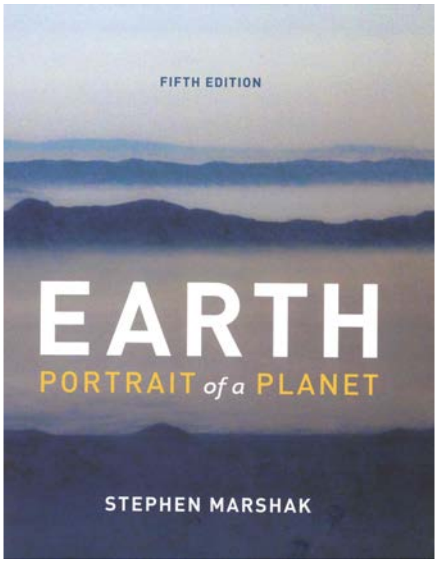
CEEES/SC 10110-20110

Patterns in Nature: Minerals



Earth

Portrait of a Planet

Fifth Edition

Chapter 5

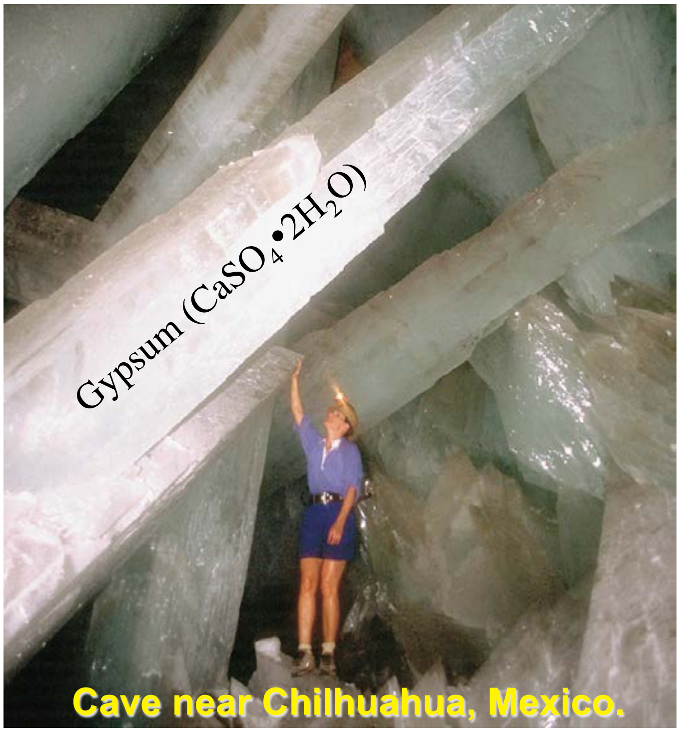
Quiz Time

One space = One Word;

Look for context: if the space is preceded by "an" the word begins with a vowel.

Once a word is used, it is not used again.

Gypsum Crystals - Precipitated from Water



Mineralogy: Study of minerals.
Mineralogist: people who study minerals.

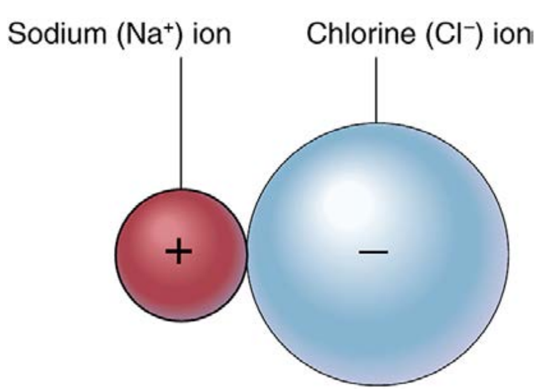
ELEMENT: A pure substance that cannot be broken down by chemical processes.

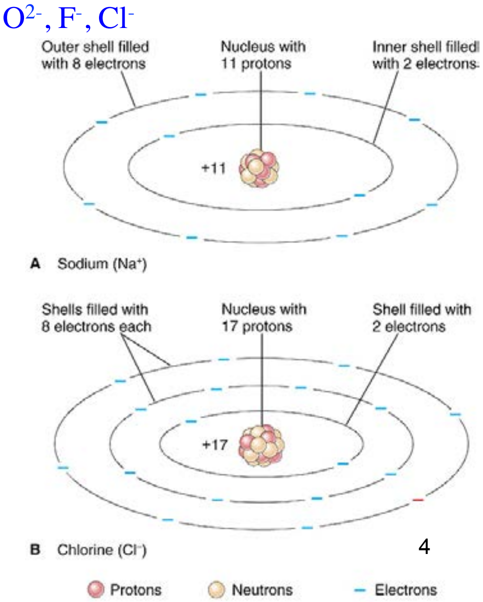
ATOM: smallest particle of an element that retains its chemical identity. Contains protons, neutrons, & electrons.

Ionization: addition/subtraction of electrons.
CATIONS: positively charged, electrons removed. Al^{3+}, Si^{4+}, Fe^{2+} or Fe^{3+}
ANIONS: negatively charged, electrons added. O^{2-}, F^{-}, Cl^{-}

MOLECULE: two or more atoms combined.

Anions and cations bound together to form neutral species or ***minerals***.





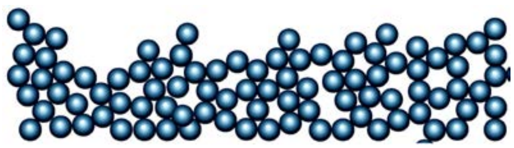
MINERALS – BUILDING BLOCKS OF THE EARTH: A naturally occurring homogeneous[1] solid with a definite, but generally not fixed[2], chemical composition and a highly ordered[3] atomic arrangement.

1. homogeneous = constant physical proportions, single phase.
2. contains specific elements, some substitution permitted.
3. crystal structure – orderly (i.e., not glass). Structure preserves translational symmetry. “Crystal lattice”.

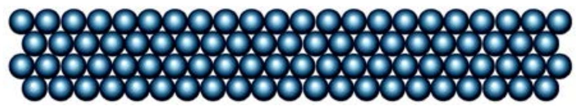
4,000 mineral species, but ~125 added each year!!

Chemical behavior of elements, controlled by valence electrons, dictates the physical properties of minerals – very diverse!

Glass: inorganic solid, but structure is (semi)chaotic and irregular.



Disordered Structure

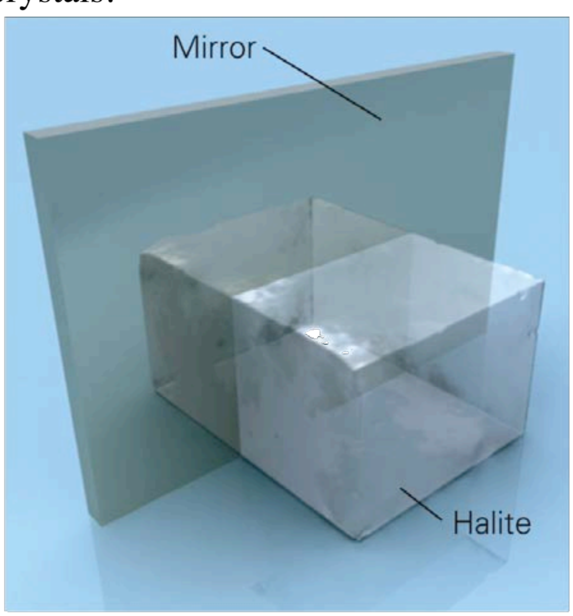


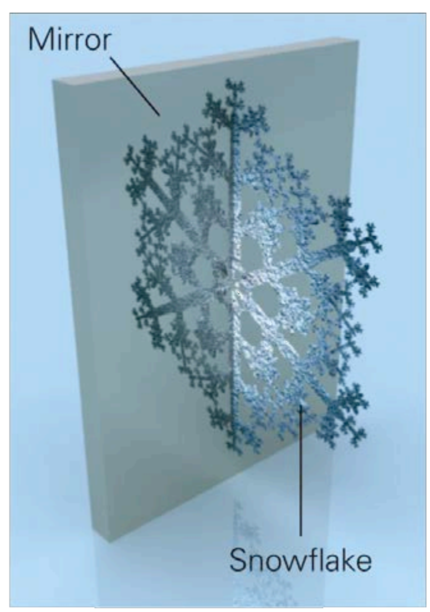
Ordered Structure

5

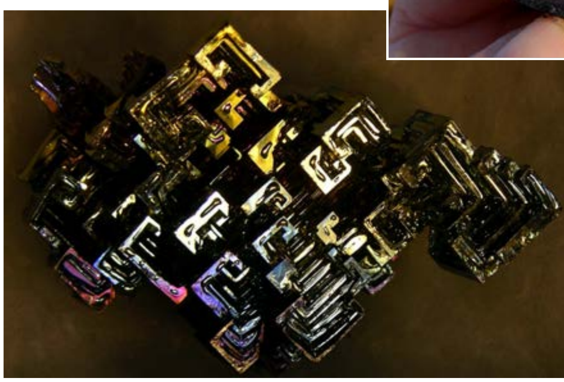
Symmetry

The ordered atomic arrangement inside minerals imparts symmetry to crystals.





Minerals are *generally* formed by inorganic processes, but can have biogenic mineralization – formed by living organisms.



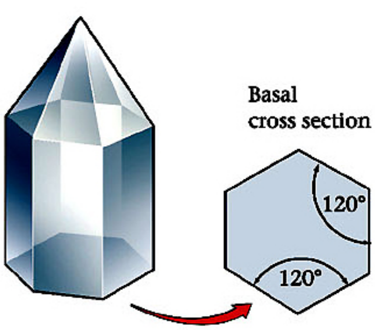
Minerals must be created by natural processes. Humans can recreate natural processes to make mineral equivalents. These are called ***synthetic minerals***.

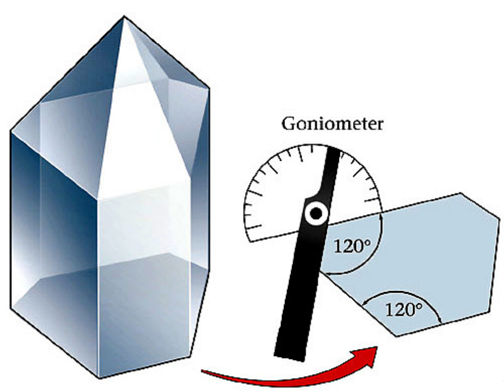
What is a Crystal?

<u>Crystal</u>: single, continuous (uninterrupted) piece of crystalline solid bounded by flat surfaces (Crystal Faces) that grew naturally as the mineral grew.

For a given mineral, the angle between two adjacent faces of one specimen is identical to the angle between the corresponding faces of another specimen.

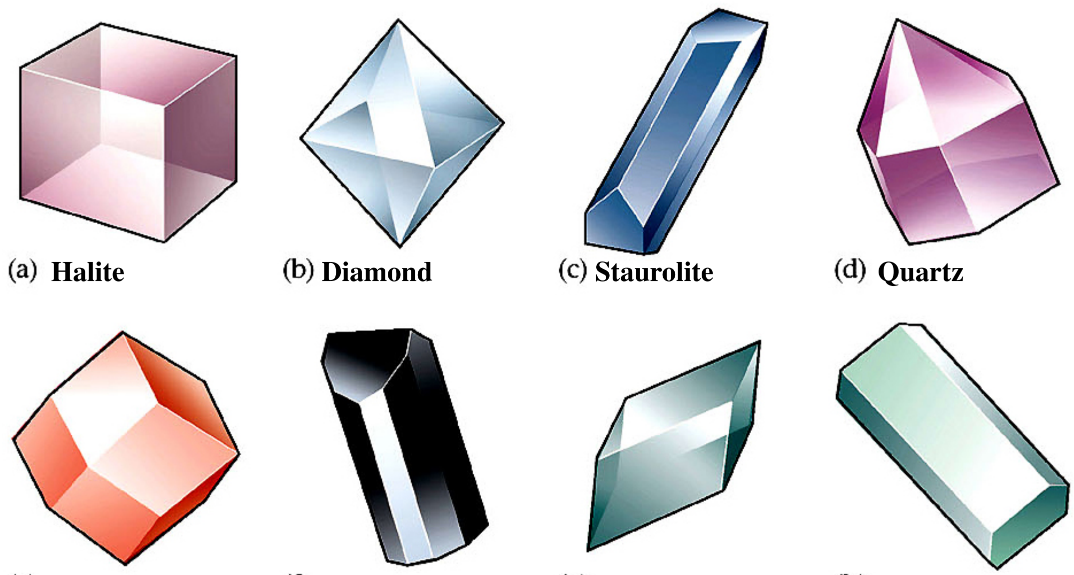
Crystals of Quartz





What is a Crystal?

Crystals come in a variety of shapes.



(a) **Halite** (b) **Diamond** (c) **Staurolite** (d) **Quartz**

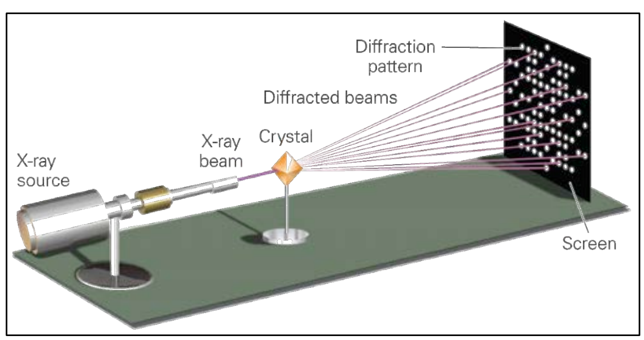
(e) **Garnet** (f) **Stibnite** (g) **Calcite** (h) **Kyanite**

What's Inside a Crystal?

X-rays are diffracted by a crystal; waves interfere and where they are reinforced, a distinctive pattern is formed.

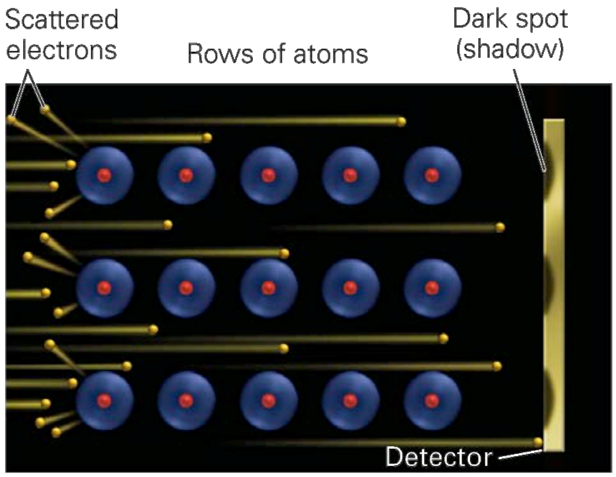
This defines the "**crystal structure**".

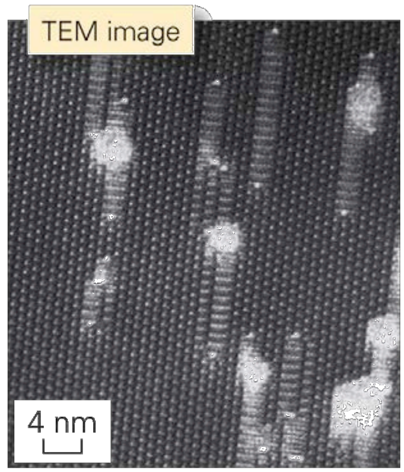
Physical properties of a mineral depend on the elements and how they are bonded in the crystal structure.



What's Inside a Crystal?

A Transmission Electron Microscope (TEM) shoots beams of electrons at a material.Some electrons scatter off atoms, but some pass between gaps and make a dark spot on a recorder. The result is an image that shows the pattern of atoms in the material.





Chemical Bonds

The type of atomic bonding determines many of the physical properties of a mineral.

Five types of bonds:

Ionic: mutual attraction of ions of opposite charge (e.g., Na^+Cl^-).

Covalent: atoms share electrons (e.g., diamond, H_2O).

Metallic: outer shells of atoms move easily from one to another. Allows electricity to move

Hydrogen: in water, the electron on H is attracted to the O atom - the O side of the molecule is more negative than the H side and attracts other water molecules and makes it a good solvent.

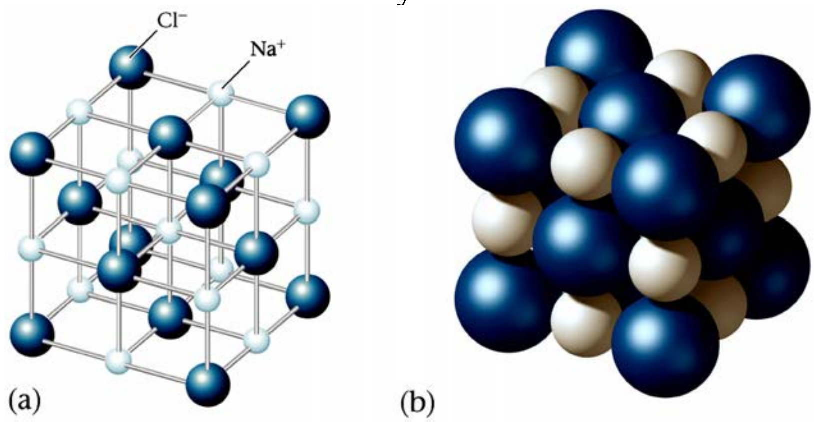
Van der Waals: these bonds exist because electrons temporarily cluster on one side of each molecule.

Chemical Bonds

Harder minerals = stronger bonds.

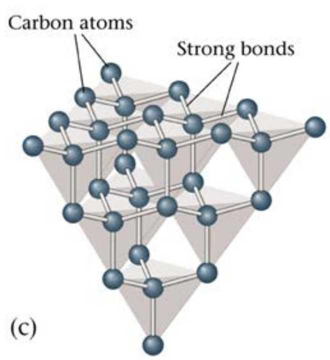
If bonds form more easily in one direction than another, the crystal will grow faster in that direction. [High bond density]
If a mineral has weaker bonds in one direction it will preferentially break along that direction. [Low bond density]

Halite: Each Na^{+} is surrounded by 6 Cl^{-}.

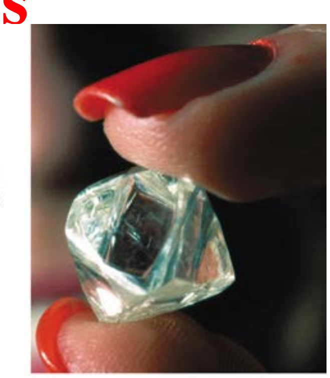


Chemical Bonds

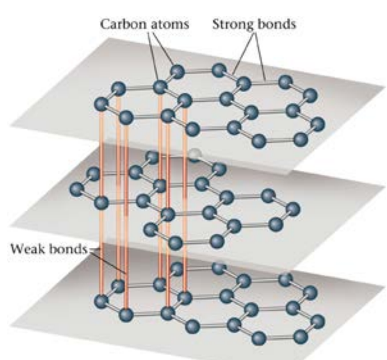
Diamond: each C atom is covalently bonded to 4 other C atoms (tetrahedron).



(c)



(d)



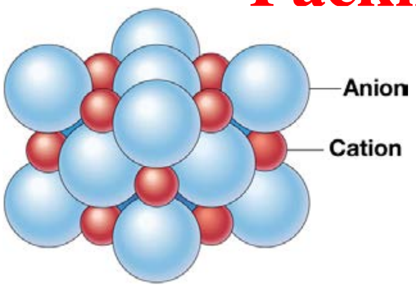
(e)

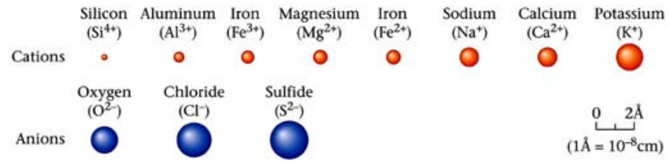
(f)

Graphite: C atoms arranged in sheets. Sheets are connected by weak Van der Waal's bonds.

Diamond & Graphite = **Polymorphs**.

Packing of the Atoms

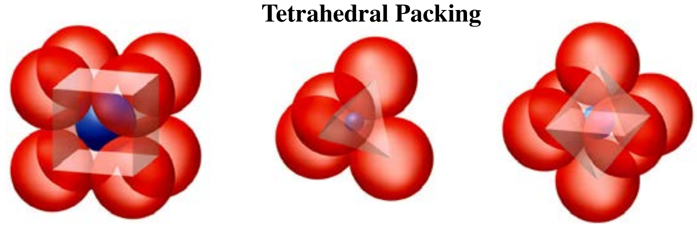




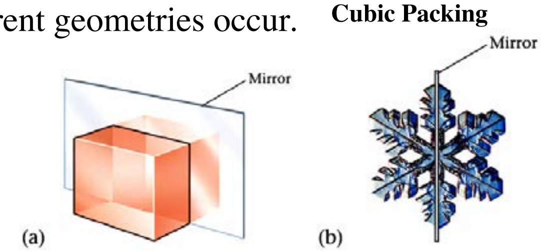
Cations are smaller than anions.

Cations fit into the spaces between anions.
As many anions as possible will fit around a cation.
Depending on the ion, different geometries occur.

Tetrahedral Packing



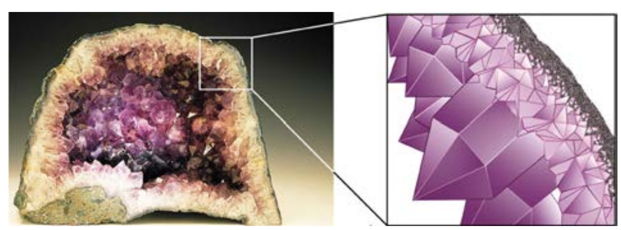
Cubic Packing **Octahedral Packing**

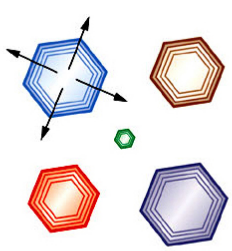


The orderly arrangement of the atoms controls the outward appearance of the crystal and controls the symmetry of the crystal.

Formation of Minerals

Solidification of a melt.
Precipitation from a solution.
Solid state diffusion.

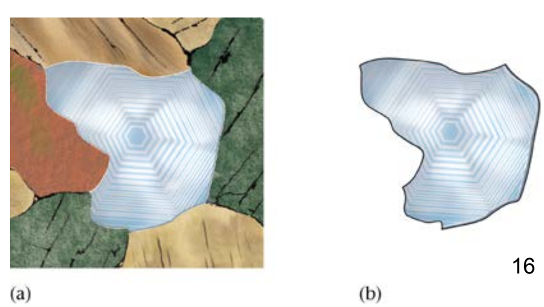




Crystals grow with well defined crystal faces = **Euhedral**;

Crystals interfere with each other so their shape cannot be maintained = **Anhedral/Subhedral**.

Crystals can be destroyed by melting, dissolving, or chemical reaction (including the action of microbes.



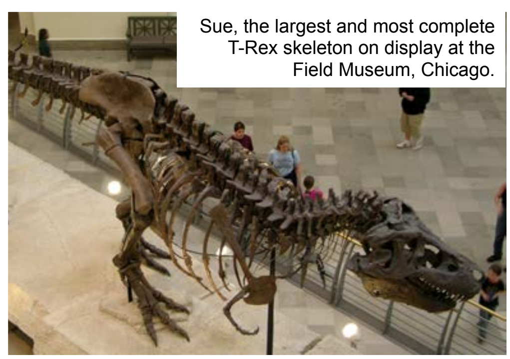
MINERAL FORMATION

When a melt solidifies. Quick cooling results in tiny crystals; slow cooling creates large crystals.

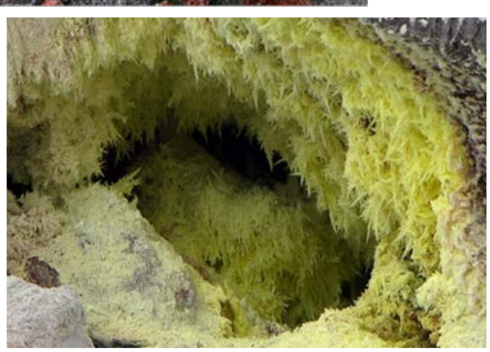
From an aqueous solution when dissolved solids become saturated.

MINERAL FORMATION

When rocks are buried to great depths.



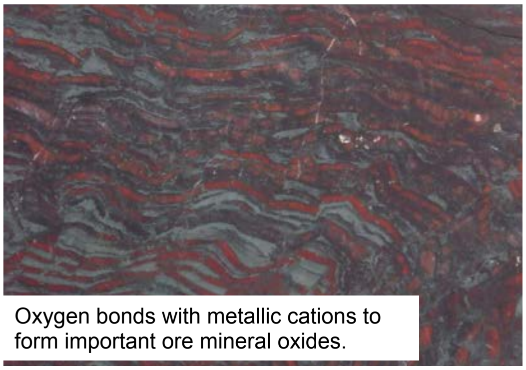
Biomineralization



Directly from a gas – volcanic vents or "**fumaroles**" ("fumarolic activity").

ORE MINERALS

Mineral containing elements/molecules that are concentrated enough to be extracted economically if there is an accumulation of the ore mineral.



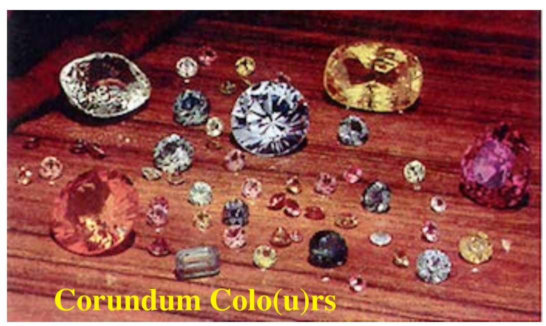
Oxygen bonds with metallic cations to form important ore mineral oxides.

Sulfide (S^{-}) combines with metallic cations to form many of our most important metal ore minerals.

MINERAL PROPERTIES

Colo(u)r:

First thing that is recognizable about a mineral (some are colo(u)rless, white, or strongly colo(u)red). Can be useful for identifying some minerals, but others with variable chemical compositions can have variable colo(u)rs (e.g., garnet).



Corundum Colo(u)rs

Quartz Colo(u)rs

Colo(u)r is associated with electron transfers amongst the valence bands. Some minerals are colo(u)red by major elements (wt.%), whereas others are colo(u)red by trace elements (ppm) (e.g., Quartz).

MINERAL PROPERTIES

Physical properties of minerals are dictated by the nature of the underlying atomic structure, nature and arrangement of chemical bonds, and energy levels of valence electrons.

Streak: color of the powdered mineral (if it is softer than the *streak plate*); body (specimen) color shows more variability than streak color; sometimes streak color is not the same color as the specimen.

Calcite always gives a white streak even if it is pink.
Hematite gives a dark red streak although it can be black.

CARE: sometimes the mineral is harder than the streak plate – the apparent white streak is actually the streak plate.

MINERAL PROPERTIES

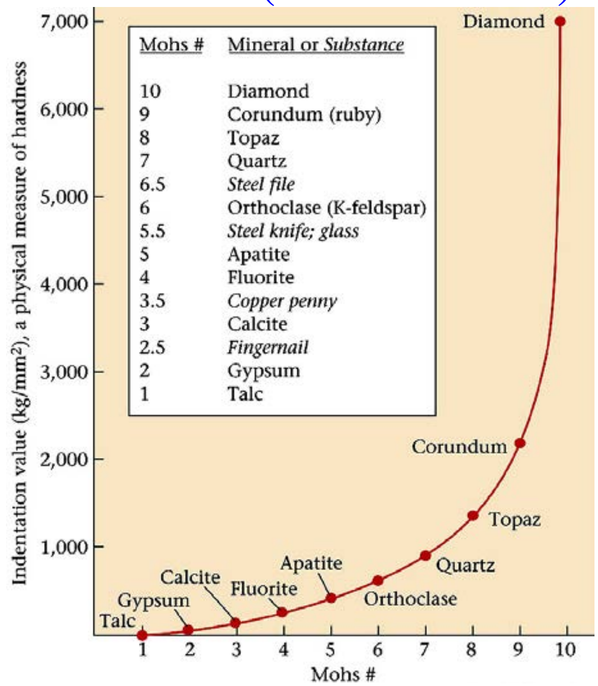
Luster: quality and intensity of reflected light. Described as, for example, earthy or dull, resinous, pearly, silky, greasy, vitreous (glassy).

Metallic

Non-metallic

Hardness: MOH’S Hardness Scale (NOT absolute):

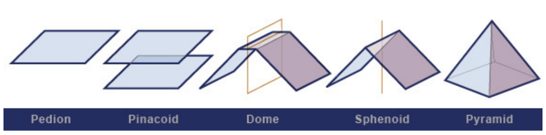
Talc	**1**
Gypsum	**2**
Calcite	**3**
Fluorite	**4**
Apatite	**5**
Orthoclase	**6**
Quartz	**7**
Topaz	**8**
Corundum	**9**
Diamond	**10**

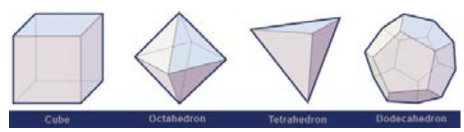


IMPORTANT!

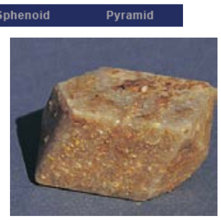
External Crystal Form: e.g., Massive, Granular, etc. Describes the form of a mass of the same mineral.

Strict definition: Any grouping of crystal faces or facets that are arranged in the same symmetry is called a "form.” Open & closed forms exist. A ***crystal form*** is **a set of crystal faces that are related to each other by symmetry.**



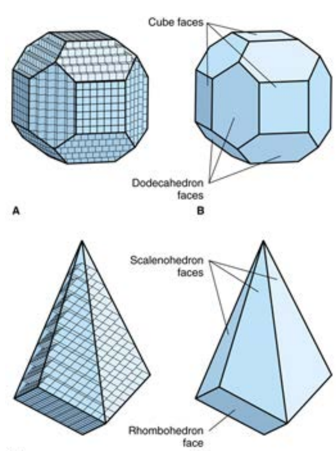


Fluorite



Feldspar

Geometric forms built by stacking cubes. Cubes can be stacked for cubic and dodecahedral (12-sided) crystal forms.



External Crystal Habit

Bladed Crystals: Kyanite

Needle-like (acicular) or fibrous

Prismatic

Habit: The term used to describe general shape of a crystal**.** It describes nature of a single crystal (bladed, fibrous, acicular, prismatic, cubic, blocky, equant, columnar, platy).

Crystal habit reflects the symmetry of the atomic arrangement of the underlying crystal structure, but the absence of form does not imply the absence of structure (some minerals do not show well-developed crystals).

CLEAVAGE: splitting along preferred directions due to weak bonds within the atomic structure. Cleavage is described as perfect, good, poor.

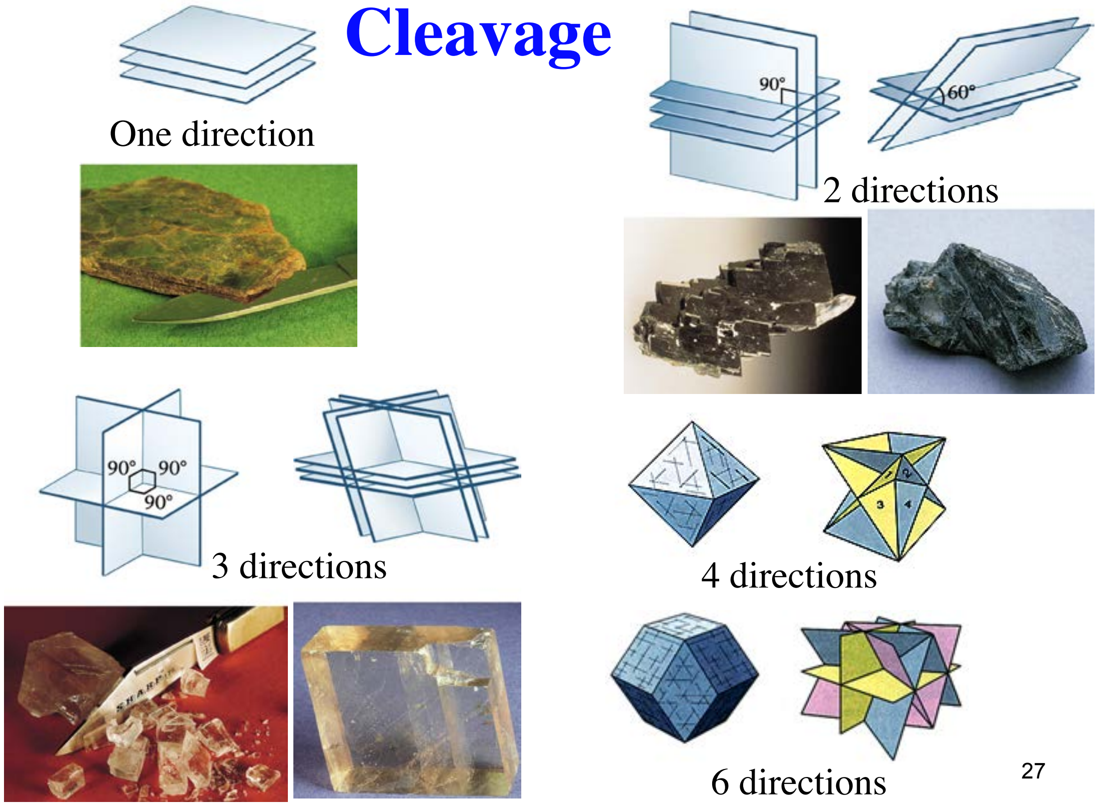
This is a property of crystals – be careful that you are looking at single crystals and not crystal aggregates.

Cleavages can be confused with crystal faces – can often see cleavage *planes* perpendicular to crystal *faces*. [Cleavage planes = low bond density; Crystal faces = high bond density]

Some crystals do not show cleavage due to similar bond strengths **[densities]** throughout the crystal structure. However, a crystal can have 1, 2, 3… directions of cleavage. It is important to note: (i) the number of cleavage directions, and (ii) their angular relationship:

1 direction; 2 directions at 90˚; 2 directions, inclined;
3 directions, cubic; 3 directions, rhombohedral;
4 directions, octahedral; 6 directions dodecahedral.

Cleavage



Cleavage - Definitions

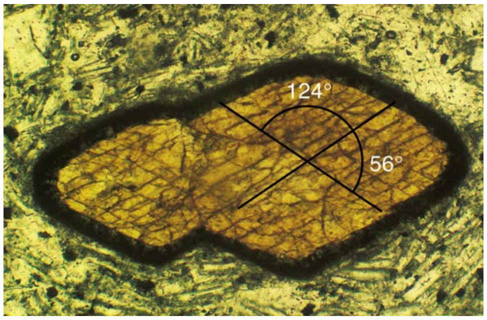
Minerals with **perfect** cleavage cleave without leaving any rough surfaces; a full, smooth plane is formed where the crystal broke.
Minerals with **good** cleavage also leave smooth surfaces, but often leave over some rough surfaces.
In minerals with **poor** cleavage, the smooth crystal edge is barely visible, since the rough surface is dominant.
Minerals with no cleavage (**none**) never exhibit any cleavage, thus broken surfaces are jagged and rough.
If a mineral exhibits cleavage, but it so poor that it is hardly noticeable, it has **"indistinct"** cleavage.

Parting

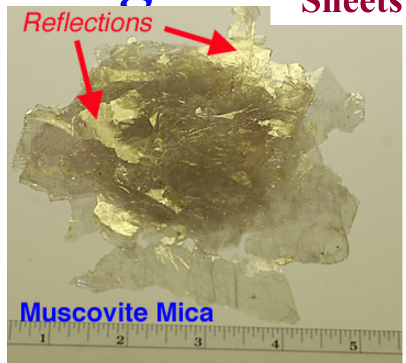
Characteristically similar to cleavage.
It is easily confused with cleavage, and is often present on minerals that do not exhibit any cleavage.
There are two causes of parting:
1. Two separate pressures pushed toward the center of a crystal after its formation, causing the crystal interior to evenly dislodge on a flat, smooth plane.
2. Twin crystals that separated from one another, leaving a flat, smooth plane.

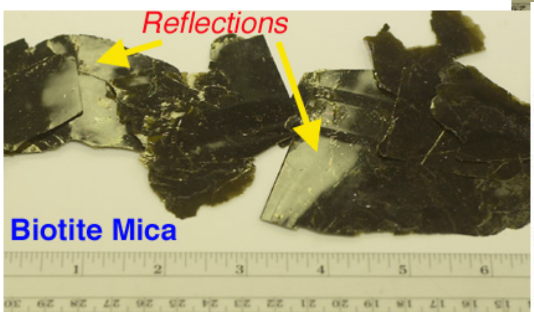
Cleavage

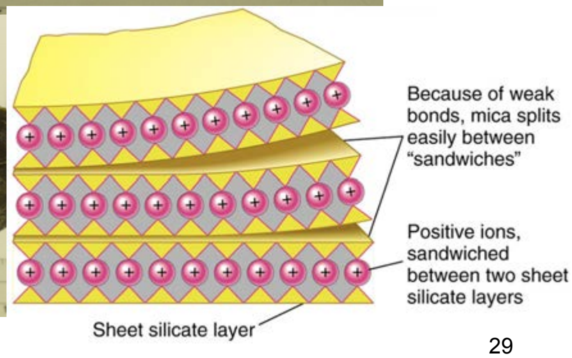
Amphibole



"Sheets" of Mica.

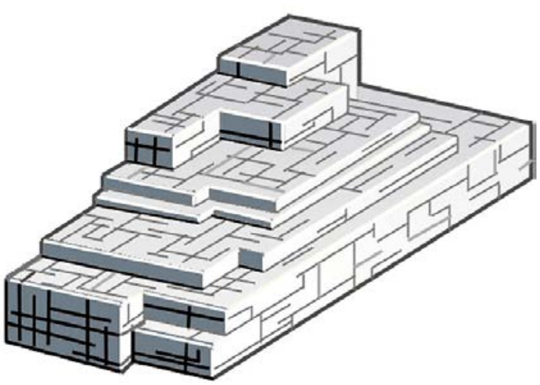




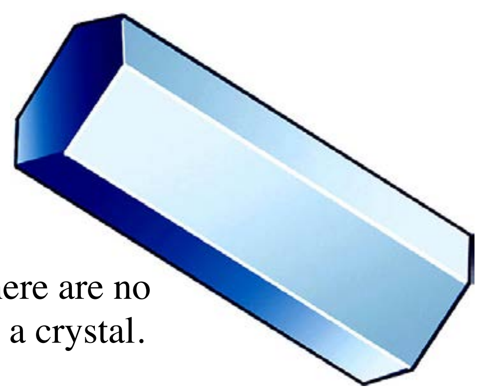


Crystal Face or Cleavage Plane

You can distinguish between cleavage planes and crystal faces because:



Cleavage planes can be repeated like a series of steps or terraces.



A crystal face is a single surface - there are no repetitions of the crystal face within a crystal.

Crystal Face - High bond density; Cleavage Plane – low bond density.

Fracture: the way a substance breaks where not controlled by cleavage. Described as: conchoidal, irregular, splintery, blocky, hackly.

Specific Gravity: unitless property, defined by

$$\frac{\text{mass of substance}}{\text{mass of equal vol. of } H_2O}$$

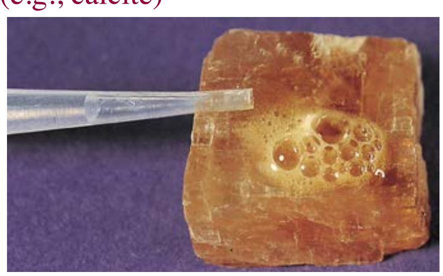
Ice:	**0.9**
Quartz:	**2.65**
Most silicates:	**2.5-3.0**
Galena	**7.5**
Gold	**19.3**

Special Properties

Magnetism: (e.g., Magnetite – Fe_3O_4; Pyrrhotite – FeS)

Striations: (e.g., Plagioclase)

Solubility in Acid: dilute HCl (e.g., calcite)



Play of Colors: *Schiller* affect (e.g., Ca-rich plagioclase).

Taste: Halite = salty; Sylvite = bitter.

Classification: Based upon the dominant ***anion*** or ***anionic group*** in the atomic structure.

Oxides (Hematite - Fe_2O_3; Corundum - Al_2O_3): O^{2-}

Silicates (Quartz – SiO_2; olivine – Mg_2SiO_4): $\left[Si^{4+}O_4^{2-}\right]^{4-}$

Carbonates (Calcite – $CaCO_3$): $\left[C^{4+}O_3^{2-}\right]^{2-}$

Hydroxides (Brucite – $Mg(OH)_2$): OH^-

Sulfates (Gypsum – $CaSO_4$ $(H_2O)_2$): $\left[S^{6+}O_4^{2-}\right]^{2-}$

Sulfides (Pyrite – FeS_2; Galena – PbS): S_2^{2-}

Halides (e.g., Halite – NaCl; Sylvite – KCl; Fluorite - CaF_2): F^-, Cl^-

Native Metals (e.g., Copper, Gold).

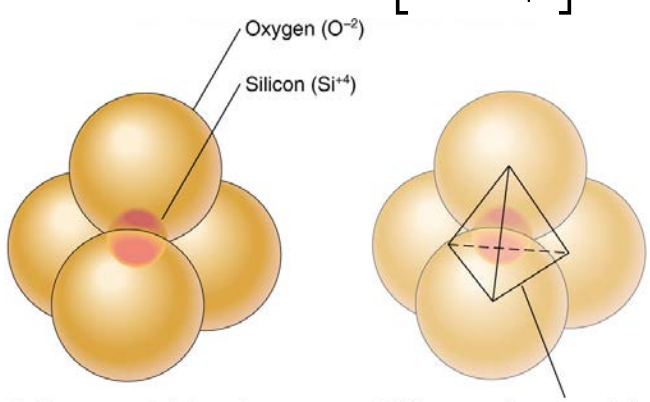
Silicates are important because:

Magma is usually silicate in composition: ~50-70 wt% SiO_2;
The rest is made up of Al_2O_3, Fe_2O_3, FeO, Na_2O MgO, K_2O, CaO, P_2O_5, TiO_2.
A continuous range of magma chemistries is observed.

Silicate Minerals:
Form the bulk of the Earth's crust.

Contain SiO_4 tetrahedra – a complex anion of:

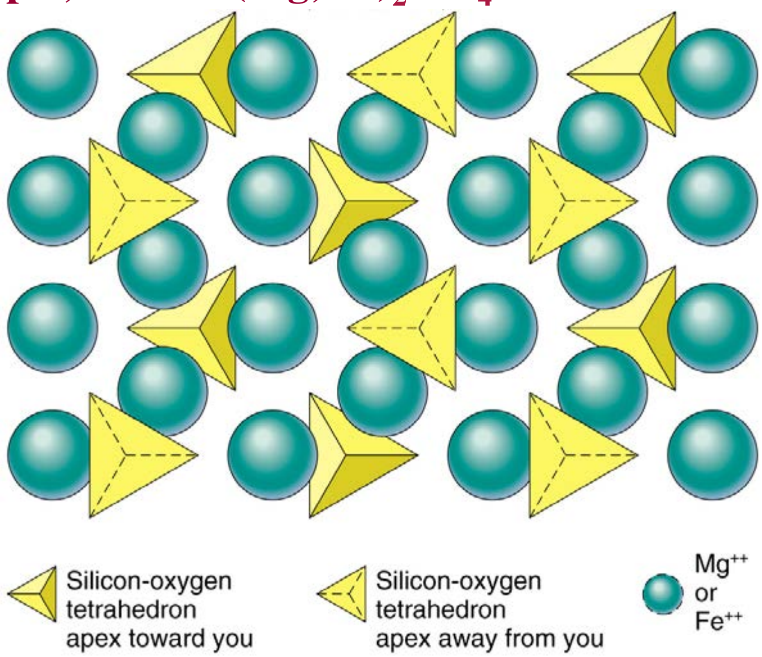
$$Si^{4+} + O^{2-} \rightarrow \left[Si^{4+}O_4^{2-}\right]^{4-}$$



A Arrangement of atoms in silicon-oxygen tetrahedron

B Diagrammatic representation of a silicon-oxygen tetrahedron

Silica tetrahedra may occur isolated in a crystal structure, with cations surrounding them. For example, Olivine $(Mg, Fe)_2SiO_4$



Polymerization of tetrahedra to form chains, double chains, rings, sheets and a 3D network.

Isolated tetrahedra: (*nesosilicates* or *orthosilicates*)

Paired silicate tetrahedra: (*sorosilicates*)

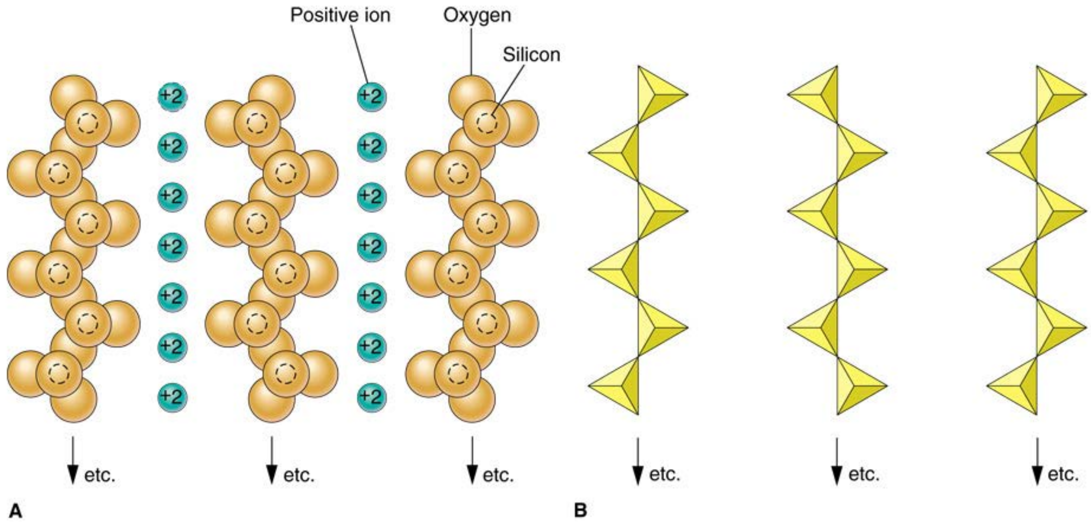
Silicate tetrahedra forming rings: (*cyclosilicates*)

Single & double chains of tetrahedra: (*inosilicates*)

Sheets of tetrahedra: (*phyllosilicates*)

3D framework of tetrahedra: (*tectosilicates*)

"Real" and Schematic Representations of Crystal Structures



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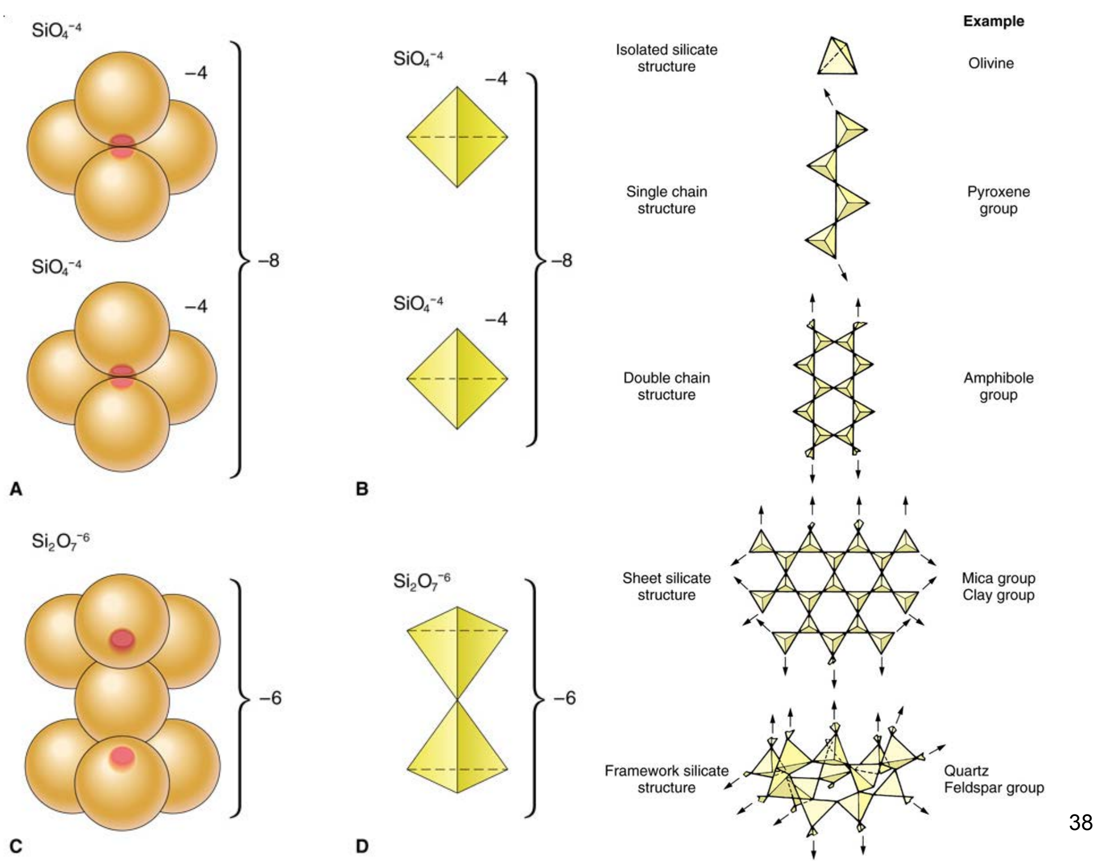

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Gemstones

Gemstone = mineral of value (rare).
Gem = a cut gemstone.
Pearl & Amber: biomineralization

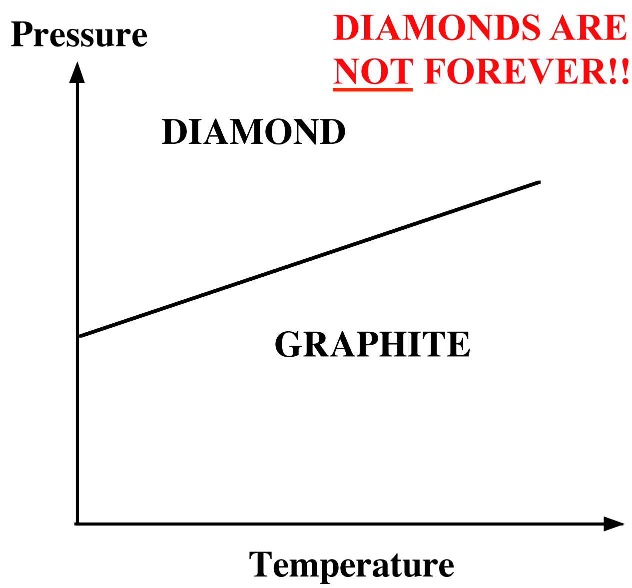
1 carat = 200 mg.

TABLE 5.2 Precious and Semi-Precious Materials

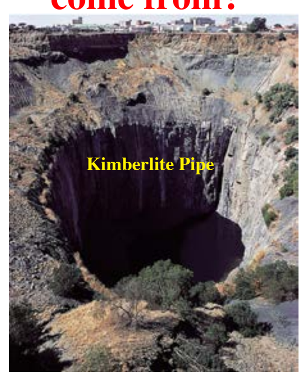
Gem Name	*Material/Formula*	*Comments*
Amber	Fossilized tree sap	Composed of organic chemicals; amber is not strictly a mineral.
Amethyst	Quartz/SiO_2	The best examples precipitate from water in openings in igneous rocks; a deep-purple version of quartz.
Aquamarine	Beryl/$Be_3Al_2Si_6O_{18}$	A bluish version of emerald.
Diamond	Diamond/C	Brought to the surface from the mantle in igneous bodies called diamond pipes; may later be mixed in deposits of sediment.
Emerald	Beryl/$Be_3Al_2Si_6O_{18}$	Occurs in coarse igneous rocks (pegmatites) (see Chapter 6).
Garnet	Garnet/(e.g., $Mg_3Al_2[SiO_4]_3$)	A variety of types differ in composition (Ca, Fe, Mg, and Mn versions); occurs in metamorphic rocks (see Chapter 8).
Jade	Jadeite/$NaAlSi_2O_6$ Nephrite/$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$	Jade can be one of two minerals, jadeite (a pyroxene) or nephrite (an amphibole); both occur in metamorphic rocks.
Opal	Composed of microscopic spheres of hydrated silica packed together	Most opal comes from a single mining district in central Australia; occurs in bedrock that has reacted with water near the surface.
Pearl	Aragonite/$CaCO_3$	Formed by oysters, which secrete coatings around sand grains that are accidentally embedded in the soft parts of the organism. Cultured pearls are formed the same way, but the impurity is a spherical bead that is intentionally introduced.
Ruby	Corundum/Al_2O_3	The red color is due to chromium impurities; found in coarse igneous rocks called pegmatites and as a result of contact metamorphism (see Chapters 6 and 8).
Sapphire	Corundum/Al_2O_3	A blue version of ruby.
Topaz	$Al_2SiO_4(F,OH)_2$	Found in igneous rocks, and as a result of the reaction of rock with hot water.
Tourmaline	$Na(Mg,Fe)_3Al_6(BO_3)_3(Si_6O_{18})(OH,F)_4$	Forms in igneous and metamorphic rocks.
Turquoise	$CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$	Found in copper-bearing rocks; a popular jewelry gem in the American Southwest.

Phase transition.
Diamond = metastable persistence.

DIAMONDS ARE NOT FOREVER!!



Where do diamonds come from?



Summary

Element: Atoms, Cations, Anions, Molecules.

Mineral definition, Mineralogist.

What is a Crystal? Definitions, Shape, Crystal Structure;

Chemical Bonds: Ionic, Covalent; Metallic, Hydrogen, van der Waals.

Packing: Cubic, Tetrahedral, Octahedral.

Formation: Solidification of a melt; Precipitation from solution; Solid state diffusion.

Mineral Properties: Color, Streak, Luster, Hardness, Crystal Form, Habit, Cleavage, Fracture, Specific Gravity, Magnetism, Striations, Reaction with acid, Play of colors, Double refraction.

Mineral Classification: Silicates; Oxides; Carbonates; Sulfates; Sulfides; Halides; Hydroxides; Native Metals.

Silicates: Nesosilicates; Sorosilicates; Cyclosilicates; Inosilicates; Phyllosilicates; Tectosilicates.

Gemstones, Diamonds.