- Clinopyroxenes (monoclinic)
- Aegirine (Sodium Iron Silicate)
- Augite (Calcium Sodium Magnesium Iron Aluminium Silicate)
- Clinoenstatite (Magnesium Silicate)
- Diopside (Calcium Magnesium Silicate, $\text{CaMgSi}_2\text{O}_6$)
- Esseneite (Calcium Iron Aluminium Silicate)
- Hedenbergite (Calcium Iron Silicate)
- Jadeite (Sodium Aluminium Silicate)
- Jervisite (Sodium Calcium Iron Scandium Magnesium Silicate)
- Johannsenite (Calcium Manganese Silicate)
- Kanoite (Manganese Magnesium Silicate)
- Kosmochlor (Sodium Chromium Silicate)
- Namansilite (Sodium Manganese Silicate)
- Natalyite (Sodium Vanadium Chromium Silicate)
- Omphacite (Calcium Sodium Magnesium Iron Aluminium Silicate)
- Petedunnite (Calcium Zinc Manganese Iron Magnesium Silicate)
- Pigeonite (Calcium Magnesium Iron Silicate)
- Spodumene (Lithium Aluminium Silicate)
- Orthopyroxenes (orthorhombic)

- Hypersthene (Magnesium Iron Silicate)
- Donpeacorite, (MgMn)MgSi₂O₆
- Enstatite, Mg₂Si₂O₆
- Ferrosilite, Fe₂Si₂O₆
- Nchwaningite (Hydrated Manganese Silicate)

Category	Chain silicate
Chemical formula	(Mg, Fe ₂)Si ₂ O ₆
Color	dark
Crystal habit	Massive to granular
Crystal system	Orthorhombic, monoclinic
Cleavage	good
Fracture	even
Mohs scalehardness	6.5–7
Luster	Vitreous
Streak	Blackish green
Specific gravity	3.27–3.37

GARNET GROUP:

The garnet group includes a group of minerals that have been used since the Bronze Age as gemstones and abrasives. The name "garnet" may come from either the Middle English word garnet meaning 'dark red', or the Latin granatus ("grain"), possibly a reference to the Punica granatum ("pomegranate"), a plant with red seeds similar in shape, size, and color to some garnet crystals.

Crystal structure

Garnets are nesosilicates having the general formula X₃Y₂(SiO₄)₃. The X site is usually occupied by divalent cations (Ca²⁺, Mg²⁺, Fe²⁺) and the Y site by trivalent cations (Al³⁺, Fe³⁺, Cr³⁺) in an octahedral/tetrahedral framework with [SiO₄]⁴⁻ occupying the tetrahedral

Garnet group end-member species

Pyrospite garnets - Aluminium in Y site

- Almandine: Fe₃Al₂(SiO₄)₃
- Pyrope: Mg₃Al₂(SiO₄)₃
- Spessartine: Mn₃Al₂(SiO₄)₃

Ugrandite group - calcium in X site

- Andradite: Ca₃Fe₂(SiO₄)₃
- Grossular: Ca₃Al₂(SiO₄)₃
- Uvarovite: Ca₃Cr₂(SiO₄)₃

Garnet structural group

Formula: $X_3Z_2(TO_4)_3$ (X = Ca, Fe, etc., Z = Al, Cr, etc., T = Si, As, V, Fe, Al)

All are cubic or strongly pseudocubic.

Genesis

The Garnet group is a key mineral in interpreting the genesis of many igneous and metamorphic rocks via geo-thermo-barometry. Diffusion of elements is relatively slow in garnet compared to rates in many other minerals, and garnets are also relatively resistant to alteration.

Uses of garnets

1. Garnet sand is a good abrasive, and a common replacement for silica sand in sand blasting. Alluvial garnet grains which are rounder are more suitable for such blasting treatments. Mixed with very high pressure water, garnet is used to cut steel and other materials in water jets.
2. Garnet paper is favored by cabinetmakers for finishing bare wood.
3. Garnet sand is also used for water filtration media.

Category	Nesosilicate
Chemical formula	The general formula $X_3Y_2(SiO_4)_3$
Color	virtually all colors
Crystal habit	rhombic dodecahedra or cubic
Crystal system	Cubic rhombic dodecahedron, icositetrahedron
Cleavage	Indistinct
Fracture	conchoidal to uneven
Mohs scale hardness	6.5 - 7.5
Luster	vitreous to resinous
Streak	White
Specific gravity	3.1 - 4.3
Polish luster	vitreous to subadamantine

KYANITE GROUP

Kyanite, whose name derives from the Greek word kuanos sometimes referred to as "kyanos", meaning deep blue, is a typically blue silicate mineral, commonly found in

aluminium-rich metamorphic pegmatites and/or sedimentary rock. Kyanite in metamorphic rocks generally indicates pressures higher than 4 kilobars. Although potentially stable at lower pressure and low temperature, the activity of water is usually high enough under such conditions that it is replaced by hydrous alumina-silicates such as muscovite, pyrophyllite, orkaolinite. Kyanite is also known as disthene, rhaeticite and cyanite.

Kyanite is a member of the aluminosilicate series, which also includes the polymorph andalusite and the polymorph sillimanite. Kyanite is strongly anisotropic, in that its hardness varies depending on its crystallographic direction. In Kyanite, this anisotropism can be considered an identifying characteristic.

At temperatures above 1100 °C kyanite decomposes into mullite and vitreous silica via the following reaction: $3(\text{Al}_2\text{O}_3 \cdot \text{SiO}_2) \rightarrow 3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 + \text{SiO}_2$. This transformation results in an expansion.

Occurrence

Kyanite occurs in gneiss, schist, pegmatite, and quartz veins resulting from moderate to highpressure regional metamorphism of principally pelitic rocks. It occurs as detrital grains in sedimentary rocks. It occurs associated with staurolite, andalusite, sillimanite, talc, hornblende, gedrite, mullite and corundum.

Uses of kyanite

1. Kyanite is used primarily in refractory and ceramic products, including porcelain plumbing fixtures and dishware. It is also used in electronics, electrical insulators and abrasives.
2. Kyanite has been used as a semiprecious gemstone, which may display cat's eye chatoyancy, though this use is limited by its an-isotropism and perfect cleavage.

Category	Silicate mineral
Chemical formula	Al_2SiO_5
Crystal symmetry	Triclinic pinacoidal H-M Symbol: 1Space group: P1
Color	Blue, white, rarely green, gray, yellow, pink, orange, and black, can be zoned
Crystal habit	Columnar; fibrous; bladed
Crystal system	Triclinic
Twining	Lamellar on (100)
Cleavage	[100] perfect [010] imperfect with 79° angle between
Fracture	Splintery
Tenacity	Brittle
Mohs scalehardness	4.5-5 parallel to one axis 6.5-7 perpendicular to that axis
Luster	Vitreous to pearly
Streak	White
Diaphaneity	Transparent to translucent
Specific gravity	3.53 - 3.65 measured; 3.67