Bharathidasan University
Tiruchirappalli – 620 023, Tamil Nadu

6 Yr. Int. **M.Tech. Geological Technology & Geoinformatics** programme

Course Code: MTIGT0306

CRYSTALLOGRAPHY AND MINERALOGY

UNIT–5 : MINERAL GROUPS

Georgius Agricola, 'Father of Mineralogy'

German scientist '**Georg Bauer**' - named by birth;
his *First book on Mineralogy was published during* 1530
*entitled : **'Bermannus, sive de re metallica dialogus'***
(A description of the ore mountain-Ergebrge, Silver mining district)

René Just Haüy (1743 –1822)
"**Father of Modern Crystallography**"

French (Paris) Mineralogist generally known as **Abbé Haüy**

Prepared by
Dr. K.Palanivel
Professor, Department of Remote Sensing

Syllabus

- 1. **Elements of Crystallography**: Crystalline and Amorphous forms - Symmetry and Classification of Crystals - System of Crystal Notation - (Weiss and Millerian) - Forms and Habits. Crystal Systems (Isometric, Tetragonal, Hexagonal, Orthorhombic, Monoclinic, Triclinic, Twinning - Crystalline Aggregates – Columnar, Fibrous, Lamellar, Granular - Imitative shapes and Psudomorphism. **12 Hrs.**

- 2. **Crystal Properties:** Space Symmetry Elements- Translation – Rotation- Reflection - Inversion Screw and Glide-point groups and Crystal classes - Derivation of 32 Crystal classes based on Schoenflies notation - Bravais lattices and their Derivation - An outline of Space Groups. X-ray Crystallography. **12 Hrs.**

- 3. **Physical Mineralogy**: Physical Properties: (Colour – Structure – Form – Luster - Transparency – Streak – Hardness – Specific Gravity – Tenacity – Feel – Taste – Odour) - Electrical, Magnetic and Thermal properties-Determination of Specific Gravity (Jolly's spring balance, Walker's steel yard, Pycnometer methods) - Empirical and Structural formula of minerals – Isomorphism, Polymorphism and Psudomorphism - Atomic substitution and Solid solution in minerals - Non Crystalline minerals - Fluorescence in minerals - Metamict state. **16 Hrs.**

- 4. **Optical Mineralogy:** Optical Properties (Colour – Form – Cleavage - Refractive Index - Relief – Alteration – Inclusions – Zoning – Pleochroism – Extinction - Polarization colours – Birefringence) – Twinning - Optic sign (Uniaxial and biaxial)- Interference figures - Primary and Secondary Optic axes - Optic axial angle measurements – Optic Orientation – Dispersion in Crystals - Optic anomalies. **12 Hrs.**

- 5. **Mineral Groups:** Ortho and Ring Silicates (Olivine group - Garnet group). Alumino silicates (Epidote group - Zircon – Staurolite – Beryl - Cordierite and Tourmaline). Sheet Silicates (Mica group - Chlorite group and Clay minerals) - Chain Silicates (Pyroxene group - Amphibole group and Wollastonite). Frame work Silicates (Quartz -Feldspar - Feldspathoid - Zeolite and Scapolite groups) - Non-silicate (Spinel group, Carbonates and Phosphates). **12 Hrs.**

6. **Current Contours: (Not for Exam, only for Discussion):** Preparation of Field Kit for testing and identifying minerals during field survey; preparation of mineral and crystal samples for making thin sections, x-ray crystallographic studies. Lean how minerals together form different types of rocks.

References:

1. Berry Mason, L.G,Mineralogy, W.H. Freeman & co - 1961.
2. D. Perkins, (2002), Mineralogy, 2nd Edition, Pearson Education (Singapore) Pte. Ltd, Delhi, 483pp, ISBN 81-7808-831-2
3. W. D. Nesse, (2000), Introduction to Mineralogy, Oxford University Press, ISBN 0-19- 510691-1
4. Naidu, P.R.J,. Optical Crystallography.
5. Wahlstrom, E.F, Optical Crystallography, John wiley, 1960.
6. Azaroff, L.V,Elements of X-ray Crystallography, 1968.
7. Deer, W.A, Howie, R.A and J.Zussman, LongmansAn Introduction to the Rock Forming Minerals, 1966.
8. Alexander N.Winchell,Elements of Optical Mineralogy, Part I and II,Wiley Eastern (p) Ltd, 1968
9. Ernest, E.Walhstrom, Optical Crystallography, John Wiley & Sons.1960.
10. Kerr B.F,Optical Mineralogy. Mc Graw Hill, 5 th Edition, New York-1995.
11. Mitra, S,Fundamentals of Optical Spectroscopic and X-ray Mineralogy.

Course outcomes:

After the successful completion of this course, the students are able to:

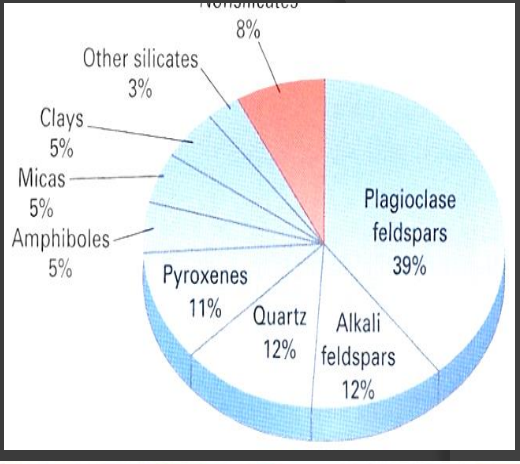
- **Gain knowledge about the source minerals as raw materials for anything on the Earth and for the survival of life**
- **Independently able to classify the crystals based on symmertical elements and face indices**
- **Understand various physical, chemical and optical properties of minerals so as to discriminate them**
- **Provide ideas about the major existence of rock forming silicates at the surface of the Earth**
- **Understand the various properties of mineral groups**
- **Know the crystal and mineral forms and their habits**

UNIT – 5 MINERAL GROUPS

- 5. **Mineral Groups:** Ortho and Ring Silicates (Olivine group - Garnet group). Alumino silicates (Epidote group - Zircon – Staurolite – Beryl - Cordierite and Tourmaline). Sheet Silicates (Mica group - Chlorite group and Clay minerals) - Chain Silicates (Pyroxene group - Amphibole group and Wollastonite). Frame work Silicates (Quartz -Feldspar - Feldspathoid - Zeolite and Scapolite groups) - Non-silicate (Spinel group, Carbonates and Phosphates).

ROCK FORMING MINERALS

1. Silicates



Structures of Silicates

- Independent tetrahedron
- Single Chain tetrahedron
- Double Chain
- Sheet structure
- Framework silicates

Table 2–1 Abundances of chemical elements in the earth's crust*

Element and symbol	Percentage by weight	Percentage by number of atoms	Percentage by volume
Oxygen (O)	46.6	62.6	93.8*
Silicon (Si)	27.7	21.2	0.9
Aluminum (Al)	8.1	6.5	0.5
Iron (Fe)	5.0	1.9	0.4
Calcium (Ca)	3.6	1.9	1.0
Sodium (Na)	2.8	2.6	1.3
Potassium (K)	2.6	1.4	1.8
Magnesium (Mg)	2.1	1.9	0.3
All other elements	1.5		
	100.0	100.0†	100.0†

*Note the high percentage of oxygen in the earth's crust.

†Includes only the first eight elements.

(Based on B. Mason, *Principles of Geochemistry*, New York, John Wiley & Sons, Inc., 1966.)

2. Non-silicates

Non-Silicates	a. Metallic	b. Non-metallic
Native Elements	Gold-Au, Silver-Ag, Copper-Cu, Platinum-Pt	Graphite, Diamond-C, Sulphur-S
Halides	Fluorite-CaF_2	Ammonium Bromide, Ammonium Iodide
Oxides	Hematite-Fe_2O_3, Bauxite-Al Hydroxide, Magnetite-FeO	Ice crystals-H_2O, BO
Sulphides	Pyrite-FeS_2, Galena-PbS, Sphalerite-ZnS	N_4S_4, F_4S_3
Sulphates	Gypsum-$CaSO_4.H_2O$, Barite-$BaSO_4$	Iodosyl Sulphate $(IO)_2SO_4$
Chlorides	Halite-NaCl, Sylvite-KCl	Hydrogen Chloride-HCl
Carbonates	Calcite-$CaCO_3$, Magnesite-$MgCO_3$, Rhodochrosite-$MnCO_3$, Witherite-$BaCO_3$	Ammonium Carbonate $(NH_4)_2CO_3$
Phosphates	Apatite-$Ca_5(PO_4)_3(OH)$ Turquoise-$CuAl_6(PO_4)_4(OH)_8 \cdot 5H_2O$	Phosphoric acid-H_3PO_4

Rock-Forming Minerals

MINERAL	COMPOSITION	PRIMARY OCCURRENCE
Ferromagnesian silicates		
Olivine	$(Mg,Fe)_2SiO_4$	Igneous, metamorphic rocks
Pyroxene group		
Augite most common	Ca, Mg, Fe, Al silicate	Igneous, metamorphic rocks
Amphibole group		
Hornblende most common	Hydrous* Na, Ca, Mg, Fe, Al silicate	Igneous, metamorphic rocks
Biotite	Hydrous K, Mg, Fe silicate	All rock types
Nonferromagnesian silicates		
Quartz	SiO_2	All rock types
Potassium feldspar group		
Orthoclase, microcline	$KAlSi_3O_8$	All rock types
Plagioclase feldspar group	Varies from $CaAl_2Si_2O_8$ to $NaAlSi_3O_3$	All rock types
Muscovite	Hydrous K, Al silicate	All rock types
Clay mineral group	Varies	Soils and sedimentary rocks
Carbonates		
Calcite	$CaCO_3$	Sedimentary rocks
Dolomite	$CaMg(CO_3)_2$	Sedimentary rocks
Sulfates		
Anhydrite	$CaSO_4$	Sedimentary rocks
Gypsum	$CaSO_4 \cdot 2H_2O$	Sedimentary rocks
Halides		
Halite	NaCl	Sedimentary rocks

*Contains elements of water in some kind of union.

Table 2–5 Common rock-forming silicate minerals

Silicate mineral	Composition	Physical properties
Quartz	Silicon dioxide (silica, SiO_2)	Hardness of 7 (on scale of 1 to 10); will not cleave (fractures unevenly); specific gravity: 2.65
Potassium feldspar group	Aluminosilicates of potassium	Hardness of 6.0–6.5; cleaves well in two directions; pink or white; specific gravity: 2.5–2.6
Plagioclase feldspar group	Aluminosilicates of sodium and calcium	Hardness of 6.0–6.5; cleaves well in two directions; white or gray; may show striations on cleavage planes; specific gravity: 2.6–2.7
Muscovite mica	Aluminosilicates of potassium with water	Hardness of 2–3; cleaves perfectly in one direction, yielding flexible thin plates; colorless; transparent in thin sheets; specific gravity: 2.8–3.0
Biotite mica	Aluminosilicates of magnesium, iron, potassium, with water	Hardness of 2.5–3.0; cleaves perfectly in one direction, yielding flexible thin plates; black to dark brown; specific gravity: 2.7–3.2
Pyroxene group	Silicates of aluminum, calcium, magnesium, and iron	Hardness of 5–6; cleaves in two directions at 90°; black to dark green; specific gravity: 3.1–3.5
Amphibole group	Silicates of aluminum, calcium, magnesium, and iron	Hardness of 5–6; cleaves in two directions at 56° and 124°; black to dark green; specific gravity: 3.0 3.3
Olivine	Silicate of magnesium and iron	Hardness of 6.5–7.0; light green; transparent to translucent; specific gravity: 3.2–3.6
Garnet group	Aluminosilicates of iron, calcium, magnesium, and manganese	Hardness of 6.5–7.5; uneven fracture, red, brown, or yellow; specific gravity: 3.5–4.3

TABLE 2.3 Important Mineral Groups

Group	Member	Formula	Economic Use
Oxides	Hematite	Fe_2O_3	Ore of iron
	Magnetite	Fe_3O_4	Ore of iron
	Corundum	Al_2O_3	Gemstone, abrasive
	Ice	H_2O	Solid form of water
	Chromite	$FeCr_2O_4$	Ore of chromium
Sulfides	Galena	PbS	Ore of lead
	Sphalerite	Zns	Ore of zinc
	Pyrite	FeS_2	Fool's gold
	Chalcopyrite	$CuFeS_2$	Ore of Copper
	Bornite	Cu_5FeS_4	Ore of copper
	Cinnabar	HgS	Ore of mercury
Sulfates	Gypsum	$CaSO_4 \cdot 2H_2O$	Plaster
	Anhydrite	$CaSO_4$	Plaster
	Barite	$BaSO_4$	Drilling mud
Native elements	Gold	Au	Electronics, jewelry
	Copper	Cu	Electronics
	Diamond	C	Gemstone, abrasive
	Sulfur	S	Sulfa drugs, chemicals
	Graphite	C	Pencil lead, dry lubricant
	Silver	Ag	Jewelry, photography
	Platinum	Pt	Catalyst
Halides	Halite	$NaCl$	Common salt
	Fluorite	CaF_2	Used in steel making
	Sylvite	KCl	Fertilizer
Carbonates	Calcite	$CaCO_3$	Portland cement
	Dolomite	$CaMg(CO_3)_2$	Portland cement
	Aragonite	$CaCO_3$	Portland cement
Hydroxides	Limonite	$FeO(OH) \cdot nH_2O$	Ore of iron, pigments
	Bauxite	$Al(OH)_3 \cdot nH_2O$	Ore of aluminum
Phosphates	Apatite	$Ca_5(F,Cl,OH)(PO_4)_3$	Fertilizer
	Turquoise	$CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$	Gemstone
Silicates	(Silicate minerals make up 92 percent of the Earth's crust. Figure 2.13 summarizes the rock-forming minerals.)		

The Silicate Class

- The silicates are the largest, the most interesting and the most complicated class of minerals by far.
- Approximately 30% of all minerals are silicates and
- some geologists estimate that 90% of the Earth's crust is made up of silicates.
- With oxygen and silicon, the two most abundant elements in the earth's crust – thus silicates are in abundance.

- The basic chemical unit of silicates is the (**SiO4**) tetrahedron shaped anionic group with a negative four charge (-4).

- The central silicon ion has a charge of positive four while each oxygen has a charge of negative two (-2) and

- thus each silicon-oxygen bond is equal to one half (1/2) the total bond energy of oxygen.

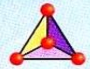
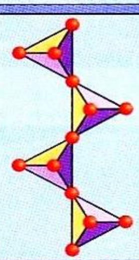
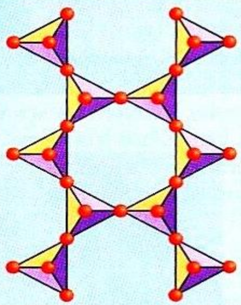
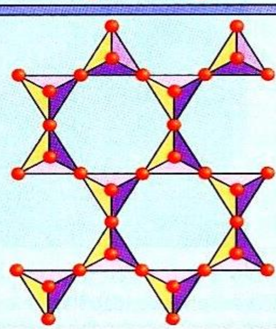
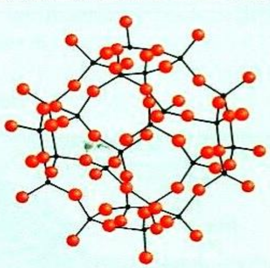
- This condition leaves the oxygens with the option of bonding to another silicon ion and therefore linking one (**SiO4**) tetrahedron to another and another, etc.

- **The structures formed by SiO_4 tetrahedron are, single units, double units, chains, sheets, rings and framework structures.**

- **The different ways that the silicate tetrahedrons combine is what makes the Silicate Class the largest, the most interesting and the most complicated class of minerals.**

The Silicates are divided into the following subclasses, not by their chemistries, but by their *structures*:

1. Nesosilicates / Orthosilicates ***(Single Tetrahedrons)*** – No Oxygen atom is shared – $(SiO_4)^{4-}$ - *Eg.* ***Olivine*** *- Mg_2SiO_4 - Fe_2SiO_4.*
2. Sorosilicates ***(Double Tetrahedrons) -*** $(Si_2O_7)^{6-}$ *- Eg.* ***Hemimorphite***
3. Inosilicates ***(3a. Single chains*** *–each tetrahedron shares two Oxygens with adjacent tetrahedra, forming a chain –* $(SiO_3)^{2-}$ ***Eg. Pyroxenes - Augite***
4. ***and 3b. Double chains –***a pair of single chains that are cross-linked by additional Oxygen sharing***)*** - $(Si_4O_{11})^{6-}$ ***– E.g. Amphiboles - Hornblende***
5. Cyclosilicates ***(Rings) -*** $(Si_6O_{18})^{12-}$ *- Eg.* ***Beryl***
6. Phyllosilicates ***(Sheets) -*** $(Si_2O_5)^{2-}$*- Eg.* ***Phlogophite***
7. Tectosilicates ***(Frameworks) -*** SiO_2 *– Eg.* ***Quartz****;* ***Orthoclase***

Class	Arrangement of SiO_4 tetrahedron	Unit composition	Mineral examples
(A) Independent tetrahedra		$(SiO_4)^{4-}$	Olivine: The composition varies between Mg_2SiO_4 and Fe_2SiO_4
(B) Single chains		$(SiO_3)^{2-}$	Pyroxene: The most common pyroxene is augite, Ca(Mg, Fe, Al)(Al, $Si)_2O_6$
(C) Double chains		$(Si_4O_{11})^{6-}$	Amphibole: The most common amphibole is hornblende, $NaCa_2$(Mg, Fe, $Al)_5$(Si, $Al)_8O_{22}(OH)_2$
(D) Sheet silicates		$(Si_2O_5)^{2-}$	Mica, clay minerals, chlorite, e.g.: muscovite, $KAl_2(Si_3Al)O_{10}(OH)_2$
(E) Framework silicates		SiO_2	Quartz: SiO_2 Feldspar: As an example, potassium feldspar is $KAlSi_3O_8$

The five silicate structures are based on sharing of oxygen atoms among silicate tetrahedra.

(A) An **Independent tetrahdra** share no Oxygen atoms.

(B) In **single chains**, each tetrahedron shares two Oxygens with adjacent tetrahedra, forming a chain.

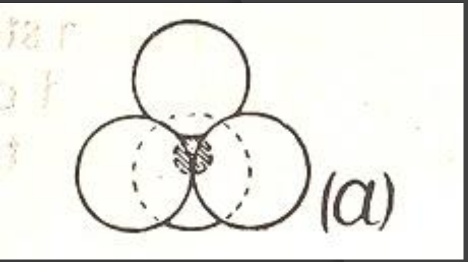
(C) A **double chain** is a pair of single chains that are cross-linked by additional Oxygen sharing.

(D) In **sheet silicates** each tetrahedron shares three Oxygens with adjacent tetrahedra.

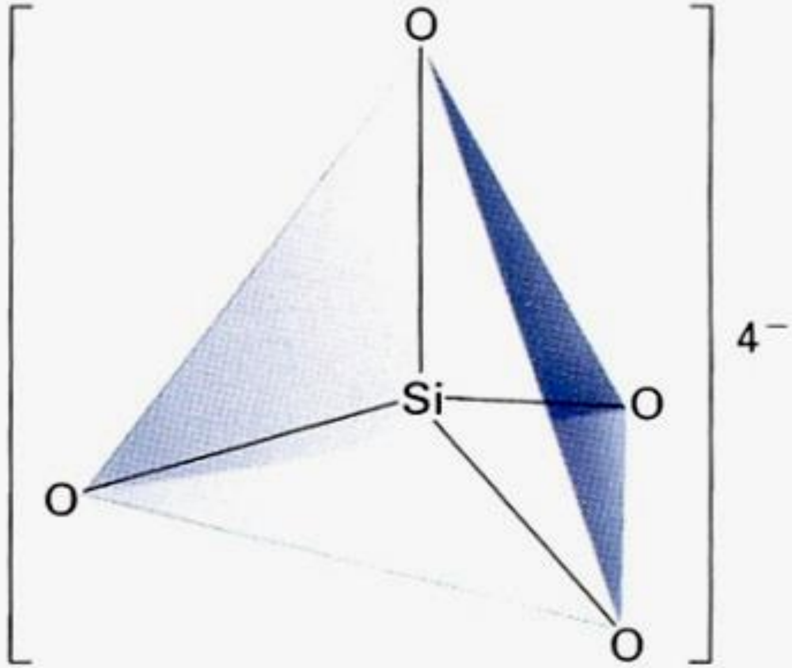
(E) A **three-dimensional silicate framework** shares all four Oxygens of each tetrahedron.

Nesosilicates / Orthosilicates

(single tetrahedrons)



- **Simplest form of all**
- (SiO_4) **tetrahedrons are unbonded to other tetrahedrons.**
- **In this way, they are similar to other mineral classes such as the** sulfates **and** phosphates**(**PO4 & SO4**).**
- **Nesosilicates, which are sometimes referred to as orthosilicates, have a structure that produces stronger bonds and a closer packing of ions**
- **Therefore a higher density, index of refraction and hardness than chemically similar silicates in other subclasses.**
- **Consequently, there are more** gemstones **in the nesosilicates than in any other silicate subclass.**


O
Si
O
O
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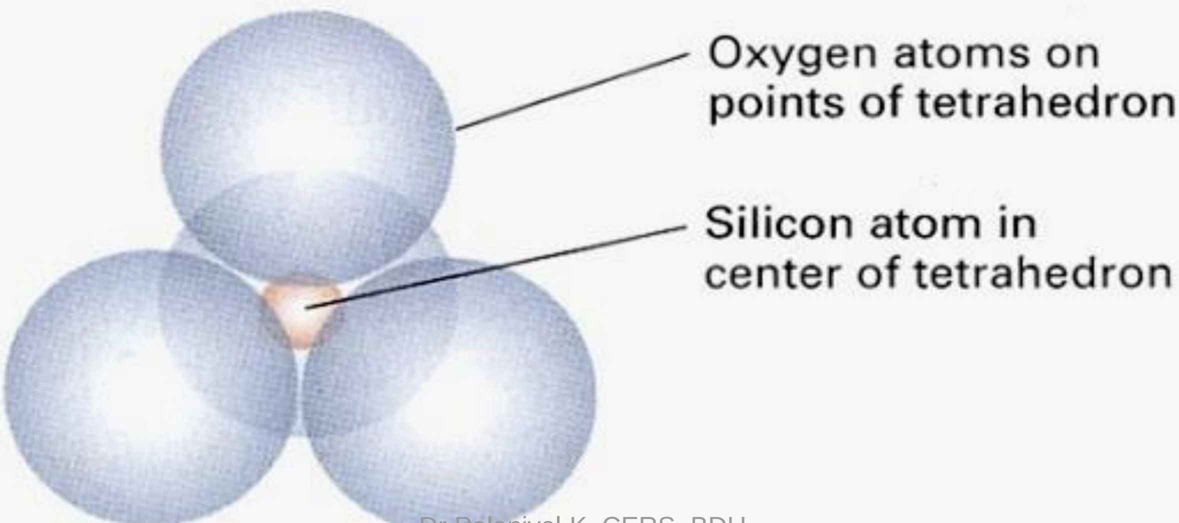
4⁻

A


Oxygen atoms on points of tetrahedron
Silicon atom in center of tetrahedron

Common members of the Nesosilicates

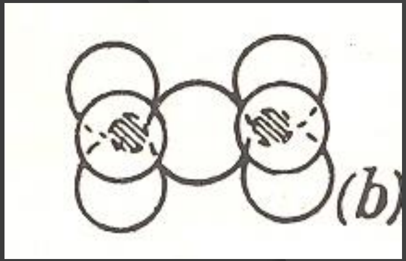
- Andalusite ***(Aluminum Silicate)***
- Chloritoid ***(Iron Magnesium Manganese Aluminum Silicate Hydroxide)***
- Datolite ***(Calcium Boro-Silicate Hydroxide)***
- Euclase ***(Beryllium Aluminum Silicate Hydroxide)***
- The Olivine Group ***(Magnesium Iron Silicate)***
- Fayalite ***(Iron Silicate)***
- Forsterite ***(Magnesium Silicate)***
- Gadolinite ***(Yttrium Iron Beryllium Silicate)***
- The Garnet Group: **1. PYRALSPITE GROUP**
  - Pyrope ***(Magnesium Aluminum Silicate)***
  - Almandine ***(Iron Aluminum Silicate)***
  - Spessartine ***(Manganese Aluminum Silicate***

  2. UGRANDITE GROUP
  - Uvarovite ***(Calcium Chromium Silicate)***
  - Grossular ***(Calcium Aluminum Silicate)***
  - Andradite ***(Calcium Iron Silicate)***

OTHER NESOSILICATES

Howlite ***(Calcium Boro-Silicate Hydroxide)***
Humite ***(Magnesium Iron Silicate Fluoride Hydroxide)***
Kyanite ***(Aluminum Silicate)***
Phenakite ***(Berylium Silicate)***
Sillimanite ***(Aluminum Silicate)***
Sphene or Titanite ***(Calcium Titanium Silicate)***
Staurolite ***(Iron Magnesium Zinc Aluminum Silicate Hydroxide)***
Thorite ***(Thorium Uranium Silicate)***
Topaz ***(Aluminum Silicate Fluoride Hydroxide)***
Uranophane ***(Hydrated Calcium Uranyl Silicate)***
Willemite ***(Zinc Silicate)***
Zircon ***(Zirconium Silicate)***

Sorosilicates (double tetrahedrons)



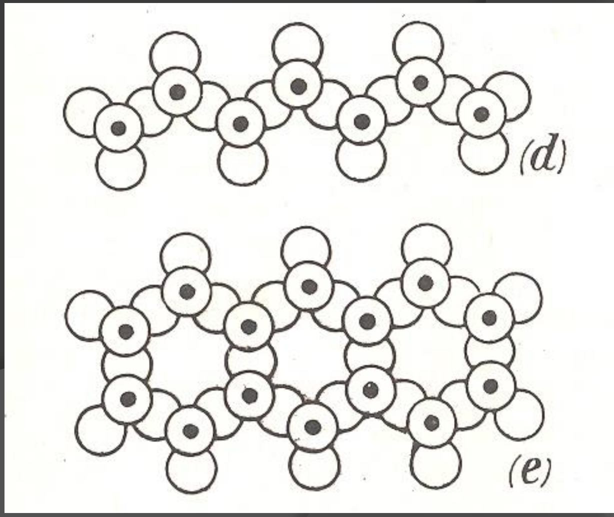
- Sorosilicates have two silicate tetrahedrons that are linked by one oxygen ion and thus the basic chemical unit is the anion group (**Si_2O_7**) with a negative six charge (-6).
- This structure forms an unusual **hourglass-like shape** and it may be due to this **oddball structure** that this subclass is the smallest of the silicate subclasses.
- It includes minerals that may also contain normal silicate tetrahedrons as well as the double tetrahedrons.
- The more complex members of this group, such as **Epidote**, contain chains of aluminum oxide tetrahedrons being held together by the individual silicate tetrahedrons and double tetrahedrons.
- Most members of this group are rare, but Epidote is widespread in many metamorphic environments.

Common members of the Sorosilicates

- Bertrandite ***(Beryllium Silicate Hydroxide)***
- Danburite ***(Calcium Boro-Silicate)***
- The Epidote group
  - Allanite (***Yttrium Cerium Calcium Aluminum Iron Silicate Hydroxide)***
  - Clinozoisite ***(Calcium Aluminum Silicate Hydroxide)***
  - Epidote ***(Calcium Iron Aluminum Silicate Hydroxide)***
  - Zoisite ***(Calcium Aluminum Silicate Hydroxide)***
- Hemimorphite ***(Hydrated Zinc Silicate Hydroxide)***
- Ilvaite ***(Calcium Iron Silicate Hydroxide)***
- Idocrase or Vesuvianite ***(Calcium Magnesium Aluminum Silicate Hydroxide)***

Inosilicates

- **Inosilicates**, or **chain silicates**, have interlocking chains of silicate tetrahedra with either SiO_3, 1:3 ratio, for single chains or Si_4O_{11}, 4:11 ratio, for double chains.
- **Single chain inosilicates**
- **Double chain inosilicates**



Single chain inosilicates

- Pyroxene group
  - Enstatite - orthoferrosilite series
    - Enstatite - $MgSiO_3$
    - Ferrosilite - $FeSiO_3$
  - Pigeonite - $Ca_{0.25}(Mg,Fe)_{1.75}Si_2O_6$
  - Diopside - Hedenbergite series
    - Diopside - $CaMgSi_2O_6$
    - Hedenbergite - $CaFeSi_2O_6$
    - Augite - $(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$
  - Sodium pyroxene series
    - Jadeite - $NaAlSi_2O_6$
    - Aegirine (Acmite) - $NaFe^{3+}Si_2O_6$
  - Spodumene - $LiAlSi_2O_6$

Pyroxenoid group

Wollastonite - $CaSiO_3$

Rhodonite - $MnSiO_3$

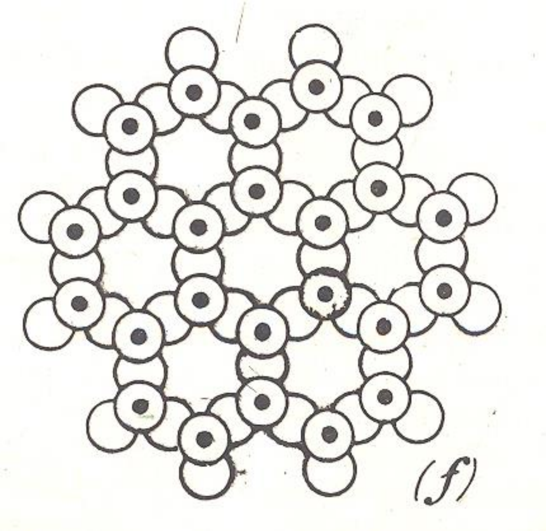
Pectolite - $NaCa_2(Si_3O_8)(OH)$

Double chain inosilicates

- Amphibole group
  - Anthophyllite - $(Mg,Fe)_7Si_8O_{22}(OH)_2$
  - Cumingtonite series
    - Cummingtonite - $Fe_2Mg_5Si_8O_{22}(OH)_2$
    - Grunerite - $Fe_7Si_8O_{22}(OH)_2$
  - Tremolite series
    - Tremolite - $Ca_2Mg_5Si_8O_{22}(OH)_2$
    - Actinolite - $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
  - Hornblende - $(Ca,Na)_{2-3}(Mg,Fe,Al)_5Si_6(Al,Si)_2O_{22}(OH)_2$
  - Sodium amphibole group
    - Glaucophane - $Na_2Mg_3Al_2Si_8O_{22}(OH)$
    - Riebeckite (asbestos) - $Na_2Fe^{2+}{}_3Fe^{3+}{}_2Si_8O_{22}(OH)_2$
    - Arfvedsonite - $Na_3(Fe,Mg)_4FeSi_8O_{22}(OH)_2$

Cyclosilicates

- **Cyclosilicate**s, or **Ring Silicates**, have linked tetrahedra with $(Si_xO_{3x})^{2x-}$ or a ratio of 1:3. These exists as 3-member $(Si_3O_9)^{6-}$, 4-member $(Si_4O_{12})^{8-}$ and 6-member $(Si_6O_{18})^{12-}$ rings.
- 3-member ring
  - Benitoite - $BaTi(Si_3O_9)$
- 4-member ring
  - Axinite - $(Ca,Fe,Mn)_3Al_2(BO_3)(Si_4O_{12})(OH)$
- 6-member ring
  - Beryl/Emerald - $Be_3Al_2(Si_6O_{18})$
  - Cordierite - $(Mg,Fe)_2Al_3(Si_5AlO_{18})$
  - Tourmaline - $(Na,Ca)(Al,Li,Mg)_{3-}(Al,Fe,Mn)_6(Si_6O_{18})(BO_3)_3(OH)_4$



Phyllosilicates

- **Phyllosilicates** (from Greek φύλλον *phyllon*, leaf), or **Sheet Silicates**, form parallel sheets of silicate tetrahedra with Si_2O_5 or a 2:5 ratio.

Kaolin

Mica

- Serpentine group
  - Antigorite - $Mg_3Si_2O_5(OH)_4$
  - Chrysotile - $Mg_3Si_2O_5(OH)_4$
  - Lizardite - $Mg_3Si_2O_5(OH)_4$
- Clay mineral group
  - Kaolinite - $Al_2Si_2O_5(OH)_4$
  - Illite - $(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
  - Smectite -
  - Montmorillonite - $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2\cdot nH_2O$
  - Vermiculite - $(MgFe,Al)_3(Al,Si)_4O_{10}(OH)_2\cdot 4H_2O$
  - Talc - $Mg_3Si_4O_{10}(OH)_2$
  - Palygorskite - $(Mg,Al)_2Si_4O_{10}(OH)\cdot 4(H_2O)$
  - Pyrophyllite - $Al_2Si_4O_{10}(OH)_2$

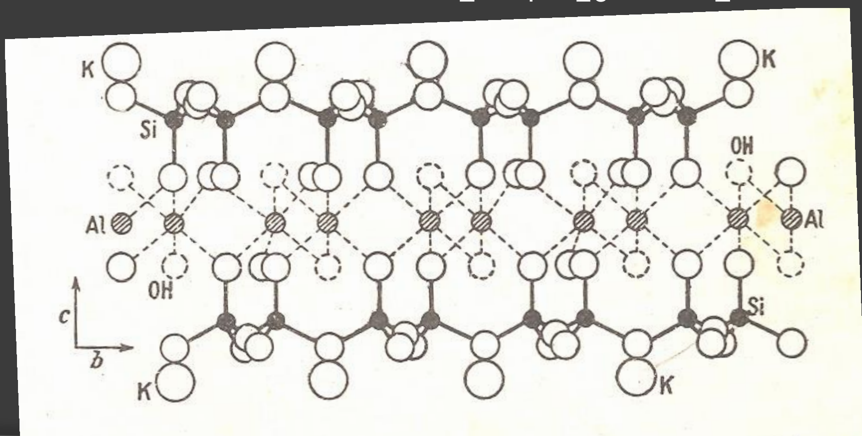


FIG. 126.—The structure of Muscovite, viewed parallel to the Si_4O_{10}-sheets. Each pair of sheets as shown is linked by Al-ions and is separated from the next pair by a layer of potassium ions.

Mica group

- Biotite - $K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$
- Muscovite - $KAl_2(AlSi_3O_{10})(OH)_2$
- Phlogopite - $KMg_3Si_4O_{10}(OH)_2$
- Lepidolite - $K(Li,Al)_{2-3}(AlSi_3O_{10})(OH)_2$
- Margarite - $CaAl_2(Al_2Si_2O_{10})(OH)_2$
- Glauconite - $(K,Na)(Al,Mg,Fe)_2(Si,Al)_4O_{10}(OH)_2$

Chlorite group

- Chlorite - $(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2\cdot(Mg,Fe)_3(OH)_6$

Tectosilicates

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

Quartz

Lunar Ferroan Anorthosite #60025 (Plagioclase Feldspar). Collected by Apollo 16 from the Lunar Highlands near

Descartes Crater.

- Quartz group
  - Quartz - SiO_2
  - Tridymite - SiO_2
  - Christobalite - SiO_2
- Feldspar group
  - Alkali-feldspars
    - Potassium-feldspars
      - Microcline - $KAlSi_3O_8$
      - Orthoclase - $KAlSi_3O_8$
      - Sanidine - $KAlSi_3O_8$
    - Anorthoclase - $(Na,K)AlSi_3O_8$
  - Plagioclase feldspars
    - Albite - $NaAlSi_3O_8$
    - Oligoclase - $(Na,Ca)(Si,Al)_4O_8$ (Na:Ca 4:1)
    - Andesine - $(Na,Ca)(Si,Al)_4O_8$ (Na:Ca 3:2)
    - Labradorite - $(Na,Ca)(Si,Al)_4O_8$ (Na:Ca 2:3)
    - Bytownite - $(Na,Ca)(Si,Al)_4O_8$ (Na:Ca 1:4)
    - Anorthite - $CaAl_2Si_2O_8$

- Feldspathoid group
  - Nosean - $Na_8Al_6Si_6O_{24}(SO_4)$
  - Cancrinite - $Na_6Ca_2(CO_3,Al_6Si_6O_{24}).2H_2O$
  - Leucite - $KAlSi_2O_6$
  - Nepheline - $(Na,K)AlSiO_4$
  - Sodalite - $Na_8(AlSiO_4)_6Cl_2$
    - Hauyne - $(Na,Ca)_{4-8}Al_6Si_6(O,S)24(SO_4,Cl)_{1-2}$
  - Lazurite - $(Na,Ca)_8(AlSiO_4)_6(SO_4,S,Cl)_2$
- Petalite - $LiAlSi_4O_{10}$
- Scapolite group
  - Marialite - $Na_4(AlSi_3O_8)_3(Cl_2,CO_3,SO_4)$
  - Meionite - $Ca_4(Al_2Si_2O_8)_3(Cl_2CO_3,SO_4)$
- Analcime - $NaAlSi_2O_6 \cdot H_2O$
- Zeolite group
  - Natrolite - $Na_2Al_2Si_3O_{10} \cdot 2H_2O$
  - Chabazite - $CaAl_2Si_4O_{12} \cdot 6H_2O$
  - Heulandite - $CaAl_2Si_7O_{18} \cdot 6H_2O$
  - Stilbite - $NaCa_2Al_5Si_{13}O_{36} \cdot 17H_2O$

Flowchart for the IDENTIFICATION OF MINERALS

Keys for Mineral Identification:

- Light coloured
  - Metallic
  - Non-metallic
    - Hard
      - Cleavage Excellent / Good
        - Check other physical properties
      - Cleavage Poor / Absent
    - Soft
- Dark coloured
  - Metallic
  - Non-metallic

<u>Check other physical properties:</u>

How many sets of cleavages?
Angle of intersection of cleavages?
Has striations on facets or not?
Correct Hardness value?
Streak?
Lustre?
Odour?
Tenacity?
Effervesces on acid?
Magnetic / Non-magnetic – for metallic

Light-coloured minerals with non-metallic lustre

LIGHT-COLORED NONMETALLIC MINERALS

Step 1: What is the mineral's hardness?	Step 2: What is the mineral's cleavage?	Step 3: Compare the mineral's physical properties to other distinctive properties below.	Step 4: Find mineral name(s) and check the mineral database for additional properties (Figure 2.25).
HARD (H > 5.5) Scratches glass. Not scratched by masonry nail or knife blade	Cleavage excellent or good	White or gray; 2 cleavages at nearly right angles and with striations; H 6	Plagioclase feldspar
		Orange, brown, white, gray, green, or pink; H 6; 2 cleavages at nearly right angles; exsolution lamellae	Potassium feldspar
		Pale brown, white, or gray; Long slender prisms; 1 excellent cleavage plus fracture surfaces; H 6–7	Sillimanite
		Blue, very pale green, white, or gray; Crystals are blades; H 4–7	Kyanite
	Cleavage poor or absent	Colorless, white, gray, or other colors; Greasy luster; Massive or hexagonal prisms … Transparent or translucent; H …	Quartz … ine Quartz … nk var.)
		Opaque gray or white; Luster waxy; H 7	Chert (variety of quartz)
		Colorless, white, yellow, light brown, or pastel colors; Translucent or opaque; Laminated or massive; Cryptocrystalline; Luster waxy; H 7	Chalcedony (variety of quartz)
		Pale olive green to yellow; Conchoidal fracture; Transparent or translucent; Forms short stout prisms; H 7	Olivine
SOFT (H ≤ 5.5) Does not scratch glass. Scratched by masonry nail or knife blade	Cleavage excellent or good	Colorless, white, yellow, green, pink, or brown; 3 excellent cleavages; Breaks into rhombohedrons; Effervesces in dilute HCl; H 3	Calcite
		Colorless, white, gray, creme, or pink; 3 excellent cleavages; Breaks into rhombohedrons; Effervesces in dilute HCl only if powdered; H 3.5–4	Dolomite
		Colorless or white with tints of brown, yellow, blue, black; Short tabular crystals and roses; Very heavy; H 3–3.5	Barite
		Colorless, white, or gray; Massive or tabular crystals, blades, or needles; Can be scratched with your fingernail; H 2	Gypsum
		Colorless, white, gray, or pale green, yellow, or red; Spheres of radiating needles; Luster silky; H 5–5.5	Natrolite
		Colorless, white, yellow, blue, brown, or red; Cubic crystals; Breaks into cubes; Salty taste; H 2.5	Halite
		Colorless, purple, blue, gray, green, yellow; Cubes with octahedral cleavage; H 4	Fluorite
		Colorless, yellow, brown, or red-brown; Short opaque prisms; Splits along 1 excellent cleavage into thin flexible transparent sheets; H 2–2.5	Muscovite mica
	Cleavage poor or absent	Yellow crystals or earthy masses; Luster greasy; H 1.5–2.5	Sulfur
		Opaque pale blue to blue-green; Amorphous crusts or massive; Very light blue streak; H 2–4	Chrysocolla
		Opaque green, yellow, or gray; Dull or silky masses or asbestos; White streak; H 2–5	Serpentine
		Opaque white, gray, green, or brown; Can be scratched with fingernail; Greasy or soapy feel; H 1	Talc
		Opaque earthy white to very light brown; H 1–2	Kaolinite
		Colorless to white, orange, yellow, brown, blue, gray, green, or red; May have play of colors; Conchoidal fracture; H 5–5.5	Opal
		Colorless or pale green, brown, blue, white, or purple; Brittle hexagonal prisms; Conchoidal fracture; H 5	Apatite

Absence of Cleavage, Conchoidal fracture

DARK-COLORED NONMETALLIC MINERALS

Step 1: What is the mineral's hardness?	Step 2: What is the mineral's cleavage?	Step 3: Compare the mineral's physical properties to other distinctive properties below.	Step 4: Find mineral name(s) and check the mineral database for additional properties (Figure 2.25).
HARD (H > 5.5) Scratches glass. Not scratched by masonry nail or knife blade	Cleavage excellent or good	Translucent dark gray, blue-gray, or black; may have silvery iridescence; 2 cleavages at nearly 90° and with striations; H 6	Plagioclase feldspar
		Translucent brown, gray, green, or red; 2 cleavages at nearly right angles; exsolution lamellae; H 6	Potassium feldspar
		Opaque dark green in long prisms or needles; 2 cleavages at about 60° and 120°; H 5.5	Actinolite (Amphibole)
		Opaque black; 2 cleavages at about 60° and 120°; H 5.5	Hornblende (Amphibole)
		Opaque black; 2 cleavages at nearly 90°; H 5.5–6	Augite (Pyroxene)
	Cleavage poor or absent	Transparent or translucent gray, brown, or purple; Greasy luster; Massive or hexagonal prisms and pyramids; H 7	Quartz Smoky Quartz (black/brown var.), Amethyst (purple var.)
		Transparent, translucent, or opaque red-gray, or gray; Short hexagonal prisms with striated flat ends; H 9	Corundum
		Opaque red-brown or brown; Luster waxy; Cryptocrystalline; H 7	Jasper (variety of quartz)
		Transparent to translucent dark red to black; H 7	Garnet
		Opaque gray; Luster waxy; Cryptocrystalline; H 7	Chert (variety of quartz)
		Opaque black; Luster waxy; Cryptocrystalline; H 7	Flint (variety of quartz)
		Black or dark green; Long striated prisms; H 7–7.5	Tourmaline
		Transparent or translucent olive green; Conchoidal fracture; Transparent or translucent, H 7	Olivine
		Opaque green; Poor cleavage; H 6–7	Epidote
		Opaque brown prisms that interpenetrate to form crosses; H 7	Staurolite
SOFT (H ≤ 5.5) Does not scratch glass. Scratched by masonry nail or knife blade	Cleavage excellent or good	Translucent to opaque yellow-brown to brown; may appear submetallic; Octahedral cleavage; H 3.5–4	Sphalerite
		Purple cubes or octahedrons with octahedral cleavage; H 4	Fluorite
		Black short opaque prisms; Splits easily along 1 excellent cleavage into thin sheets; H 2.5–3	Biotite mica
		Green short opaque prisms; Splits easily along 1 excellent cleavage into thin sheets; H 2–3	Chlorite
	Cleavage poor or absent	Opaque rusty brown or yellow-brown; Massive and amorphous; Yellow-brown streak; H 1.5–5.5	Limonite
		Opaque rusty brown to brown-gray rock with shades of gray, yellow, and white; Contains pea-sized spheres that are laminated internally; Pale brown streak; H 1–3	Bauxite
		Deep blue; Crusts, small crystals, or massive; Light blue streak; H 3.5–4	Azurite
		Opaque green or gray-green; Dull or silky masses or asbestos; White streak; H 2–5	Serpentine
		Opaque green in laminated crusts or massive; Streak pale green; Effervesces in dilute HCl: H 3.5–4	Malachite
		Translucent or opaque dark green; Can be scratched with your fingernail; Feels greasy or soapy; H 1	Talc
		Opaque earthy red; red to red-brown streak; H 1.5–6	Hematite
		Transparent or translucent green, brown, blue, or purple; Brittle hexagonal prisms; Conchoidal fracture; H 5	Apatite

Dark-coloured minerals with non-metallic lustre

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster	Hardness	Streak	Distinctive Properties	Some Uses
ACTINOLITE (amphibole)	Nonmetallic (NM)	5.5–6	White	Color dark green or pale green; Forms needles, prisms, and asbestose fibers; Good cleavage at 56° and 124°; SG = 3.1	Gemstone (Nephrite), Asbestose products
AMPHIBOLE: See HORNEBLENDE and ACTINOLITE					
APATITE $Ca_5F(PO_4)_3$ calcium fluorophosphate	Nonmetallic (NM)	5	White	Color pale or dark green, brown, blue, white, or purple; Sometimes colorless; Transparent or opaque; Brittle; Conchoidal fracture; Forms hexagonal prisms; SG = 3.1–3.4	Used for pesticides and fertilizers
ASBESTOSE: fibrous varieties of AMPHIBOLE and SERPENTINE					
AUGITE (pyroxene) calcium ferromagnesian silicate	Nonmetallic (NM)	5.5–6	White to pale gray	Color green to black; Forms opaque, short, 8-sided prisms; Two good cleavages that intersect at 87° and 93° (nearly right angles); SG = 3.2–3.5	Some pyroxene mined as an ore of lithium, for making steel
AZURITE $Cu_3(CO_3)_2(OH)_2$ hydrous copper carbonate	Nonmetallic (NM)	3.5–4	Light blue	Color a distinctive deep blue; Forms crusts of small crystals, opaque earthy masses, or short and long prisms; Brittle; Effervesces in dilute HCl; SG = 3.7–3.8	Ore of copper for pipes, electrical circuits, coins, ammunition, gemstone
BARITE $BaSO_4$ barium sulfate	Nonmetallic (NM)	3–3.5	White	Colorless to white, with tints of brown, yellow, blue, or red; Forms short tabular crystals and rose-shaped masses (Barite roses); Brittle; Cleavage good to excellent; Very heavy, SG = 4.5	Used in rubber, paint, glass, oil-well drilling fluids
BAUXITE Mixture of aluminum hydroxides	Nonmetallic (NM)	1–3	White	Brown earthy rock with shades of gray, white, and yellow; Amorphous; Often contains rounded pea-sized structures with laminations; SG = 2.3	Ore of Aluminum
BIOTITE MICA ferromagnesian potassium, hydrous aluminum silicate	Nonmetallic (NM)	2.5–3	Gray-brown	Color black, green-black, or brown-black; Cleavage excellent; Forms very short prisms that split easily into very thin, flexible sheets; SG = 2.7–3.1	Used for fire-resistant tiles, rubber, paint
BORNITE Cu_5FeS_4 copper-iron sulfide	Metallic (M)	3	Dark gray to black	Color opaque silvery blue or copper-red; Tarnishes to iridescent purple and blue; Forms dense, brittle masses; Cleavage poor to absent	Ore of copper for pipes, electrical circuits, coins, ammunition, brass, bronze
CALCITE $CaCO_3$ calcium carbonate	Nonmetallic (NM)	3	White	Usually colorless, white, or yellow, but may be green, brown, or pink; Opaque or transparent; Excellent cleavage in 3 directions not at 90°; Forms prisms, rhombohedrons, or scalenohedrons that break into rhombohedrons; Effervesces in dilute HCl; SG = 2.7	Used to make antacid tablets, fertilizer, cement; Ore of calcium
CHALCEDONY SiO_2 cryptocrystalline quartz	Nonmetallic (NM)	7	White	Colorless, white, yellow, light brown, or other pastel colors in laminations; Often translucent; Conchoidal fracture; Luster waxy; Cryptocrystalline; SG = 2.5–2.8	Used as an abrasive; Used to make glass, gemstones (agate, chrysoprase)

Alphabetical list of minerals with their distinctive physical / optical properties and uses

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster	Hardness	Streak	Distinctive Properties	Some Uses
CHALCOPYRITE $CuFeS_2$ copper-iron sulfide	Metallic (M)	3.5–4	Dark gray	Color golden or brassy yellow; Tarnishes brown, or iridescent blue, green, and red; Forms elongate tetrahedra; Brittle; Cleavage poor; SG = 4.1–4.3	Ore of copper for pipes, electrical circuits, coins, ammunition, brass, bronze
CHERT SiO_2 cryptocrystalline quartz	Nonmetallic (NM)	7	White	Opaque gray or white; Luster waxy; Conchoidal fracture; SG = 2.5–2.8	Used as an abrasive; Used to make glass, gemstones
CHLORITE ferromagnesian aluminum silicate	Nonmetallic (NM)	2–2.5	White	Color dark green; Cleavage excellent; Forms short prisms that split easily into thin flexible sheets; Luster shiny or dull; SG = 2–3	Used for fire-resistant tiles, rubber, paint, art sculpture medium
CHROMITE $FeCr_2O_4$ iron-chromium oxide	Metallic (M)	5.5–6	Dark brown	Color silvery black to black; Tarnishes gray; Forms octahedrons; Brittle; No cleavage; May be weakly magnetic; SG = 4.6–4.8	Ore of chromium for making chrome, stainless steel, mirrors, paint and used in leather tanning
CHRYSOCOLLA $CuSiO_3 \cdot 2H_2O$ hydrated copper silicate	Nonmetallic (NM)	2–4	Very light blue	Color pale blue to blue-green; Opaque; Forms amorphous crusts or may be massive; Conchoidal fracture; Luster shiny or earthy; SG = 2.0–2.4	Ore of copper for pipes, electrical circuits, coins, ammunition; gemstone
COPPER (NATIVE COPPER) Cu copper	Metallic (M)	2.5–3	Copper	Color copper; Tarnishes brown or green; Forms distorted cubes octahedrons, and dendritic (root-like) masses; Malleable; Opaque; Cleavage absent; SG = 8.8–8.9	Ore of copper for pipes, electrical circuits, coins, ammunition, brass, bronze
CORUNDUM Al_2O_3 aluminum oxide	Nonmetallic (NM)	9	White	Color gray, blue, red, brown; Transparent or opaque; Forms short hexagonal prisms with striated flat ends; Cleavage absent; SG = 3.9–4.1	Used for abrasive powders to polish lenses; gemstones (red ruby, blue sapphire)
DOLOMITE $CaMg(CO_3)_2$ magnesian calcium carbonate	Nonmetallic (NM)	3.5–4	White	Color white, gray, creme, or pink; Usually opaque; Cleavage excellent in 3 directions; Breaks into rhombohedrons; Resembles calcite, but will effervesce in dilute HCl only if powdered; SG = 2.8–2.9	Ore of magnesium metal; soft abrasive; used to make paper
EPIDOTE complex silicate	Nonmetallic (NM)	6–7	White	Color pale or dark green to yellow-green; Massive or forms striated prisms; Cleavage poor, SG = 3.3–3.5	Gemstone
FELDSPAR: See PLAGIOCLASE (Na-Ca Feldspars) and POTASSIUM FELDSPAR (K-Spar)					
FLINT SiO_2 cryptocrystalline quartz	Nonmetallic (NM)	7	White	Color black to very dark gray; Opaque to translucent; Conchoidal fracture; Crypto-crystalline; SG = 2.5–2.8	Used as an abrasive; Used to make glass, gemstones
FLUORITE CaF_2 calcium fluoride	Nonmetallic (NM)	4	White	Colorless, purple, blue, gray, green, or yellow; Cleavage excellent; Crystals usually cubes; Transparent or opaque; Brittle; SG = 3.0–3.3	Source of fluorine for processing aluminum; flux in steel making

Alphabetical list of minerals with their distinctive physical / optical properties and uses

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster	Hardness	Streak	Distinctive Properties	Some Uses
GALENA PbS lead sulfide	Metallic (M)	2.5	Gray to dark gray	Color silvery gray; Tarnishes dull gray; Forms cubes and octahedrons; Brittle; Cleavage good in three directions, so breaks into cubes; SG = 7.6	Ore of lead for TV glass, auto batteries, solder, ammunition, paint
GARNET complex silicate	Nonmetallic (NM)	7	White	Color usually red, black, or brown; sometimes yellow, green, pink; Forms dodecahedrons; Cleavage absent; Brittle; Translucent to opaque; SG = 3.5–4.3	Used as an abrasive; gemstone
GOETHITE $FeO(OH)$ hydrous iron oxide	Metallic (M)	5–5.5	Yellow-brown	Color dark brown to black; Tarnishes yellow-brown; Forms layers of radiating microscopic crystals; SG = 4.3	Ore of iron for steel, brass, bronze, tools, vehicles, nails and bolts, bridges, etc.
GRAPHITE C carbon	Metallic (M)	1	Dark gray	Color silvery gray to black; Forms flakes, short hexagonal prisms, and earthy masses; Greasy feel; Very soft, Cleavage excellent in 1 direction; SG = 2.1–2.3	Used as a lubricant (as in graphite oil), pencil leads, fishing rods
GYPSUM $CaSO_4 \cdot 2H_2O$ calcium sulfate	Nonmetallic (NM)	2	White	Colorless, white, or gray; Forms tabular crystals, prisms, blades, or needles (satin spar variety); Transparent to translucent; Very soft; Cleavage good; SG = 2.3	Plaster-of-paris, wallboard, drywall, art sculpture medium (alabaster)
HALITE $NaCl$ sodium chloride	Nonmetallic (NM)	2.5	White	Colorless, white, yellow, blue, brown or red; Transparent to translucent; Brittle; Forms cubes; Cleavage excellent in 3 directions, so breaks into cubes; Salty taste; SG = 2.1–2.6	Table salt, road salt; Used in water softeners and as a preservative; Sodium ore
HEMATITE Fe_2O_3 iron oxide	Metallic (M) or Nonmetallic (NM)	1.5–6	Red to red-brown	Color silvery gray, black, or brick red; Tarnishes red; Opaque; Soft (earthy) and hard (metallic) varieties have same streak; Forms thin tabular crystals or massive; SG = 2.1–2.6	Red pigment; Ore of iron for steel tools, vehicles, nails and bolts, bridges, etc.
HORNBLENDE (amphibole) calcium ferromagnesian aluminum silicate	Nonmetallic (NM)	5.5	Gray-green or white	Color dark green to black; Opaque; Forms prisms with good cleavage at 60° and 120°; Brittle; Splintery or asbestos forms; SG = 3.0–3.3	Fibrous varieties used for fire-resistant clothing, tiles, brake linings
JASPER SiO_2 cryptocrystalline quartz	Nonmetallic (NM)	7	White	Color red-brown, or yellow; Opaque; Waxy luster; Conchoidal fracture; Cryptocrystalline; SG = 2.5–2.8	Used as an abrasive; Used to make glass, gemstones
KAOLINITE $Al_4(Si_4O_{10})(OH)_8$ hydrous aluminum silicate	Nonmetallic (NM)	1–2	White	Color white to very light brown; Commonly forms earthy, microcrystalline masses; Cleavage excellent but absent in hand samples; SG = 2.6	Used for pottery, clays, polishing compounds, pencil leads, paper
K-SPAR: See POTASSIUM FELSDPAR					
KYANITE $Al_2(SiO_4)O$ aluminum silicate	Nonmetallic (NM)	4–7	White	Color blue, pale green, white, or gray; Translucent to transparent; Forms blades; SG = 3.6–3.7	High temperature ceramics, spark plugs

Alphabetical list of minerals with their distinctive physical / optical properties and uses

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster	Hardness	Streak	Distinctive Properties	Some Uses
LIMONITE $Fe_2O_3 \cdot nH_2O$ hydrous iron oxide	Metallic (M) or Nonmetallic (NM)	1.5–5.5	Yellow-brown	Color yellow brown to dark brown; Tarnishes yellow to brown; Amorphous masses; Luster dull or earthy; Hard or soft; SG = 3.6–4.0	Yellow pigment; Ore of iron for steel tools, vehicles, nails and bolts, bridges, etc.
MAGNETITE Fe_3O_4 iron oxide	Metallic (M)	6	Dark gray	Color silvery gray to black; Opaque; Forms octahedrons; Tarnishes gray; No cleavage; Attracted to a magnet and can be magnetized; SG = 5.2	Ore of iron for steel, brass, bronze, tools, vehicles, nails and bolts, bridges, etc.
MALACHITE $Cu_2CO_3(OH)_2$ hydrous copper carbonate	Nonmetallic (NM)	3.5–4	Green	Color green, pale green, or gray green; Usually in crusts, laminated masses, or microcrystals; Effervesces in dilute HCl; SG = 3.9–4.0	Ore of copper for pipes, electrical circuits, coins, ammunition; gemstone
MICA: See BIOTITE and MUSCOVITE.					
NATIVE COPPER: See COPPER.					
NATIVE SULFUR: See SULFUR.					
NATROLITE (ZEOLITE) $Na_2(Al_2Si_3O_{10}) \cdot 2H_2O$ hydrous sodium aluminum silicate	Nonmetallic (NM)	5–5.5	White	Colorless, white, gray, or pale green, yellow, or red; Forms masses of radiating needles; Silky luster; SG = 2.2–2.4	Water softeners
MUSCOVITE MICA potassium hydrous aluminum silicate	Nonmetallic (NM)	2–2.5	White	Colorless, yellow, brown, or red-brown; Forms short opaque prisms; Cleavage excellent in 1 direction, can be split into thin flexible transparent sheets; SG = 2.7–3.0	Computer chip substrates, electrical insulation, roof shingles, facial makeup
OLIVINE $(Fe,Mg)_2SiO_4$ ferromagnesian silicate	Nonmetallic (NM)	7	White	Color pale or dark olive-green to yellow, or brown; Forms short flat prisms; Conchoidal fracture; Cleavage absent; Brittle; SG = 3.3–3.4	Gemstone (peridot); Ore of magnesium metal
OPAL $SiO_2 \cdot nH_2O$ hydrated silicon dioxide	Nonmetallic (NM)	5–5.5	White	Colorless to white, orange, yellow, brown, blue, gray, green, or red; may have play of colors (opalescence); Amorphous; Cleavage absent; Conchoidal fracture; SG = 1.9–2.3	Gemstone
PLAGIOCLASE FELDSPAR $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$ calcium-sodium aluminum silicate	Nonmetallic (NM)	6	White	Colorless, white, gray, or black; may have iridescent play of color from within; Translucent; Forms striated tabular crystals or blades; Cleavage good in two directions at nearly 90°; SG = 2.6–2.8	Used to make ceramics, glass, enamel, soap, false teeth, scouring powders
POTASSIUM FELDSPAR $KAlSi_3O_8$ potassium aluminum silicate	Nonmetallic (NM)	6	White	Color orange, brown, white, green, or pink; Forms translucent prisms with subparallel exsolution lamellae; Cleavage excellent in two directions at nearly 90°; SG = 2.5–2.6	Used to make ceramics, glass, enamel, soap, false teeth, scouring powders
PYRITE ("fool's gold") FeS_2 iron sulfide	Metallic (M)	6–6.5	Dark gray	Color brass yellow; Opaque; Tarnishes brown; Forms cubes or octahedrons; Brittle; No cleavage; SG = 5.0	Ore of sulfur, for sulfuric acid, explosives, fertilizers, pulp processing, insecticides

Alphabetical list of minerals with their distinctive physical / optical properties and uses

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster	Hardness	Streak	Distinctive Properties	Some Uses
PYROXENE: See AUGITE.					
QUARTZ SiO_2 silicon dioxide	Nonmetallic (NM)	7	White	Usually colorless, white, or gray but uncommon varieties occur in all colors; Transparent to translucent; Luster greasy; No cleavage; Forms hexagonal prism and pyramids; SG = 2.7	Used as an abrasive; Used to make glass, gemstones
SERPENTINE $Mg_6Si_4O_{10}(OH)_8$ hydrous magnesian silicate	Nonmetallic (NM)	2–5	White	Color pale or dark green, yellow, gray; Forms dull or silky masses and asbestos forms; No cleavage; SG = 2.2–2.6	Fibrous varieties used for fire-resistant clothing, tiles, brake linings
SILLIMANITE $Al_2(SiO_4)O$ aluminum silicate	Nonmetallic (NM)	6–7	White	Color pale brown, white, or gray; One good cleavage plus fracture surfaces; Forms slender prisms; SG = 3.2	High-temperature ceramics
SPHALERITE ZnS zinc sulfide	Metallic (M) or Nonmetallic (NM)	3.5–4	White to pale yellow-brown	Color usually yellow-brown to brown or black; Luster submetallic to non-metallic; Forms misshapen tetrahedrons or dodecahedrons; Cleavage excellent; SG = 3.9–4.0	Ore of zinc for die-cast automobile parts, brass, galvanizing, batteries
STAUROLITE iron magnesium zinc aluminum silicate	Nonmetallic (NM)	7	White to gray	Color brown to gray-brown; Tarnishes dull brown; Forms prisms that interpenetrate to form natural crosses; Cleavage poor; SG = 3.7–3.8	Gemstone crosses called "fairy crosses"
SULFUR (NATIVE SULFUR) S sulfur	Nonmetallic (NM)	1.5–2.5	Pale yellow	Color bright yellow; Forms transparent to translucent crystals or earthy masses; Cleavage poor; Luster greasy to earthy; Brittle; SG = 2.1	Used for drugs, sulfuric acid, explosives, fertilizers, pulp processing, insecticides
TALC $Mg_3Si_4O_{10}(OH)_2$ hydrous magnesian silicate	Nonmetallic (NM)	1	White	Color white, gray, pale green, or brown; Forms cryptocrystalline masses that show no cleavage; Luster silky to greasy; Feels greasy or soapy (talcum powder); Very soft; SG = 2.7–2.8	Used for talcum powder, facial makeup, ceramics, paint, sculptures
TOURMALINE complex silicate	Nonmetallic (NM)	7–7.5	White	Color usually opaque black or green, but may be transparent or translucent green, red, yellow, pink or blue; Forms long striated prisms with triangular cross sections; Cleavage absent; SG = 3.0–3.2	Crystals used in radio transmitters; gemstone
ZEOLITE: A group of calcium or sodium hydrous aluminum silicates. See NATROLITE.					

Alphabetical list of minerals with their distinctive physical / optical properties and uses

Thank you

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