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Genesis of Minerals

Composition of the Earth’s Crust

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Study of Minerals with Emphasis on Rock-forming Minerals

Properties regarding strength and breaking of minerals

Tenacity

Tenacity is the resistance of a mineral to breaking, crushing, or bending. Already you have read how this property is related to atomic bonding. Tenacity can be described by the following terms:

- Brittle - Breaks or powders easily.
- Malleable- can be hammered into thin sheets.
- Sectile- can be cut into thin shavings with a knife.
- Ductile- bends easily and does not return to its original shape.
- Flexible- bends somewhat and does not return to its original shape.
- Elastic- bends but does return to its original shape.

Cleavage

Crystals often contain planes of atoms along which the bonding between the atoms is weaker than along other planes. In such a case, if the mineral is struck with a hard object, it will tend to break along these planes. This property of breaking along specific planes is termed cleavage. Cleavage occurs along planes in the crystal lattice.

The cleavage can be described in terms of its quality, i.e., if it cleaves along perfect planes it is said to be perfect, and if it cleaves along poorly defined planes it is said to be poor.

Note: Please do not attempt to cleave the minerals in the laboratory. Many of the specimens you examine cannot be readily replaced. Cleavage is usually induced in the mineral when it is extracted from the rock when it is found, and can usually be seen as planes running through the mineral. Therefore, you do not have to break the mineral in order to see its cleavage.

The directions and type of cleavage may be described as the following:

- If only 1 set of parallel plane is seen, then 1 direction of cleavage is denoted (e.g., mica)
- If only 2 sets of parallel planes are seen, then the intersection angle of the 2 planes should be given. If the intersect at right angles, 2 directions of cleavage at 90^o is denoted.

Parting

Parting is also a plane of weakness in the crystal structure, but it is along planes that are weakened by some applied force. It therefore may not be apparent in all specimens of the same mineral, but may appear if the mineral has been subjected to the right stress conditions.

Fracture

If the mineral contains no planes of weakness, it will break along random directions called fracture. Several different kinds of fracture patterns are observed.

- Conchoidal fracture - breaks along smooth curved surfaces.
- Fibrous and splintery - similar to the way wood breaks.
- Hackly - jagged fractures with sharp edges.
- Uneven or Irregular - rough irregular surfaces.

Hardness

Hardness is determined by scratching the mineral with a mineral or substance of known hardness. Hardness is a relative scale, thus to determine a mineral's hardness, you must determine that a substance with a hardness greater than the mineral does indeed scratch the unknown mineral, and that the unknown mineral scratches a known mineral of lesser hardness.

Hardness is determined on the basis of Moh's relative scale of hardness exhibited by some common minerals. These minerals are listed below, along with the hardness of some common objects.

Hardness	Mineral	Common Objects
1	Talc	
2	Gypsum	Fingernail (2+)
3	Calcite	Copper Penny (3+)
4	Fluorite	
5	Apatite	Steel knife blade (5+), Window glass (5.5)
6	Orthoclase	Steel file
7	Quartz	
8	Topaz	
9	Corundum	
10	Diamond	

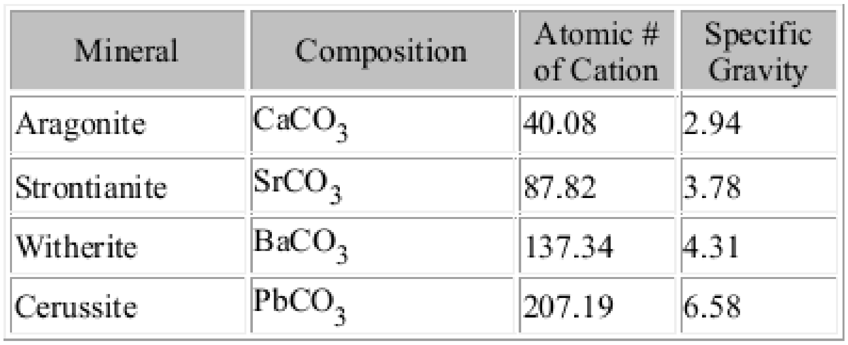
Several precautions are necessary for performing the hardness test.

- If you attempt to scratch a soft mineral on the surface of a harder mineral some of the softer substance may leave a mark of fine powder on the harder mineral. This should not be mistaken for a scratch on the harder mineral. A powder will easily rub off, but a scratch will occur as a permanent indentation on the scratched mineral.
- Some minerals have surfaces that are altered to a different substance that may be softer than the original mineral. A scratch in this softer alteration product will not reflect the true hardness of the mineral. Always use a fresh surface to perform the hardness test.

- Sometimes the habit of the mineral will make a difference. For example aggregates of minerals may break apart leaving the impression that the mineral is soft. Or, minerals that show fibrous or splintery habit may break easily into fibers or splinters. It is therefore wise to always perform the hardness test in reverse. If one mineral appears to scratch another mineral, make sure that the other mineral does not scratch the apparently harder mineral before you declare which of the minerals is harder.
- In some minerals hardness is very dependent on direction, since hardness is a vectorial property. When there is significant difference in hardness in different directions, it can be a very diagnostic property of the mineral. It is thus wise to perform the hardness test by attempting to scratch the mineral in different directions. Examples are kyanite (hardness 5 and 7) and calcite (hardness 3 and 2)

Density and Specific Gravity

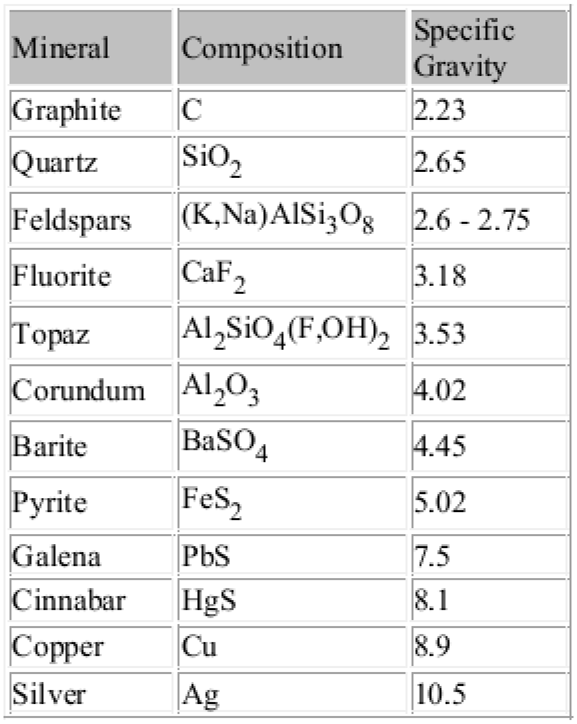
Density refers to the mass per unit volume. Specific Gravity is the relative density, (weight of substance divided by the weight of an equal volume of water). In cgs units density is grams per cm^3, and since water has a density of 1 g/cm^3, specific gravity would have the same numerical value has density, but no units (units would cancel). Specific gravity is often a very diagnostic property for those minerals that have high specific gravities. In general, if a mineral has higher atomic number cations it has a higher specific gravity. For example, in the carbonate minerals the following is observed:



Mineral	Composition	Atomic # of Cation	Specific Gravity
Aragonite	$CaCO_3$	40.08	2.94
Strontianite	$SrCO_3$	87.82	3.78
Witherite	$BaCO_3$	137.34	4.31
Cerussite	$PbCO_3$	207.19	6.58

Specific gravity can usually be qualitatively measured by the heft of a mineral, in other words those with high specific gravities usually feel heavier. Most common silicate minerals have a specific gravity between about 2.5 and 3.0. These would feel light compared to minerals with high specific gravities.

For comparison, examine the following table:



Mineral	Composition	Specific Gravity
Graphite	C	2.23
Quartz	SiO_2	2.65
Feldspars	$(K,Na)AlSi_3O_8$	2.6 - 2.75
Fluorite	CaF_2	3.18
Topaz	$Al_2SiO_4(F,OH)_2$	3.53
Corundum	Al_2O_3	4.02
Barite	$BaSO_4$	4.45
Pyrite	FeS_2	5.02
Galena	PbS	7.5
Cinnabar	HgS	8.1
Copper	Cu	8.9
Silver	Ag	10.5

Magnetism

Magnetic minerals result from properties that are specific to a number of elements. Minerals that do not have these elements, and thus have no magnetism are called **diamagnetic**. Examples of diamagnetic minerals are quartz, plagioclase, calcite, and apatite.

Elements like Ti, Cr, V, Mn, Fe, Co, Ni, and Cu can sometimes result in magnetism. Minerals that contain these elements may be weakly magnetic and can be separated from each other by their various degrees of magnetic susceptibility. These are called **paramagnetic** minerals. Paramagnetic minerals only show magnetic properties when subjected to an external magnetic field. When the magnetic field is removed, the minerals have no magnetism.

Ferromagnetic minerals have permanent magnetism if the temperature is below the Curie Temperature. These materials will become magnetized when placed in a magnetic field, and will remain magnetic after the external field is removed. Examples of such minerals are magnetite, hematite-ilmenite solid solutions (Fe_2O_3-$FeTiO_3$), and pyrrhotite ($Fe_{1-x}S$).

Electric Properties

On the basis of their electrical properties, minerals can be divided as conductors, nonconductors (sometimes referred to as dielectrics or insulators), and semiconductors.

Electrical charges are induced in some nonconducting minerals due to changes in temperature. This phenomenon is called **pyroelectricity** and the minerals shoing such property are called to be **pyroelectric**. Pyroelectricity was first discovered in gemmy tourmaline crystals being transported from Ceylon by Dutch traders, who noticed that a crystal dropped in warm ashes attracted ash particles at one end but not at the other end.

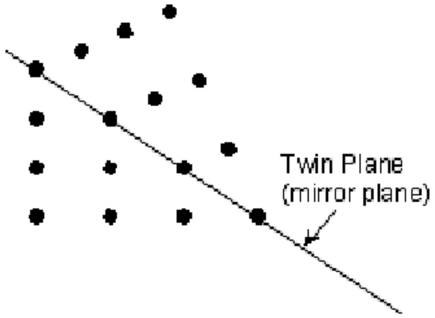
Piezoelectricity is the electric charge that accumulates in certain nonconductor minerals in response to applied mechanical stress. The word piezoelectricity means electricity resulting from pressure. Examples of piezoelectric minerals are quartz, topaz, tourmaline etc.

Reaction to Dilute Hydrochloric Acid

One chemical property, the reaction to dilute (5%) hydrochloric acid (HCl) is included here because it is diagnostic for calcite, one of the most common minerals on the Earth's crust. Drops of acid placed on coarse sample cause obvious bubbling or fizzing, called **effervescence**. Dolomite, a closely related carbonate mineral, effervesces when finely powdered but not when coarse.

Twinning

Sometimes during the growth of a crystal, or if the crystal is subjected to stress or temperature/pressure conditions different from those under which it originally formed, two or more intergrown crystals are formed in a symmetrical fashion. These symmetrical intergrowths of crystals are called twinned crystals. Twinning is important to recognize, because when it occurs, it is often one of the most diagnostic features enabling identification of the mineral.



What happens is that lattice points in one crystal are shared as lattice points in another crystal adding apparent symmetry to the crystal pairs. Twinning, because it adds symmetry, never occurs in relation to the existing symmetry of the crystal.

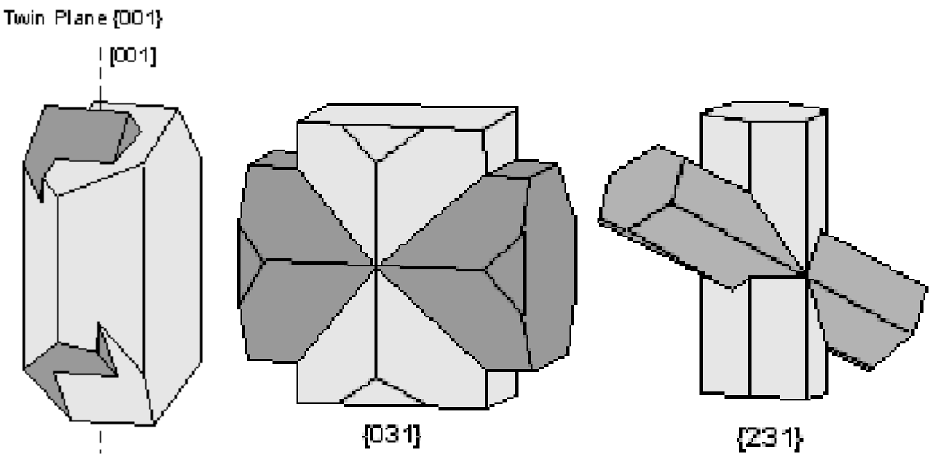


Figure 1: Twining in monoclinic (the left most crystal only) and orthorhombic crystals.

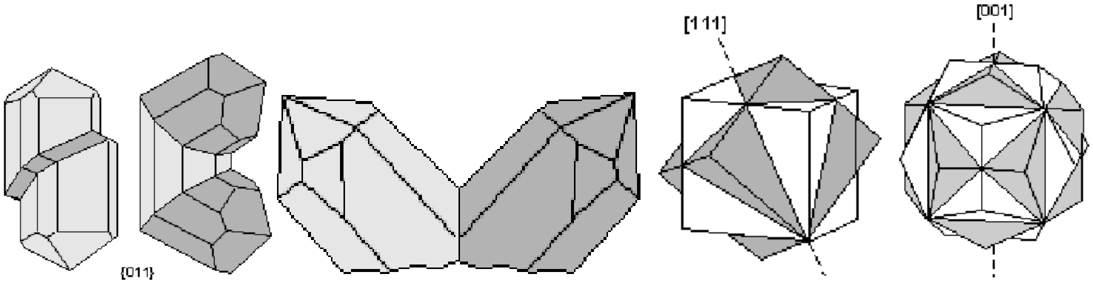


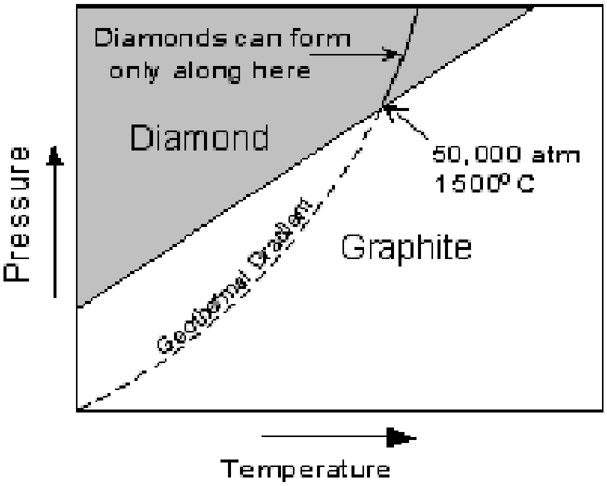
Figure 2: Twinning in tetragonal (1st one from the left), hexagonal (2nd from the left) , and isometric (the rest 2) crystals.

Polymorphism

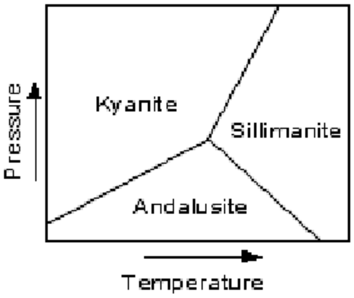
Polymorphism means "many forms". In mineralogy it means that a single chemical composition can exist with two or more different crystal structures. As we will see when we look more closely at crystal structures, if a crystal is subjected to different pressures and temperatures, the arrangement of atoms depends on the sizes of the atoms, and the sizes change with temperature and pressure. In general, as pressure increases the volume of a crystal will decrease and a point may be reached where a more compact crystal structure is more stable. The crystal structure will then change to that of the more stable structure, and a different mineral will be in existence. Similarly, if the temperature is increased, the atoms on the crystal structure will tend to vibrate more and increase their effective size. In this case, a point may be reached where a less compact crystal structure is more stable. When the crystal structure changes to the more stable structure, a different mineral will form.

The change that takes place between crystal structures of the same chemical compound are called **polymorphic transformations**.

Carbon has two polymorphs. At high pressure carbon has an isometric crystal structure that is called diamond. As temperature and/or pressure are decreased diamond should undergo a *reconstructive* transformation to the hexagonal structure of graphite. Because this transformation involves a drastic rearrangement of atoms on the crystal structure, as evidenced by the fact that diamond is the hardest naturally occurring substance and graphite is one of the softest.

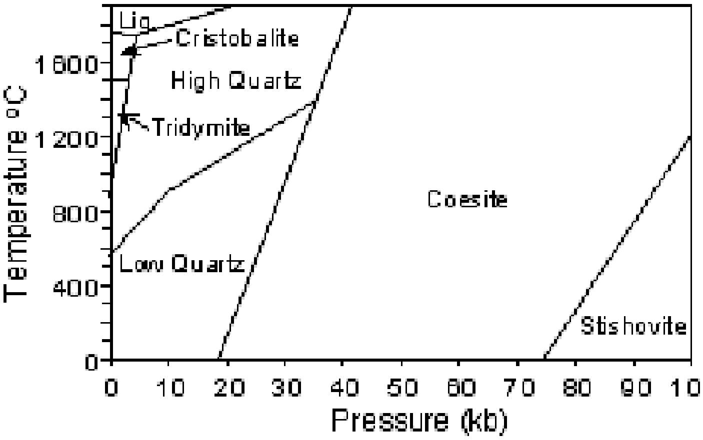


Al_2SiO_5 has three polymorphs. The high pressure form is kyanite (Triclinic), the high temperature form is sillimanite (orthorhombic), and the low temperature and low pressure form is andalusite (orthorhombic).



$CaCO_3$ has two polymorphs. The high pressure form is aragonite (orthorhombic) and the low pressure form is calcite (hexagonal).

SiO_2 has 6 polymorphs. With decreasing temperature at low pressure, cristobalite (isometric) undergoes a reconstructive transformation to tridymite (hexagonal). Further lowering of temperature results in tridymite undergoing a reconstructive transformation to high quartz (also hexagonal). Further lowering of the temperature results in low quartz.



Cristobalite and tridymite can exist at the low temperatures near the Earth's surface, and thus are found in rocks. But high quartz will also transform to low quartz before it reaches temperatures present at the Earth's surface, so it is never found in rocks.

With increasing pressure, at low temperature low quartz undergoes *displace* transformation to coesite (Monoclinic), and coesite undergoes a reconstructive transformation to stishovite (tetragonal) at even higher pressures. Thus, coesite and stishovite can be found in rocks.

$KAlSi_3O_8$ compound has three polymorphs that undergo *order-disorder* transformations with lowering of temperature. The high temperature polymorph is sanidine (monoclinic). It is usually only found in volcanic rocks that have cooled very rapidly so that a higher state of order is not achieved. With slower cooling, sanidine eventually undergoes a transformation to orthoclase (also monoclinic), and orthoclase eventually transforms to microcline (triclinic) with further slow cooling.

Metamict minerals

Metamict minerals are minerals whose crystal structure has been partially destroyed by radiation from contained radioactive elements. The breakdown of the crystal structure results from bombardment of a particles emitted by the decay of U and Th radioactive isotopes.

The mineral zircon ($ZrSiO_4$) often has U and Th atoms substituting for Zr in the crystals structure. Since U and Th have radioactive isotopes, Zircon is often seen to occur in various stages of metamictization.

Pseudomorphism

Pseudomorphism is the existence of a mineral that has the appearance of another mineral. Pseudomorph means false form. Pseudomorphism occurs when a mineral is altered in such a way that its internal structure and chemical composition is changed but its external form is preserved. Three mechanisms of pseudomorphism can be defined:

1. Substitution. In this mechanism chemical constituents are simultaneously removed and replaced by other chemical constituents during alteration. An example is the replacement of wood fibers by quartz to form petrified wood that has the outward appearance of the original wood, but is composed of quartz. Another example is the alteration of fluorite which forms isometric crystals and is sometimes replaced by quartz during alteration. The resulting quartz crystals look isometric, and are said to be pseudomorphed after fluorite.
2. Encrustation. If during the alteration process a thin crust of new mineral forms on the surface of a preexisting mineral, then the preexisting mineral is removed, leaving the crust behind, we say that pseudomorphism has resulted from encrustation. In this case the thin crust of the new mineral will have casts of the form of the original mineral.
3. Alteration. If only partial removal of the original mineral and only partial replacement by the new mineral has taken place, then it is possible to have a the space once occupied entirely by the original mineral be partially composed of the new mineral. This results for example in serpentine pseudomorphed after olivine or pyroxene, anhydrite ($CaSO_4$)

pseudomorphed after gypsum ($CaSO_4.2H_2O$), limonite [$FeO(OH).nH_2O$] after pyrite (FeS_2), and anglesite ($PbSO_4$) after galena (PbS).