

# Classification and Nomenclature of Minerals

Unit 3

# Introduction to Berzelian Classification

- \* The Berzelian mineral classification system was named in honor of the Swedish chemist and mineralogist Jons Jakob Berzelius (1779-1848).
- \* The Berzelian system categorizes mineral species according to the main anion group present in their chemical structure.
- \* All mineral species of a certain class are therefore chemically similar because they possess the same main anion group.
- \* Mineral classes may then be further subdivided according to physical features, which cations are present, the presence or absence of water or the hydroxyl anion, or internal structure.

# Introduction to Berzelian Classification

- \* The main classes which are recognized under Berzelius' scheme include the **native elements**; **sulfides** and **sulfosalts**; **oxides** and **hydroxides**; **halides**; **carbonates**, **nitrates** and **borates**; **sulfates**; **phosphates**; and **silicates**.
- \* The **antimonides**, **arsenides**, **selenides**, and **tellurides** closely resemble the **sulfides** in composition.
- \* The **chromates**, **molybdates** and **tungstates** resemble the **sulfates**.
- \* The **arsenates** and **vanadates** are closely akin to the **phosphates**.

# Periodic Table of Elements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18						
1	1 <b>H</b> Hydrogen 1.00794	Atomic # Symbol Name Atomic Mass																2 <b>He</b> Helium 4.002602						
2	3 <b>Li</b> Lithium 6.941	4 <b>Be</b> Beryllium 9.012182	<b>C</b> Solid		<b>Metals</b>								<b>Nonmetals</b>											
			<b>Hg</b> Liquid		Alkali metals		Alkaline earth metals		Lanthanoids		Transition metals	Poor metals	Other nonmetals	Noble gases										
			<b>H</b> Gas				Actinoids																	
3	11 <b>Na</b> Sodium 22.98976928	12 <b>Mg</b> Magnesium 24.3050	<b>Rf</b> Unknown																					
																			5 <b>B</b> Boron 10.811	6 <b>C</b> Carbon 12.0107	7 <b>N</b> Nitrogen 14.0067	8 <b>O</b> Oxygen 15.9994	9 <b>F</b> Fluorine 18.9984032	10 <b>Ne</b> Neon 20.1797
																			13 <b>Al</b> Aluminum 26.9815386	14 <b>Si</b> Silicon 28.0855	15 <b>P</b> Phosphorus 30.973762	16 <b>S</b> Sulfur 32.065	17 <b>Cl</b> Chlorine 35.453	18 <b>Ar</b> Argon 39.948
4	19 <b>K</b> Potassium 39.0983	20 <b>Ca</b> Calcium 40.078	21 <b>Sc</b> Scandium 44.955912	22 <b>Ti</b> Titanium 47.867	23 <b>V</b> Vanadium 50.9415	24 <b>Cr</b> Chromium 51.9961	25 <b>Mn</b> Manganese 54.938045	26 <b>Fe</b> Iron 55.845	27 <b>Co</b> Cobalt 58.933195	28 <b>Ni</b> Nickel 58.6934	29 <b>Cu</b> Copper 63.546	30 <b>Zn</b> Zinc 65.38	31 <b>Ga</b> Gallium 69.723	32 <b>Ge</b> Germanium 72.64	33 <b>As</b> Arsenic 74.92160	34 <b>Se</b> Selenium 78.96	35 <b>Br</b> Bromine 79.904	36 <b>Kr</b> Krypton 83.798						
5	37 <b>Rb</b> Rubidium 85.4678	38 <b>Sr</b> Strontium 87.62	39 <b>Y</b> Yttrium 88.90585	40 <b>Zr</b> Zirconium 91.224	41 <b>Nb</b> Niobium 92.90638	42 <b>Mo</b> Molybdenum 95.96	43 <b>Tc</b> Technetium (97.9072)	44 <b>Ru</b> Ruthenium 101.07	45 <b>Rh</b> Rhodium 102.90550	46 <b>Pd</b> Palladium 106.42	47 <b>Ag</b> Silver 107.8682	48 <b>Cd</b> Cadmium 112.411	49 <b>In</b> Indium 114.818	50 <b>Sn</b> Tin 118.710	51 <b>Sb</b> Antimony 121.760	52 <b>Te</b> Tellurium 127.60	53 <b>I</b> Iodine 126.90447	54 <b>Xe</b> Xenon 131.293						
6	55 <b>Cs</b> Caesium 132.9054519	56 <b>Ba</b> Barium 137.327	57–71		72 <b>Hf</b> Hafnium 178.49	73 <b>Ta</b> Tantalum 180.94788	74 <b>W</b> Tungsten 183.84	75 <b>Re</b> Rhenium 186.207	76 <b>Os</b> Osmium 190.23	77 <b>Ir</b> Iridium 192.217	78 <b>Pt</b> Platinum 195.084	79 <b>Au</b> Gold 196.966569	80 <b>Hg</b> Mercury 200.59	81 <b>Tl</b> Thallium 204.3833	82 <b>Pb</b> Lead 207.2	83 <b>Bi</b> Bismuth 208.98040	84 <b>Po</b> Polonium (209)	85 <b>At</b> Astatine (209)	86 <b>Rn</b> Radon (222.0176)					
7	87 <b>Fr</b> Francium (223)	88 <b>Ra</b> Radium (226)	89–103		104 <b>Rf</b> Rutherfordium (261)	105 <b>Db</b> Dubnium (262)	106 <b>Sg</b> Seaborgium (266)	107 <b>Bh</b> Bohrium (264)	108 <b>Hs</b> Hassium (277)	109 <b>Mt</b> Meitnerium (268)	110 <b>Ds</b> Darmstadtium (271)	111 <b>Rg</b> Roentgenium (272)	112 <b>Uub</b> Ununbium (285)	113 <b>Uut</b> Ununtrium (284)	114 <b>Uuq</b> Ununquadium (289)	115 <b>Uup</b> Ununpentium (288)	116 <b>Uuh</b> Ununhexium (292)	117 <b>Uus</b> Ununseptium	118 <b>Uuo</b> Ununoctium (294)					

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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57 <b>La</b> Lanthanum 138.90547	58 <b>Ce</b> Cerium 140.116	59 <b>Pr</b> Praseodymium 140.90766	60 <b>Nd</b> Neodymium 144.242	61 <b>Pm</b> Promethium (145)	62 <b>Sm</b> Samarium 150.36	63 <b>Eu</b> Europium 151.964	64 <b>Gd</b> Gadolinium 157.25	65 <b>Tb</b> Terbium 158.92535	66 <b>Dy</b> Dysprosium 162.500	67 <b>Ho</b> Holmium 164.93032	68 <b>Er</b> Erbium 167.259	69 <b>Tm</b> Thulium 168.93421	70 <b>Yb</b> Ytterbium 173.054	71 <b>Lu</b> Lutetium 174.9668
89 <b>Ac</b> Actinium (227)	90 <b>Th</b> Thorium 232.03806	91 <b>Pa</b> Protactinium 231.03688	92 <b>U</b> Uranium 238.02891	93 <b>Np</b> Neptunium (237)	94 <b>Pu</b> Plutonium (244)	95 <b>Am</b> Americium (243)	96 <b>Cm</b> Curium (247)	97 <b>Bk</b> Berkelium (247)	98 <b>Cf</b> Californium (251)	99 <b>Es</b> Einsteinium (252)	100 <b>Fm</b> Fermium (257)	101 <b>Md</b> Mendelevium (258)	102 <b>No</b> Nobelium (259)	103 <b>Lr</b> Lawrencium (262)

# Introduction to Berzelian Classification

- \* The **native elements** include all mineral species which are composed entirely of atoms in an uncombined state.
- \* Such minerals either contain the atoms of only one element or else are metal alloys.
- \* The native elements are divided into **metallic**, **semimetallic**, and **nonmetallic** subgroups.
- \* **Metals** tend to be dense and malleable substances which possess a characteristic metallic luster and conduct electricity well.
- \* **Semimetals** and **nonmetals** are brittle and conduct poorly compared to metals.

# Introduction to Berzelian Classification

- \* Minerals of the **sulfide class** are compounds which contain the nonmetallic element **sulfur** (S) in combination with atoms of a metal or a semimetal.
- \* Compounds in which anions of antimony (Sb), arsenic (As), selenium (Se), or tellurium (Te) replace the sulfur anion and bond with metallic or semimetallic cations are classed respectively as **antimonides**, **arsenides**, **selenides**, and **tellurides**.
- \* If the sulfur anion, a metallic element, and a semimetal are all present then the mineral is categorized as one of the rare **sulfosalts**.
- \* Most **sulfides** and **sulfosalts** are soft, dark, heavy, and brittle, possessing a distinct metallic luster and high conductivity.

# Introduction to Berzelian Classification

- \* The minerals of the **oxide class (O)** are those which contain oxygen bonded to one or more metallic elements.
- \* **Hydroxides** are compounds of a metallic element and water or the **hydroxyl anion (OH)<sup>-</sup>**.
- \* The oxide minerals tend to be relatively hard, and some of them may be used as gemstones.
- \* Many provide economically important metal ores.
- \* Minerals of the hydroxide class tend to be softer and less dense than oxides.



# Introduction to Berzelian Classification

- \* In members of the **halide class** an element of the halogen group such as fluorine (F), chlorine (Cl), bromine (Br), or iodine (I) bonds to a metal or semimetal cation such as sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), aluminum (Al), copper (Cu), or silver (Ag).
- \* Halides are constructed entirely of ionic bonds.
- \* The halide minerals tend to be soft, brittle, easily soluble in water, and possess medium to high melting points.
- \* They are poor conductors when in solid state.



# Introduction to Berzelian Classification

- \* Mineral species which are members of the **carbonate class** are compounds of a metal or semimetal with the carbonate anion ( $\text{CO}_3$ )<sup>2-</sup>.
- \* The plane triangular carbonate anion groups thus form the basic unit from which carbonate minerals are constructed.
- \* The **nitrates** are structurally very closely akin to the carbonates.
- \* Nitrogen bonds to three oxygen atoms to form the nitrate radical, ( $\text{NO}_3$ )<sup>-</sup>, which forms the basic building block of the minerals of this species.
- \* The nitrates tend to be softer and to possess lower melting points than the carbonates.

# Introduction to Berzelian Classification

- \* Atoms of the element boron (B) join to three oxygen atoms in order to form the **borate** radical,  $(\text{BO}_3)^{3-}$ .
- \* This anion group closely resembles the carbonate and nitrate radicals in structure.
- \* However, the oxygen atoms of the borate radical may, unlike those of the carbonate or nitrate radicals, be shared between anion groups.
- \* Borate radicals may therefore be linked into **polymerized chains, sheets, or multiple groups**.
- \* These are the chemical structures which compose the minerals of the borate class.

# Introduction to Berzelian Classification

- \* The sulfur cation may form very strong bonds with four oxygen atoms, producing the anion group **(SO<sub>4</sub>)<sup>2-</sup>**.
- \* This **sulfate** radical forms the basic structural unit of the minerals of the **sulfate class**.
- \* The sulfate radical does not share oxygen atoms and cannot polymerize.
- \* Minerals of the **chromate** class are compounds of metallic cations with the **chromate anion** group **(CrO<sub>4</sub>)<sup>2-</sup>**.

# Introduction to Berzelian Classification

- \* Just as sulfur and chromium form the anion groups  $(\text{SO}_4)^{2-}$  and  $(\text{CrO}_4)^{2-}$ , the ions of **molybdenum** (Mo) and **tungsten** (W) bond with oxygen atoms to create the anion groups  $(\text{MoO}_4)^{2-}$  and  $(\text{WO}_4)^{2-}$ .
- \* These anion groups then bond with metal cations to form the minerals of the **molybdate** and **tungstate** classes.
- \* Molybdenum and tungsten may freely substitute for one another within the ionic groups  $(\text{MoO}_4)^{2-}$  and  $(\text{WO}_4)^{2-}$ , allowing the formation of series of solid solution.
- \* They may not, however, substitute for sulfur within the sulfate radical  $(\text{SO}_4)^{2-}$  or form solid solution with minerals of the sulfate or chromate classes.
- \* Species of the molybdate and tungstate classes are typically heavy, soft, and brittle.
- \* They tend to be **dark or vividly colored**.

# Introduction to Berzelian Classification

- \* Like sulfur, the elements phosphorous (P), arsenic (As), and vanadium (V) form tetrahedral anion groups in combination with oxygen.
- \* The resulting **phosphate radical**,  $(\text{PO}_4)^{3-}$ , provides the basic structural unit of the minerals of the **phosphate** class; the **arsenate** class  $(\text{AsO}_4)^{3-}$  and **vanadate** class  $(\text{VaO}_4)^{3-}$ .
- \* The mineral species of these three classes are thus composed of the respective phosphate, arsenate, and vanadate radicals linked by various metal and semimetal cations.
- \* Phosphate, arsenic and vanadium ions may substitute for one another within the three anion groups, forming series of solid solution.

# Introduction to Berzelian Classification

- \* The basic constituent of the minerals of the silicate class is the **silicate radical**  $(\text{SiO}_4)^{4-}$ .
- \* Each oxygen atom within a silicate radical may bond with another silicon ion, becoming part of a second silicate radical and linking the two radicals together.
- \* One, two, three, or four of the oxygen atoms in each silicate anion group may bind to other silicate tetrahedra in this way.
- \* Many different structures are therefore possible; silicate radicals may remain structurally isolate, join together in pairs, or link into frameworks, sheets, chains, or rings.
- \* The various species of the silicate class are grouped according to their structural type.
- \* **Silicate minerals** are usually of relatively great hardness, and single crystals are often translucent.

# 1. Native Elements (Metals)

- \* The native elements are those minerals formed wholly from elements which occur in an uncombined state.
- \* No ionic or covalent bonding may join atoms of one element to atoms of another within the lattice structure of such a mineral.
- \* Usually only one type of atom is present in the molecular structure of these species.
- \* However, the metal alloys, which contain two or more metals in solid solution, are also classified as native elements because the different species of atom present in their lattices are joined only by metallic bonds, not by ionic or covalent bonds.
- \* The native elements are further categorized into subgroups containing metals, semimetals, and nonmetals.





# Native Elements (Metals)

- \* The most common native metals are members of the **gold group**.
- \* These include the elements **gold (Au)**, **silver (Ag)**, **copper (Cu)**, and **lead (Pb)**.
- \* Mineral species composed of uncombined atoms of the gold group elements possess face-centered cubic lattices, which schema is also known as cubic closest packing.
- \* This cubic closest packing results in a high number of atoms per unit volume and thus in a mineral of relatively high density.
- \* In such lattices there exist no atomic planes distinguished by higher or lower density; minerals of the gold group therefore demonstrate hackly fracture and possess no cleavage.



# Native Elements (Metals)

- \* Gold and silver atoms possess equal 1.44 angstrom atomic radii.
- \* These two substances are thus mutually soluble, and occur in mixtures with a wide range of relative compositions.
- \* Copper, however, has a radius of 1.28 angstrom.
- \* For this reason it is present only in tiny amounts within mixtures of gold and silver and conversely contains only tiny amounts of gold and silver in solution.



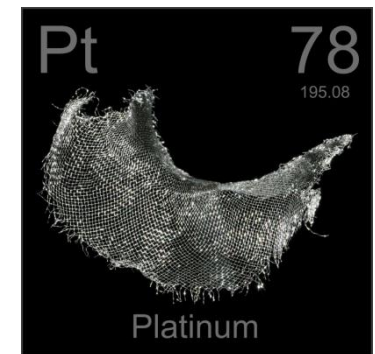
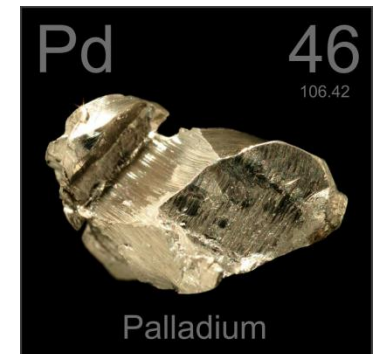
# Native Elements (Metals)

- \* The **iron group** contains iron (Fe) and nickel (Ni).
- \* These metals possess a body-centered cubic structure.
- \* Nickel and iron are mutually soluble because their atomic radii are both equal to 1.24 angstrom.
- \* This solid solution is frequently found in **meteorites** and probably constitutes much of the **earth's core**.



# Native Elements (Metals)

- \* Platinum (Pt), palladium (Pd), iridium (Ir), and osmium (Os) number among the less common metallic native elements and are classified as the **platinum group**.
- \* The mineral species which form from the uncombined atoms of these elements are **platinum, palladium, platiniridium and iridosmine**.
- \* Platiniridium is a rare alloy of iridium and platinum, while iridosmine is an equally rare alloy of iridium and osmium.
- \* Both alloys possess hexagonal close-packed structure, while platinum and palladium are cubic close packed.
- \* The metals of the platinum group are harder and possess higher melting points than those of the gold group



# Native Elements (Semi-metals)

- \* The native semi-metals include arsenic (As), antimony (Sb), and bismuth (Bi), as well as the less common elements selenium (Se) and tellurium (Te).
- \* Arsenic, antimony and bismuth crystallize in the hexagonal-scalenohedral class while selenium and tellurium crystallize in the trigonal-trapezoidal class.
- \* Natural crystals of all three species are rare.
- \* The semimetals are brittle, and conduct heat and electricity poorly compared to the metals. However, like the metals they display a metallic luster.
- \* The lattices of the semimetals are composed of bonds intermediate in type between metallic and covalent
- \* The semimetals thus display the unusual property of expansion upon crystallization





# Native Elements (Non-metals)

- \* The native **nonmetals** include carbon (C), in the form of diamond and graphite, and sulphur (S).
- \* The mineral species diamond and graphite offer a spectacular example of the trait of **polymorphism**.
- \* Polymorphism occurs when two or more mineral species contain exactly the same elements in exactly the same proportions, and therefore share a chemical formula, yet possess dissimilar lattice structures.
- \* Two polymorphic minerals possess identical chemical formulae but different crystal structures; the minerals may therefore exhibit very different physical traits.



# Polymorphism

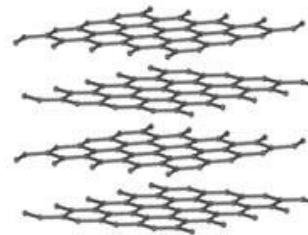
- \* Diamond possesses an exceptionally strong lattice in which each carbon atom is bonded by four covalent bonds to four neighboring carbon atoms, which occupy the apices of a regular tetrahedron.
- \* All four valence electrons are taken up by covalent bonds, so that none are free to conduct electricity; hence diamond forms a highly successful insulator.
- \* Graphite, on the other hand, is composed of sheets of six-atom rings in which each carbon has three neighboring atoms positioned at the corners of an equilateral triangle.
- \* Three valence electrons are occupied by covalent bonds; the fourth is free to act as a conductor of electricity. Graphite thus conducts relatively well.
- \* The sheets are stacked a distance much greater than one angstrom apart, and the van der Waals forces which bind the stacked sheets together are very weak. The wide separation and weak binding forces between parallel sheets result in perfect basal cleavage.

## Graphite vs Diamond

*Graphite*



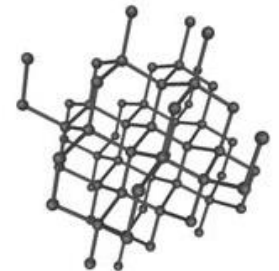
*Dull, opaque, soft, common*



*Diamond*



*Brilliant, transparent, hard, rare*





## 2. Sulfides, Antimonides, Arsenides, Selenides, Tellurides, and Sulfosalts

### Sulfides

- \* Sulfide minerals are compounds of one or more metal or semimetal elements with the nonmetallic element sulfur (S).
- \* In a sulfide, the sulfur anion ( $S^{2+}$ ) is thus combined with metallic cations such as iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), molybdenum (Mo), silver (Ag), cadmium (Cd), tin (Sn), platinum (Pt), gold (Au), mercury (Hg), tellurium (Tl), lead (Pb), and the semimetals arsenic (As), antimony (Sb), and bismuth (Bi).
- \* Compounds of sulfur and one of the semimetals are termed semimetal sulfides.
- \* Most sulfides are structured by ionic bonds, although some may contain metallic bonding and display metallic properties.

# Sulfides, Antimonides, Arsenides, Selenides, Tellurides, and Sulfosalts

## Antimonides, Arsenides, Selenides, Tellurides

- \* When the semimetals antimony (Sb), arsenic (As), selenium (Se), and tellurium (Te) occupy the role of a nonmetal and substitute for the sulfur anion, the minerals formed possess a chemical structure very similar to that of the sulfides.
- \* These are classified respectively as antimonides, arsenides, selenides, and tellurides according to which semimetal is present.
- \* Niccolite (NiAs): **Arsenide**, Calaverite (AuTe<sub>2</sub>): **Telluride**
- \* When the semimetals arsenic (As) and antimony (Sb) form compounds with sulfur, however, they occupy the role of a metal cation and the minerals which contain them are termed **semimetal sulfides**. Orpiment (As<sub>2</sub>S<sub>3</sub>) and Bismuthinite (Bi<sub>2</sub>S<sub>3</sub>).
- \* If a metal, a semimetal, and nonmetallic sulfur are all present then the mineral is categorized as one of the rare **sulfosalts**.

# Sulfides, Antimonides, Arsenides, Selenides, Tellurides, and Sulfosalts

## Sulfosalts

- \* The rare minerals which are compounds of sulfur (S), a semimetal such as arsenic (As) or antimony (Sb), and one or more metals are termed **sulfosalts**.
- \* In these species the semimetal plays the role of a metal.
- \* The mineral **cobaltite**, which possesses the chemical formula  $\text{CoAsS}$ , is a sulfosalt.
- \* The metallic element in this compound is cobalt (Co); the semimetal, which also donates electrons, is arsenic (As), and the nonmetal sulfur receives the electrons donated by both the cobalt and the arsenic.

# Antimonides, Arsenides, Selenides, Tellurides, and Sulfosalts

<b>AX</b> galena sphalerite chalcopyrite covellite cinnabar realgar niccolite breithauptite	PbS ZnS CuFeS <sub>2</sub> CuS HgS AsS NiAs NiSb	sulfide sulfide sulfide sulfide sulfide semimetal sulfide arsenide antimonide
<b>A<sub>2</sub>X</b> chalcocite	Cu <sub>2</sub> S	sulfide
<b>AX<sub>2</sub></b> pyrite cobaltite molybdenite calaverite	FeS <sub>2</sub> CoAsS MoS <sub>2</sub> AuTe <sub>2</sub>	sulfide sulfosalt sulfide telluride
<b>AX<sub>3</sub></b> skutterudite	CoAs <sub>3</sub>	sulfide
<b>A<sub>2</sub>X<sub>3</sub></b> orpiment bismuthinite	As <sub>2</sub> S <sub>3</sub> Bi <sub>2</sub> S <sub>3</sub>	semimetal sulfide semimetal sulfide
<b>A<sub>4</sub>S<sub>3</sub></b> pyrargyrite proustite	Ag <sub>3</sub> SbS <sub>3</sub> Ag <sub>3</sub> AsS <sub>3</sub>	sulfosalt sulfosalt

# Oxides and Hydroxides

## Simple and Multiple Oxides

- \* Members of the oxide class are minerals in which an oxygen anion is combined with one or more metals.
- \* The oxides can be divided into two categories consisting of **simple oxides**, which contain a single metallic element, and **multiple oxides**, which are compounds of oxygen and two or more metals.
- \* Simple oxides are compounds of a single metallic element and oxygen.
- \* Examples of such species include zincite (ZnO), tenorite (CuO), cuprite (Cu<sub>2</sub>O), rutile (TiO<sub>2</sub>), uraninite (UO<sub>2</sub>), corundum (Al<sub>2</sub>O<sub>3</sub>), hematite (Fe<sub>2</sub>O<sub>3</sub>), and magnetite (Fe<sub>3</sub>O<sub>4</sub>).
- \* Ice (H<sub>2</sub>O) provides an unusual example of a simple oxide in which hydrogen replaces a metal in order to act as the cation.
- \* Multiple oxides, in contrast, are compounds of oxygen with two or more metallic elements.
- \* Examples are ilmenite (FeTiO<sub>3</sub>), spinel (MgAl<sub>2</sub>O<sub>4</sub>), chromite (FeCr<sub>2</sub>O<sub>4</sub>), and chrysoberyl (BeAl<sub>2</sub>O<sub>4</sub>). Many of these species are colorful, relatively hard, and may be used as gemstones.

# 3. Oxides and Hydroxides

- \* The oxide class contains several metal ores of great economic importance.
- \* Among these are the iron ores, hematite and magnetite; chromite, an ore of chromium; manganite ( $\text{MnO}(\text{OH})$ ), which provides manganese; zincite, which contains zinc; and gibbsite ( $\text{Al}(\text{OH})_3$ ), which offers a source of aluminum.
- \* However, the oxides may alternatively be subdivided so that the chemical formula of each mineral species is categorized according to the ratio of metal to oxygen which it contains.
- \* If the capital letter A represents a metal atom, then the formulae  $\text{AO}$ ,  $\text{A}_2\text{O}$ ,  $\text{AO}_2$ ,  $\text{A}_2\text{O}_3$ , and  $\text{A}_3\text{O}_4$  each represent the chemical formulae of a group of mineral species.
- \* Examples of the **AO** type are provided by zincite ( $\text{ZnO}$ ) and tenorite ( $\text{CuO}$ ), while **cuprite** ( $\text{Cu}_2\text{O}$ ) offers an example of the **A<sub>2</sub>O** type. Species of the **AO<sub>2</sub>** type are **rutile** ( $\text{TiO}_2$ ) and **uraninite** ( $\text{UO}_2$ ). The **A<sub>2</sub>O<sub>3</sub>** type is represented by corundum ( $\text{Al}_2\text{O}_3$ ), hematite ( $\text{Fe}_2\text{O}_3$ ), and ilmenite ( $\text{FeTiO}_3$ ), while the **A<sub>3</sub>O<sub>4</sub>** type is represented by spinel ( $\text{MgAl}_2\text{O}_4$ ), magnetite ( $\text{Fe}_3\text{O}_4$ ), chromite ( $\text{FeCr}_2\text{O}_4$ ), and chrysoberyl ( $\text{BeAl}_2\text{O}_4$ ).

# Oxides and Hydroxides

## Hydroxides

- \* **Hydroxides** are compounds of metallic elements with water or the hydroxyl anion ( $\text{OH}^-$ ).
- \* Examples of hydroxides are manganite ( $\text{MnO}(\text{OH})$ ), goethite ( $\text{FeO}(\text{OH})$ ), and gibbsite ( $\text{Al}(\text{OH})_3$ ; one of the main components of bauxite).
- \* Minerals of the hydroxide class are typically softer than oxides and are of low to medium density.
- \* In terms of chemical composition, quartz ( $\text{SiO}_2$ ) is a member of the oxide class. However in terms of molecular structure, which in the Berzelian classification system is considered to be more fundamental than chemical composition, quartz is classified as a silicate.



# 4. Halides

- \* The halide class is composed of minerals in which an element of the halogen group such as fluorine (F), chlorine (Cl), bromine (Br), or iodine (I) provides the anion.
- \* Halides have ionic bonds.
- \* Both cations and anions behave as almost spherical bodies which pack in a highly symmetric manner; most common halites possess isometric hexoctahedral crystalline structure.
- \* The halides tend to be soft, brittle, easily soluble in water, and possess medium to high melting points.
- \* They are poor conductors of heat and electricity when in solid state but good conductors when molten.
- \* Example members of the halide class are the mineral species **halite** ( $\text{NaCl}$ ; also known as rock salt), **sylvite** ( $\text{KCl}$ ), **fluorite** ( $\text{CaF}_2$ ), and **chlorargyrite** ( $\text{AgCl}$ , also known as horn silver).



# 5. Carbonates

- \* Mineral species which are members of the **carbonate** class are compounds of a metal or semimetal with the carbonate anion  $(\text{CO}_3)^{2-}$ .
- \* The bond between the carbon and the two oxygen atoms of the  $(\text{CO}_3)^{2-}$  anion is strong.
- \* However, when brought in contact with the hydrogen ion ( $\text{H}^+$ ) the carbonate radical decomposes, producing carbon dioxide and water.
- \* Minerals of the carbonate class thus react easily with acids such as hydrochloric acid (HCl).
- \* For example, calcite (calcium carbonate,  $\text{CaCO}_3$ ) effervesces when placed in an aqueous solution of HCl, producing carbon dioxide and calcium chloride:



- \* This reaction provides a means for the identification of carbonate species which is easily applicable in the field.

# Carbonates

## Anhydrous Carbonates

- \* The anhydrous carbonates lack both the hydroxyl anion ( $\text{OH}^-$ ) and water ( $\text{H}_2\text{O}$ ) in their chemical formulae.
- \* These carbonates are divided into three isostructural groups, called the calcite group, the dolomite group, and the aragonite group.
- \* The **calcite group** contains **calcite** ( $\text{CaCO}_3$ ), **magnesite** ( $\text{MgCO}_3$ ), **rhodocrosite** ( $\text{MnCO}_3$ ), and **siderite** ( $\text{FeCO}_3$ ).
- \* Each of these minerals is composed of the carbonate anion and cations of a single metal.
- \* Although the bonds within the carbonate anion are covalent, the bonds between the carbonate anion and the metal cation are ionic
- \* Members of the calcite group are also called the rhombohedral carbonates, because the unit cell and the cleavage both form rhombohedra.

# Carbonates

## Anhydrous Carbonates

- \* **The dolomite group** contains the minerals dolomite ( $\text{CaMg}(\text{CO}_3)_2$ ) and ankerite ( $\text{CaFe}(\text{CO}_3)_2$ ).
- \* Each of these species contains the semimetal calcium and a metal cation together with the carbonate anion.
- \* Like the members of the calcite group, those of the dolomite group adhere to the rhombohedral crystal system.
- \* The **aragonite group** is composed of the orthorhombic carbonates, of **which aragonite** ( $\text{CaCO}_3$ ), **strontianite** ( $\text{SrCO}_3$ ) and **cerussite** ( $\text{PbCO}_3$ ) provide examples.
- \* The members of the aragonite group adhere to the orthorhombic crystal system rather than the rhombohedral crystal system preferred by the calcite and dolomite groups.
- \* Structurally calcite and aragonite are thus quite different.

# Polymorphism in Calcite and Aragonite

- \* The two different mineral species calcite and aragonite both possess the chemical formula  $\text{CaCO}_3$ .
- \* Although chemically identical, these two species are structurally very different; calcite crystalizes according to the rhombohedral crystal system while aragonite crystalizes according to the orthorhombic crystal system.
- \* Aragonite is harder and has a higher specific gravity than calcite.
- \* Two mineral species such as calcite and aragonite which are chemically identical and yet differ structurally and possess different physical properties are said to be **polymorphs**.

# Carbonates

## Hydrous Carbonates

- \* The **hydrous carbonates** consist of the **copper carbonates**, which contain both copper and the hydroxyl radical ( $\text{OH}^-$ ).
- \* The **copper carbonates** azurite ( $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$ ), malachite ( $\text{Cu}_2\text{CO}_3(\text{OH})_2$ ), and aurichalcite ( $\text{Cu}_5(\text{CO}_3)_2(\text{OH})_6$ ) contain both copper and the hydroxyl anion ( $\text{OH}^-$ ).
- \* The element copper is a strong pigmenting agent and renders **azurite a bright, distinctive azure blue, malachite a vivid green, and aurichalcite green to blue**.
- \* Both azurite and malachite are of the monoclinic crystal system while aurichalcite is of the orthorhombic crystal system.
- \* Malachite frequently forms a pseudomorph of azurite; azurite is less stable than malachite, and gradually inverts to it over long periods of time.



# 6. Nitrates

- \* The **nitrates** are chemically closely akin to the carbonates.
- \* Nitrogen bonds to three oxygen atoms in a structure very similar to the carbonate anion group  $(\text{CO}_3)^{2-}$ .
- \* This nitrate radical,  $(\text{NO}_3)^-$ , forms the basic building block of the nitrates.
- \* Because nitrogen is more electronegative than carbon, the nitrate anion group  $(\text{NO}_3)^-$  is less stable than  $(\text{CO}_3)^{2-}$ .
- \* Mineral species of the nitrate class thus tend to occur less frequently in geologic formations than do the carbonates.
- \*  $(\text{NO}_3)^-$  is less charged than  $(\text{CO}_3)^{2-}$ ; the nitrates tend therefore to be softer than the carbonates and also to possess lower melting points.
- \* The nitrates yield oxygen as the nitrate anion decomposes upon heating.



# Nitrates

- \* Several mineral species of the nitrate class form structures analogous to certain of the carbonates.
- \* For example, **nitratine** (or soda niter; **NaNO<sub>3</sub>**) and the carbonate calcite (**CaCO<sub>3</sub>**) are isostructural and possess the same rhombohedral cleavage.
- \* Nitratine is softer than calcite and melts at a lower temperature, both of which are expected of a nitrate as compared to a carbonate).
- \* **Niter** (**KNO<sub>3</sub>**, known colloquially as saltpeter) is in turn isostructural with the orthorhombic carbonate aragonite (**CaCO<sub>3</sub>**).

# 7. Borates

- \* The boron atom joins to three oxygen atoms to form the borate radical,  $(\text{BO}_3)^{3-}$ .
- \* After this anion group has formed, each oxygen atom still has one electron available for bonding.
- \* Thus the oxygen atoms of the borate radical may, unlike those of the carbonate or nitrate radicals, be shared between anion groups.
- \* Borate radicals may therefore be linked into polymerized chains, sheets, or multiple groups.
- \* The most common **borate minerals** are composed of sheets of radicals which are linked together through the sharing of all three oxygen atoms.
- \* Two example members of the borate class are borax, which possesses the chemical formula  $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ , and **colemanite**,  $\text{Ca}_2\text{B}_5\text{O}_{11} \cdot 5\text{H}_2\text{O}$ .

# 8. Sulfates

- \* The sulfur cation forms very strong bonds with four oxygen atoms, producing the anion group  $(\text{SO}_4)^{2-}$ .
- \* This sulfate radical forms the basic structural unit of the minerals of the sulfate class.
- \* All members of the sulfate class contain the tetrahedral sulfate radical  $(\text{SO}_4)^{2-}$ .
- \* These tightly bound anion groups do not share oxygen atoms and cannot polymerize.

# Sulfates

## Anhydrous Sulfates

- \* **Anhydrous sulfates** contain neither water molecules ( $\text{H}_2\text{O}$ ) nor the hydroxyl anion ( $\text{OH}^-$ ) within their lattice structures.
- \* The anhydrous sulfates consist of the **barite group** and the mineral species **anhydrite** ( $\text{CaSO}_4$ ).
- \* The members of the barite group include barite ( $\text{BaSO}_4$ ), celestite ( $\text{SrSO}_4$ ), and anglesite ( $\text{PbSO}_4$ ).
- \* These species are isostructural and may form a solid solution by exchanging atoms of strontium and lead for those of barium.
- \* The minerals of the barite group all possess orthorhombic symmetry, as does anhydrite.

# Sulfates

## Hydrous Sulfates

- \* Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) is the most prevalent and important of the **hydrous sulfates**.
- \* It possesses a sheet like structure which consists of layers of calcium ions and sulfate anions separated by water molecules ( $\text{H}_2\text{O}$ ).
- \* Gypsum demonstrates perfect cleavage along planes parallel to its sheet like layers.
- \* If the water is driven out of the gypsum structure, the mineral will collapse into the configuration of anhydrite ( $\text{CaSO}_4$ ) with a marked decrease in volume and loss of the perfect cleavage.
- \* Gypsum is frequently formed during the alteration of anhydrite.



# 9. Chromates

- \* Minerals of the chromate class are compounds of metallic cations with the chromate anion group  $(\text{CrO}_4)^{2-}$ .
- \* The species of this class of minerals are very rare.
- \* The lead chromate crocoite ( $\text{PbCrO}_4$ ) is isostructural with the sulfates of the barite group ( $\text{BaSO}_4$ ).
- \* This rare mineral is found in the oxidized zones of lead-bearing veins, particularly in places where lead veins have encountered rocks containing chromite.
- \* Due to the strong pigmenting capabilities of chromium, crocoite is a bright orange-red in color while its streak is orange.

# 10. Molybdates and Tungstates

- \* Just as sulfur and chromium form the anion groups  $(\text{SO}_4)^{2-}$  and  $(\text{CrO}_4)^{2-}$ , the ions of molybdenum (Mo) and tungsten (W) bond with oxygen atoms to create the anion groups  $(\text{MoO}_4)^{2-}$  and  $(\text{WO}_4)^{2-}$ .
- \* These anion groups then bond with metal cations to form the minerals of the molybdate and tungstate classes.
- \* Minerals containing the molybdate or tungstate anion groups are categorized as members of the molybdate or tungstate classes.
- \* These two classes are then further subdivided into the **wolframite** and **scheelite** groups.



# 11. Phosphates, Arsenates, and Vanadates

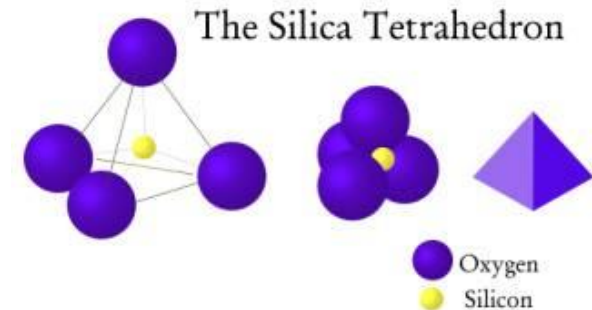
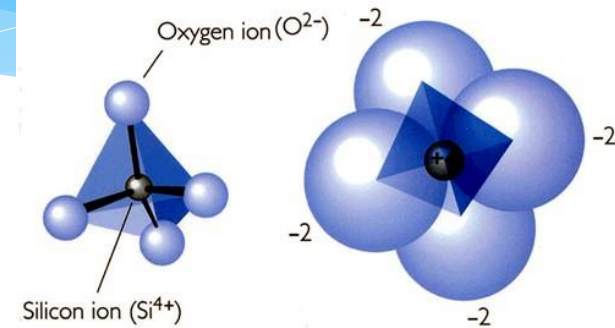
- \* Like sulfur, the elements phosphorous (P), arsenic (As), and vanadium (V) form tetrahedral anion groups in combination with oxygen.
- \* The resulting radical, provides the basic structural unit of the minerals of the **phosphate class** ( $\text{PO}_4$ )<sup>3-</sup>; the **arsenate class** ( $\text{AsO}_4$ )<sup>3-</sup> and the **vanadate class** ( $\text{VaO}_4$ )<sup>3-</sup>.
- \* The mineral species of these three classes are thus composed of the respective phosphate, arsenate, and vanadate radicals linked by various metal and semimetal cations.
- \* Phosphate, arsenic and vanadium ions may substitute for one another within the three anion groups, forming series of solid solution.
- \* The **apatite group** contains mineral species of each of the phosphate, arsenate, and vanadate classes.

# 12. Silicates

- \* The fundamental constituent of the minerals of the silicate class is the silicate radical  $(\text{SiO}_4)^{4-}$ .
- \* This anion group is composed of one silicon atom bonded to four oxygen atoms, which occupy the apices of a regular tetrahedron.
- \* The bond which holds the silicon and oxygen atoms together within the silicate radical is partially ionic and partially covalent.
- \* Silicates make up about 95 percent of the Earth's crust.
- \* They are abundant for two reasons:
  - \* First, silicon and oxygen are the two most abundant elements in the crust.
  - \* Second, silicon and oxygen combine readily.

# Silicates

- \* Every silicon atom surrounds itself with four oxygens.
- \* The bonds between each silicon and its four oxygens are very strong.
- \* The silicon atom and its four oxygens form a pyramid-shaped structure called the silicate tetrahedron with silicon in the center and oxygens at the four corners.
- \* The silicate tetrahedron has a 4- charge and forms the  $(\text{SiO}_4)^{4-}$  complex anion. The silicate tetrahedron is the fundamental building block of all silicate minerals.
- \* To make silicate minerals electrically neutral, other cations must combine with the silicate tetrahedra to balance their negative charges.
- \* Silicate tetrahedra commonly link together by sharing oxygens. Thus, two tetrahedra may share a single oxygen, bonding the tetrahedra together



# Silicates

- \* The various species of the silicate class are grouped according to their structural type.
- \* The silicate anions may exist as **isolated tetrahedra**, **paired tetrahedra**, **single or double chains**, **rings**, **sheets**, or **three-dimensional boxlike structures**.
- \* Groups of minerals containing such structures are given the respective terms **nesosilicates**, **sorosilicates**, **inosilicates**, **cyclosilicates**, **phyllosilicates** and **tectosilicates**.
- \* Minerals of the silicate class are responsible for providing the bulk material out of which the earth's crust and mantle are formed. (Silicates form 95% of the crust and 97% of the mantle).
- \* Silicate minerals are usually of relatively great hardness, and single crystals are often translucent.

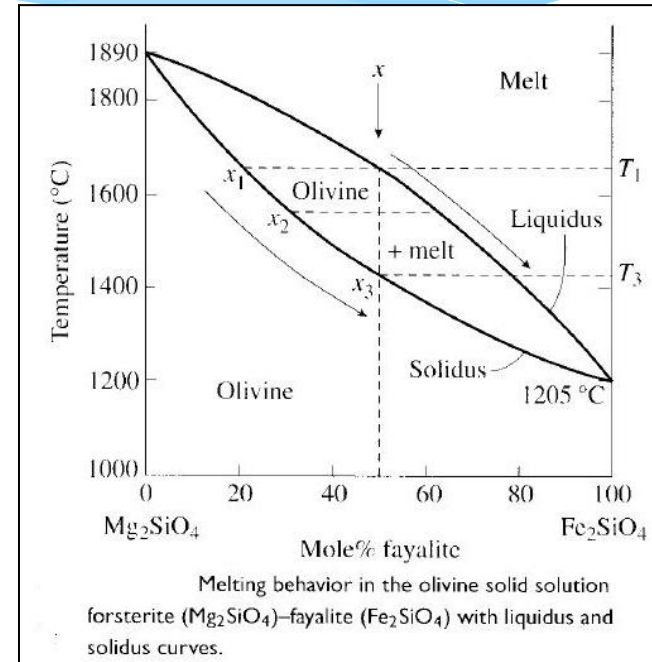
# Nesosilicates (Island Silicates)



- \* If the corner oxygens are not shared with other  $\text{SiO}_4^{4-}$  tetrahedrons, each tetrahedron will be isolated.
- \* Thus, this group is often referred to as the island silicate group.
- \* The basic structural unit is then  $\text{SiO}_4^{4-}$ . In this group the oxygens are shared with octahedral groups that contain other cations like  $\text{Mg}^{+2}$ ,  $\text{Fe}^{+2}$ , or  $\text{Ca}^{+2}$ .
- \* Examples of the nesosilicates are provided by members of the **olivine group**, which contains forsterite ( $\text{Mg}_2(\text{SiO}_4)$ ) and fayalite ( $\text{Fe}_2(\text{SiO}_4)$ ); as well as members of the **garnet group**; zircon ( $\text{Zr}(\text{SiO}_4)$ ); and topaz ( $\text{Al}_2(\text{SiO}_4)(\text{F},\text{OH})_2$ ).

# Nesosilicates (Island Silicates)

- \* The olivines consist of a complete solid solution between  $\text{Mg}_2\text{SiO}_4$  (forsterite, Fo) and  $\text{Fe}_2\text{SiO}_4$  (fayalite, Fa).
- \* The phase diagram for the common end members of the olivine solid solution series shows that pure forsterite melts at  $1890^\circ\text{C}$  and pure fayalite melts at  $1205^\circ\text{C}$ .
- \* Thus, the olivines are sometimes seen to be zoned from Mg-rich cores to more Fe-rich rims, although such zoning is usually limited to 5 to 10% difference between the cores and the rims.



# Nesosilicates (Island Silicates)

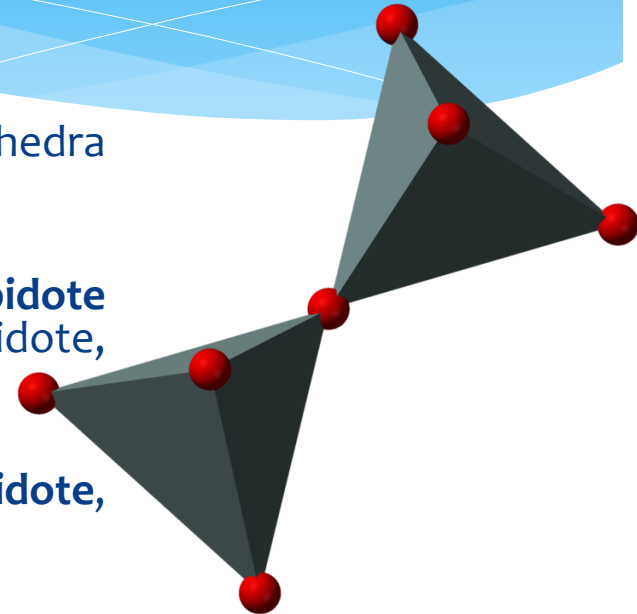
## OLIVINE

- \* Pure forsterite is limited to metamorphosed Mg-rich limestones and dolomitic metamorphic rocks.
- \*  $\text{Fo}_{90-95}$  is found in ultrabasic igneous rocks, particularly dunites (>90% by volume olivine), and peridotites (Olivine + Cpx + Opx).
- \*  $\text{Fo}_{60-90}$  is found in basic igneous rocks like basalts and gabbros, and sometimes in andesites, where it occurs with plagioclase and pyroxene.
- \*  $\text{Fa}_{100-40}$  is found in Fe-rich siliceous igneous rocks like rhyolites and granites.
- \* Mg-rich olivines rarely occur in quartz bearing rocks and quartz rarely occurs with Mg-rich olivine.
- \* The olivines are orthorhombic (2/m2/m2/m) and usually green colored in hand specimen.



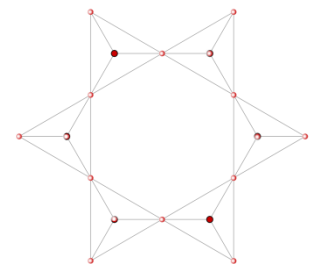
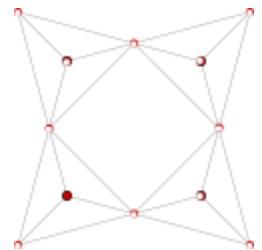
# Sorosilicates

- \* **Sorosilicates** are the double island silicates.
- \* In the **sorosilicates** or **couplet silicates** two silicate tetrahedra are linked into a pair by sharing a single oxygen ion.
- \* The most prevalent sorosilicates are members of the **epidote group** and are characterized by the mineral epidote,  $\text{Ca}_2(\text{Al,Fe})\text{Al}_2\text{O}(\text{SiO}_4)(\text{Si}_2\text{O}_7)(\text{OH})$ .
- \* The important minerals in the epidote group are **epidote**, **clinozoisite**, and **zoisite**.
- \* Epidote is a common mineral in low grade metamorphic rocks, particularly metamorphosed volcanic rocks and Fe-Al rich meta shales.
- \* Both Clinozoisite and epidote occur as alteration products of plagioclase and as veins in granitic rocks.



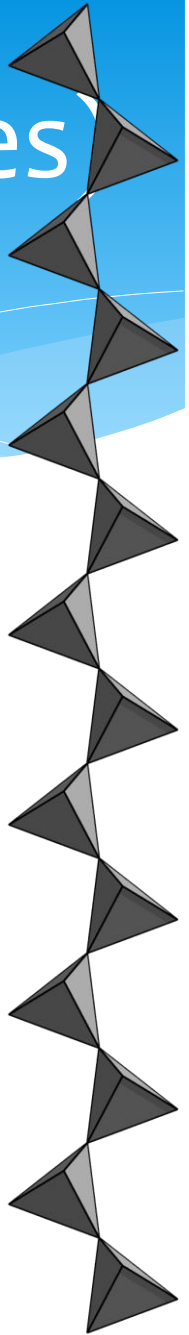
# Cyclosilicates

- \* The cyclosilicates are based on rings of  $\text{SiO}_4$  tetrahedra, with a Si:O ratio of 1:3.
- \* The most common minerals based on this structure are **Beryl**, **Cordierite**, and **Tourmaline**.
- \* Three possible ring configurations exist; these are the  $\text{Si}_3\text{O}_9$  ring; the  $\text{Si}_4\text{O}_{12}$  ring; and the  $\text{Si}_6\text{O}_{18}$  ring, which is found in beryl and tourmaline.
- \* The  $\text{Si}_6\text{O}_{18}$  rings are hexagonal and arranged in planar sheets.
- \* In beryl these parallel sheets are so strongly bonded together by beryllium and aluminum cations that they demonstrate only poor cleavage.
- \* Two example members of the cyclosilicate group are **beryl** ( $\text{Be}_3\text{Al}_2(\text{Si}_6\text{O}_{18})$ ), of which varieties are known as **aquamarine**, **morganite**, and **emerald**, and **tourmaline** ( $\text{Na}(\text{Mg,Fe})_3\text{Al}_6(\text{BO}_3)_3(\text{Si}_6\text{O}_{18})(\text{OH,F})_4$ ).



# Inosilicates (Single Chain Silicates)

- \* The single chain silicates have a basic structural unit consisting of linked  $\text{SiO}_4$  tetrahedra that each share 2 of their oxygens in such a way as to build long chains of  $\text{SiO}_4$ .
- \* The basic structural group is thus  $\text{Si}_2\text{O}_6$  with an Si:O ratio of 1:3.
- \* The most important inosilicates are the pyroxenes.



# Inosilicates (Single Chain Silicates)

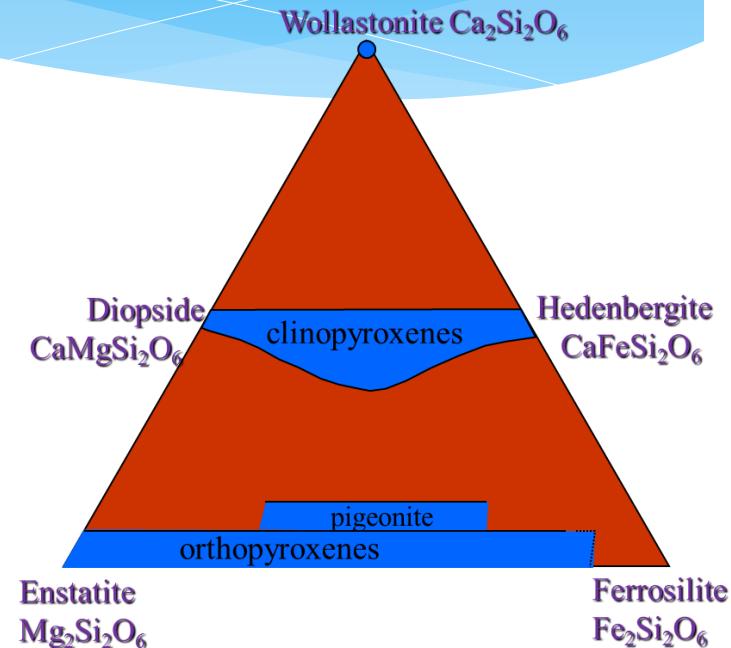
- \* The pyroxenes can be divided into several groups based on chemistry and crystallography:

- \* **Orthorhombic Pyroxenes (Orthopyroxenes - Opx)**

- \* These consist of a range of compositions between enstatite -  $\text{MgSiO}_3$  and ferrosilite -  $\text{FeSiO}_3$

- \* **Monoclinic Pyroxenes (Clinopyroxenes - Cpx)**

- \* The Diopside-Hedenbergite series - Diopside ( $\text{CaMgSi}_2\text{O}_6$ ) - Ferrohedenbergite ( $\text{CaFeSi}_2\text{O}_6$ )
- \* The Sodic Pyroxenes - Jadeite ( $\text{NaAlSi}_2\text{O}_6$ ) and Aegerine ( $\text{NaFe}^{+3}\text{Si}_2\text{O}_6$ )
- \* **Augite** is closely related to the diopside - Hedenbergite series with addition of Al and minor Na substitution -  $(\text{Ca,Na})(\text{Mg,Fe,Al})(\text{Si,Al})_2\text{O}_6$
- \* **Pigeonite** is also a monoclinic pyroxene with a composition similar to the orthopyroxenes with more Ca substituting for Fe, and Mg.



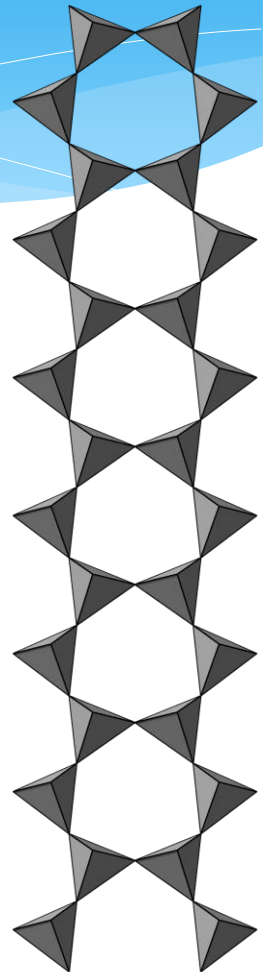
# Inosilicates (Single Chain Silicates)

## Occurrence of the Pyroxenes

- \* **Augite** - is commonly found in both plutonic and volcanic igneous rocks, as well as high grade meta-igneous rocks like gneisses and granulites. It is easily distinguished from amphiboles by the nearly 90° cleavage angles.
- \* **Hypersthene** - is commonly found in both plutonic and volcanic igneous rocks and in meta-igneous rocks as well.
- \* **Pigeonite** - is generally only found in volcanic igneous rocks, although, as mentioned above, it can occur as exsolution lamellae in augites of more slowly cooled igneous rocks.
- \* **Aegerine Augite** - are sodic pyroxenes and thus are found in alkalic igneous rocks associated with sodic amphiboles, alkali feldspars, and nepheline.
- \* **Jadeite** - is a sodium aluminum pyroxene that is characterized by its presence in metamorphic rocks formed at relatively high pressure.

# Inosilicates (Double Chain Silicates)

- \* In order to form double chains, half of the silicate radicals share three oxygens rather than two, while the other half continue to share two; the extra bonds affix two chains together into a double chain.
- \* The amphibole group of minerals is based on the double-chain silicate structure as shown here.
- \* The basic structural unit is  $(\text{Si}_4\text{O}_{11})^{-6}$ .



# Inosilicates (Double Chain Silicates)

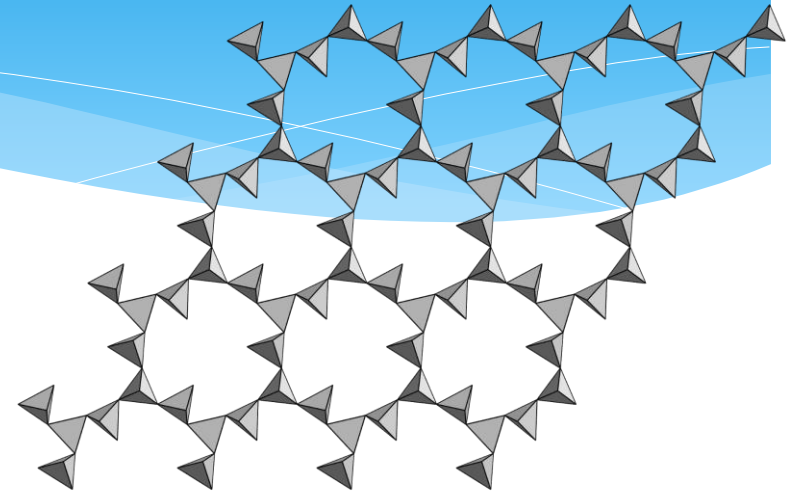
## Occurrence of the Amphiboles

- \* **Tremolite** - Occurs almost exclusively in low grade metamorphic rocks, particularly those with a high Ca concentration, such as meta-dolomites, meta-ultrabasic rocks.
- \* Tremolite in hand specimen is white in color and shows a fibrous habit and the characteristic amphibole cleavage.
- \* **Actinolite** - Also occurs almost exclusively in low grade metamorphic rocks, particularly in meta-basalts and meta-gabbros where it is commonly associated with chlorite.
- \* It is green in hand specimen and shows the characteristic amphibole cleavage, usually showing an elongated habit.
- \* **Hornblende** - is a common mineral in both igneous and metamorphic rocks.
- \* In igneous rocks it is found in andesites, dacites, and rhyolites, as well as in gabbros, diorites, and granites.
- \* In metamorphic rocks it is a common constituent of meta-basalts that have been metamorphosed to intermediate grades of regional metamorphism (amphibolites).
- \* In hand specimen it is dark brown to black in color and shows the characteristic amphibole cleavage.



# Phyllosilicates

- \* The **phyllosilicates** or **layer silicates** contain sheetlike planes of  $(\text{SiO}_4)^{4-}$  tetrahedra in which three of the four possible oxygen atoms are shared between different silicate tetrahedra.
- \* The term 'phyllosilicate' is derived from the Greek word phyllon, or 'leaf'; because of their sheeted structure the phyllosilicates tend to cleave into flakes or leaves.
- \* All members of the phyllosilicate group therefore have platy or flaky habit and display a single, prominent cleavage. Such minerals are soft and possess a low specific gravity.
- \* Example members of the phyllosilicate class are **kaolinite**  $(\text{Al}_4(\text{Si}_4\text{O}_{10})(\text{OH})_4)$ , which is a major component of clay, **serpentine**  $(\text{Mg}_6(\text{Si}_4\text{O}_{10})(\text{OH})_8)$ , **talca**  $(\text{Mg}_3(\text{Si}_4\text{O}_{10})(\text{OH})_2)$ , **muscovite**  $(\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{OH})_2)$  and **biotite**  $(\text{KMg}_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2)$



# Phyllosilicates

## Occurrence of the Phyllosilicate minerals

- \* **Talc** has the chemical formula -  $\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$ .
- \* It is probably best known for its low hardness.
- \* It is found in low grade metamorphic rocks that originated as ultrabasic to basic igneous rocks.
- \* Rocks composed almost entirely of talc have a greasy feel and are referred to as **soapstone**.
- \* Talc is most easily distinguished in hand specimen by its low hardness, greasy feel, and association with other Mg-bearing minerals.

# Phyllosilicates

## Occurrence of the Phyllosilicate minerals

- \* **Mica Group: Muscovite** and **Biotite** are the most common micas, but the Lithium- rich, pink mica, Lepidolite,  $\text{K}(\text{Li},\text{Al})_2\text{AlSi}_3\text{O}_{10}(\text{OH})_2$  is also common, being found mostly in pegmatites.
- \* **Muscovite** is common constituent of Al-rich medium grade metamorphic rocks where is found in Al-rich schists and contributes to the schistose foliation found in these rocks.
- \* Muscovite is also found in siliceous, Al-rich plutonic igneous rocks (muscovite granites).
- \* Muscovite is easily identified in hand specimen by its white to sometimes light brownish color and its perfect cleavage

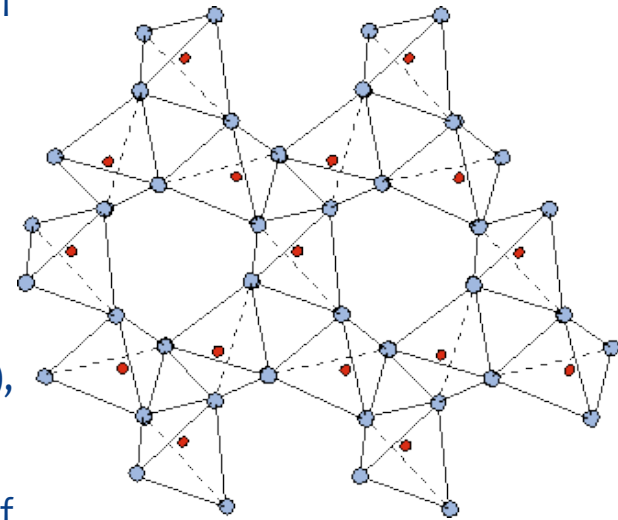
# Phyllosilicates

## Occurrence of the Phyllosilicate minerals

- \* **Biotite:** Nearly pure **phlogopite** is found in hydrous ultrabasic rocks like kimberlite, and is also found in metamorphosed dolomites.
- \* Biotite, with more Fe-rich compositions is common in dacitic, rhyolitic, and trachytic volcanic rocks, granitic plutonic rocks, and a wide variety of metamorphic rocks.
- \* In metamorphic rocks, biotite usually shows a preferred orientation with its forms parallel to the schistose foliation.
- \* In hand specimen, Biotite is brown to black and shows the perfect micaceous cleavage.

# Tectosilicates

- \* The **tectosilicates** or **framework silicates** are constructed in the form of a three-dimensional framework of  $(\text{SiO}_4)^{4-}$  tetrahedra.
- \* In this structure all four of the oxygen ions belonging to each silicate tetrahedra are shared with nearby tetrahedra, forging a stable and strongly bonded network. The ratio of silicon to oxygen in this type of structure is 1:2.
- \* The **silica minerals (Quartz)** are a subgroup of the tectosilicates.
- \* The **feldspar group** forms another subgroup of the tectosilicates.
- \* The feldspars are aluminum silicates which contain potassium (K), sodium (Na), or calcium (Ca) cations.
- \* Orthoclase ( $\text{K}(\text{AlSi}_3\text{O}_8)$ ) and albite ( $\text{Na}(\text{AlSi}_3\text{O}_8)$ ) offer two examples of feldspar minerals.
- \* A third subgroup of the tectosilicates is composed of the **zeolites**, which are hydrous aluminum silicates.



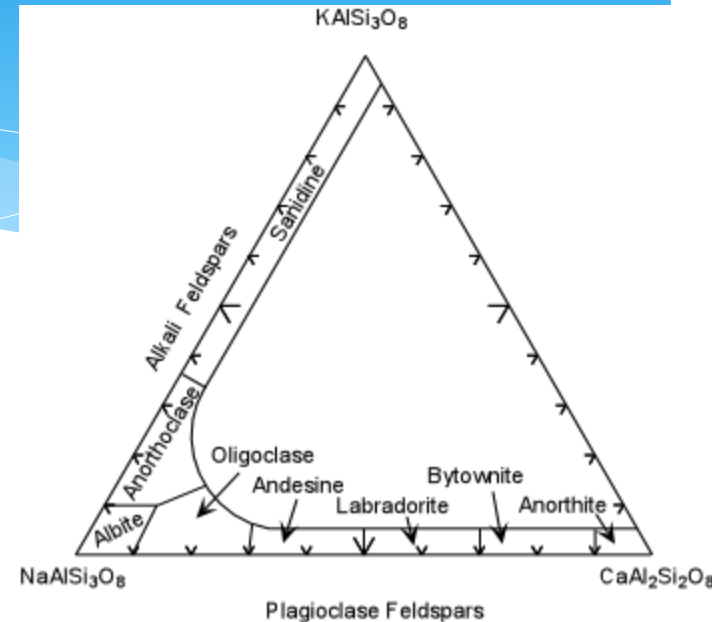
# Tectosilicates

- \* **Quartz:** Quartz is hexagonal and commonly occurs as crystals ranging in size from microscopic to crystals weighing several tons.
- \* Where it crystallizes unhindered by other crystals, such as in cavities in rock or in a liquid containing few other crystals, it shows well-developed hexagonal prisms and sometimes showing apparent hexagonal pyramids or dipyramid.
- \* It is also found as microcrystalline masses, such as in the rock chert, and as fibrous masses, such as in chalcedony.
- \* As visible crystals, Quartz is one of the more common rock forming minerals.
- \* It occurs in siliceous igneous rocks such as volcanic rhyolite and plutonic granitic rocks.
- \* It is common in metamorphic rocks at all grades of metamorphism, and is the chief constituent of sand.
- \* Because it is highly resistant to chemical weathering, it is found in a wide variety of sedimentary rocks.

# Tectosilicates

## Feldspars

- \* The feldspars are the most common minerals in the Earth's crust.
- \* They consist of three end-members: **KAlSi<sub>3</sub>O<sub>8</sub> - Orthoclase (or), NaAlSi<sub>3</sub>O<sub>8</sub> - Albite (ab), and CaAl<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> - Anorthite (an)**
- \* KAlSi<sub>3</sub>O<sub>8</sub> and NaAlSi<sub>3</sub>O<sub>8</sub> form a complete solid solution series, known as the **alkali feldspars** and NaAlSi<sub>3</sub>O<sub>8</sub> and CaAl<sub>2</sub>Si<sub>2</sub>O<sub>8</sub> form a complete solid solution series known as the **plagioclase feldspars**.
- \* The Alkali Feldspars form a complete solid solution between ab and or, with up to 5% of the an component.
- \* The high temperature more K-rich variety is called **Sanidine** and the more Na-rich variety is called **anorthoclase**.
- \* The plagioclase feldspars are a complete solid solution series between **Albite** and **Anorthite**.



**Albite**  
**Oligoclase**  
**Andesine**  
**Labradorite**  
**Bytownite**  
**Anorthite**



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- \* Plagioclase occurs in basalts, andesites, dacites, rhyolites, gabbros, diorites, granodiorites, and granites.
- \* Plagioclase also occurs in a wide variety of metamorphic rocks.
- \* Plagioclase can be a component of clastic sedimentary rocks, although it is less stable near the Earth's surface than alkali feldspar and quartz, and usually breaks down to clay minerals during weathering.