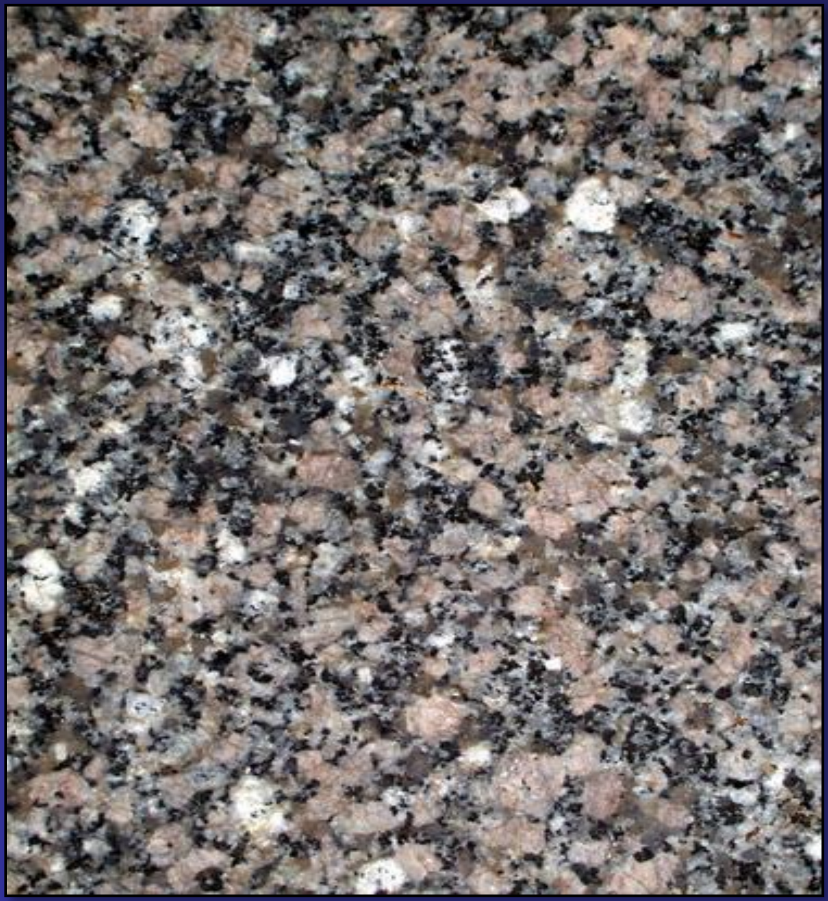
Minerals

Gypsum Crystals - Mexico

Rocks

- Rocks are Earth materials made from minerals.
- Most rocks have more than one kind of mineral.
  - Example: **Granite**
    - Potassium feldspar.
    - Plagioclase Feldspar.
    - Quartz.
    - Hornblende.
    - Biotite



- Some are **monomineralic**.
  - Limestone (Calcite).
  - Rock salt (Halite).
  - Glacial ice.

Minerals

- If geology was a language:

Minerals = Letters of the Alphabet
Rocks = Words

- So, in order to understand the language of geology, one must be able to properly **identify the letters of the language.**

- **Mineralogy** – The study of minerals

- **Mineralogist** – Someone who studies minerals, their composition, uses, and properties

Galena crystals – lead sulfate

What is a Mineral?

Definition: a [1]homogeneous, [2]naturally-occurring, [3]solid, and [4] generally inorganic substance with a [5]definable chemical composition and an [6]orderly internal arrangement of atoms

Six parts to the definition – each is important and necessary

Does not include "minerals" in the nutritional sense

1- Homogeneous

- *Definition*: Something that is the same through and through
  - Cannot be broken into simpler components

2- Naturally Occurring

- Minerals are the result of natural geological processes
  - Man-made minerals are called **synthetic minerals** (e.g. industrial diamonds)

3- Solid

- Minerals must be able to maintain a **set shape** nearly indefinitely
  - liquids are not minerals

4- Definable Chemical Composition

- A mineral can be described by a chemical formula
  - Quartz: **SiO^2**
  - Biotite: **$K(Mg, Fe)_3\,(AlSi_3O_{10})(OH)_2$**
  - Diamond: **C**

5- Orderly Arrangement of Atoms

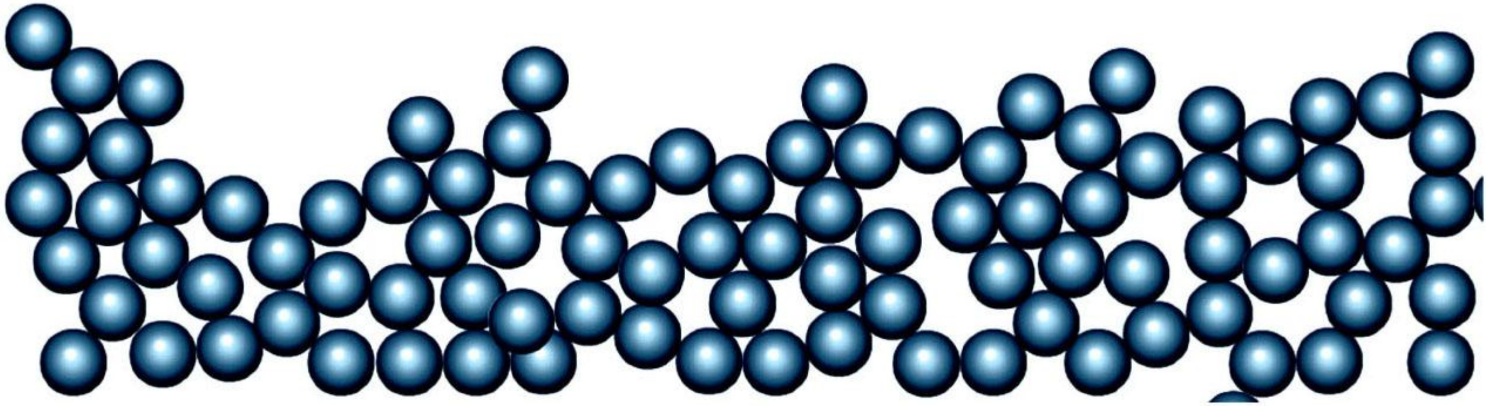
- Minerals have a fixed **atomic pattern** that repeats itself over a large region relative to the size of atoms
  - Crystal solid, or crystal lattice: The organized structure of a mineral
  - A glass is not a mineral; no organized structure

6- Generally Inorganic

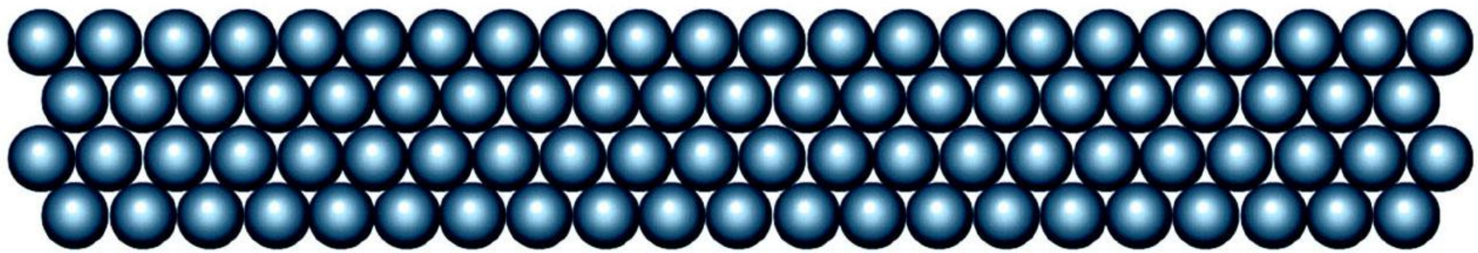
- ***Organic***: **A substance composed of C bonded to H, with varying amounts of O, N and other elements. C, alone, is not organic!**
- Only a few organic substances are considered minerals, all other minerals are inorganic

Organized Crystal Lattice

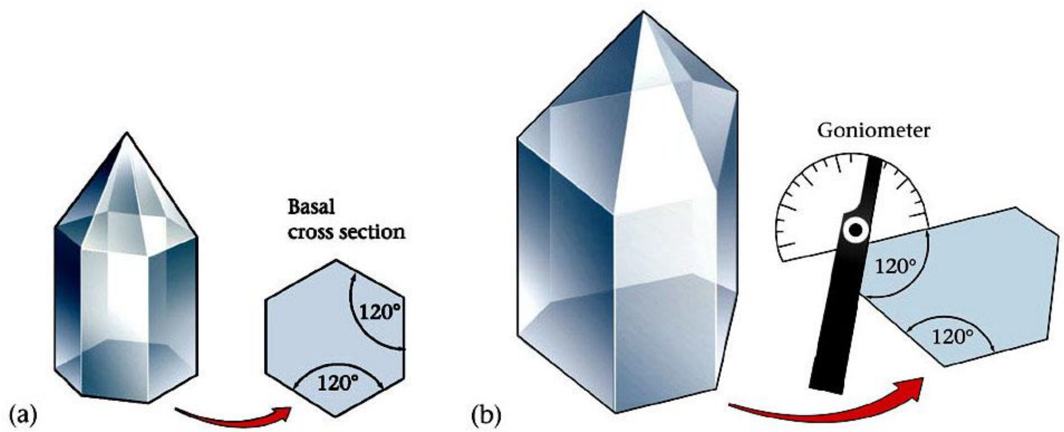
- ***Glass:*** no organized molecular structure



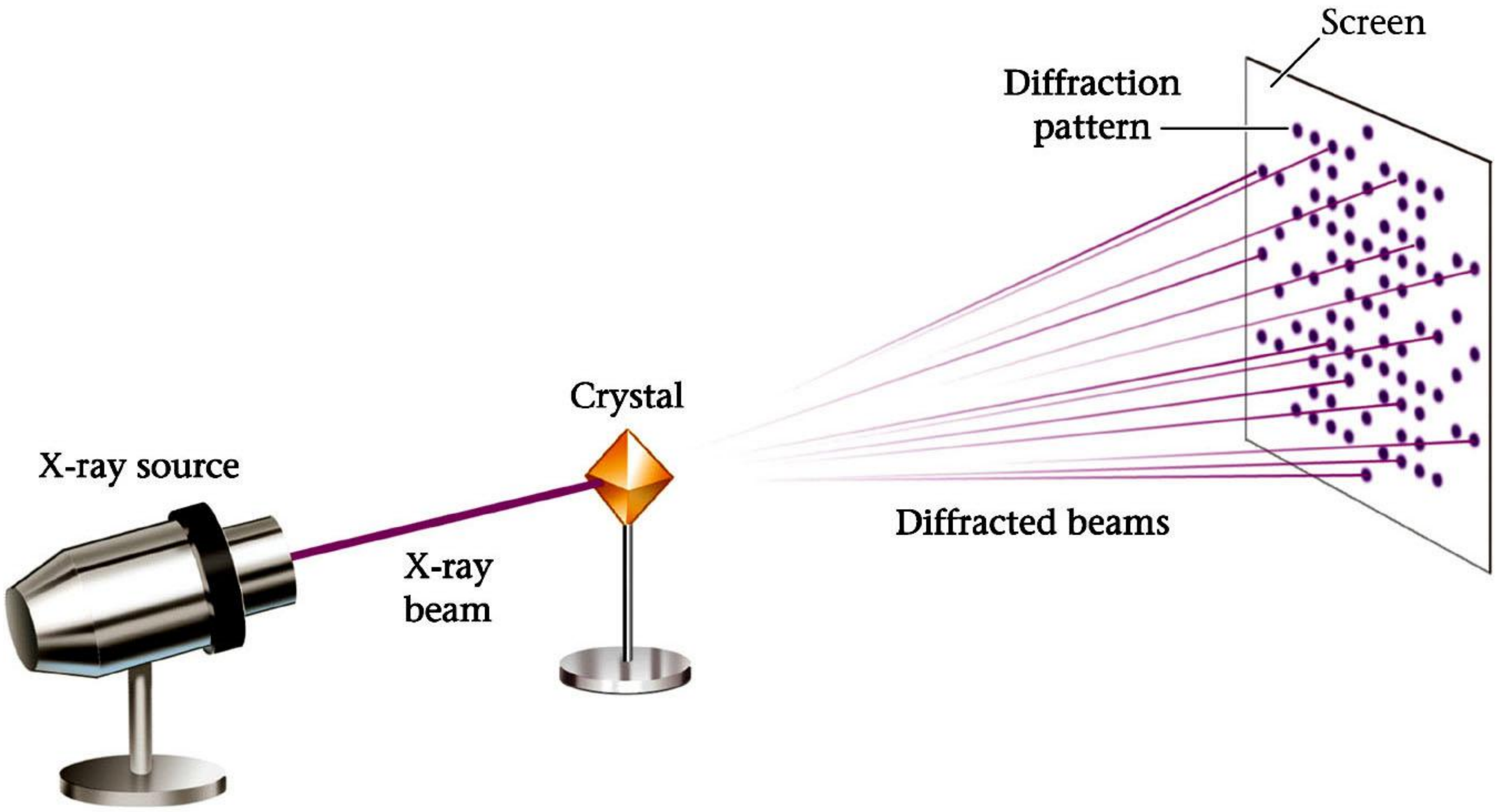
- ***Minerals:*** organized molecules



- ***Example: Quartz***
  - Although different crystals may look different, they share certain consistent characteristics



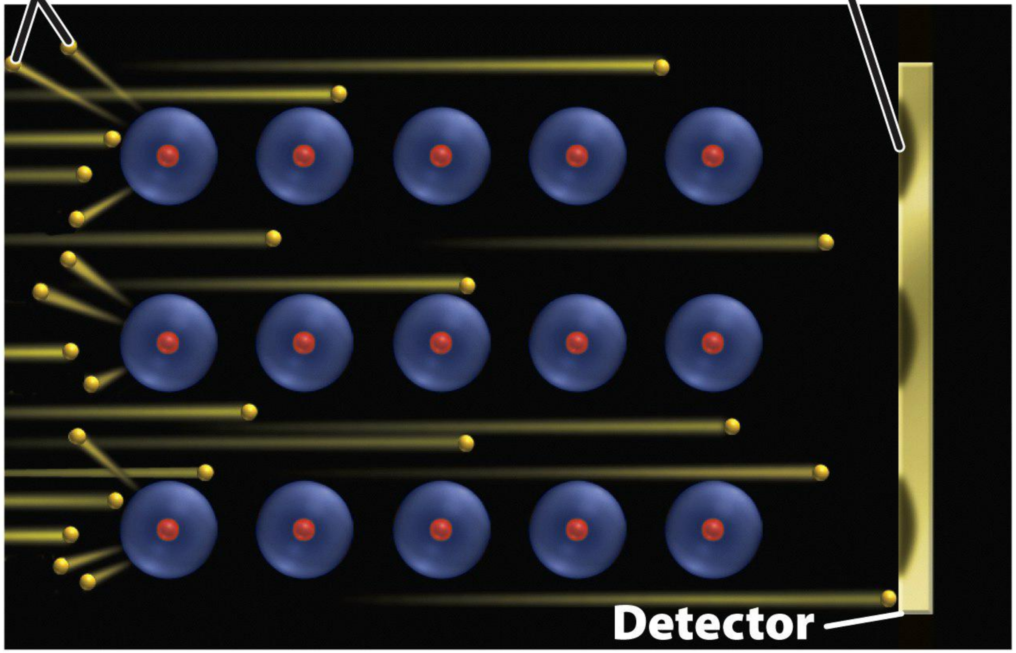
Identifying Crystal Structures



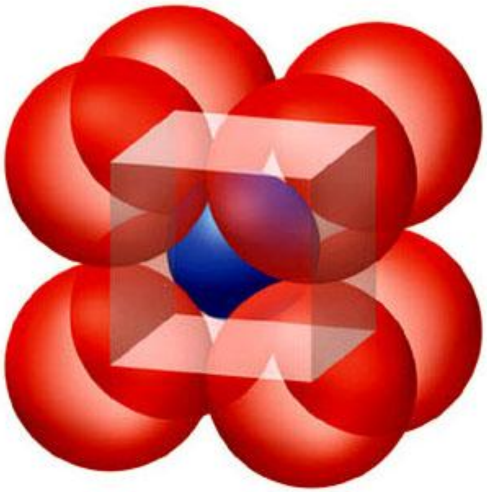
- Some mineralogists use **x-ray diffraction** patterns to identify minerals.

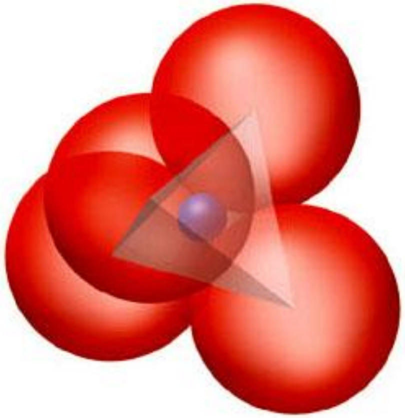
Seeing Into Crystals

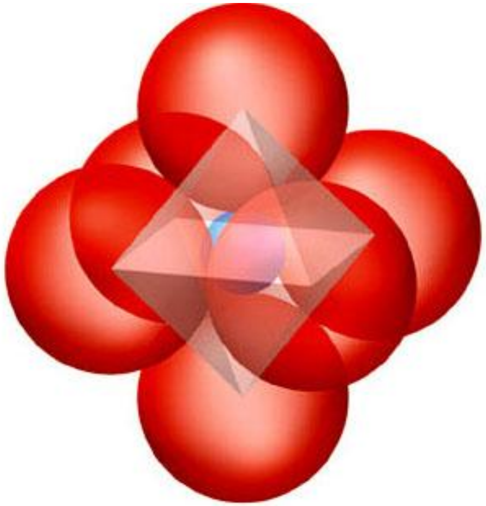
- Modern instrumentation allows us to “see” atoms.
  - A beam of electrons passes through material.
  - Atoms scatter electrons, which pass between them.
  - A shadow on the detector indicates a row of atoms.
  - This principle drives the electron microscope.



Crystal Shape – Its Atomic!

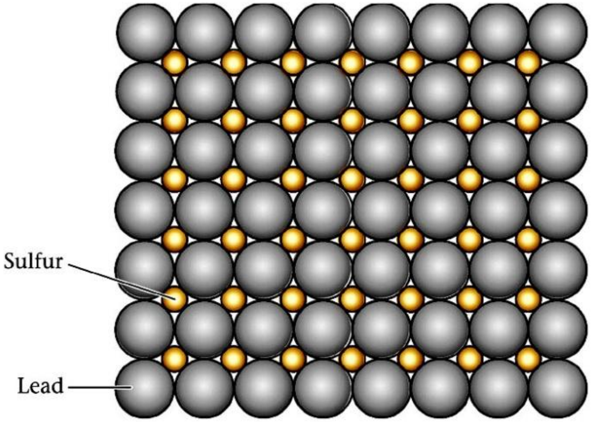




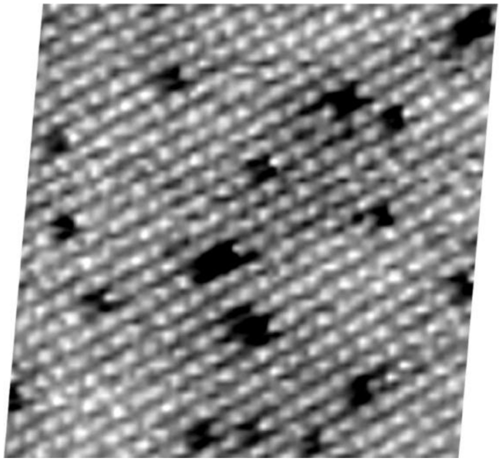


- **In the end, it is the shape of the crystal lattice that controls the shape and many properties of minerals**

Model of galena molecule (PbS)

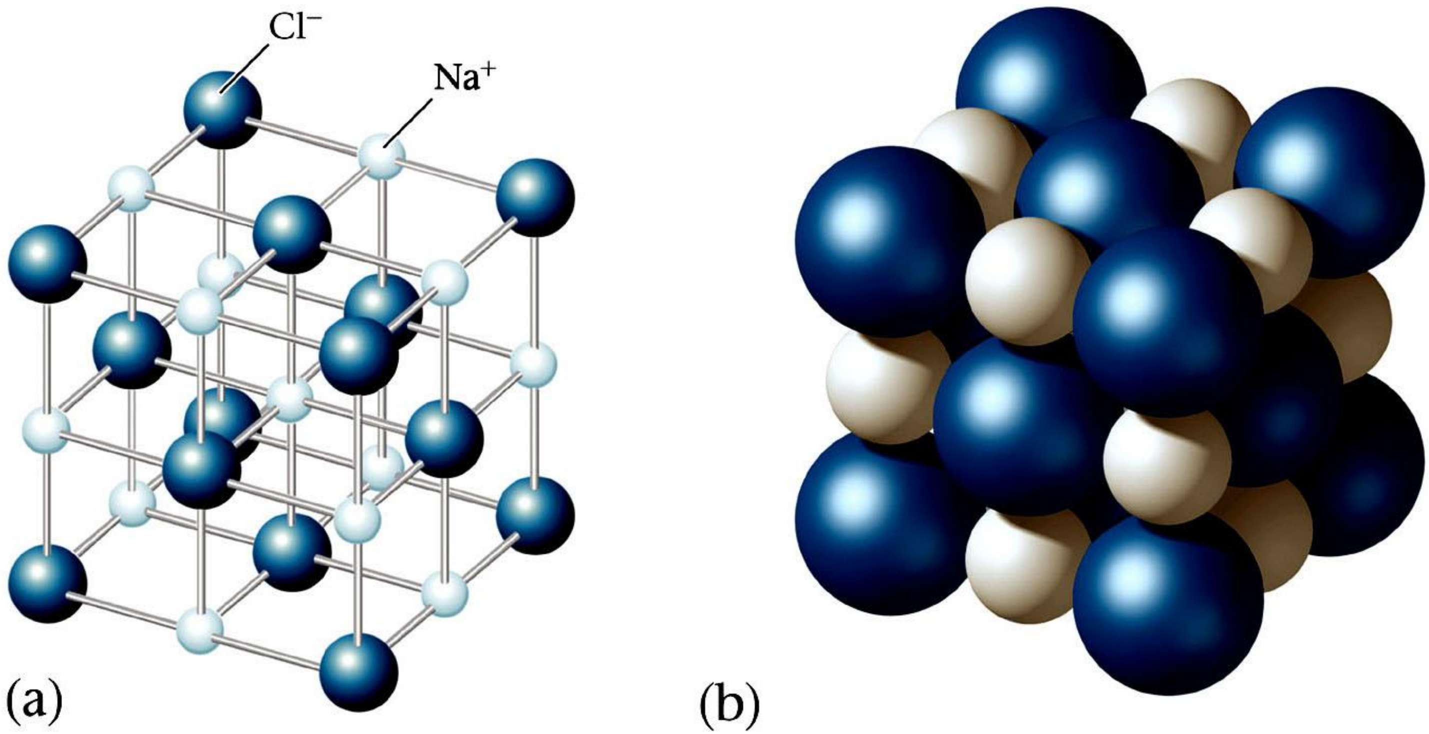


Electron microscope picture of galena crystal surface



Hand sample of Galena

Crystal Structure (Lattice)

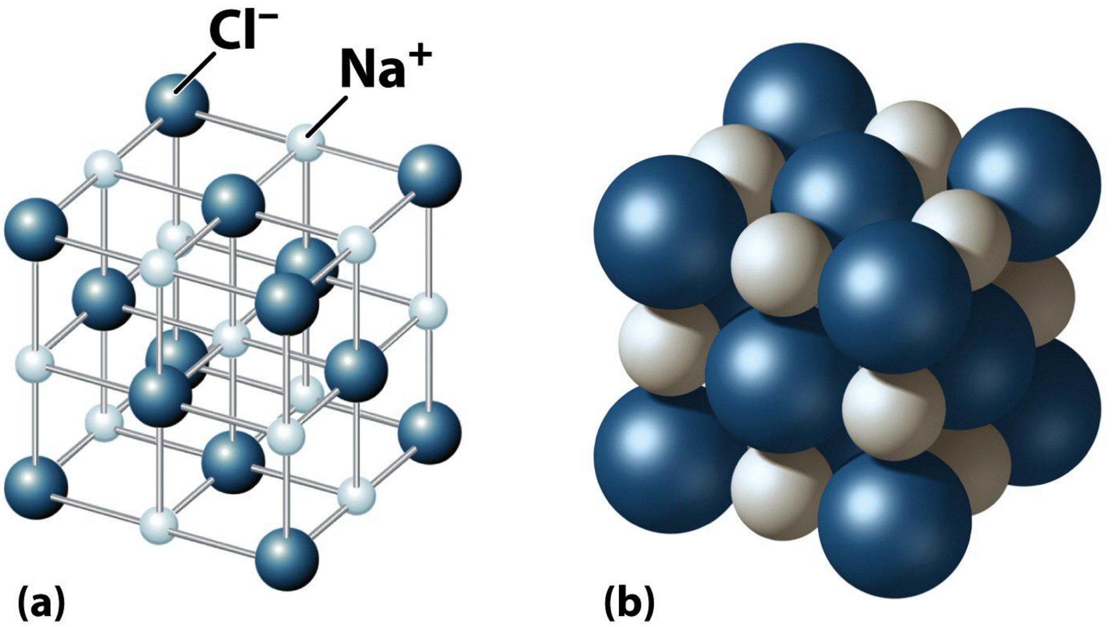


- Halite

  NaCl

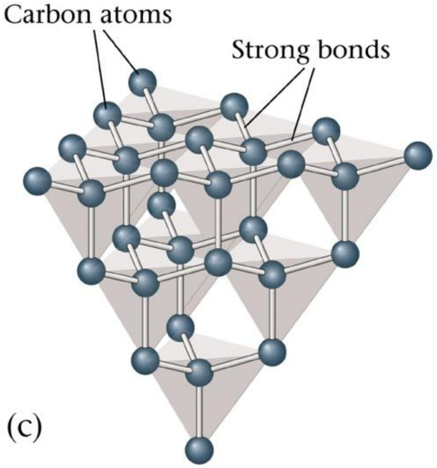
Atomic Bonding & The Crystal Lattice

- Lattice atoms are held in place by atomic bonds.
- Bond characteristics govern mineral properties.
- 5 recognized types of bonds.
  - Covalent.
  - Ionic.
  - Metallic.
  - Van der Waals.
  - Hydrogen.



- Models depict atoms, bonds, and lattices.

Polymorphs: Two minerals that have the same composition but different crystal form



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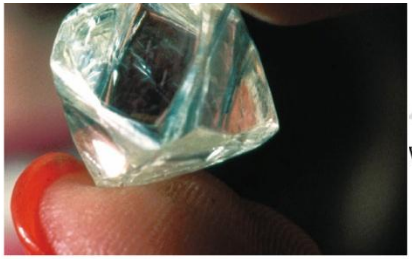

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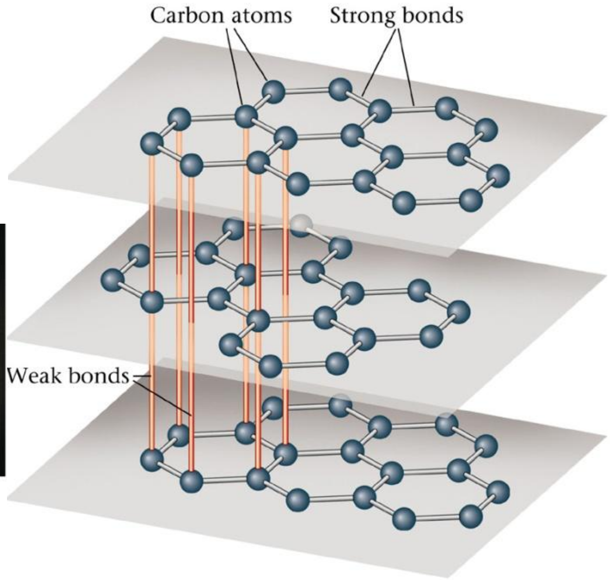


- Diamond: C
  - Carbon atoms covalently bond in tetrahedral networks
  - Forms strong bonds that are hard to break, so diamonds are very hard
  - Diamonds are more dense (3.5 g/cm^3) than graphite (2.1 g/cm^3)because of formation under great pressure.

- Graphite: C
  - Carbon atoms bond in planar sheets; sheets are weakly bonded
  - Sheets are easy to break; graphite is very soft

    Why are golf clubs and bikes made of graphite?

Mineral Identification

- Since we can’t all have x-ray diffraction machines and electron microscopes, we identify minerals by visual and chemical properties called ***physical properties*.**
- **Types of physical properties that geologists use include:**
  - ***Color, Streak, Luster, Hardness, Specific Gravity, Crystal Habit, and Cleavage***
- Properties depend upon…
  - **Chemical composition.**
  - **Crystal structure.**
- Some are diagnostic.
- Minerals have a unique set of physical properties.

1- Color

- Color may be diagnostic for a few minerals, but in general, a given mineral can have a range of colors.

Various colors of quartz, SiO_2

2- Streak

- The color of the pulverized powder of a mineral.
  - More consistent than color
  - Found by scraping a mineral against a porcelain plate

Hematite (Fe_2O_3) can have various colors, but its streak is always red-brown

3- Luster

- The way a mineral's surface scatters light

Metallic luster

Nonmetallic luster

4- Hardness

- The measure of a mineral to resist scratching
- Represents the strength of bonds in the crystal lattice
  - Measured on a qualitative scale **called *Mohs Hardness Scale***

Vitreous luster (Nonmetallic)

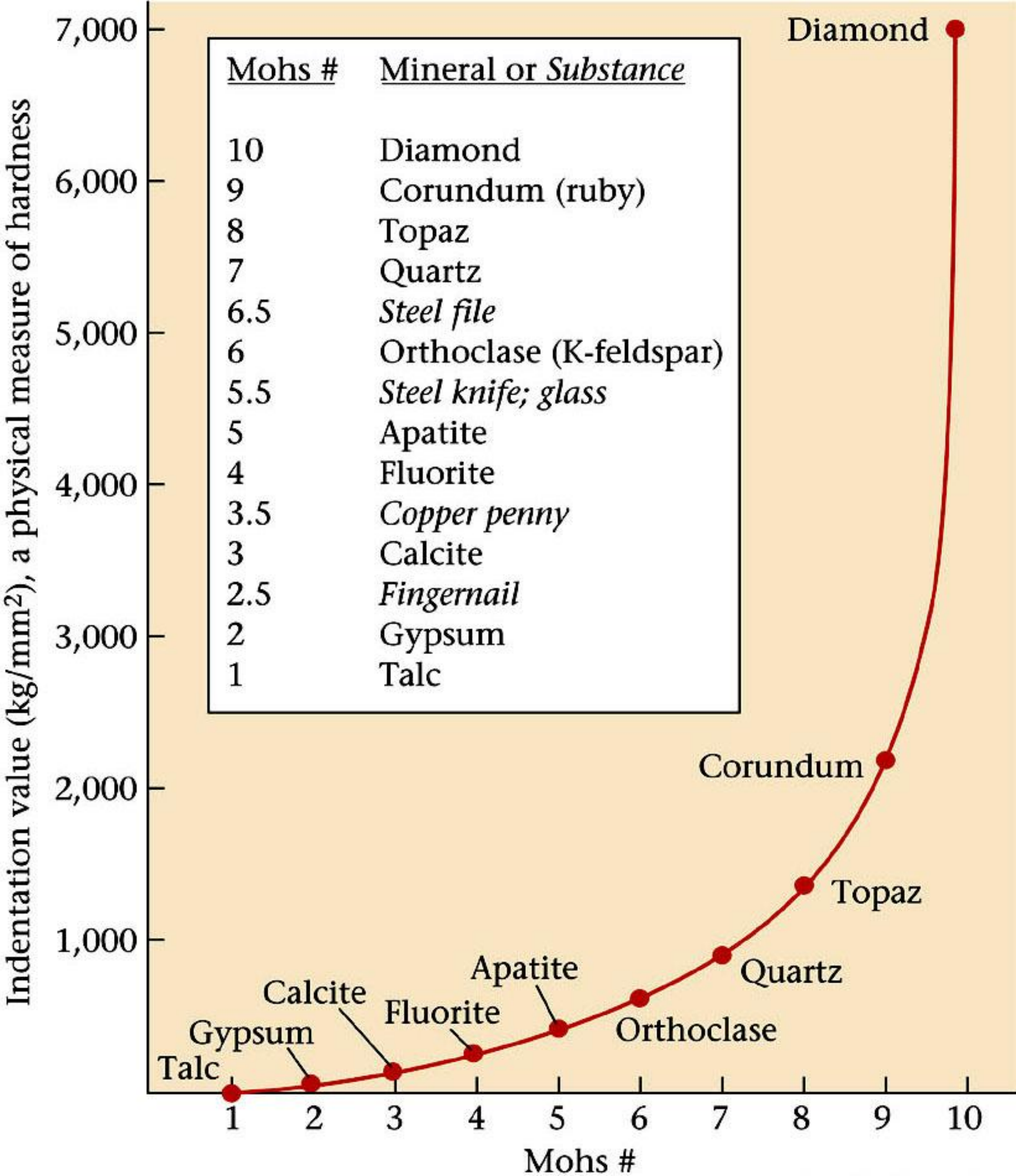
Adamantine luster (Nonmetallic)

Moh's Hardness Scale

- Fingernail = 2.5
- Glass = 5.5
- Streak Plate = 6.5
- Talc =1
- Quartz = 7
- Diamond = 10

This doesn't mean that diamonds are 10 times harder than talc…

that's why we call this a ***qualitative*** measure, not ***quantitative*** measure



5- Specific Gravity

- Specific Gravity: The weight of a substance divided by the weight of an equal volume of water
  - *Same as density!!*

6- Crystal Habit

- A description of a mineral's consistent shape

Prismatic

Needle-like or fibrous

Blade-like or

Elongated

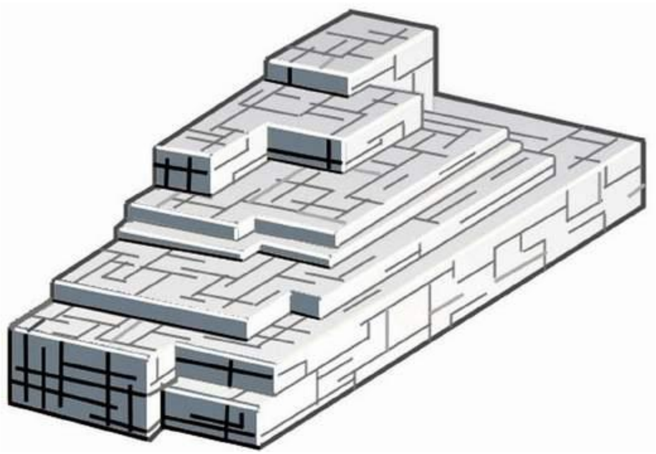
Fracture and Cleavage

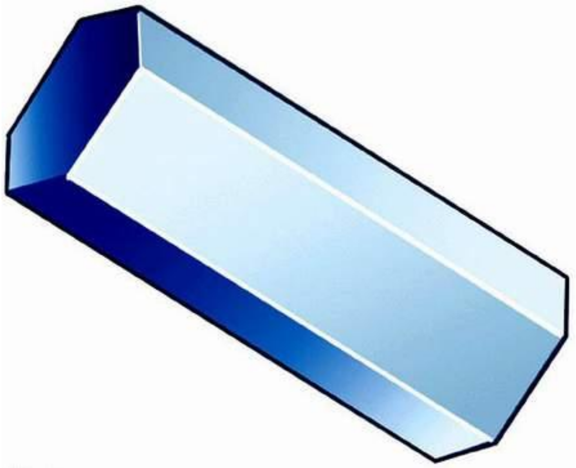
- **Cleavage:** The tendency of a mineral to break along a plane of weakness in the crystal lattice.
- ***Fracture:*** The mineral breaks in no consistent manner
  - Equal bond strength in all directions
- **Conchoidal Fracture:** The tendency for a mineral to break along irregular scoop-shaped fractures that are not related to weaknesses in the crystal structure

Obsidian, a volcanic glass, and quartz commonly exhibit conchoidal fracture, which is why Indians used them as cutting tools.

Cleavage

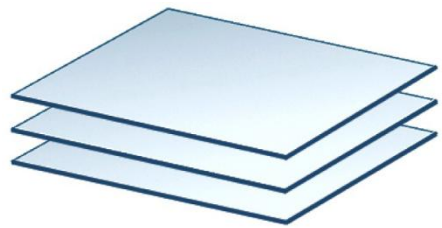
- Tendency to break along planes of weakness.
- Cleavage produces flat, shiny surfaces.
- Described by number of planes and their angles.
- Sometimes mistaken for crystal habit.
  - Cleavage is through-going; often forms parallel "steps."
  - Crystal habit is only on external surfaces.
- 1, 2, 3, 4, and 6 cleavage planes possible.



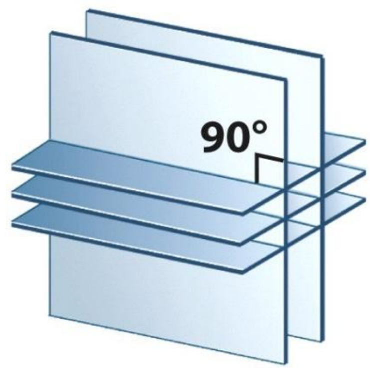


Cleavage

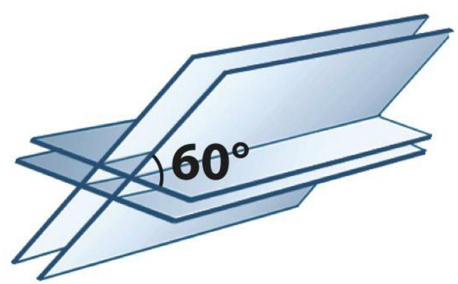
- Examples of Cleavage:
  - 1 direction



  - 2 directions at 90º

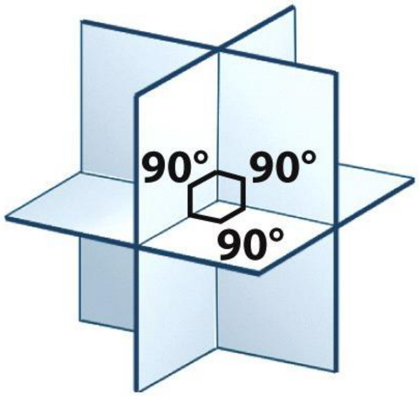


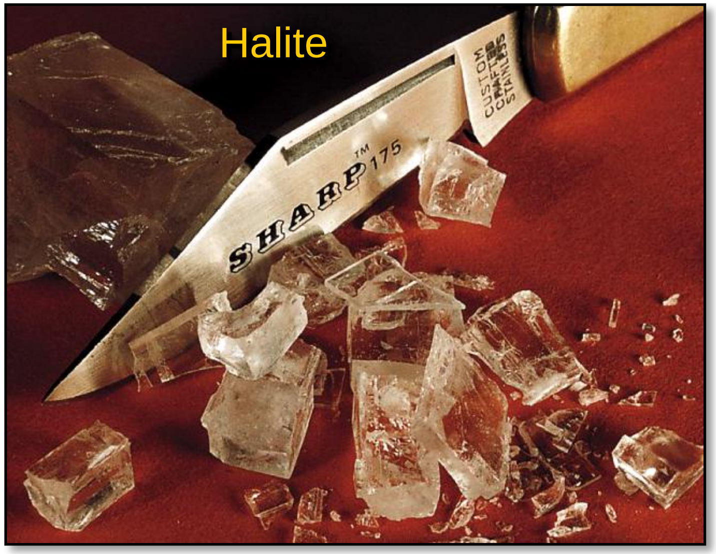
  - 2 directions NOT at 90º



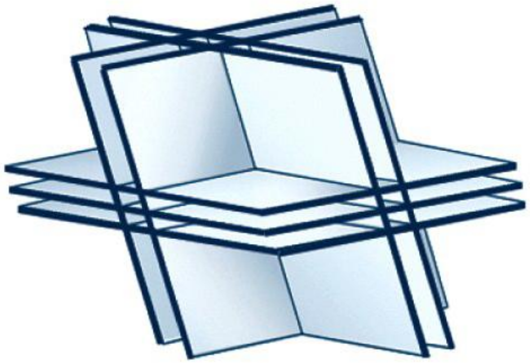
Cleavage

- Examples of Cleavage:
  - 3 directions at 90º





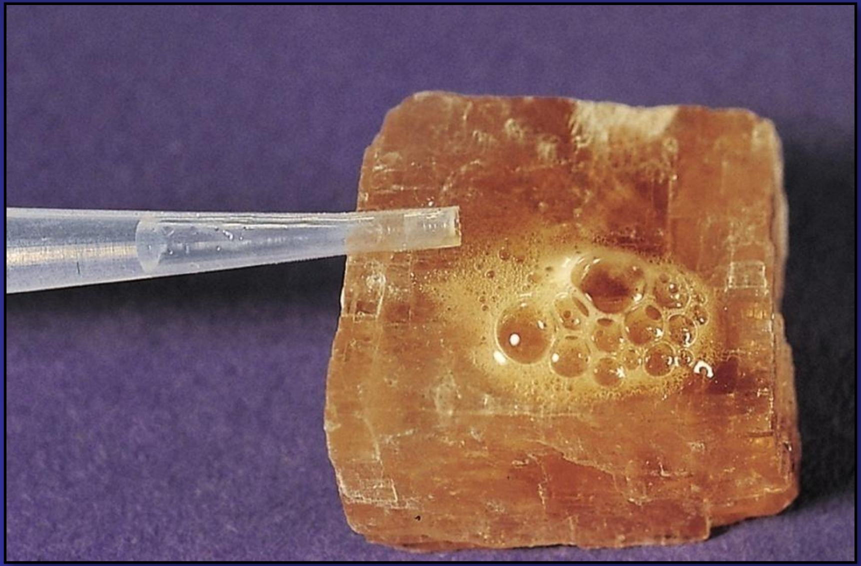
  - 3 directions NOT at 90º



Special Characteristics

- **There are other special characteristics that some minerals exhibit that allow us to identify them**
  - Reacts to Acid *[Calcite and Dolomite: $CaCO_3$ & $Ca(Mg)CO_3$]*
  - Magnetic *[Magnetite: Fe_3O_4]*
  - Salty taste *[Halite: NaCl]*
  - Striations *[Plagioclase Feldspar: $NaAlSi_3O_8$ - $CaAl_2Si_2O_8$, Pyrite - FeS_2, Quartz - SiO_2]*

Striations on Pyrite



Calcite reacts with HCl and gives off CO_2

Mineral Compositions

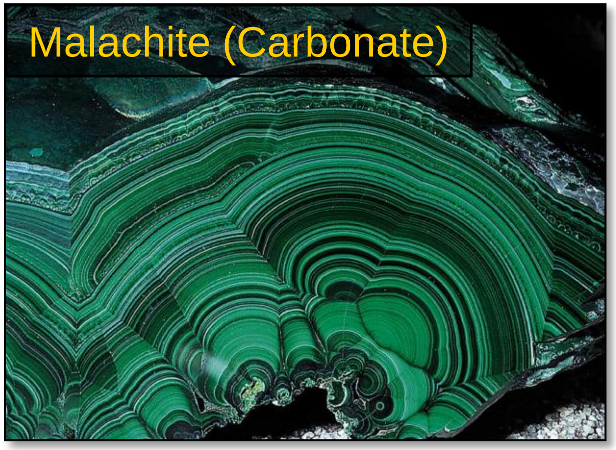
- Only about 50 minerals are abundant.
- 98.5% of crustal mineral mass is from 8 elements.
  - Oxygen O 46.6%
  - Silicon Si 27.7%
  - Aluminum Al 8.1%
  - Iron Fe 5.0%
  - Calcium Ca 3.6%
  - Sodium Na 2.8%
  - Potassium K 2.6%
  - Magnesium Mg 2.1%
  - All others 1.5%

74.3% of crustal minerals !!!

Mineral Classes

- Minerals are classified by their dominant anion.

– **Silicates**	SiO_2^{4-}	**Rock-forming mins**
– **Oxides**	O^{2-}	**Magnetite, Hematite**
– **Sulfides**	S^{-}	**Pyrite, Galena**
– **Sulfates**	SO_4^{2-}	**Gypsum**
– **Halides**	Cl^{-} or F^{-}	**Fluorite, Halite**
– **Carbonates**	CO_3^{2-}	**Calcite, Dolomite**
– **Native Elements**	**Cu, Au, C**	**Copper, Graphite**

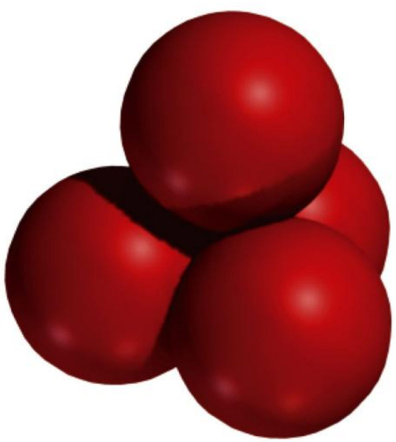


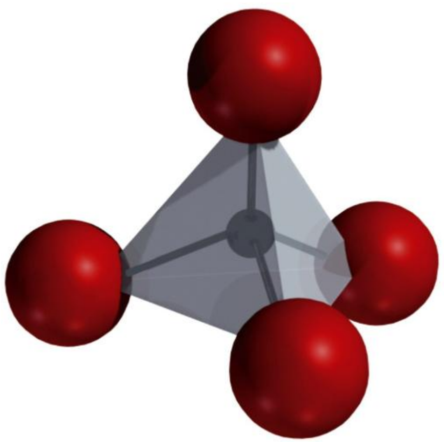
Silicate Minerals

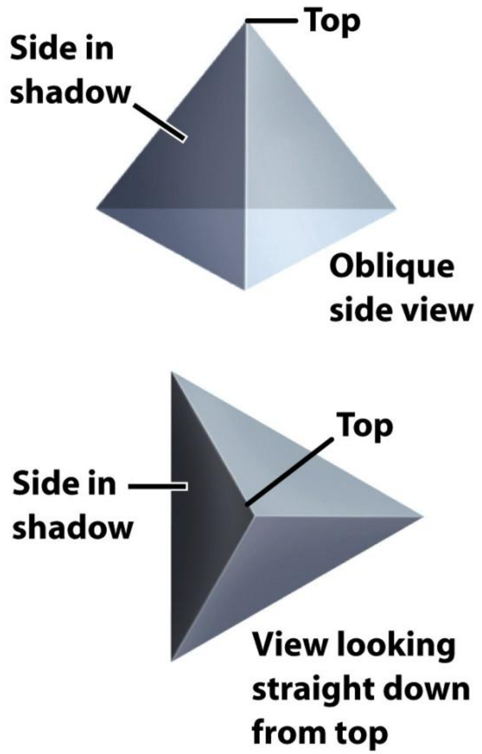
- Silicates are known as the rock-forming minerals.
- They dominate the Earth's crust.
  - **Oxygen and silicon…**
    - **Make up 94.7 % of crustal volume, and...**
    - **74.3 % of crustal mass.**

Silicate Minerals

- The anionic unit is the silica tetrahedron.
  - 4 oxygen atoms are bonded to 1 silicon atom (SiO_4^{4-}).
  - Silicon is tiny; oxygen is huge.
  - The silica tetrahedron has a net -4 ionic charge.
  - The silicate unit can be depicted by…
    - Spheres.
    - A ball and stick model.
    - Polyhedra.







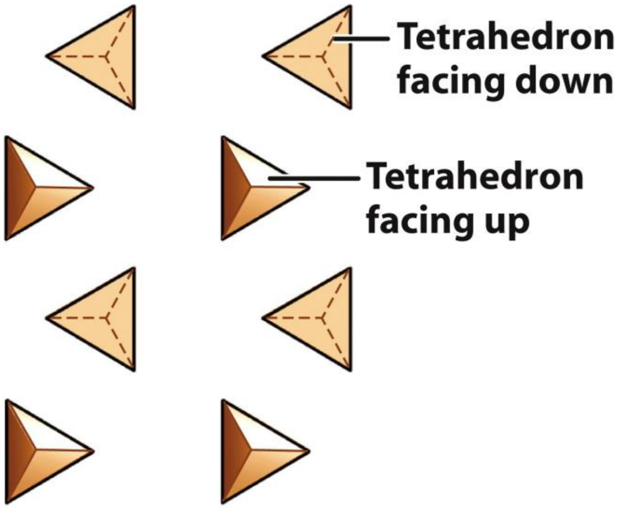
Silicate Minerals

- **Silica tetrahedra link together by sharing oxygens.**
- More shared oxygen = lower Si:O ratio; governs…
  - Melting temperature.
  - Mineral structure and cations present.
  - Susceptibility to chemical weathering.

Type of Silicate Structure	Formula	Si:O Ratio
Independent Tetrahedra	SiO_4	0.25
Double Tetrahedra	Si_2O_7	0.29
Ring Silicates	Si_6O_{18}	0.33
Single Chains	SiO_3	0.33
Double Chains	Si_4O_{11}	0.36
Sheet Silicates	Si_2O_5	0.40
Framework Silicates	SiO_2	0.50

Independent Tetrahedra

- Tetrahedra share no oxygens - **linked by cations**.
  - **Olivine Group**
    - High temperature Fe-Mg silicate.
    - Small green crystals; no cleavage.
  - **Garnet Group**
    - Equant crystals with no cleavage.
    - Dodecahedral (12 sided) crystals.

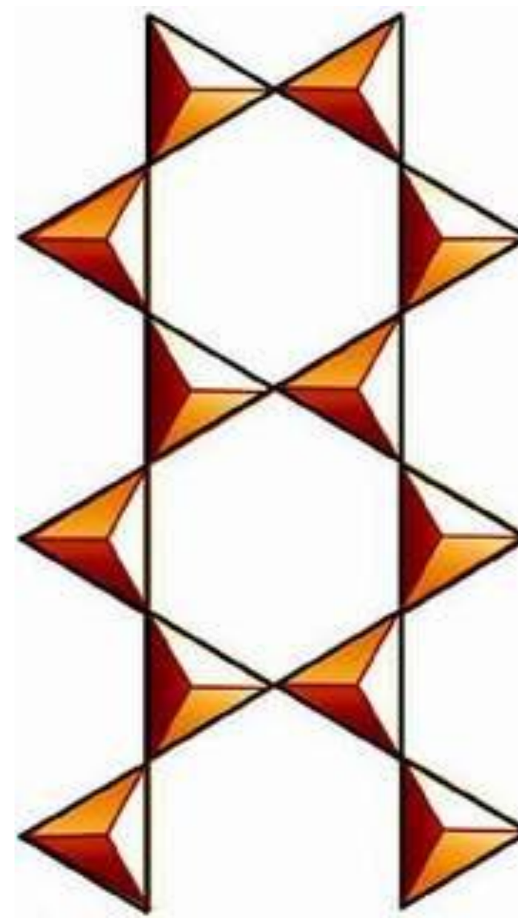


Single-Chain Silicates

- Single-chain structures bonded with Fe and Mg.
  - **Pyroxene Group**
    - Black to green color.
    - Augite is the most common pyroxene.

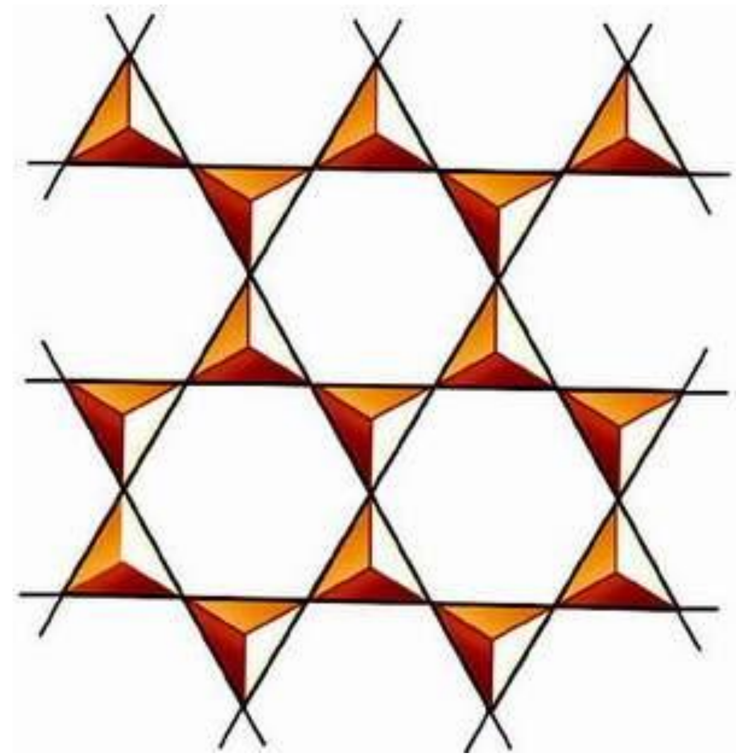
Double-Chain Silicates

- Double chain of silica tetrahedra bonded together.
- Contain a variety of cations.
  - **Amphibole Group**



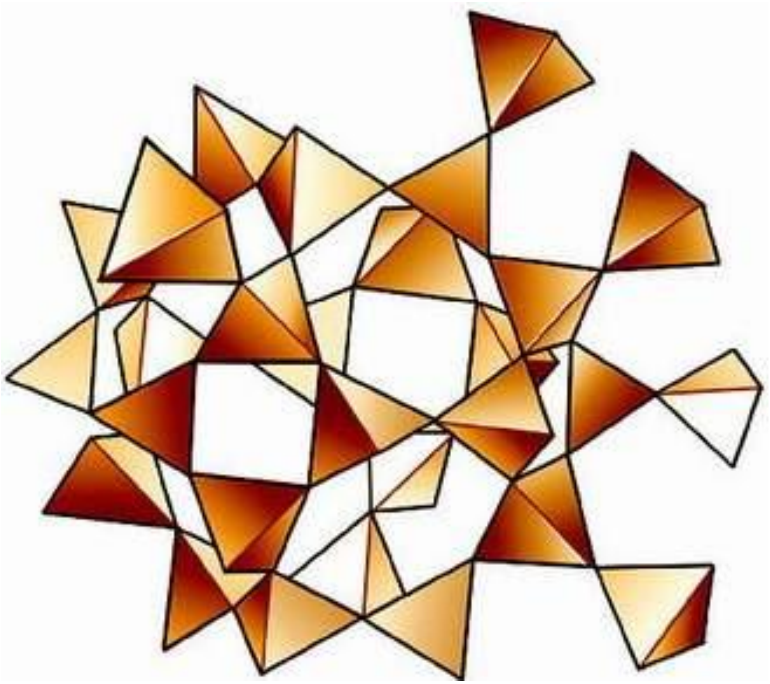
Sheet Silicates

- 2-dimensional sheets of linked tetrahedra.
- Characterized by one direction of perfect cleavage.
  - **Mica Group** – Biotite (dark) and Mucsovite (light).
  - **Clay Mineral Group** – Feldspar weathering residue; tiny.



Framework Silicates

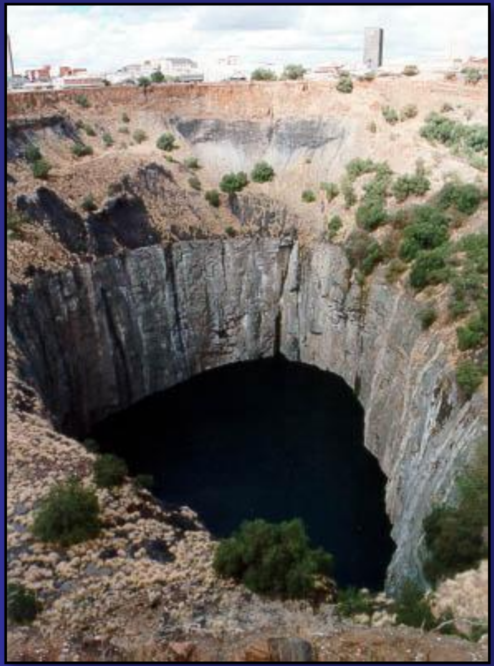
- All 4 oxygens in the silica tetrahedra are shared.
  - **Feldspar Group** – Plagioclase and potassium feldspar.
  - **Silica (Quartz) Group** – Contains only Si and O.
  - Most complex structure of the silicates



Precious Stones: Gems

- Gems have equivalent mineral names, but gemologists usually name gemstones something marketable.
- Diamonds
  - Made of C
  - Form in high pressure volcanic environments called ***kimberlites***

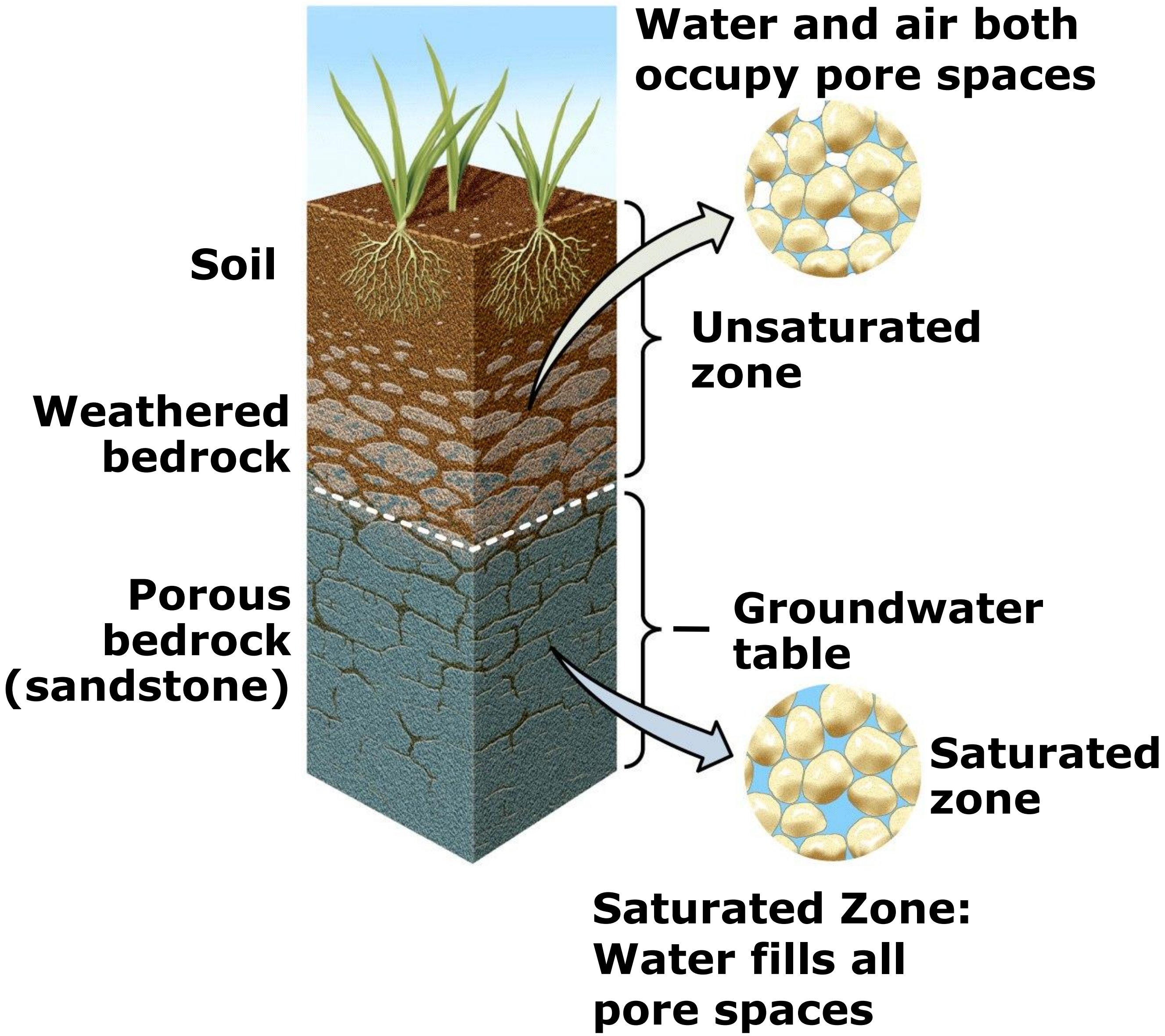
Emeralds, sapphires, and aquamarine are made of the mineral, Beryl



The first kimberlite pipe mine with the DeBeers sorting facility in the distance

Diamonds form in high pressure kimberlite pipes

Where Do Mineral Deposits Come From?

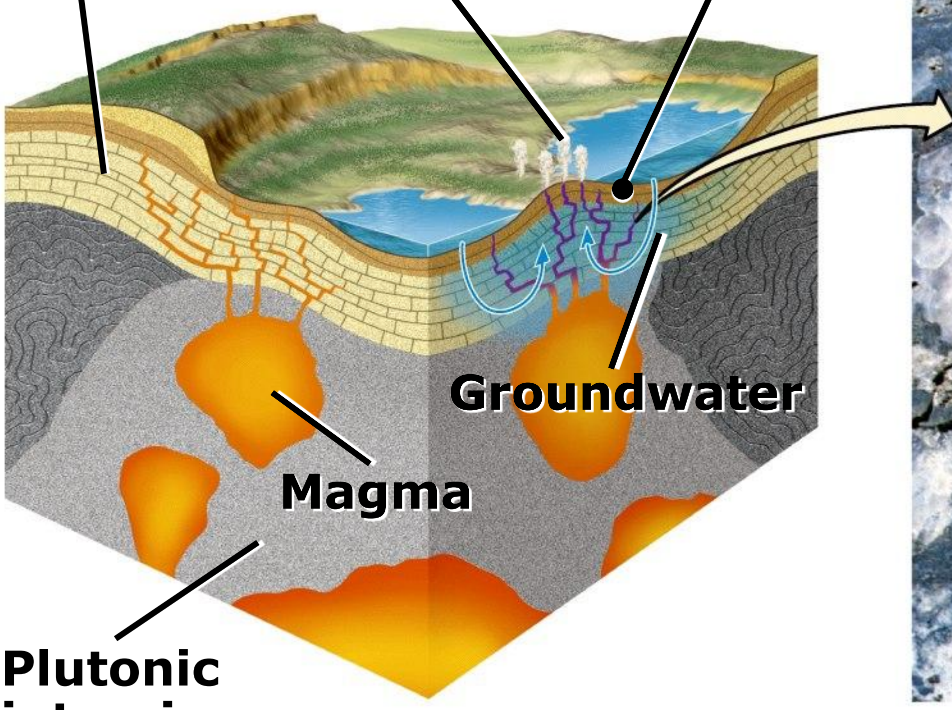


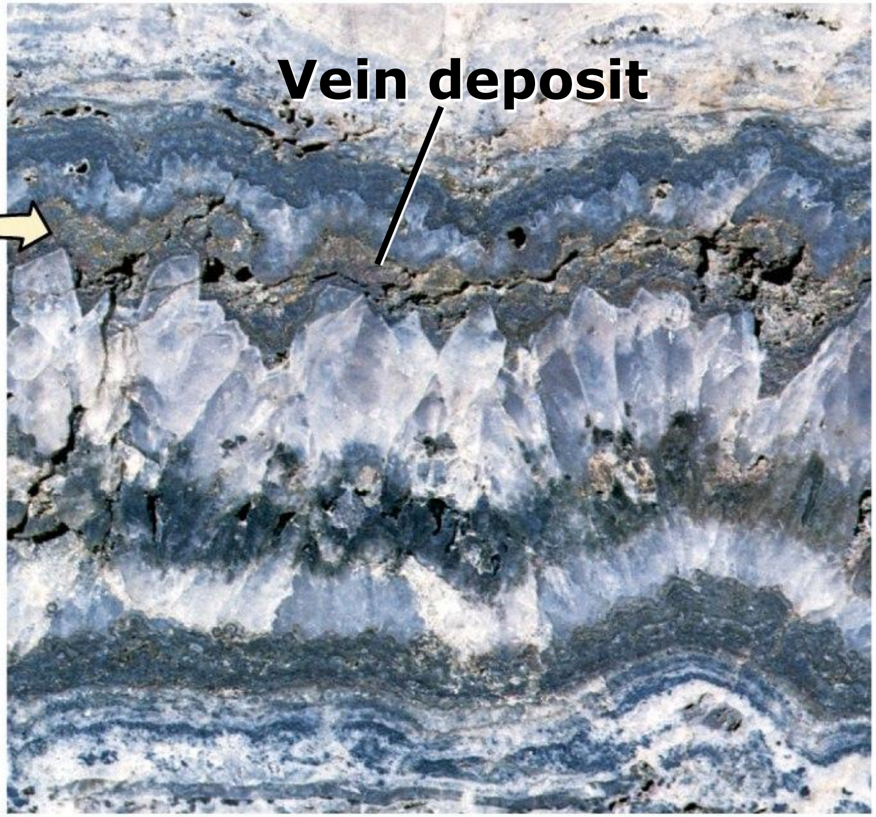
Water carries compounds dissolved in solution

Over time, water can leave behind mineral deposits in rocks or cracks

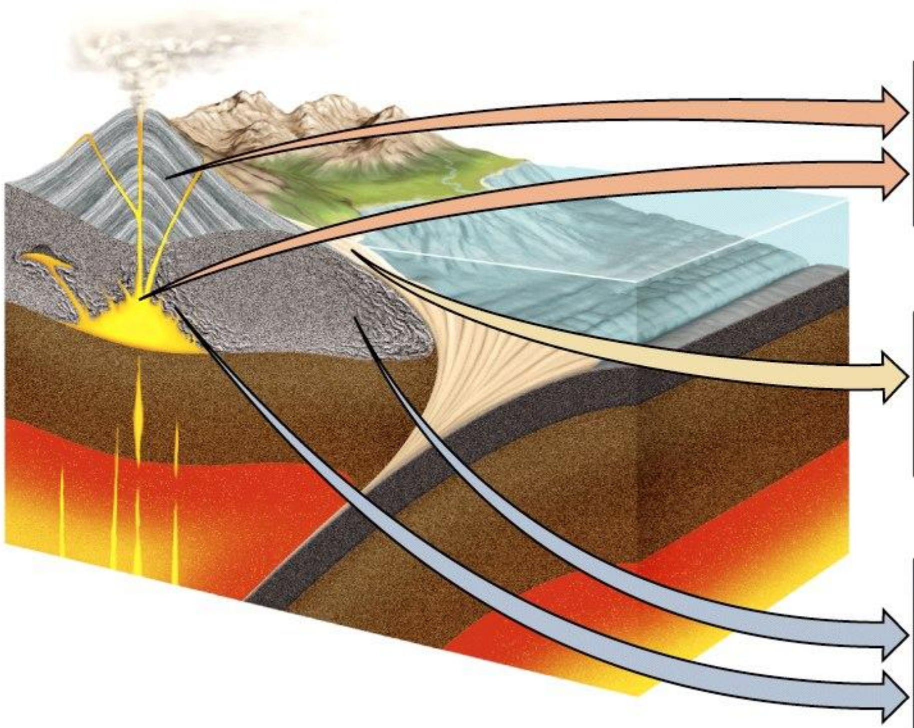
Where Do Mineral Deposits Come From?

Groundwater dissolves metal oxides and sulfides. Heated by the magma, it rises, precipitating metal ores in joints.





The Three Basic Types of Rocks



Type of rock and source material	Rock-forming process	Example
IGNEOUS Melting of rocks	Crystallization	 Coarsely crystallized granite
SEDIMENTARY Weathering and erosion of Exposed rocks	Deposition, burial, and lithification	 Cross-bedded sandstone
METAMORPHIC Rocks under high temperatures and pressures	Recrystallization neocrystallization	 Gneiss

We will discuss these three rock types in detail in the next three chapters.

Rock-forming minerals

Out of 4000 minerals being named, not more than a few dozen are abundant, rock-forming minerals. Only 8 elements make up the bulk of these minerals and represent 98% (by weight) of the continental crust.

Most abundant elements in Earth's crust (weight percentage)

Oxygen (O)	46.6	Sodium (Na)	2.8
Silicon (Si)	27.7	Potassium (K)	2.6
Aluminum(Al)	8.1	Magnesium (Mg)	2.1
Iron (Fe)	5.0	all others	1.7
Calcium (Ca)	3.6		

- **Nearly all rocks are made of Minerals.**
- **12 minerals are considered common.**

> Olivine, Augite, Hornblende, Biotite

darker colors- Green, Blue, Black, Brown

> Quartz,

>Orthoclase, Plagioclase (feldspars),

> Muscovite, Calcite, Dolomite, Gypsum, Halite

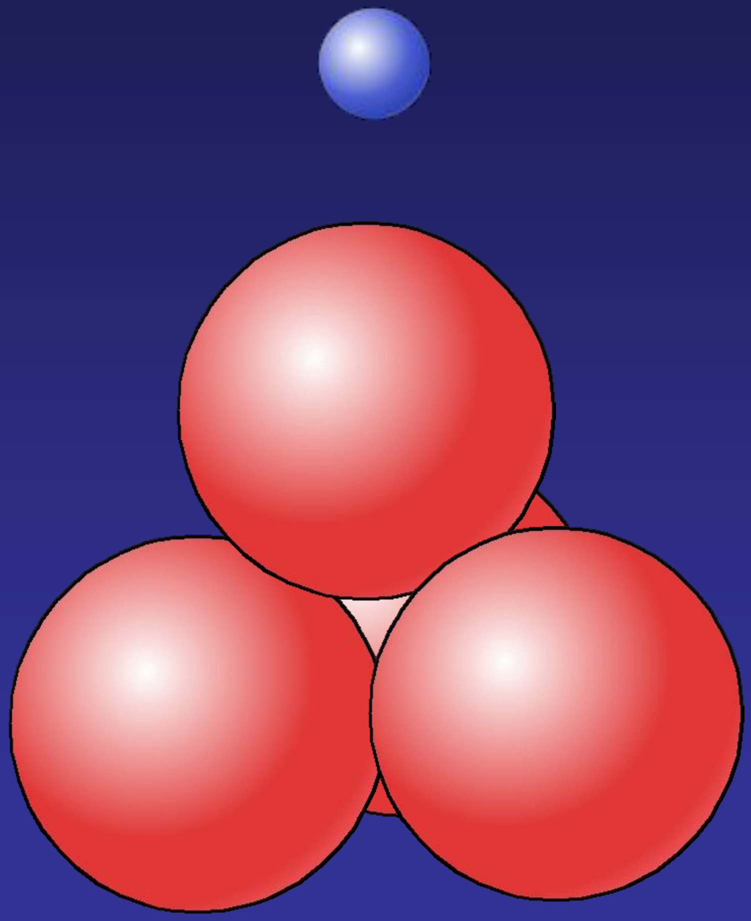
lighter colors- Pink, White, Yellow, Gray, Clear

Rock-forming minerals

silicates (-SiO_4)
oxide
sulfide
carbonates (-CO_3)
sulfates (-SO_4)

Silica Tetrahedra

- The building block of most common rock forming minerals
  - Four **O**$^{2-}$ in a tetrahedral configuration
  - One **Si**$^{4+}$ nested in the center
  - $(4 \times \mathbf{-2}) \mathbf{+4} = -4$
  - $(\mathbf{SiO}_4)^{-4}$



Silica Tetrahedra

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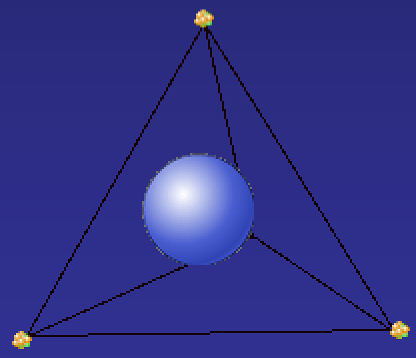
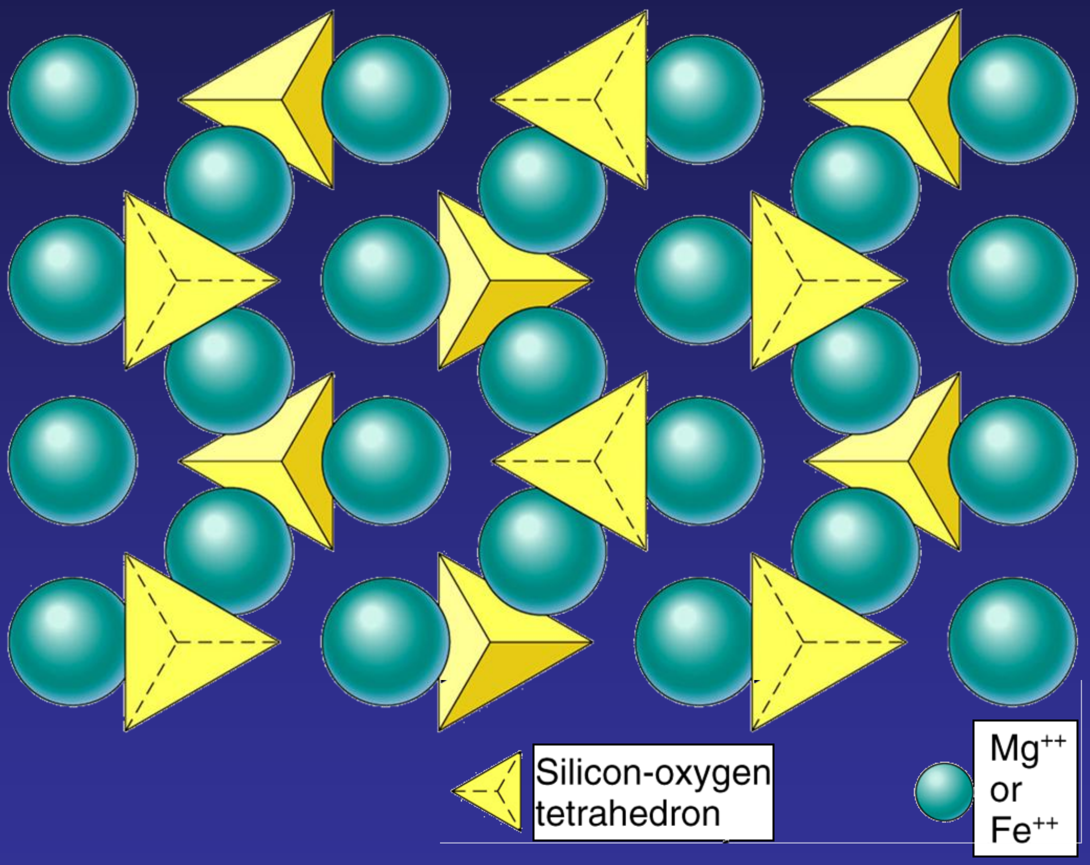


Silicate Minerals: Examples

- E.g., **Olivine**
  - Isolated silicate structure
  - $(SiO_4)^{-4} + 2\times Fe^{+2}$
  - Fe_2SiO_4
  - Fe Mg SiO_4
  - Mg_2SiO_4

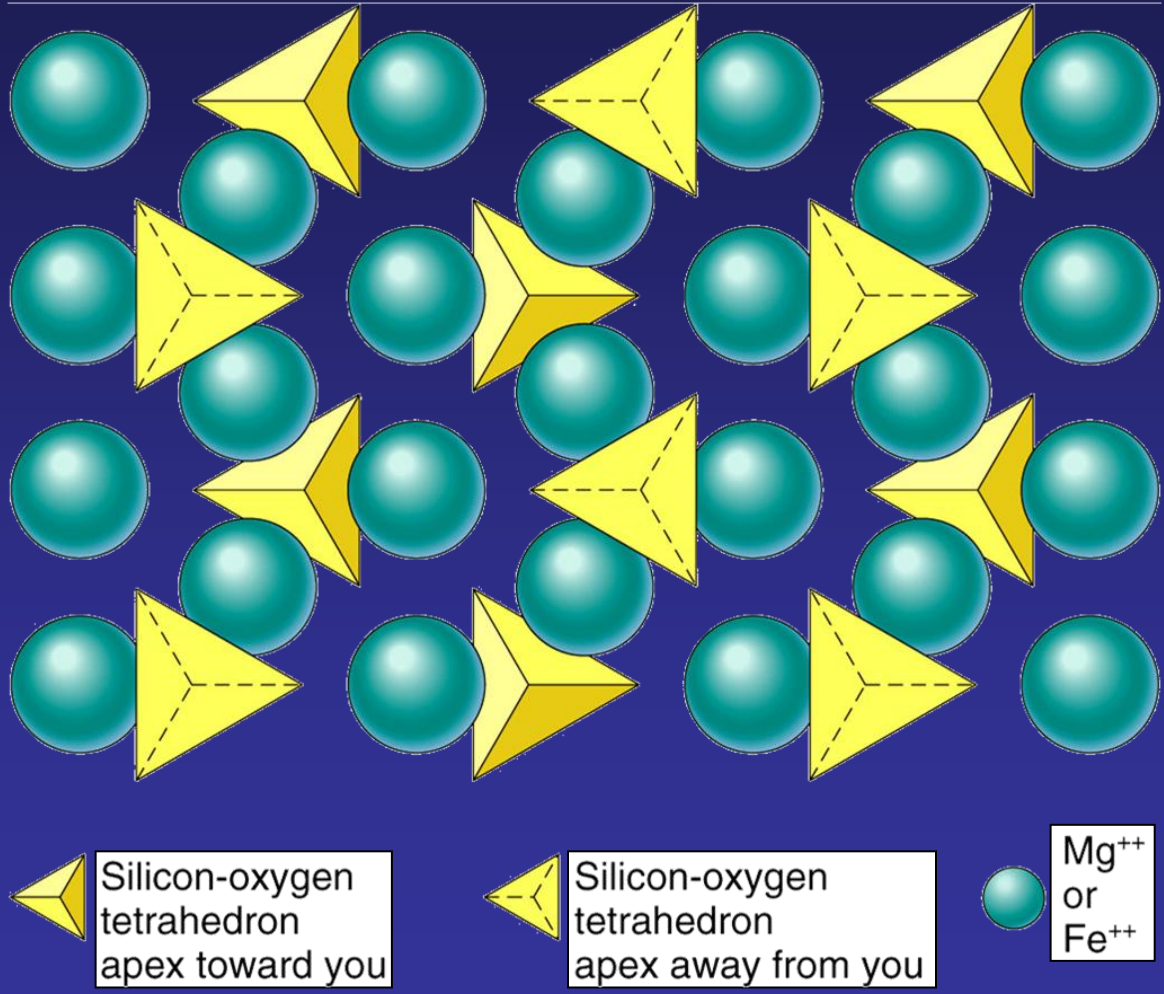
Definite Range



- $(Fe,Mg)_2\ SiO_4$ ➔ Olivine **Mineral Group**

Silicate Minerals: Examples

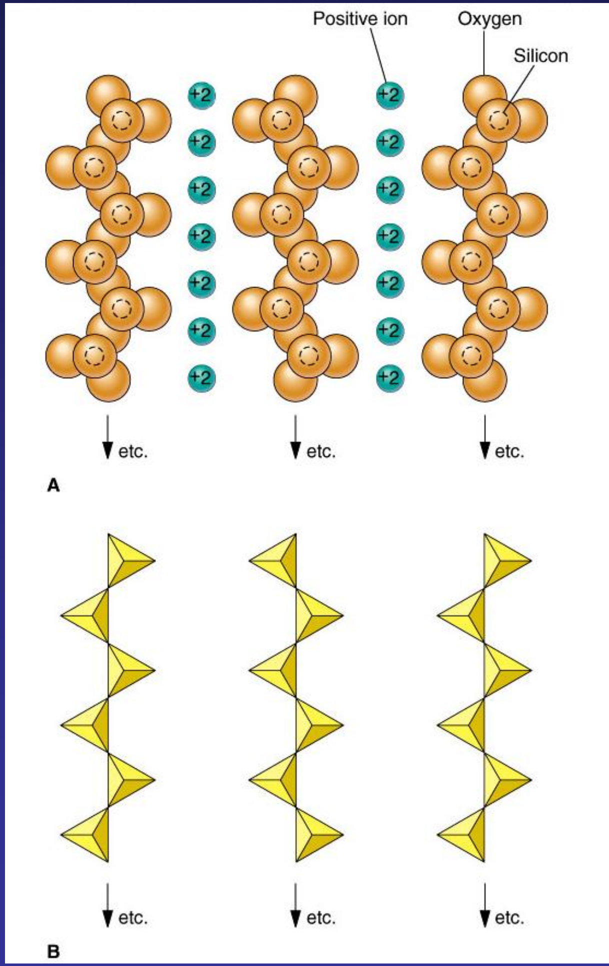
- E.g., **Olivine**
  - Isolated silicate structure
  - bonded with iron and magnesium
  - Makes up much of the mantle
  - Fe/Mg rich >50%
  - Silica poor <45%



Silicate Minerals: Examples

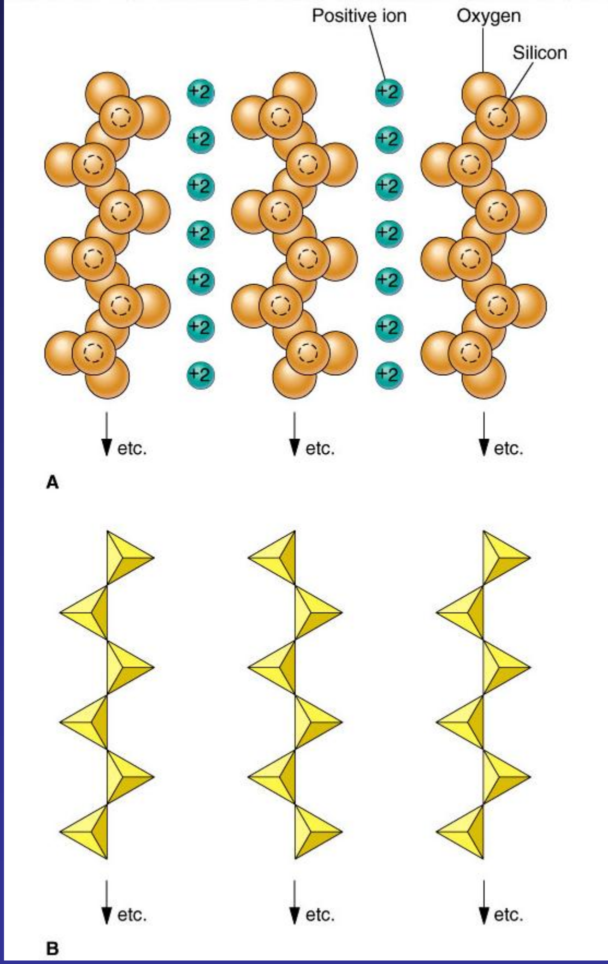
- E.g., **Pyroxenes** (Mineral Group)
  - **Single Chain Silicate** structure
  - $(SiO_3)^{-2} + Fe^{+2}$
  - $FeSiO_3$
    ↓
  - $(Fe,Mg)\ SiO_3$
    ↓
  - $MgSiO_3$

  $(Fe,Mg)\ SiO_3$ ➔ Pyroxene
  - Mineral Group
  - Ferromagnesian



Silicate Minerals: Examples

- E.g., **Pyroxenes** (Group of minerals)
  - **Single Chain Silicate** structure
  - bonded with **Fe, Mg**, Ca, and Al
  - Found in **Oceanic Crust**
  - Fe/Mg/Ca rich
  - Silica poor



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Silicate Minerals: Examples

- E.g., **Amphiboles** (Group of minerals)
  - **Double Chain Silicate** structure
  - bonded with **Fe, Mg,** Ca, and Al
  - Found in **Continental** Crust
  - **More silica** and less iron than pyroxenes

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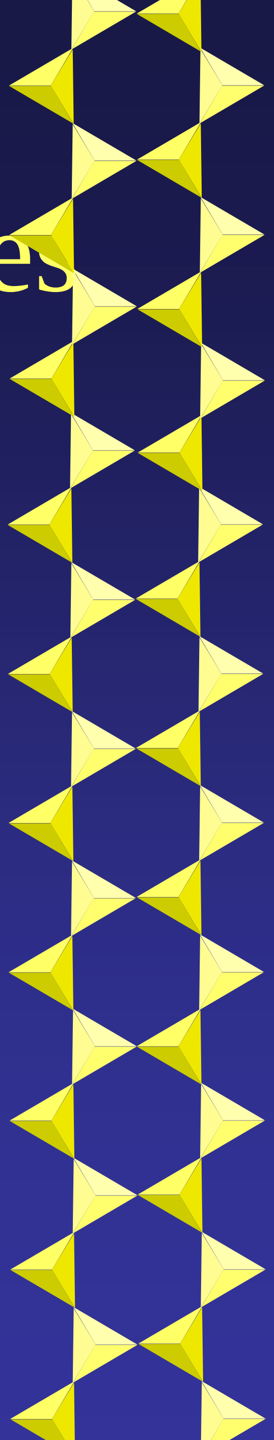
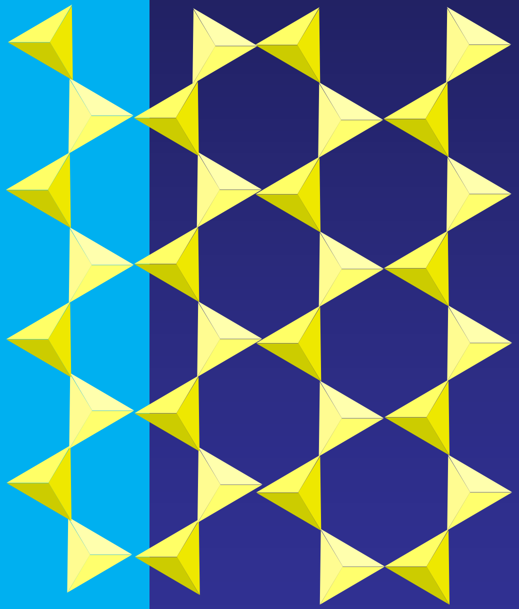


Silicate Minerals: Examples

- E.g., **Micas** (Muscovite and Biotite)
  - **Sheet** **Silicate** structure
  - bonded with **Al**, K,
    (biotite has **Fe, Mg**)
  - Found in **Continental** Crust
  - **More silica** and less iron than Amphiboles
- E.g., **Clays** (Mineral Group)
  - Hydrated, sheet silicates from weathering of other silicates



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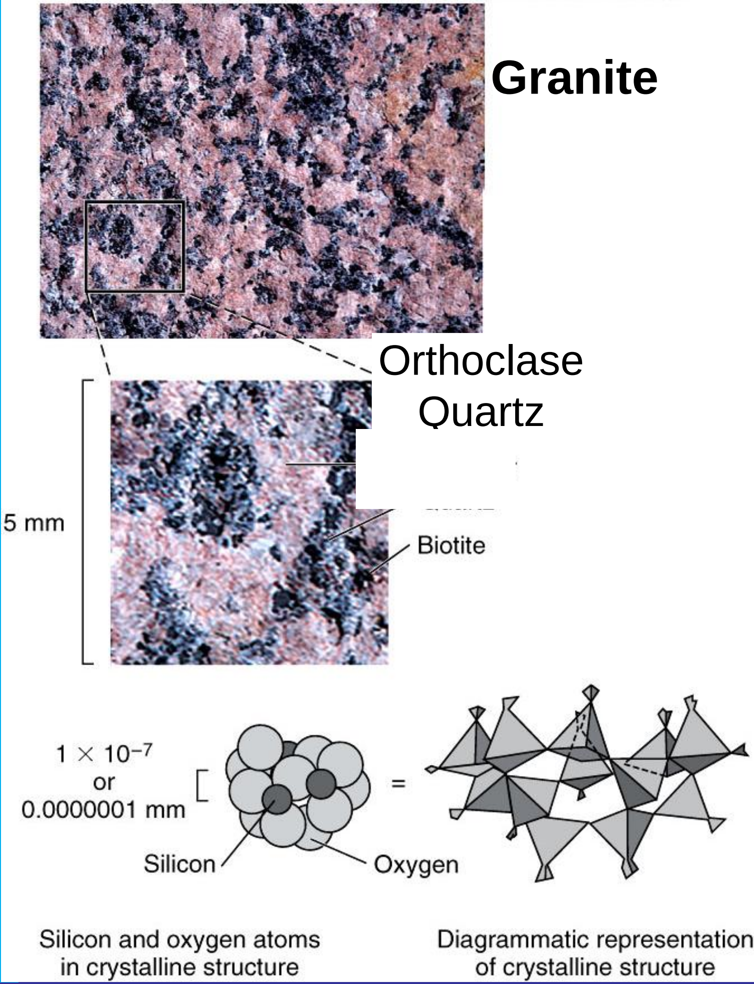
Silicate Minerals

- E.g., **Feldspars** (Orthoclase and Plagioclase) and **Quartz**
  - **Framework Silicate**
  - bonded with **Al**, and **K** (orthoclase) or **Na-Ca** (plagioclase)
  - Found in **Continental** Crust
  - **More silica** than micas, no iron



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Feldspars: the most common mineral group, two cleavage planes at 90 degrees, smooth shiny faces. (Left) orthoclase feldspar: containing K ions, white to pink. (Right) plagioclase feldspar: containing Na/Ca ions, striations, white to black.

- **Quartz**
- Quartz (SiO_2) is the second most abundant mineral after feldspars, has a variety of colors, hardness 7, conchoidal fracture, six-sided crystals, but no cleavage.

Clay minerals

- Generally fine grained, has sheet structure;
- mostly as weathering products of other silicate materials;
- constituting a major part of the soil, thus important for agriculture and engineering.

- A most common clay mineral is kaolinite (used to make chinawares)

- Some clay minerals (smectite, vermiculite) absorb large amount of water. Expansive clays are a major geologic hazard. They are landslide prone and disrupt foundations.

- **Carbonate minerals**
- Calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$): different reaction to acid. Commonly used for building stones, concrete aggregates, lime and Portland cement.

- **Oxide minerals.**
- Limonite ($FeO.H_2O$): brown streak, may be in gravel, poor for concrete because of staining and popouts after cycles of freezing and thawing.

- **Sulfide minerals**:
- The most common one is pyrite (FeS_2), brassy color, metallic luster, cubic crystal, a nuisance for concrete before of staining from oxidation.

- **Sulfate minerals**:
- gypsum, $CaSO_4.2H_2O$: hardness 2, white, soluble in ground water.
- anhydrite, $CaSO_4$: lack of effervescence in acid, swelling when wet and converting to gypsum, disastrous when presence in foundation or tunnel.

Common non-silicate minerals

Fluorite – used as a toothpaste additive
Calcite -- calcium carbonate -- Limestone is made of calcite.
Dolomite -- calcium magnesium carbonate
Gypsum -- calcium sulfate
Galena -- lead sulfide
Pyrite -- iron sulfide
Halite -- sodium chloride (table salt)