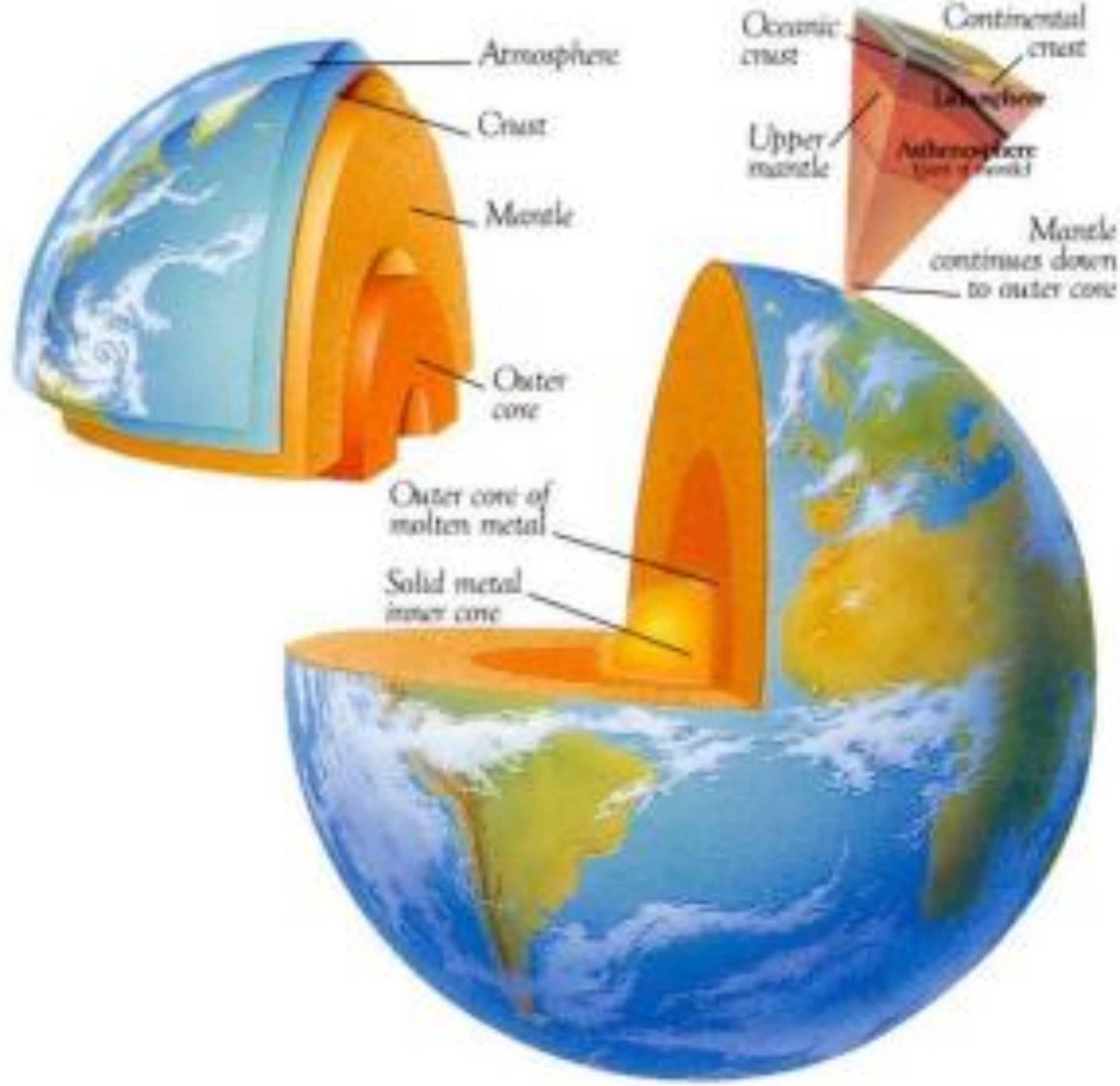
Layers of Earth - 3 distinct layers

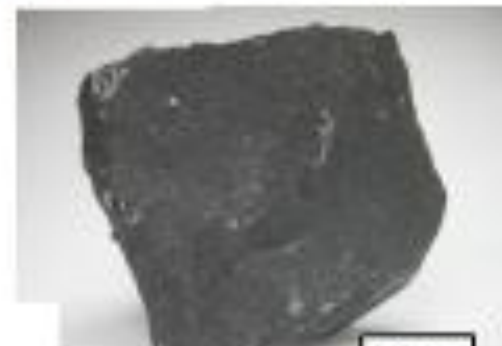
- Crust
- Mantle
- Core



Crust - Outer Layer

- Two kinds of crust: *continental* and *oceanic*.
  - Continental crust underlies continents.
    - Average thickness ~35 km
    - Silicic (granite) to intermediate in composition
  - Oceanic crust underlies ocean basins.
    - Average thickness ~7 km
    - Mafic (basalt) in composition
    - Denser than continental crust

Granite



Basalt

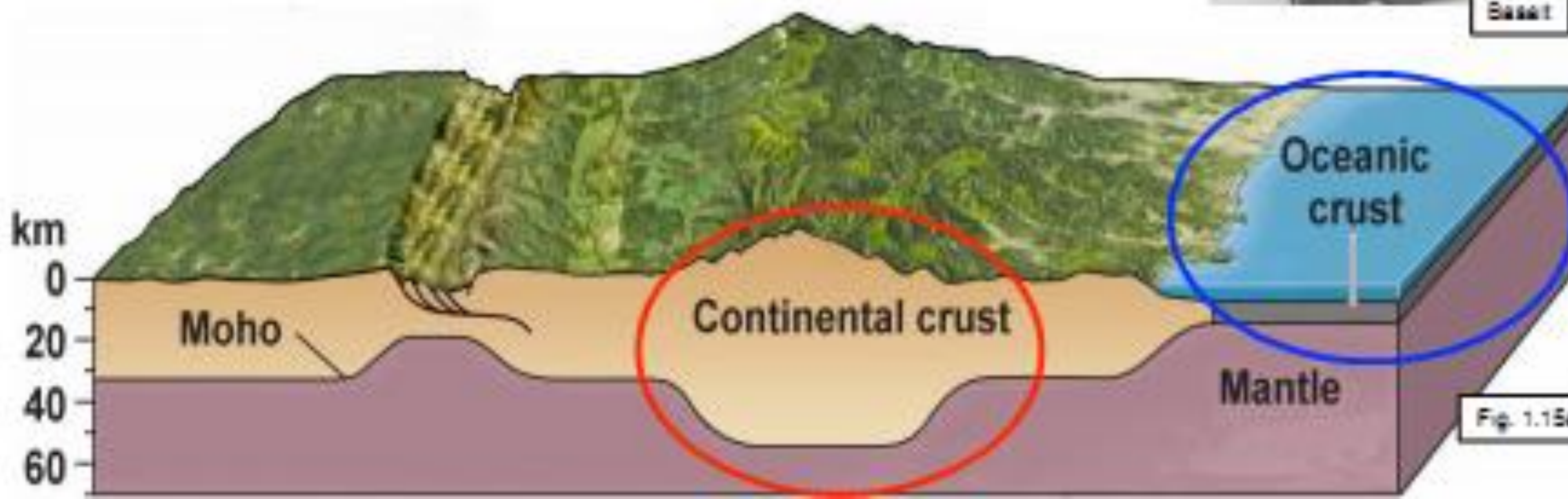
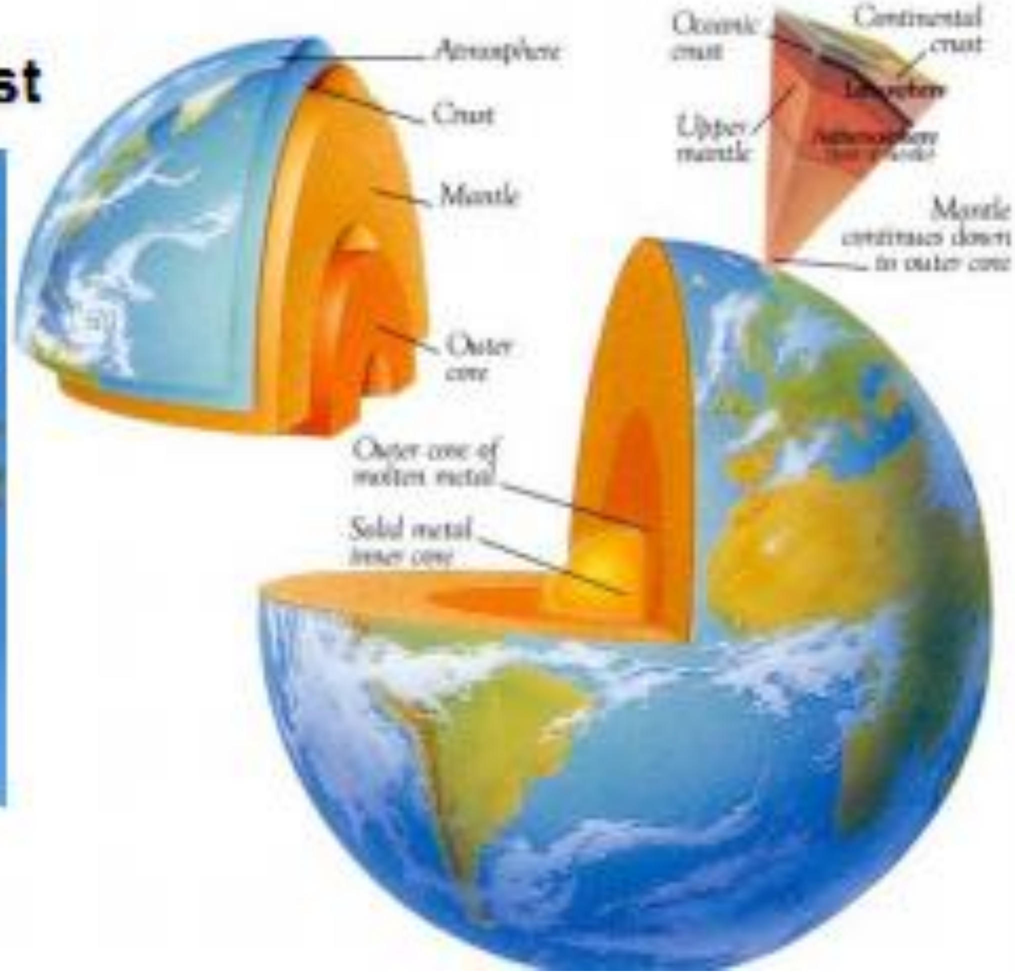


Fig. 1.15a

Mantle - Middle Layer

- Base of crust to 2,900 km
- Mostly solid ultramafic rock (peridotite)
- Denser than oceanic crust

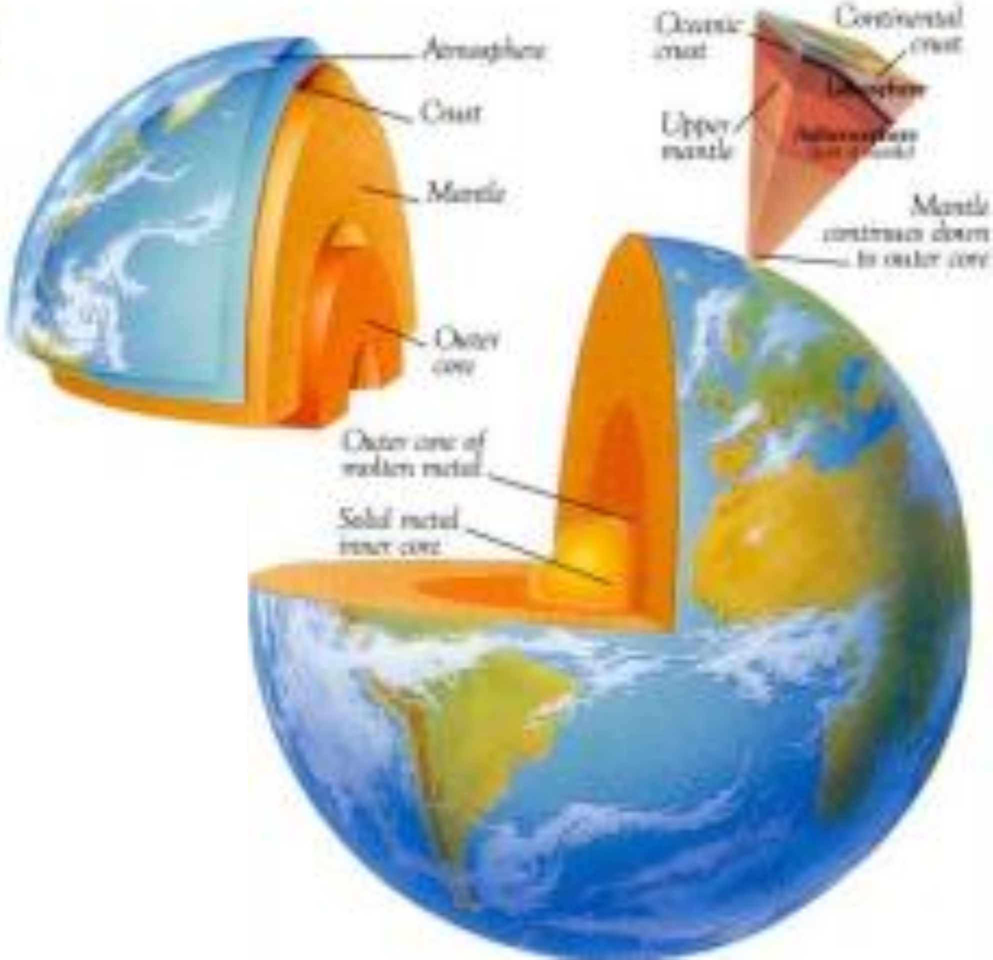
Peridotite



Core - Inner Layer

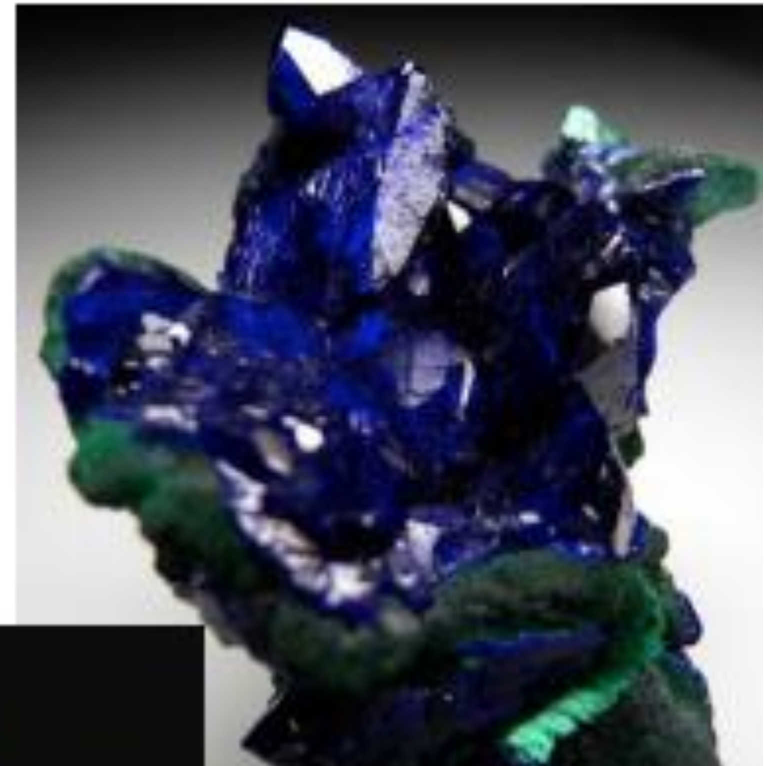
- Iron/nickel metal alloy (mostly iron)
- 2,900 km depth to Earth's center(6,370 km)
- Outer part = liquid, inner part = solid
- Circulation in liquid part of core is source of Earth's magnetic field (important for navigation and protection from damaging solar radiation)

Fe-meteorite



Earth Materials - Minerals

Diamond



Azurite

Quartz

Minerals(Building blocks of rocks)

Definition:

naturally occurring

excludes synthetic minerals

inorganic

non living processes form them

chemically specific

has a unique proportion of elements

crystalline solid

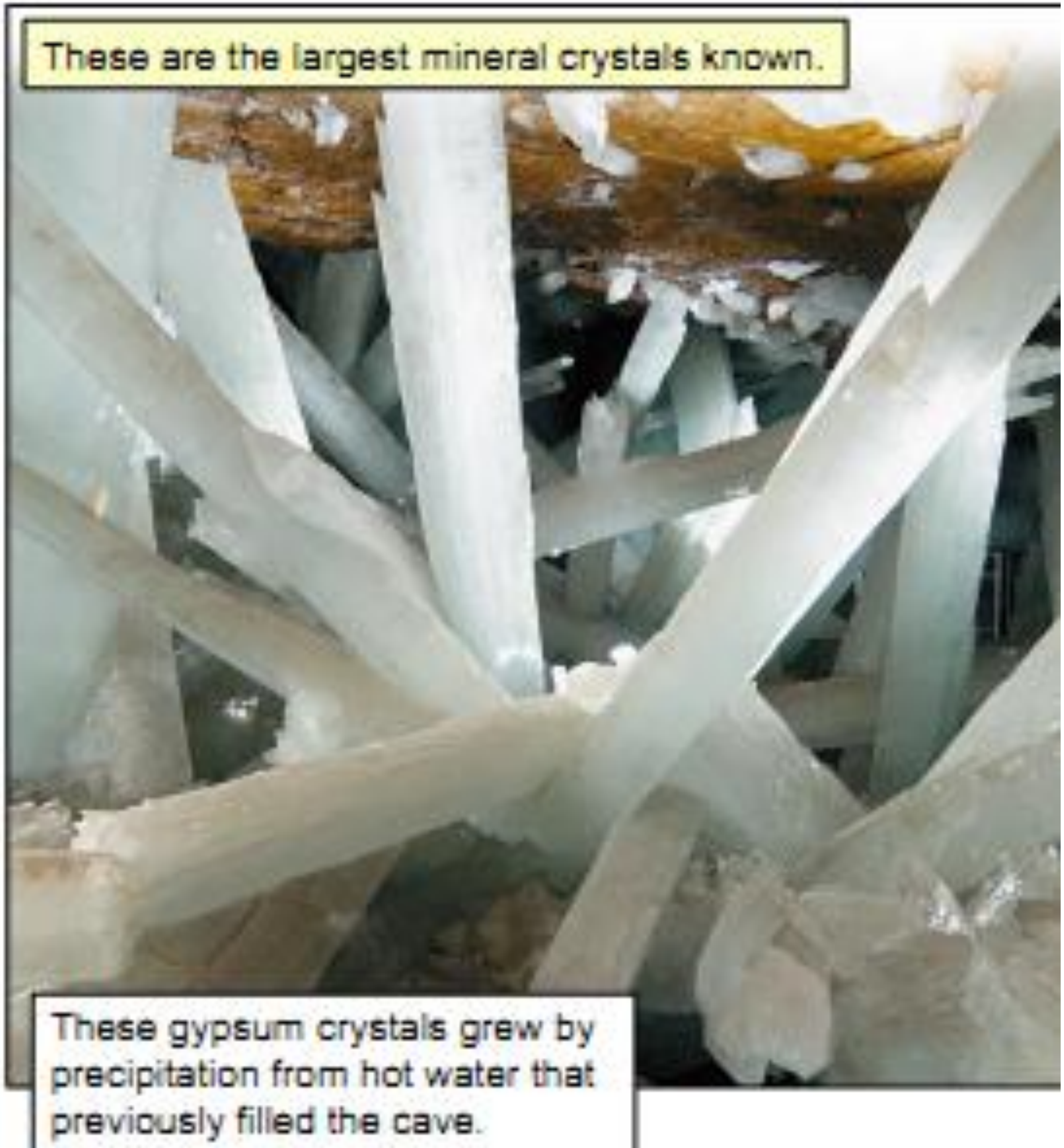
atoms are arranged in specific 3-D patterns

Part of the Geosphere; found in Hydrosphere (hard water); essential for Biosphere (life needs it!); Atmosphere assists in alteration (weathering); Exosphere provided raw materials (stars create elements).

Why Study Minerals?

- Rocks = aggregates of minerals
- Importance to Society?
- Importance to Geology?

Granite with three minerals labeled

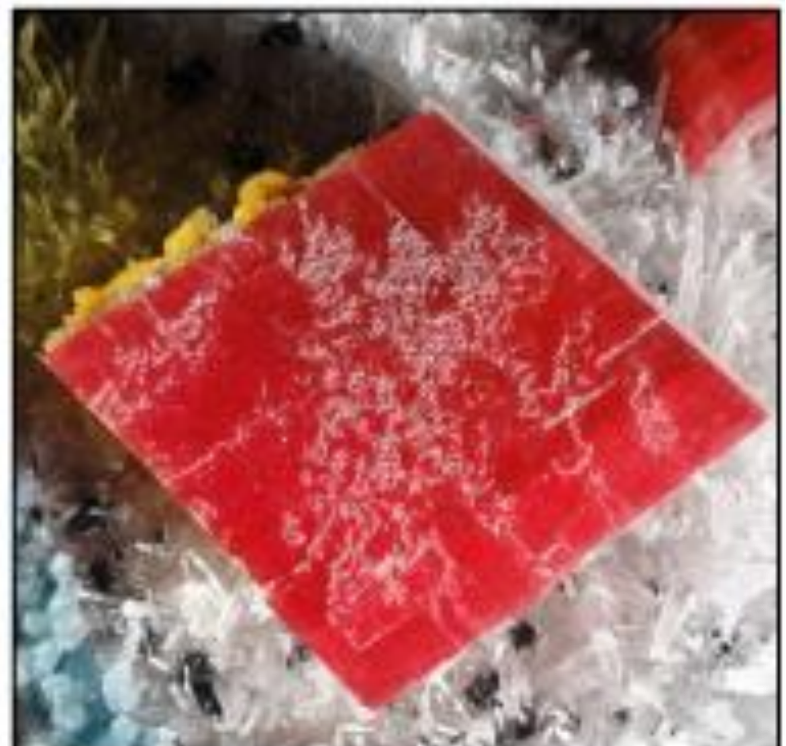

These are the largest mineral crystals known.
These gypsum crystals grew by precipitation from hot water that previously filled the cave.

What Is a Mineral?

- **<u>Naturally occurring</u> - formed by nature**

Synthetic bismuth - Not a mineral

Mineral - Rhodocrosite



What Is a Mineral?

- **Inorganic** - not organic (C-based) chemical

Mussel shell is composed of aragonite, a mineral.
Living part of mussel (inside shell) is organic and not a mineral.

What Is a Mineral?

- **<u>Solid</u>** - not liquid or gas

Liquid water is not a mineral

Ice is solid (mineral)

What Is a Mineral?

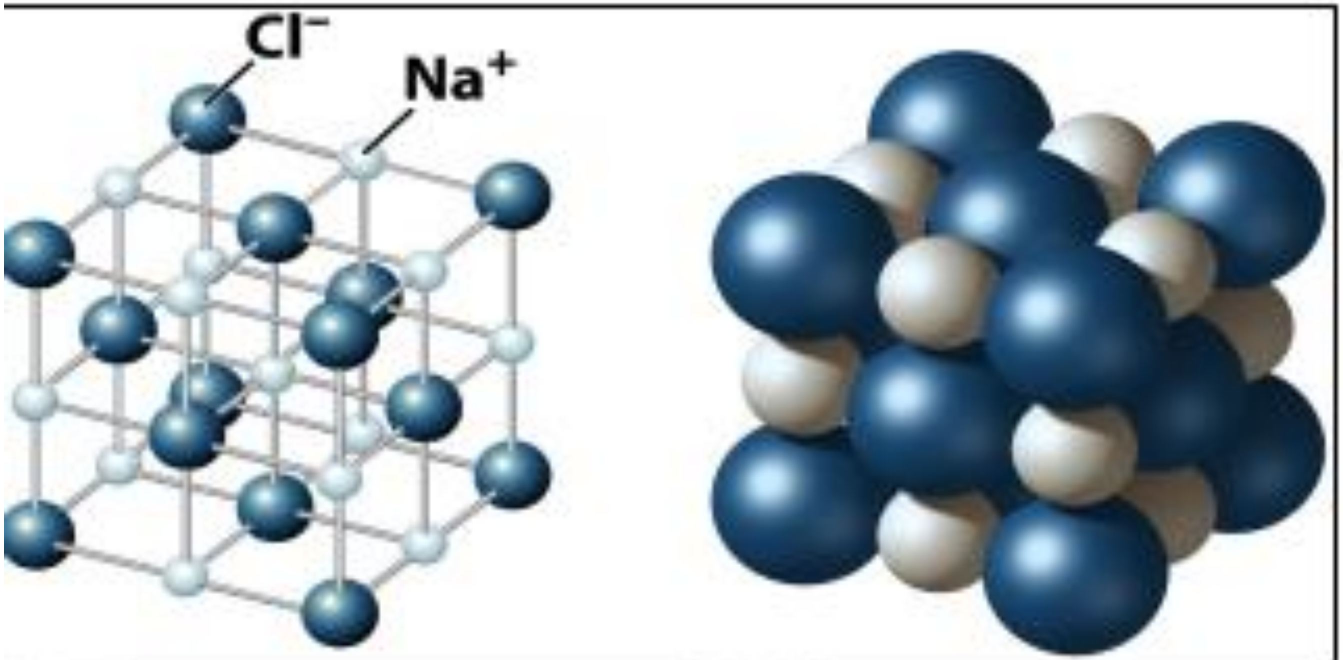
- **Definable chemical composition** - can specify types and proportions of elements (mineral chemical formula)

Quartz (SiO_2)

Calcite ($CaCO_3$)

What Is a Mineral?

- Crystal structure - Orderly arrangement of atoms
- Crystal structure controls shapes of crystal faces (flat shiny surfaces that form if mineral grows into open space)
- Glass has random atomic arrangement (amorphous)



Crystal structure of halite (NaCl) also known as salt.

Halite crystals

Mineral Identification

- Definitive way = determine chemical composition and crystal structure but NOT usually done that way
- Usually distinct set of physical properties allows mineral identification (fast and cheap)

Physical Properties of Minerals

- Color
- Luster
- Streak
- Hardness
  - Moh's Relative Scale
- Crystal Habit
  - The way it grows
- Cleavage or Fracture
  - breaks into planes (flat surfaces) or not
- Density (Specific Gravity)

- Related to the atomic structure & type of bonding

Geologists determine the identity of an unknown mineral by describing its physical properties. They then use a reference book to find out what mineral has those properties. We will learn to describe **the physical properties**.

1. Habit refers to the overall shape of the mineral use terms like: "**equant**" (3 dimensions of the mineral have about the same length, like a cube or sphere),

- "**elongate**" (one direction is long but the other 2 are short, like a pencil),
- "**platy**" (one dimension is short, other 2 are long like a sheet of paper)
- isolated tetrahedra & framework silicate minerals tend to be equant in habit;
- chain silicates tend to be elongate,
- sheet silicates are platy

2. Color

Varies in many minerals, e.g. quartz

Some minerals come in just one color; other are many colors/many varieties

3. Streak

Refers to color of mark left by rubbing mineral against a streak plate (unglazed porcelain) streak does not vary even if color does.

4. Other Properties

Some minerals are magnetic

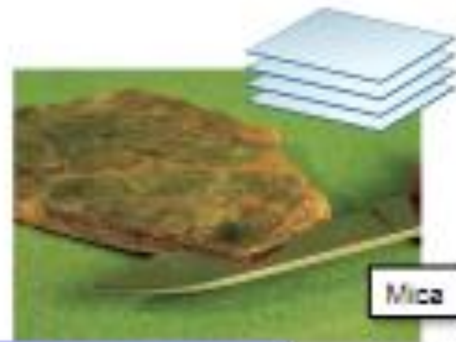
Some minerals effervesce ("fizz“-bouble) in dilute acid

Specific gravity (like density)

Cleavage

- Tendency of mineral to break along flat surfaces due to weak bonding; flat surfaces = cleavage faces

- Examples of Cleavage:
  - One direction
  - Two directions at 90°
  - Three directions NOT at 90°



Hardness

- Resistance to scratching; soft mineral is easily scratched, hard mineral is difficult scratch
- Talc is softest mineral, diamond is hardest
- Quartz is relatively hard, calcite is relatively soft

Quartz is harder than glass

Quartz is harder than calcite

Moh's Relative Hardness Scale

Controls how resistant rocks are to erosion

1 Talc- (softest)
> Texas

2 Gypsum
> Girls (or Guys)

3 Calcite
> Can

4 Fluorite
> Flirt

5 Apatite
> And

6 Feldspar
> For 6.5 steel file /nail*

7 Quartz
> Quarters

8 Topaz
> They

9 Corundum
> Can

10 Diamond- (hardest)
> Dance

* These items can be slightly harder or softer depepnding on how they were made, and what is in them

Importance as Rock Builders

- 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

- **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)**

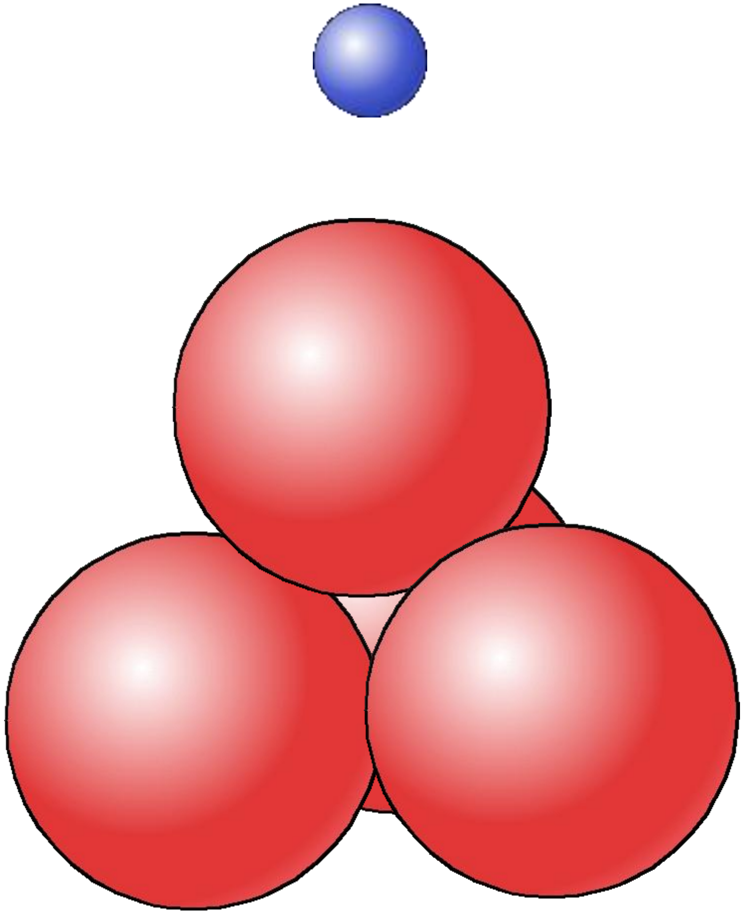
Oxygen (O)	46.6
Silicon (Si)	27.7
Aluminum (Al)	8.1
Iron (Fe)	5.0
Calcium (Ca)	3.6
Sodium (Na)	2.8
Potassium (K)	2.6
Magnesium (Mg)	2.1
all others	1.7

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
  - $(4 \times -2) +4 = -4$
  - $(SiO_4)^{-4}$



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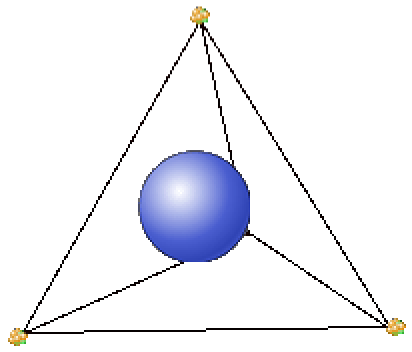
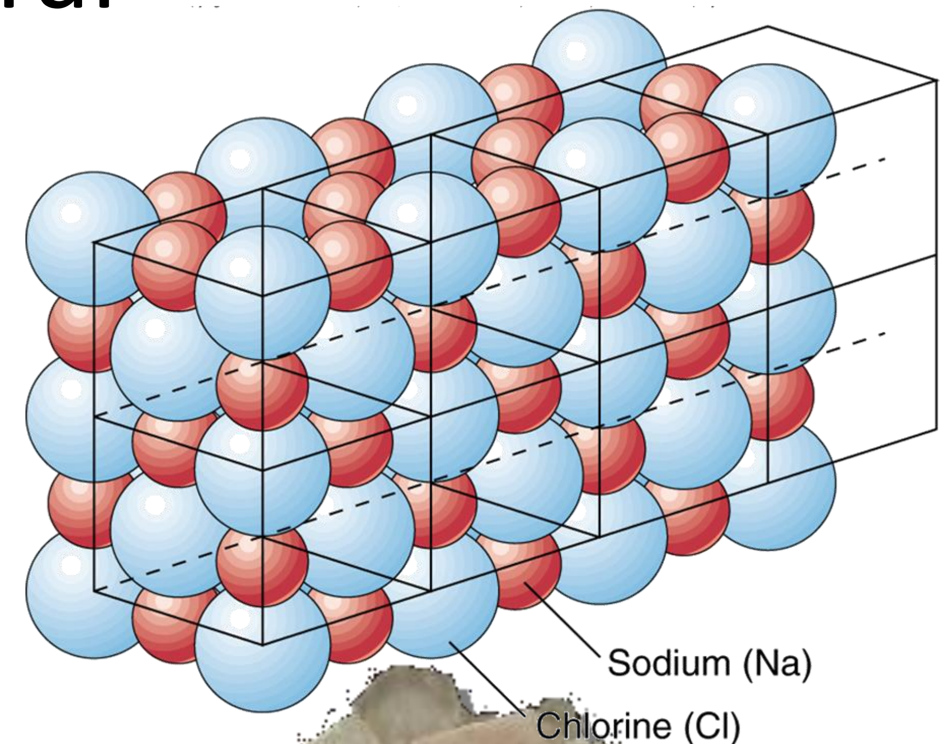
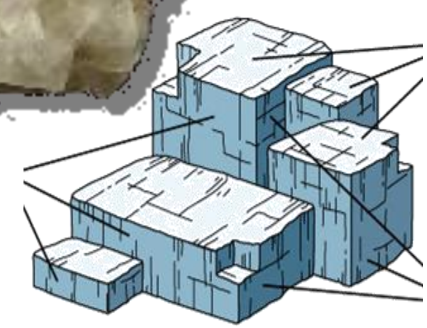


Definition of Mineral

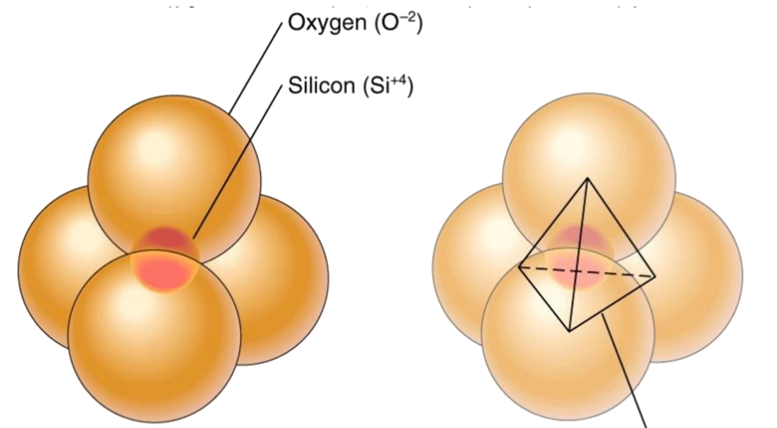
- Naturally Occurring
- Crystalline
- Solid
- With a <u>definite</u> chemical composition
  - A unique composition

    <u>or</u>
  - A definite range of compositions
    <u>Mineral Group</u>, e.g. Olivine

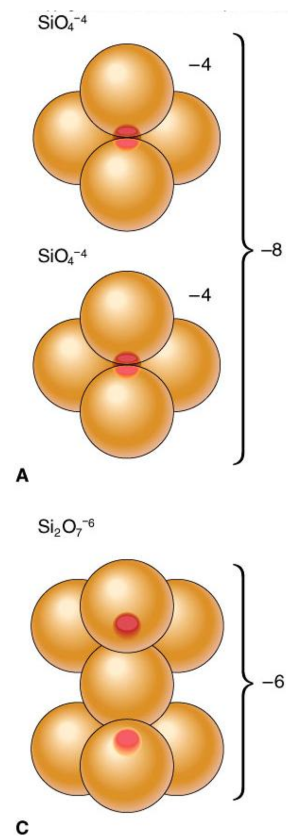


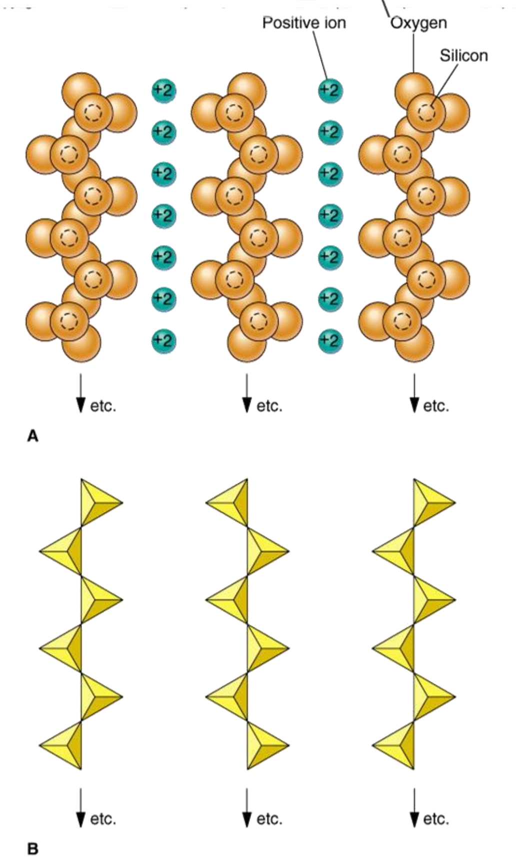


C. Silica Tetrahedra and Silicate Minerals



- Si and O bond in a **tetrahedron** shape
- The basic building block of most minerals of the crust
- Bond with other **tetrahedra** and cations to form **Silicate Minerals**





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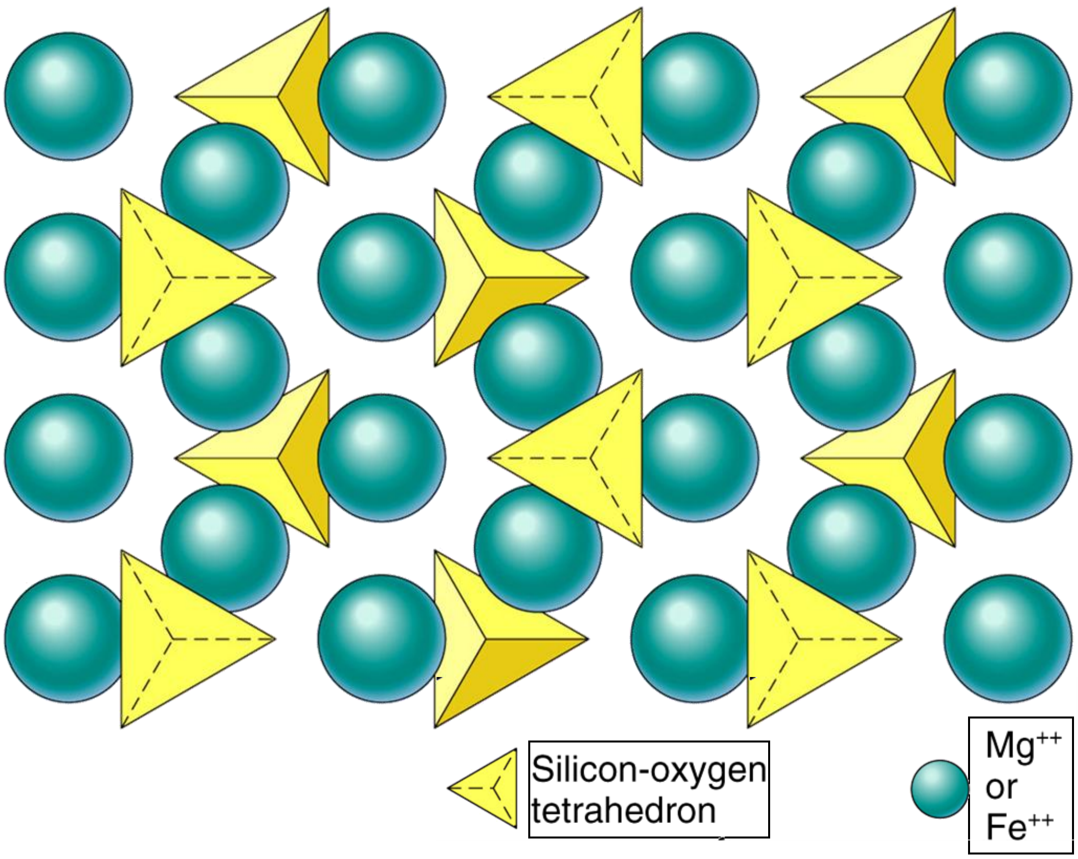
Silicate Minerals: Examples

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

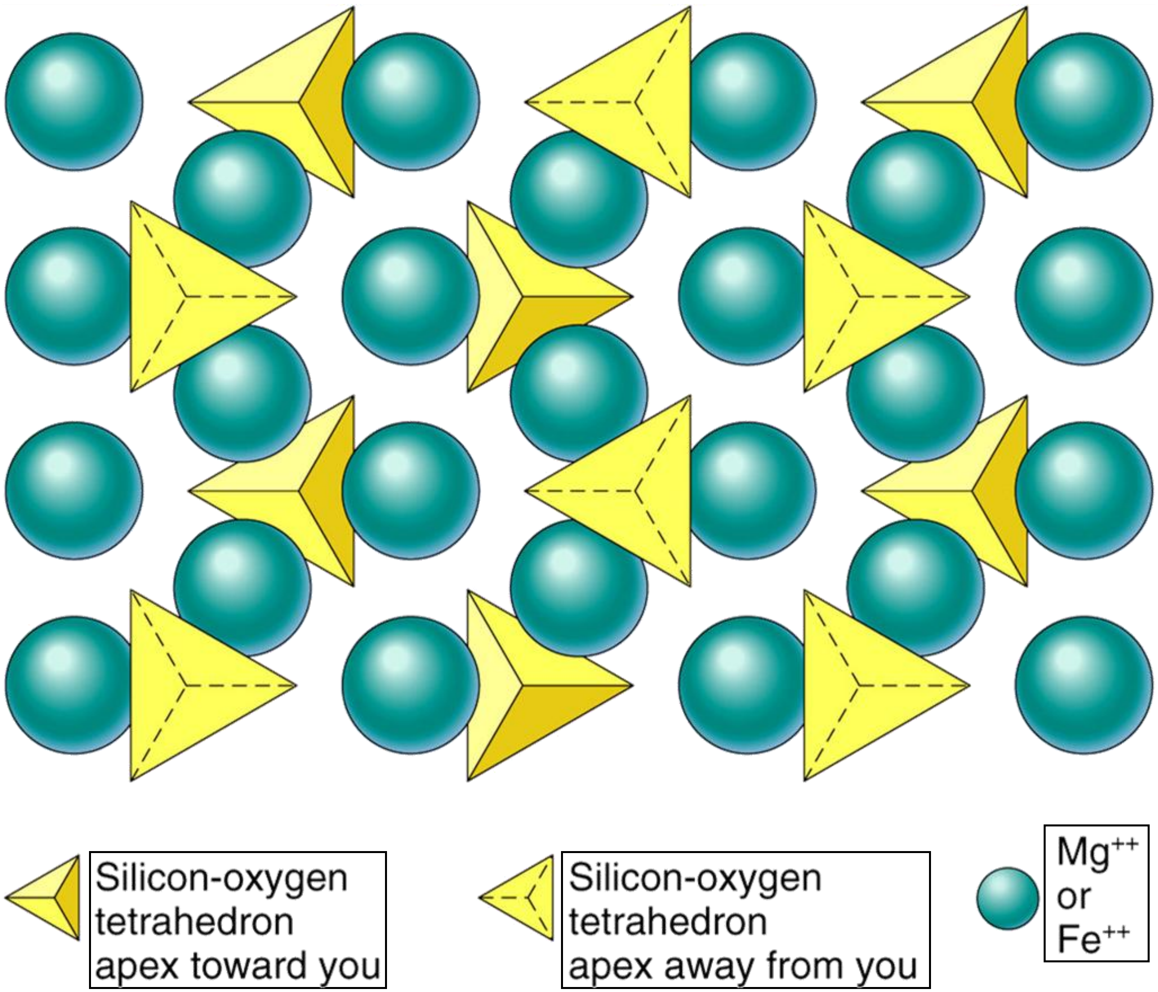
Definite Range



- $(Fe,Mg)_2\ SiO_4$ ➔ 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%



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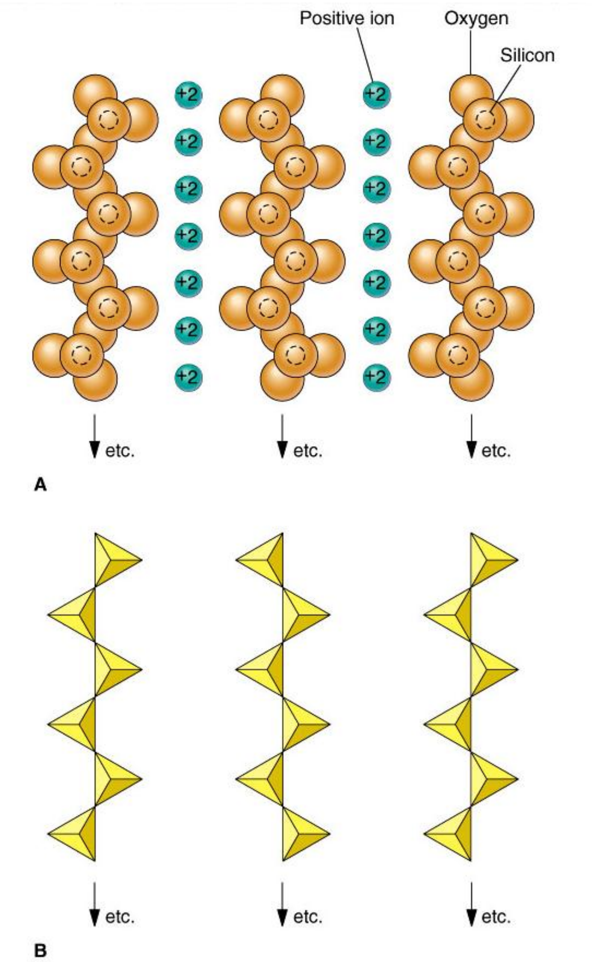
Silicate Minerals: Examples

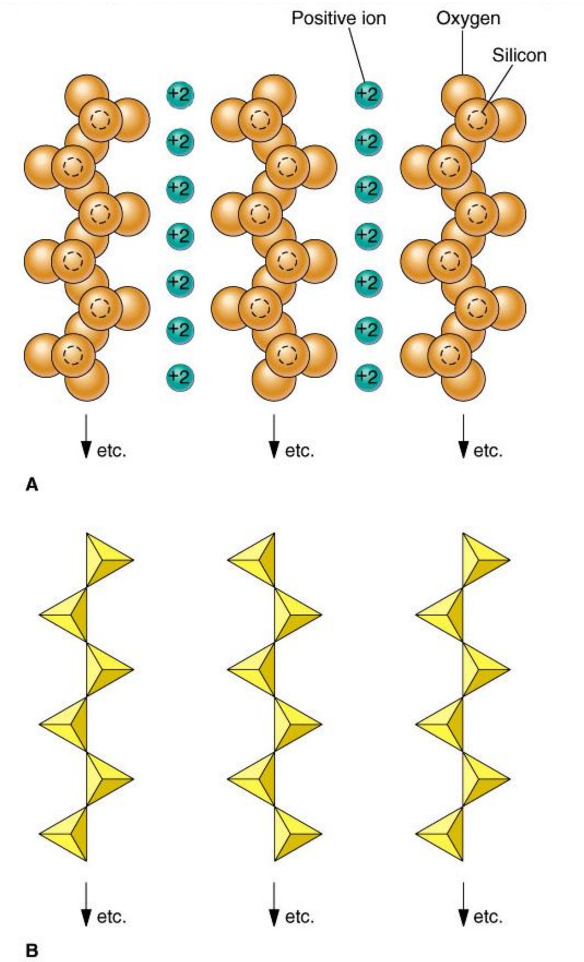
- E.g., **Pyroxenes** (Mineral Group)
  - **Single Chain Silicate** structure
  - $(SiO_3)^{-2} + Fe^{+2}$
  - $FeSiO_3$
  - ↓
  - $(Fe,Mg)\ SiO_3$
  - ↓
  - $MgSiO_3$

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



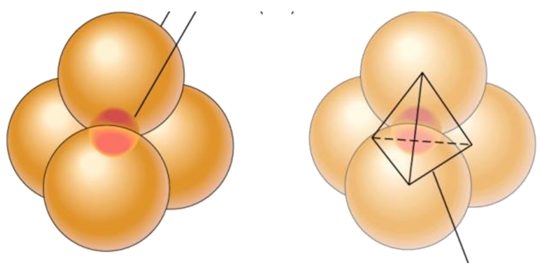
Silicate Minerals: Examples

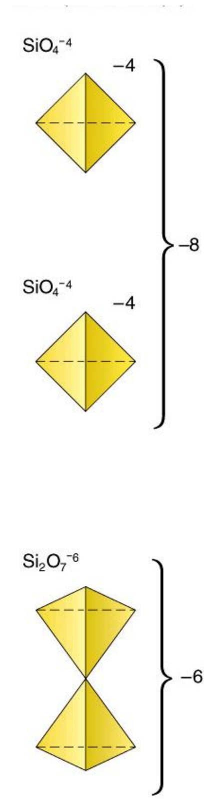
- E.g., **Pyroxenes** (Group of minerals)
  - **Single Chain Silicate** structure
  - bonded with **Fe, Mg,** Ca, and Al
  - Found in **Oceanic Crust**
  - Fe/Mg/Ca rich (20%)
  - Silica poor (<20%)



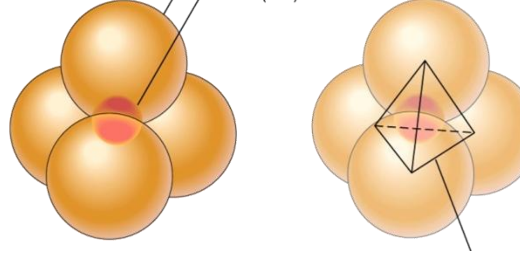
Building Silicates

- What is the net charge of:
  - a silica tetrahedron?
  - a single chain of single tetrahedra?

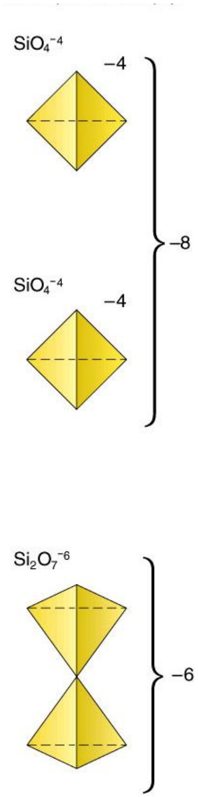


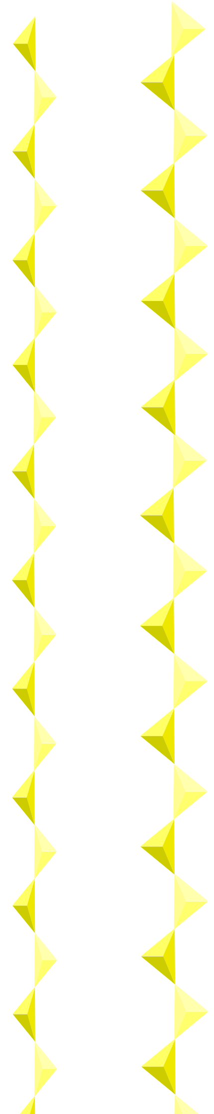


Building Silicates



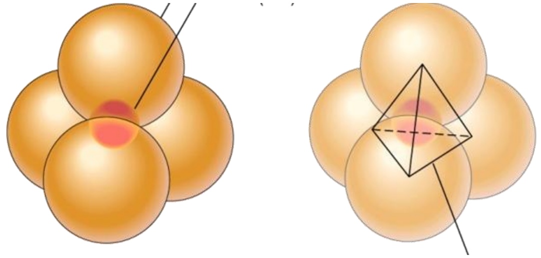
- What is the net charge of:
  - a silica tetrahedron?
  - a single chain of single tetrahedra?
  - a double chain of tetrahedra?
  - a sheet of tetrahedra?
  - a framework of tetrahedra?
  - a framework of tetrahedra with every fourth silicon replaced with an aluminum ion?
  - a framework with every other Si replaced with an Al?

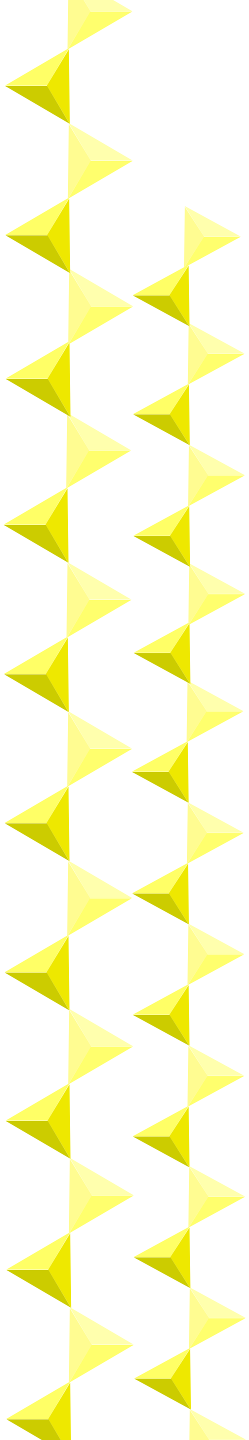




*Hint: a shared apex is ½ an Oxygen

Building Silicates

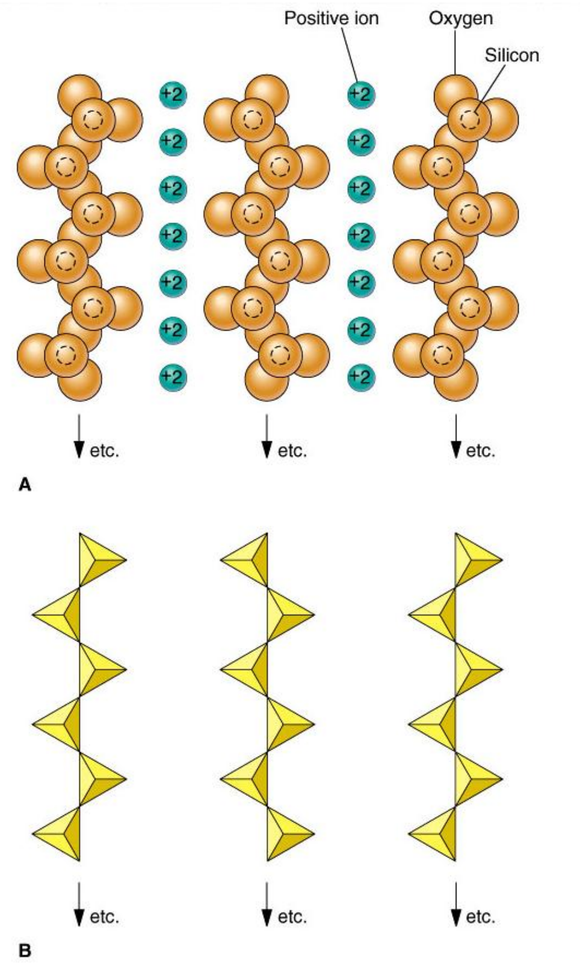




- What common elements would balance the charges of :
  - an isolated silicate?
  - a single chain silicate?
  - a double chain silicate?
  - a sheet silicate?
  - a framework silicate?
  - a framework of tetrahedra with every fourth silicon replaced with an aluminum ion?
  - a framework with every other Si replaced with an Al?

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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Single Chain Silicates

- E.g., Pyroxenes (SiO_3)

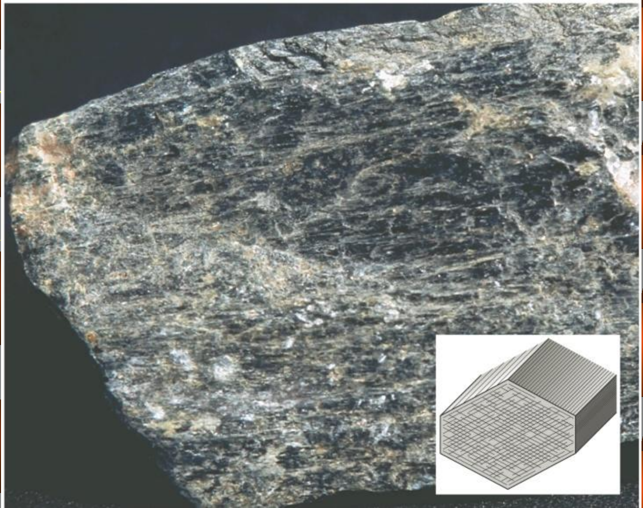
Silicate Minerals: Examples

- 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

*

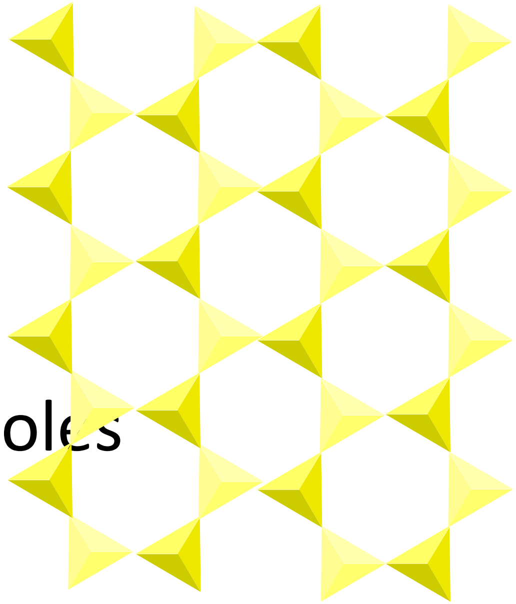
Double Chain Silicates

- E.g., Amphiboles (Si_8O_{22})



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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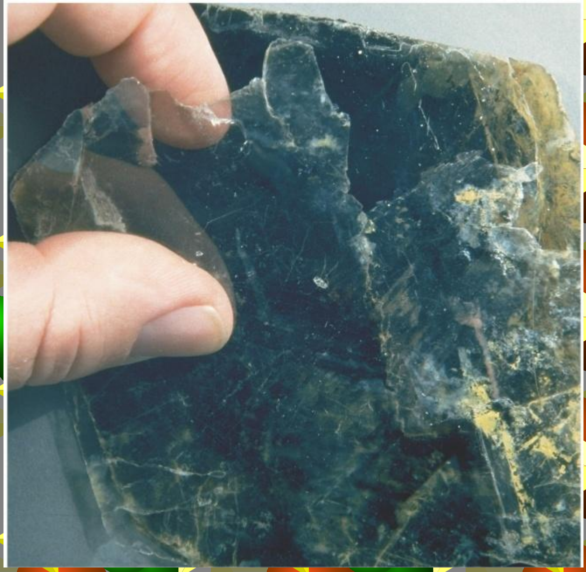
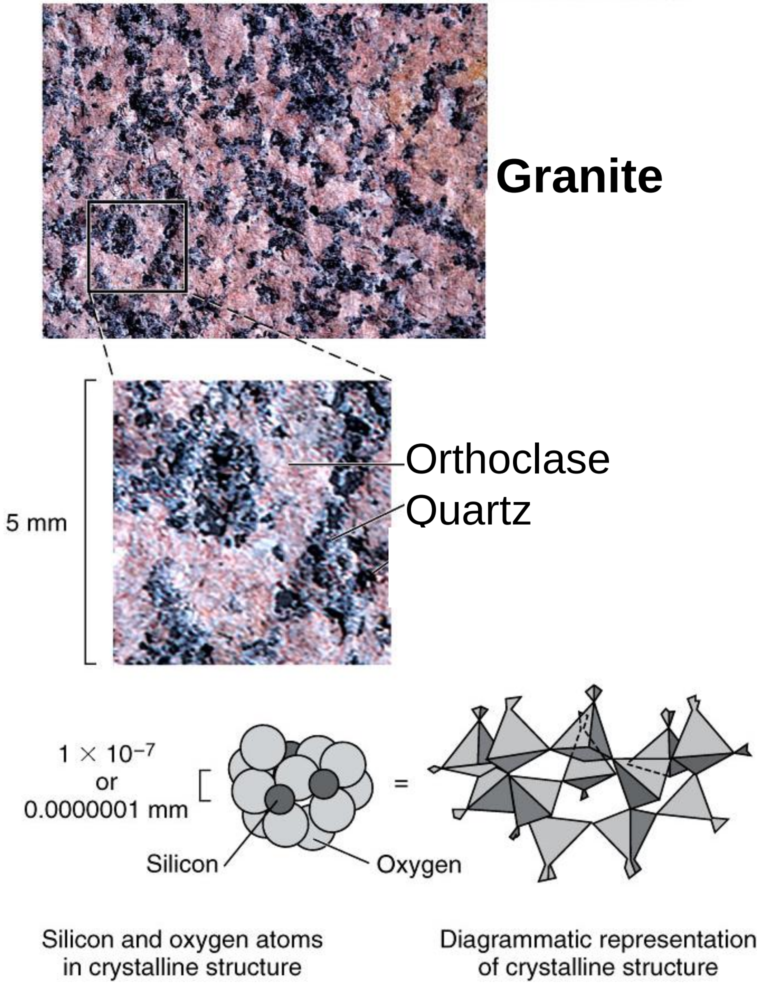
Sheet Silicates

- E.g., Micas (Biotite and Muscovite) (**Al**Si_3O_{10})



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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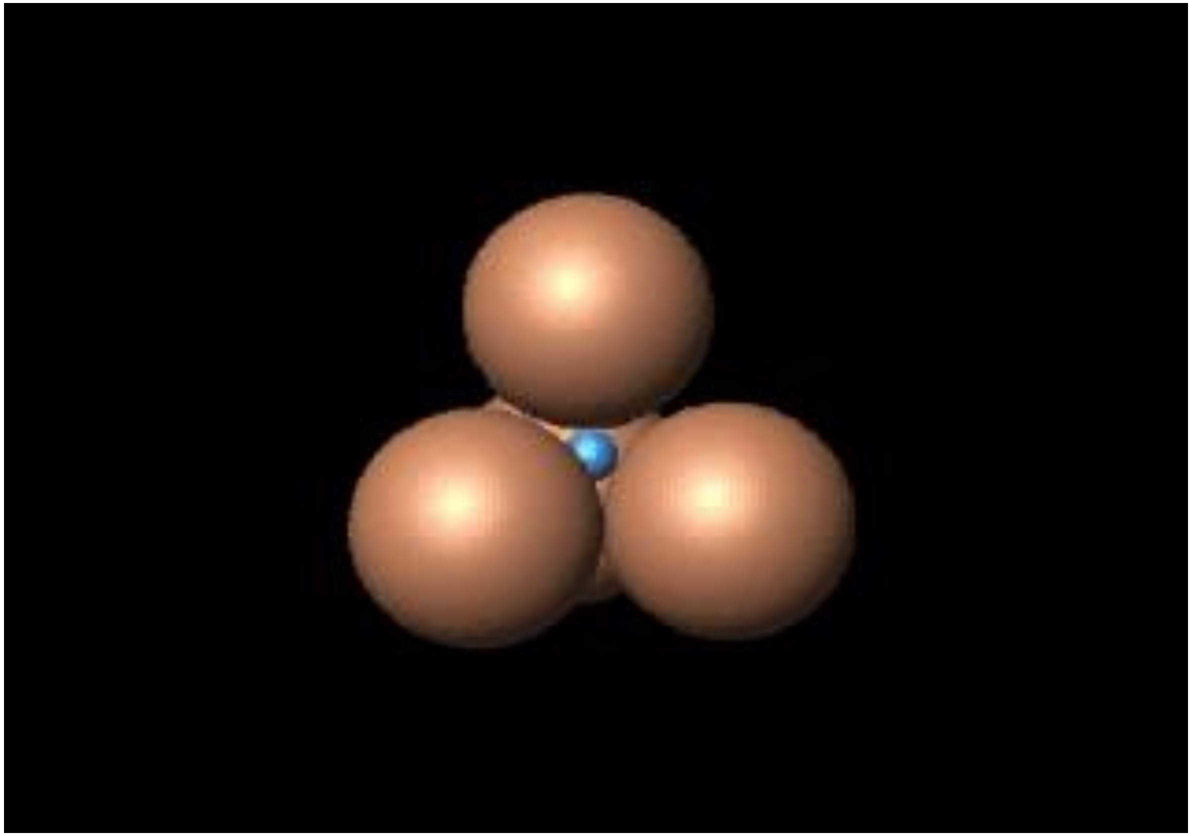
Silicates framework

- E.g., **Quartz** (SiO_2) and **Feldspars** ($AlSi_3O_8$)

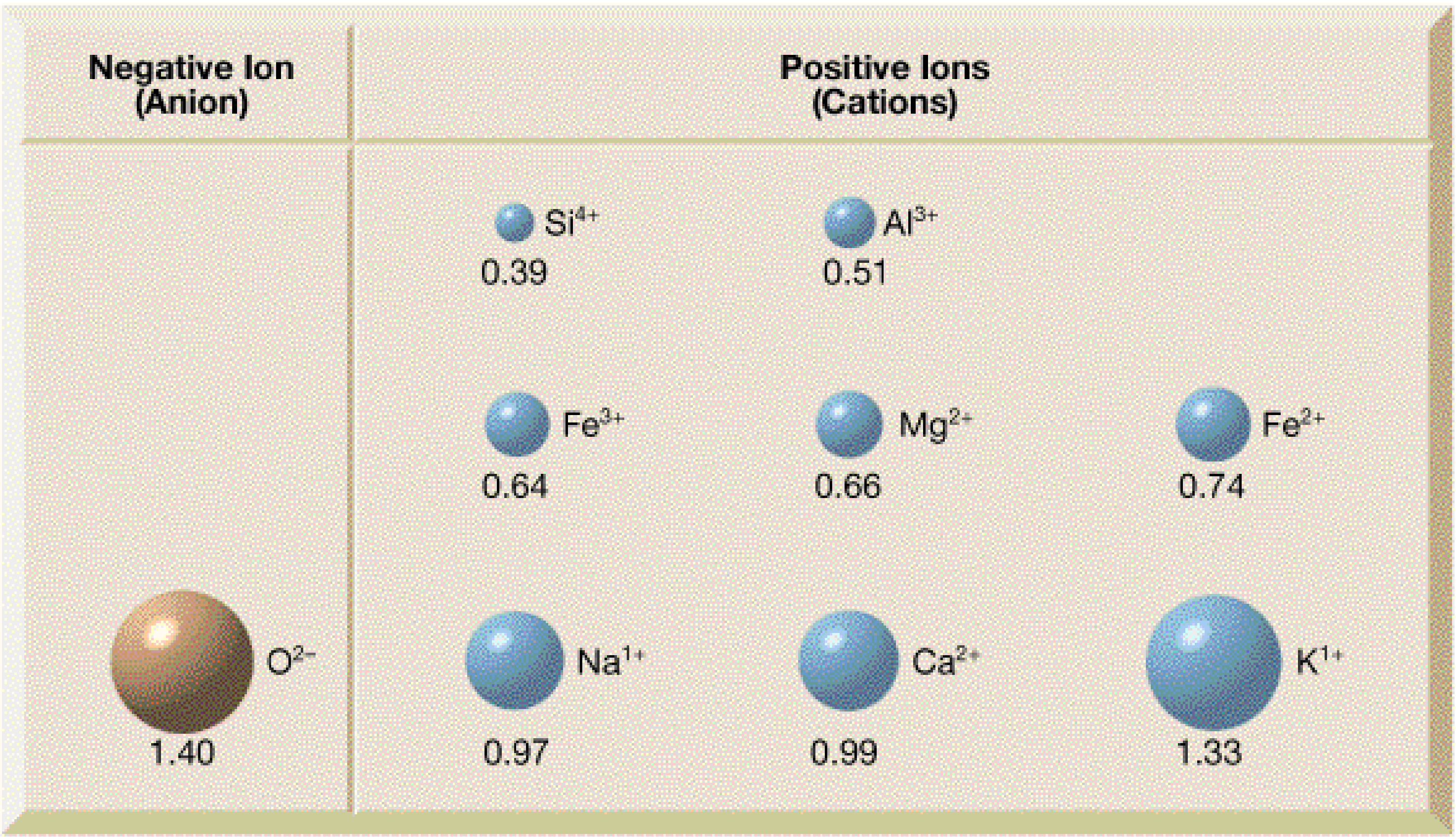
Framework Silicates

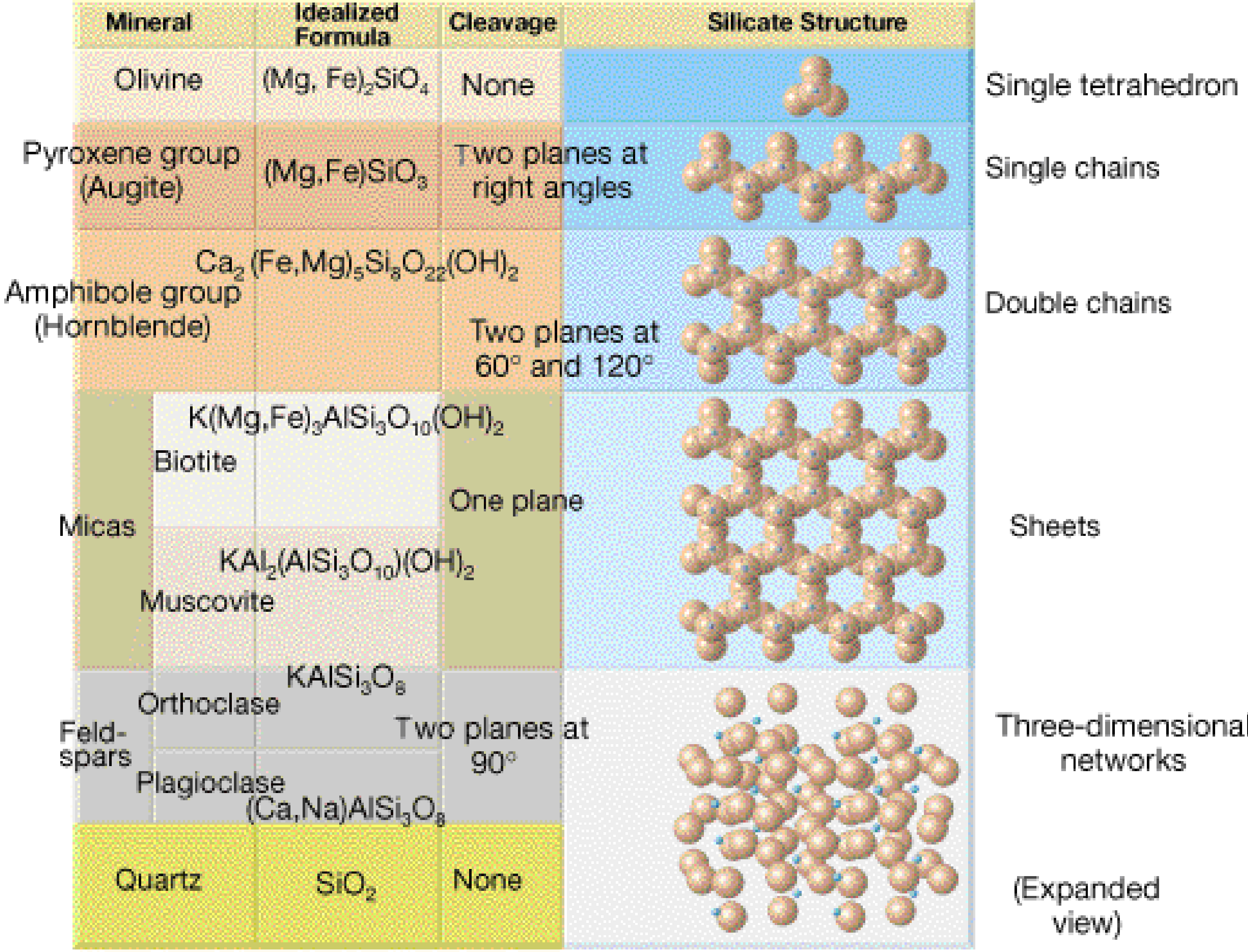
- E.g., **Quartz** (SiO_2) and **Feldspar** ($AlSi_3O_{10}$)

- The Silicates
- A silicate mineral contains the elements oxygen and silicon linked in a tetrahedron unit with four O atoms to one Si atom (SiO_4 with a charge of -4). The silicates are most common mineral group.
- Silicon-oxygen tetrahedron:



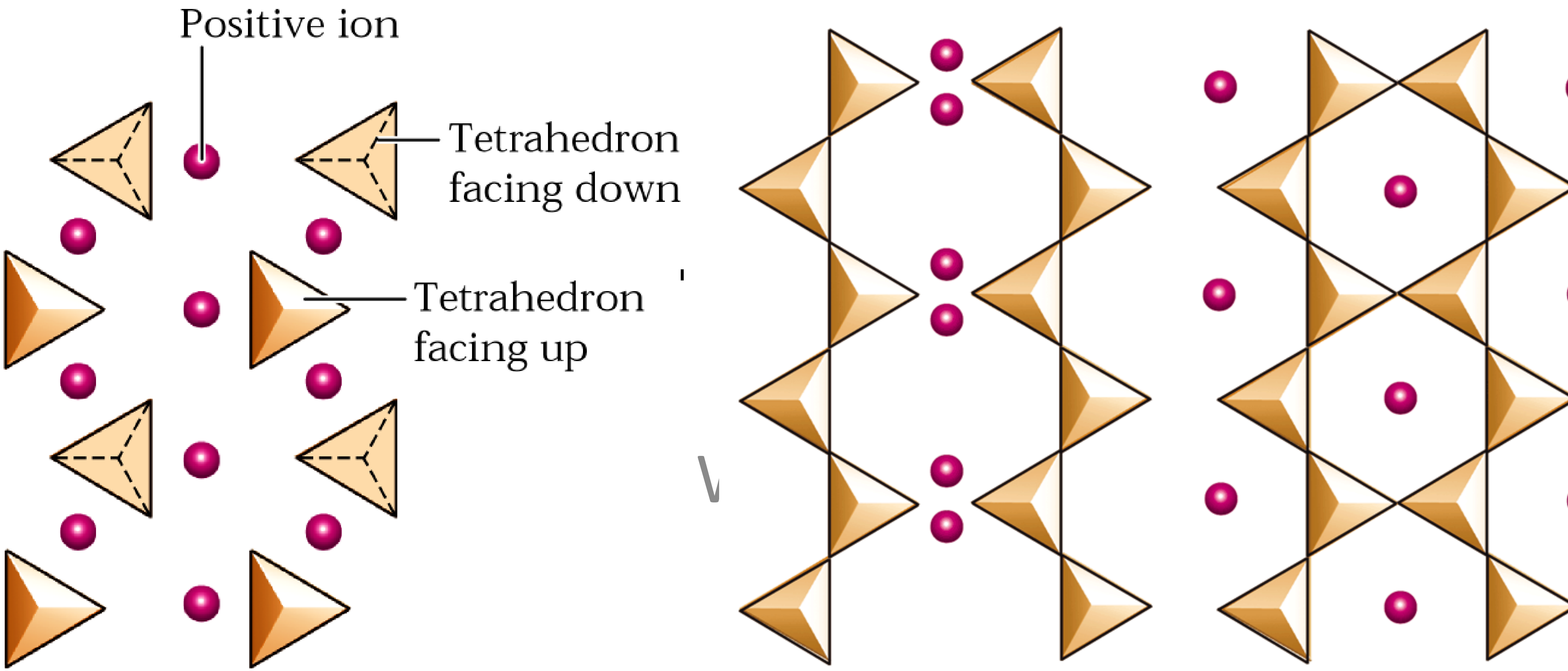
To become neutral compounds, the silica tetrahedra can join with positively charged ions. Relatives size of the ions of the eight most common elements in the crust:



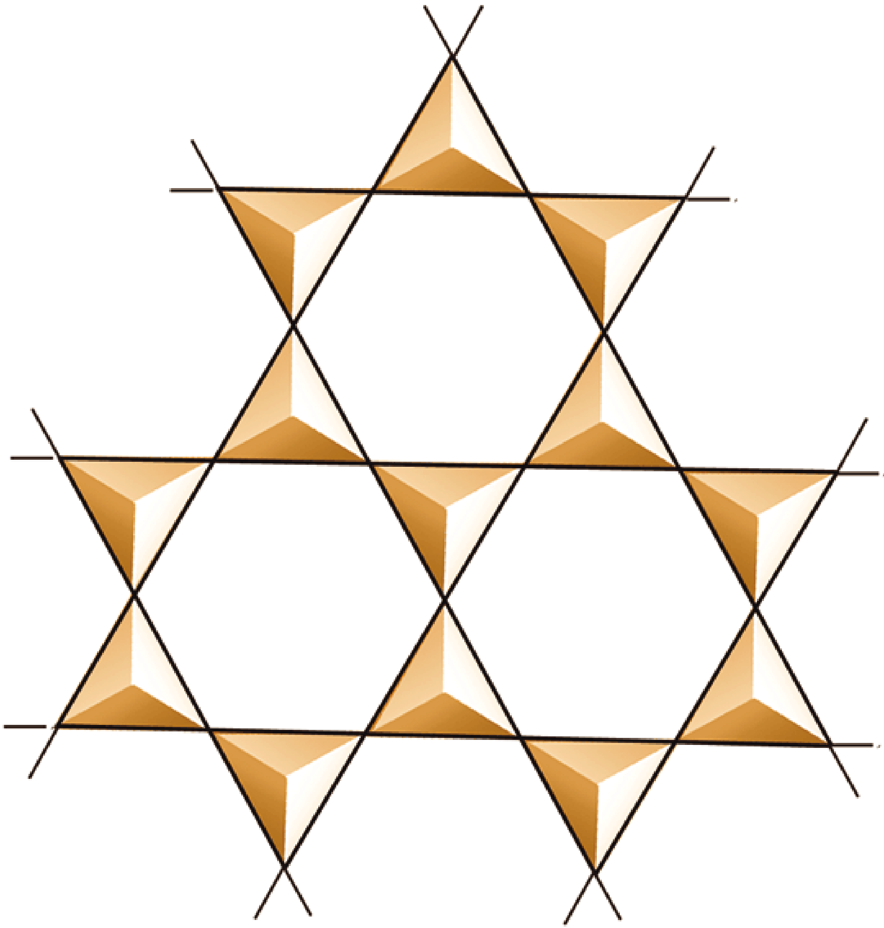


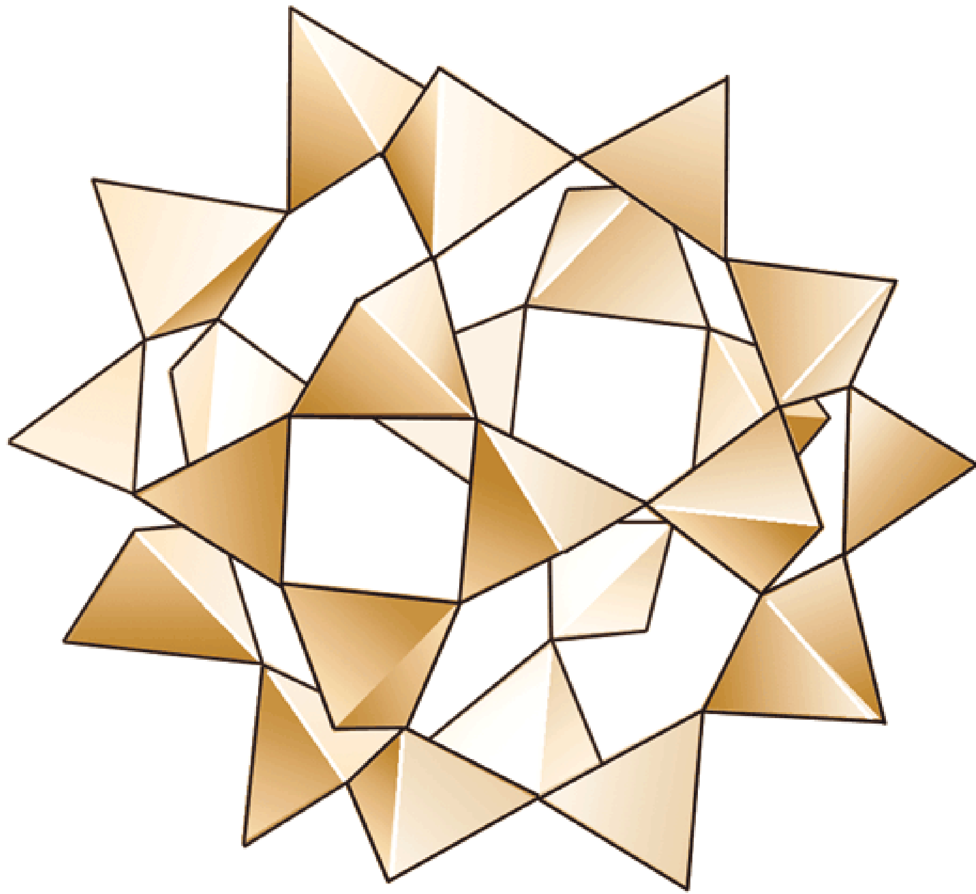
Mineral	Idealized Formula	Cleavage	Silicate Structure
Olivine	$(Mg, Fe)_2SiO_4$	None	Single tetrahedron
Pyroxene group (Augite)	$(Mg,Fe)SiO_3$	Two planes at right angles	Single chains
Amphibole group (Hornblende)	$Ca_2(Fe,Mg)_5Si_8O_{22}(OH)_2$	Two planes at 60° and 120°	Double chains
Micas: Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$	One plane	Sheets
Micas: Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$	One plane	Sheets
Feldspars: Orthoclase	$KAlSi_3O_8$	Two planes at 90°	Three-dimensional networks
Feldspars: Plagioclase	$(Ca,Na)AlSi_3O_8$	Two planes at 90°	Three-dimensional networks
Quartz	SiO_2	None	Three-dimensional networks (Expanded view)

The silica tetrahedra may also link with themselves by sharing oxygen ions. The silicate group is subdivided by the way in which silica tetrahedra interact with each other.



Positive ion
Tetrahedron facing down
Tetrahedron facing up

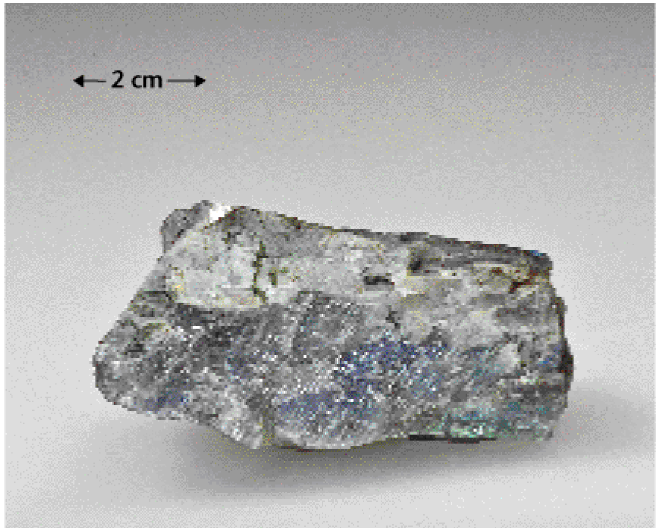




- **Common silicate minerals**

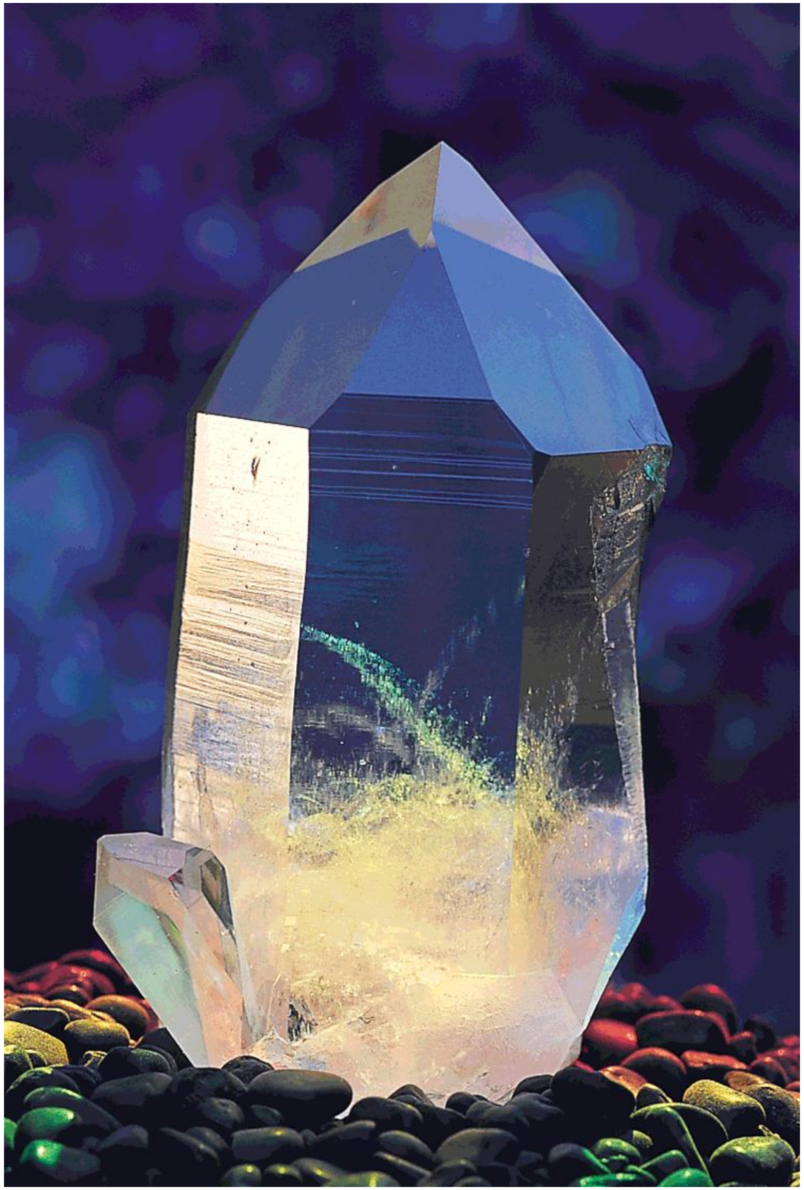
- Ferromagnesian (dark) silicates: containing ions of Fe and/or Mg, including olivine, pyroxenes, amphiboles, biotite.

- nonferromagnesian silicates: without Fe or Mg, but with Ca, Na, and K, light color, including feldspars, quartz, muscovite.



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.

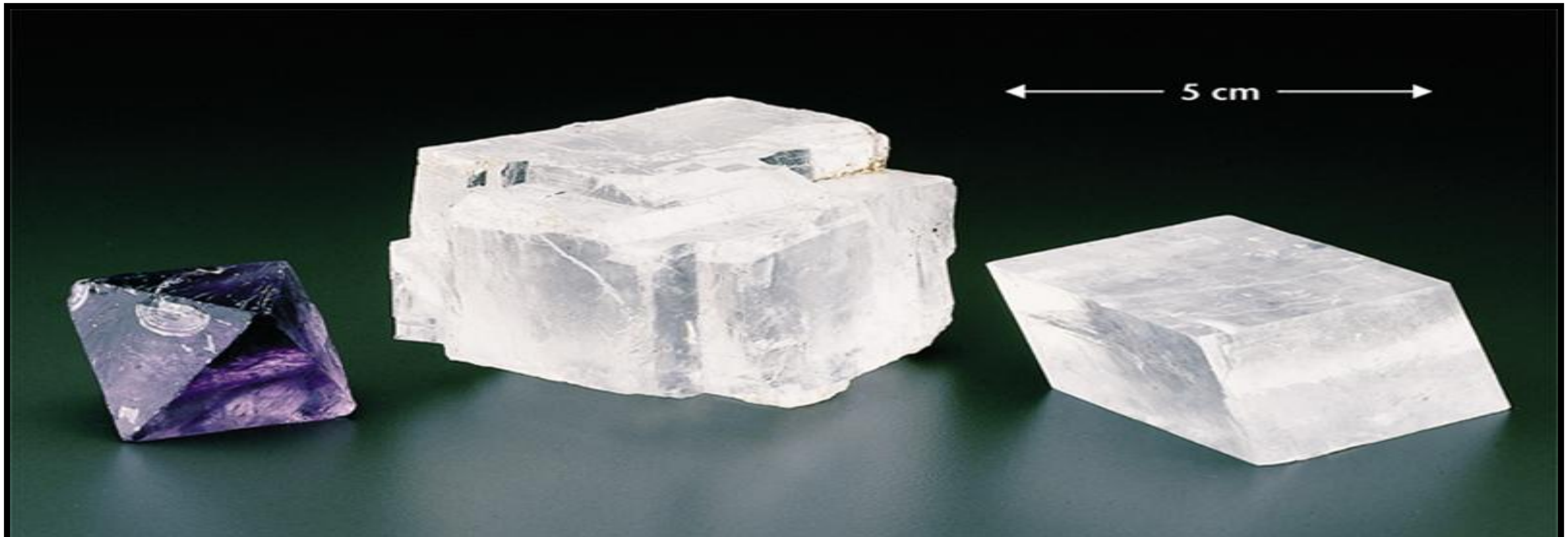
- **Oxide minerals.**
- Limonite ($FeO.H_2O$): brown streak, may be in gravel, poor for concrete because of staining and popouts after cycles of freezing and thawing.

- **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)



How to Identify Minerals: Physical Properties

Geologists determine the identity of an unknown mineral by describing its physical properties. They then use a reference book to find out what mineral has those properties. We will learn to describe the physical properties.

1. Habit refers to the overall shape of the mineral. Scientists use terms like: "equant" (3 dimensions of the mineral have about the same length, like a cube or sphere), "elongate" (one direction is long but the other 2 are short, like a pencil), or "platy" (one dimension is short, other 2 are long like a sheet of paper)

   Isolated tetrahedra & framework silicate minerals tend to be equant in habit; chain silicates tend to be elongate, sheet silicates are platy

2. Luster refers to the light reflected off of the mineral and its overall quality. Minerals can be termed: glassy, opaque, transparent, shiny, or most commonly: metallic and non-metallic.

   One of the first determinations a geologist must make is whether the mineral in metallic or non-metallic.

Non-metallic mineral

Metallic mineral

Cleavage

Refers to very smooth, flat, shiny breakage surfaces

These special breakage surfaces correspond to zones of weak bonding in the crystal structure.

To describe cleavage, one must determine the number of unique cleavage planes (directions) and their angle with respect to each other (e.g. salt breaks into cubes, with cleavage in 3 directions, all at 90 degrees)

Hardness

Refers to "scratchability" or resistance to being scratched. Harder minerals will scratch softer minerals.

Geologists rank minerals according to hardness using the Moh's scale

Moh's Hardness Scale (Commit this to memory)

1.0 TALC
2.0 GYPSUM
2.5 FINGERNAIL
3.0 CALCITE
3.5 COPPER PENNY
4.0 FLUORITE (Note the spelling!)
5.0 APATITE
5.5 STEEL KNIFE BLADE/GLASS PLATE
6.0 ORTHOCLASE FELDSPAR
7.0 QUARTZ
8.0 TOPAZ
9.0 CORUNDUM (RUBY)
10.0 DIAMOND

Color

Varies in many minerals, e.g. quartz
VERY unreliable.
Some minerals come in just one color;
other are many colors/many varieties.

Streak

Refers to color of mark left by rubbing mi plate (unglazed porcelain). Streak does not vary even if color does.

Other Properties

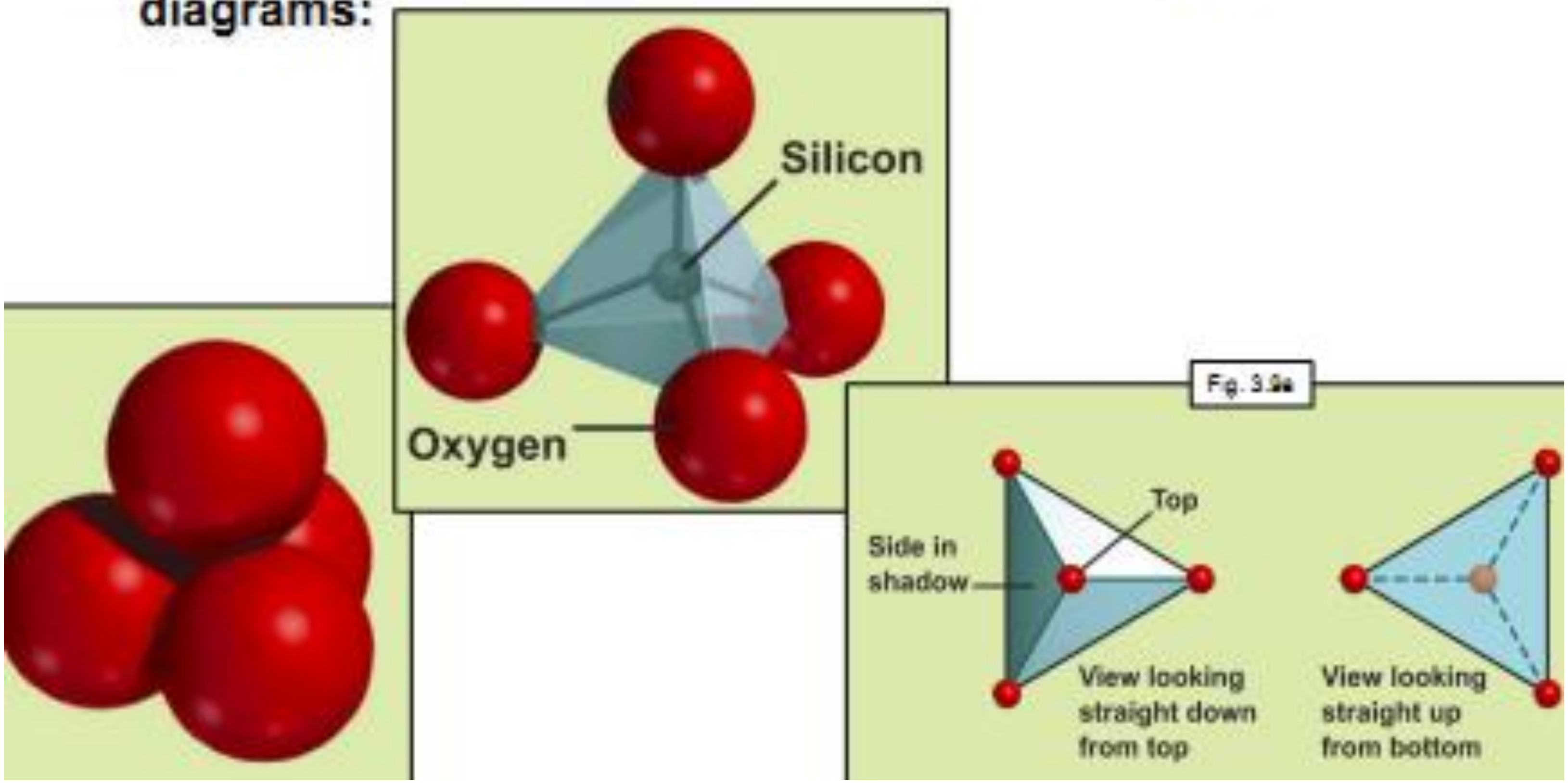
Some minerals are magnetic (i.e., magnetite)
Some minerals effervesce ("fizz") in dilute acid (calcite)
Specific gravity (like density) galena has a high specific gravity.

Classes of Minerals

- Minerals are classified by chemical composition and crystal structure
- Silicates - Most common in rocks and Earth (95% of Earth's crust); Contain silicon (Si) and oxygen (O)

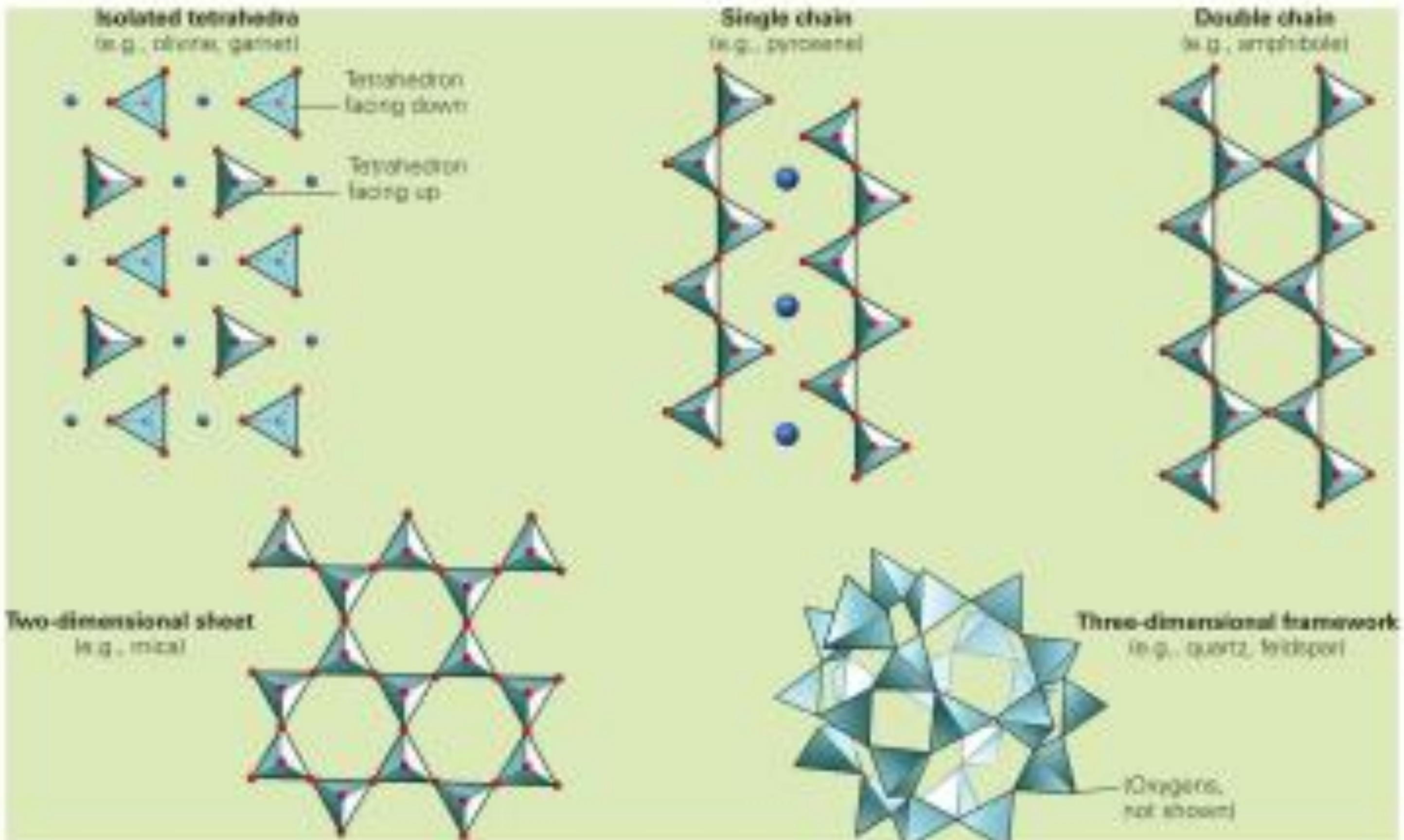
Silicate Minerals - Silica Tetrahedron

- Fundamental component of silicate minerals = <u>silica tetrahedron</u> (central Si atom surrounded by four O atoms in pyramid shape)
  - Silica tetrahedron is portrayed in different ways in below diagrams:



Silicate Minerals - Subclasses

- Silicates are divided into several groups based on how silica tetrahedra link together and are arranged
- Five major subclasses of silicates: isolated tetrahedra, single chain, double chain, sheet (2-d), framework (3-d)



Other Mineral Classes - Sulfides

- Contain sulfide (S in reduced state), galena = PbS, pyrite "fool's gold" (FeS_2)

Galena

Pyrite

Other Mineral Classes - Carbonates

- Contain CO_3 (carbonate molecule), calcite = $CaCO_3$.

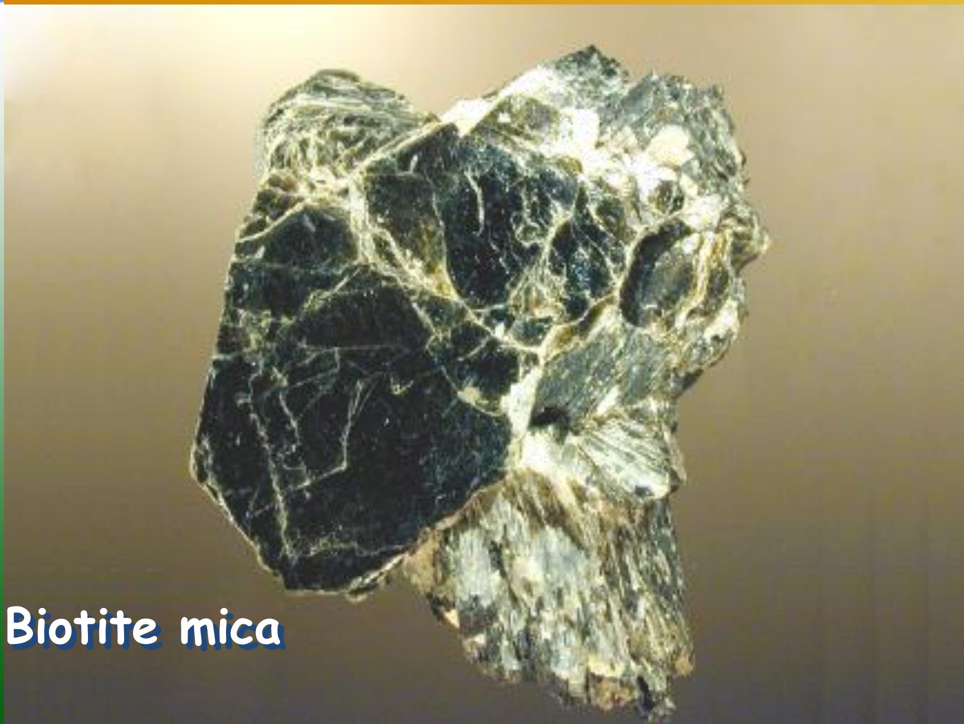
Calcite

Fe, Mg-rich Silicates

Olivine

Hornblende

Augite



Biotite mica

Quartz & Al-rich Silicates

Common elements in the crust

Silica (Si) - makes silicate minerals with oxygen

Oxygen (O) - makes silicate, oxide, carbonate, sulfate, minerals when combined with other elements

Aluminum (AL) - a “garbage can” element- in many classes

Iron (Fe) - another “garbage can” element-in many classes

Magnesium (Mg) - another “garbage can” element-in many classes

Calcium (Ca) - contributes to silicate species and carbonates

Sodium (Na) - contributes to halide and silicates

ROCK: *Usually*, an aggregate of mineral crystals or crystal fragments.

May be composed of one or more minerals, *in proportions that vary*.

May also be composed partly or entirely of rock fragments, or of organic remains.

The Rock Cycle, or Geologic Cycle (same thing)

What is most important about a rock is not the rock itself, but the process that made it.

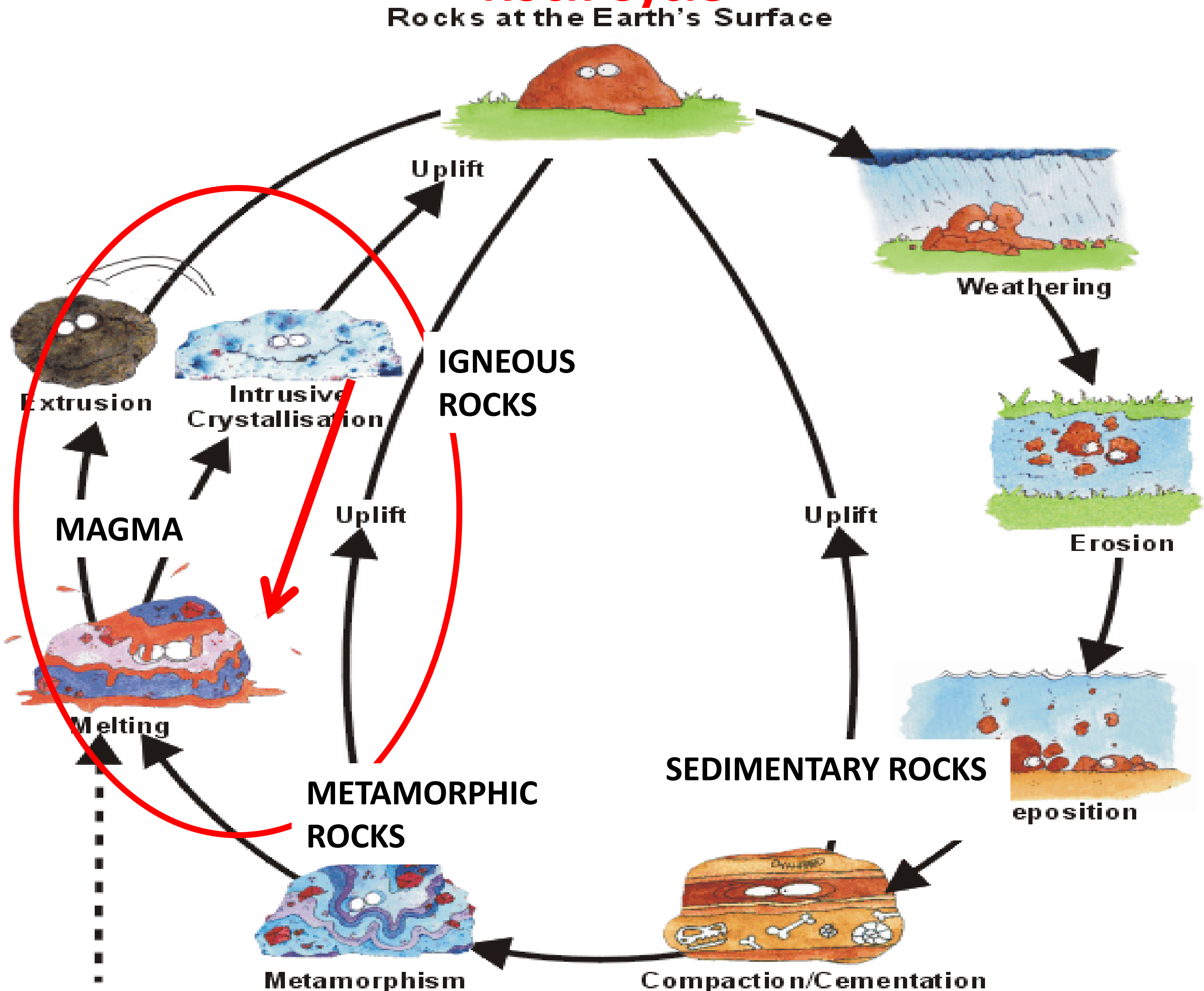
Rock-making processes are more important than the rocks they make.

Rocks undergo sequences of process called the *geologic cycle*.

Every rock contains information about how it was formed.

The job of the Earth scientist is to “read” the rock in order to decipher its origin.

Rock Cycle



Rocks at the Earth's Surface
Uplift
Weathering
Erosion
Extrusion
Intrusive Crystallisation
IGNEOUS ROCKS
MAGMA
Uplift
Uplift
Melting
METAMORPHIC ROCKS
SEDIMENTARY ROCKS
eposition
Metamorphism
Compaction/Cementation