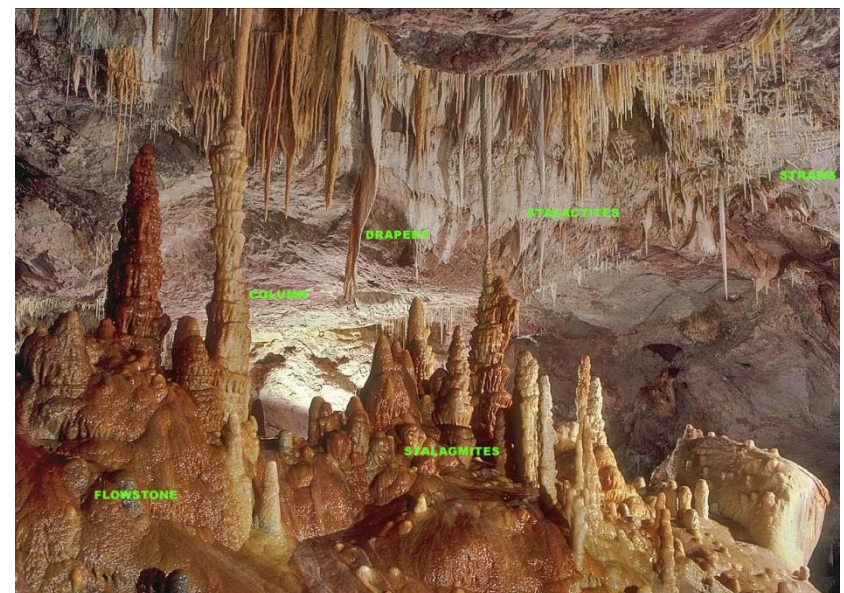




IDC 203: INTRODUCTION TO EARTH SCIENCES



Outline

- **What are minerals?**
- **The formation of minerals**
- **Classes of rock forming minerals**
- **Physical properties of minerals**

Minerals: building blocks of rocks



Mineral

- A naturally occurring, inorganic solid with an ordered internal structure and a narrow range of chemical composition
- Mineralogy is the branch of geology that studies **composition, stability, occurrence and association of minerals**

Mineral

Mineral

NATURAL

Iron ore
(hematite)

SOLID

Sand
(quartz)

INORGANIC

Rock salt
(halite)

Nonmineral

ARTIFICIAL

Cast iron
(metallic iron)

LIQUID

Seawater
(H₂O | salts)

ORGANIC

Vegetation
(cellulose)

GAS

Air
(oxygen)

ROCK

A naturally occurring consolidated mixture of minerals or mineral-like substances

Abundance of the elements (wt. %)

	CRUST	WHOLE EARTH
OXYGEN	46.3 %	29.5%
SILICON	28.2%	15.2%
ALUMINUM	8.2%	1.1%
IRON	5.6%	34.6%
CALCIUM	4.1%	1.1%
SODIUM	2.4%	0.6%
POTASSIUM	2.1%	0.1%
MAGNESIUM	2.3%	12.7%
TITANIUM	0.5%	0.1%
NICKEL	TRACE	2.4%
ALL OTHERS	TRACE	2.7%

Important ions in minerals

anions	charge
--------	--------

O	-2
---	----

cations	charge
---------	--------

Si	+4
----	----

K	+1
---	----

Ca	+2
----	----

Na	+1
----	----

Al	+3
----	----

Mg	+2
----	----

Fe	+2 or +3
----	----------

Chemical symbols

Oxygen	O	Magnesium	Mg
Silicon	Si	Iron	Fe
Aluminum	Al	Sodium	Na
Potassium	K	Calcium	Ca

Carbon	C	Titanium	Ti
Hydrogen	H	Argon	Ar
Uranium	U	Zirconium	Zr
Strontium	Sr	Lead	Pb

Formation of mineral

- **Mineral form by the process of the crystallization**
- **Magma crystallizes in to solid materials as it cools**
- **Crystallization can also occur when liquids evaporate from a solution**

Classes of mineral forming rocks

There are some 3,500 recognized minerals found on Earth.

For our purpose, we can focus on about a dozen.

**Silicates - Si, O and other elements, the most abundant mineral group
in the Earth's crust**

Carbonates - Ca, Mg and CO_3

Salts - NaCl

Classes of mineral forming rocks

Table
21

Some Chemical Classes of Minerals

Class	Defining Anions	Example
Native elements	None: no charged ions	Copper metal (Cu)
Oxides and hydroxides	Oxygen ion (O^{2-}) Hydroxyl ion (OH^-)	Hematite (Fe_2O_3) Brucite ($Mg[OH]_2$)
Halides	Chloride (Cl^-), fluoride (F^-), bromide (Br^-), iodide (I^-)	Halite (NaCl)
Carbonates	Carbonate ion (CO_3^{2-})	Calcite ($CaCO_3$)
Sulfates	Sulfate ion (SO_4^{2-})	Anhydrite ($CaSO_4$)
Silicates	Silicate ion (SiO_4^{4-})	Olivine (Mg_2SiO_4)

Native elements

- Native elements are minerals that are composed of a single element.
- Some examples are: Gold (Au), Silver (Ag), Copper (Cu), Iron (Fe), Diamonds (C), Graphite (C), and Platinum (Pt)



Oxides

- Oxides are minerals that include **one or more metal cations bonded to oxygen or hydroxyl anions.**
- Examples of oxide minerals include: Hematite (Fe_2O_3), Magnetite (Fe_3O_4), Corundum (Al_2O_3), and Ice (H_2O)



Carbonates

- Carbonates are anionic groups of carbon and oxygen. Carbonate minerals result from bonds between **these complexes and alkali earth and some transitional metals**.
- Common carbonate minerals include calcite (CaCO_3 , calcium carbonate) and dolomite $\text{CaMg}(\text{CO}_3)_2$ (calcium/magnesium carbonate).

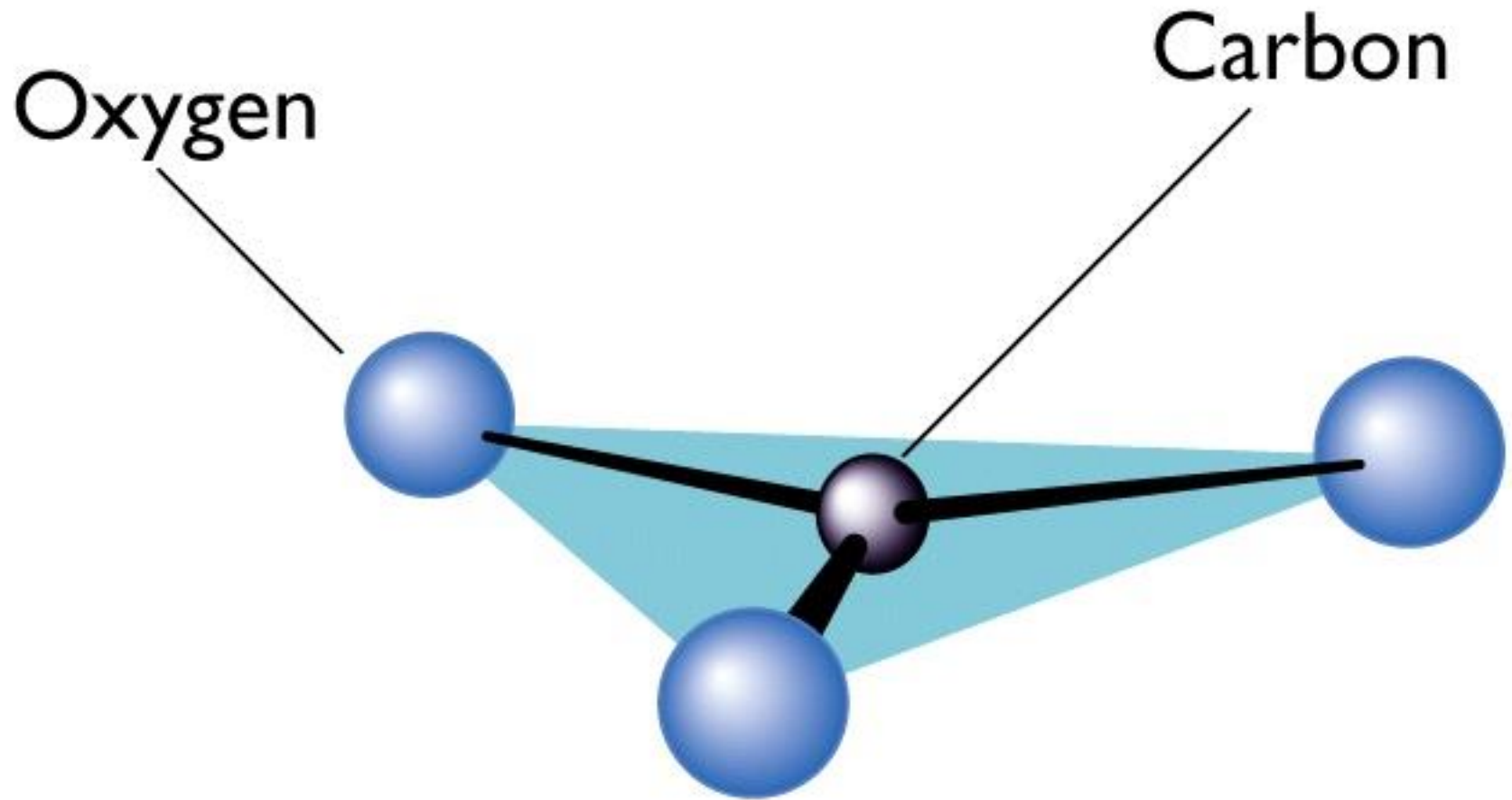


Dolomite



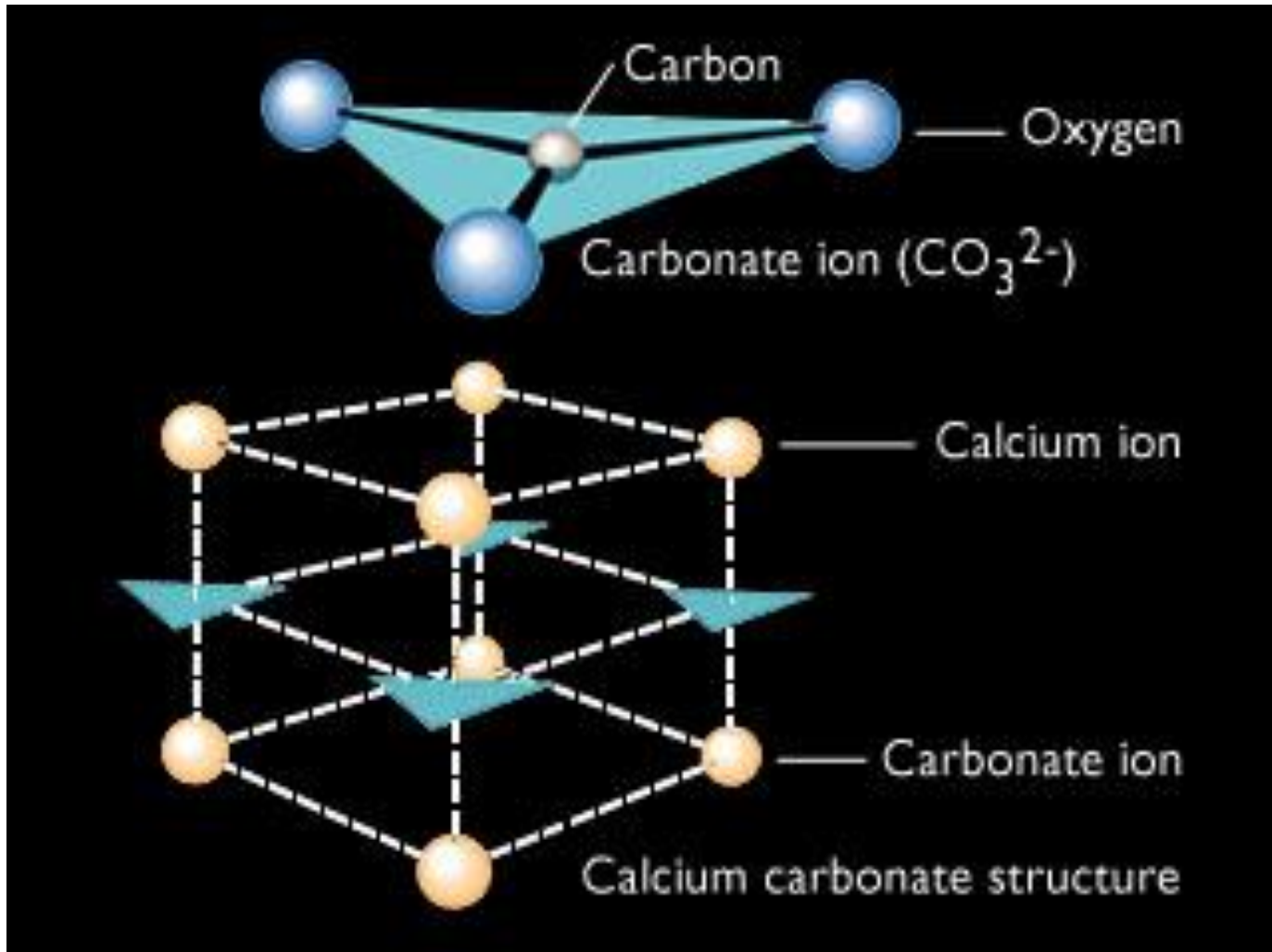
Calcite

Atomic Structure of Calcium Carbonate (Calcite)



(a) Carbonate ion (CO_3^{2-})

Atomic Structure of Calcium Carbonate (Calcite)



Halides

- Halides consist of **halogen elements**, chlorine (Cl), bromine (Br), fluorine (F), and iodine (I) forming **strong ionic bonds with alkali and alkali earth elements** sodium (Na), calcium (Ca) and potassium (K)
- Some examples include Halite (NaCl) and Fluorite (CaF₂).



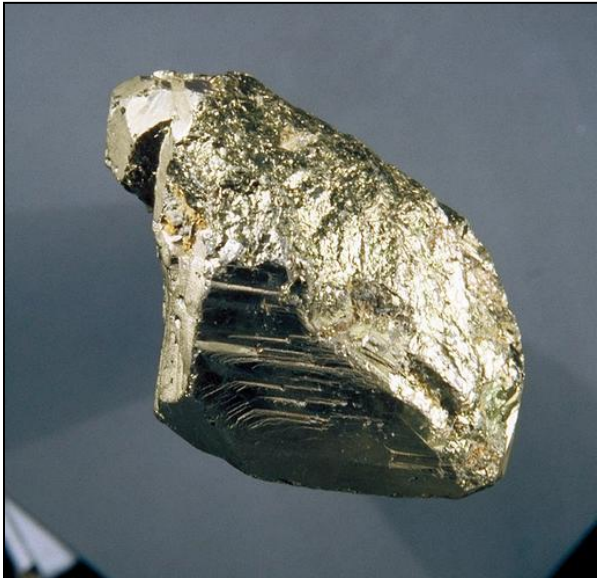
Halite



Fluorite

Sulfides

- Sulfides are minerals composed of **one or more metal cations combined with sulfur**. Many sulfides are economically important ores.
- Pyrite (FeS_2) or “fool’s gold”, Galena (PbS), Cinnabar (HgS) and Molybdenite (MoS_2) are a few commonly occurring sulfide minerals



Pyrite “Fool’s Gold”



Cinnabar

Sulfates

- Sulfates are minerals that include SO_4 anionic groups combined with alkali earth and metal cations.
- Anhydrous (no water) and hydrous (water) are the two major groups of Sulfates.
- Barite (BaSO_4) is an example of an anhydrous sulfate and Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is an example of a sulfate.



Silicates

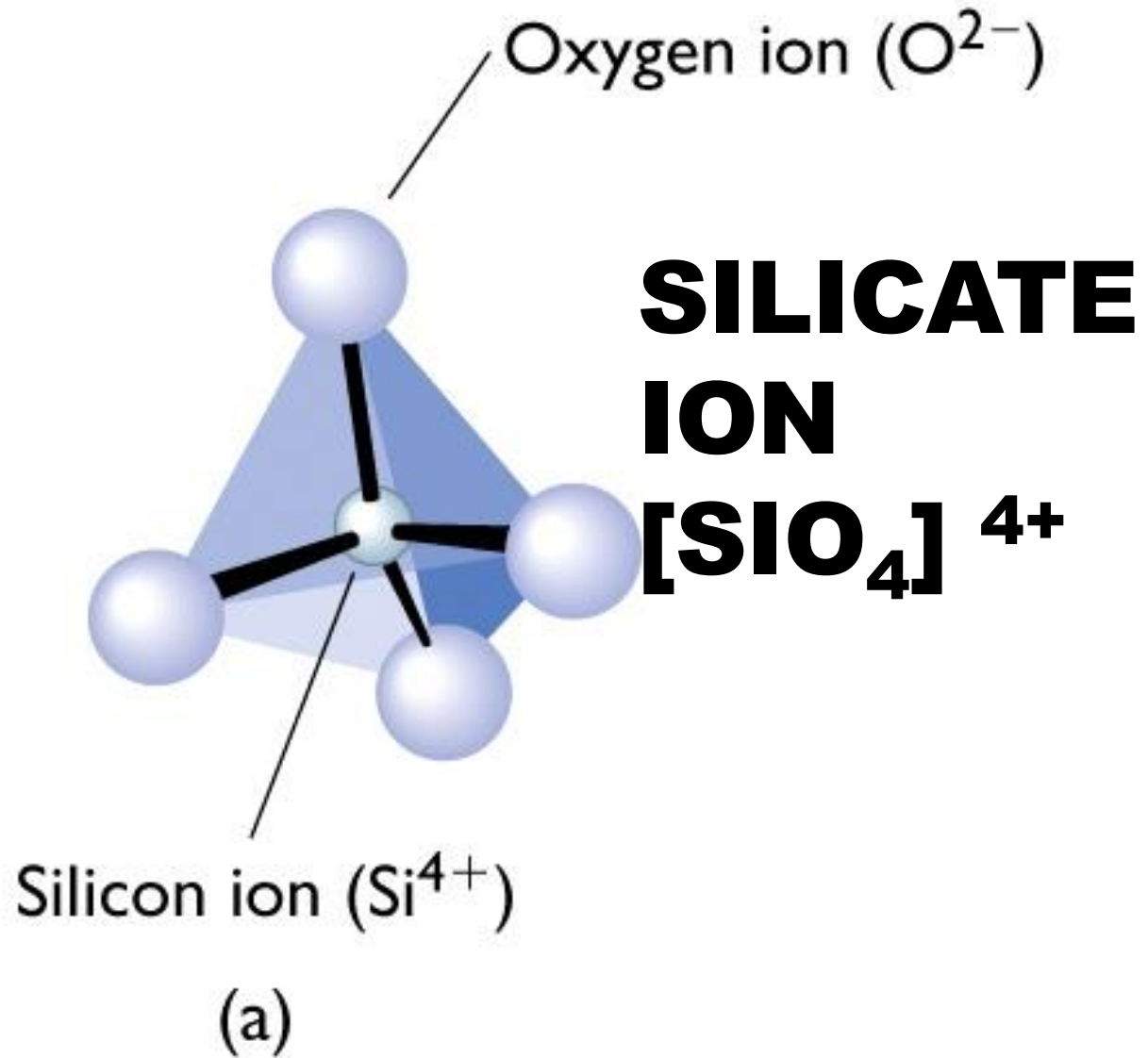
- Silicates comprise the majority of minerals in the Earth's crust and upper mantle. Over **25% of all minerals** are included in this group, with **over 40% of those** accounting for the most common and abundant minerals.

- Feldspar, Quartz, Biotite, and Amphibole are the most common silicates

Silica-oxygen tetrahedra

- **Four oxygens surrounding a silicon ion.**
- **These tetrahedra combine to make the framework of the silicates.**
- **Different combinations produce different structures.**

Silica-oxygen tetrahedra



Silicates

Composed of **silicon-oxygen tetrahedrons**, an arrangement which contains four oxygen atoms surrounding a silicon atom (SiO_4^{-4}).

Silicates are divided into two major groups: **ferromagnesian silicates** and **non-ferromagnesian silicates**

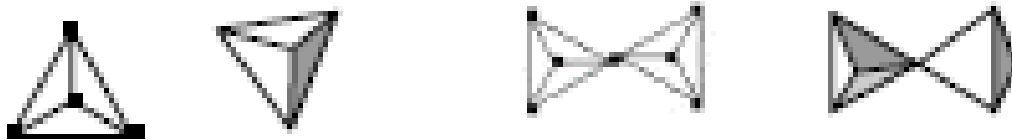
- ◆ Ferromagnesian silicates contain iron or magnesium ions joined to the silicate structure. They are darker and have a heavier specific gravity than non-ferromagnesian silicate minerals.
- ◆ Ferromagnesians include minerals such as olivine, pyroxene, hornblende, and biotite
- ◆ Non-ferromagnesians include muscovite, feldspar, and quartz

Structure of silicates

- **Isolated tetrahedrons**
- **Chain silicates**
- **Sheet silicates**
- **Framework silicates**

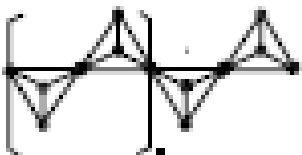
Structure of silicates

- Isolated tetrahedrons (e.g., Olivine)

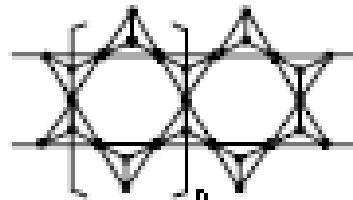
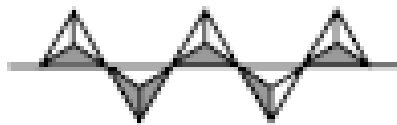


Structure of silicates

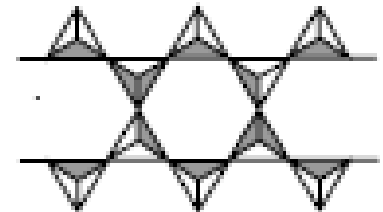
- Chain silicates (e.g., pyroxenes and amphiboles)
- Single chain: **Two oxygen ions** of each tetrahedra bond to adjacent tetrahedra
- Double chain: **Two single chains** will combine to form double chains linked to each other by shared oxygen ions



Single chain



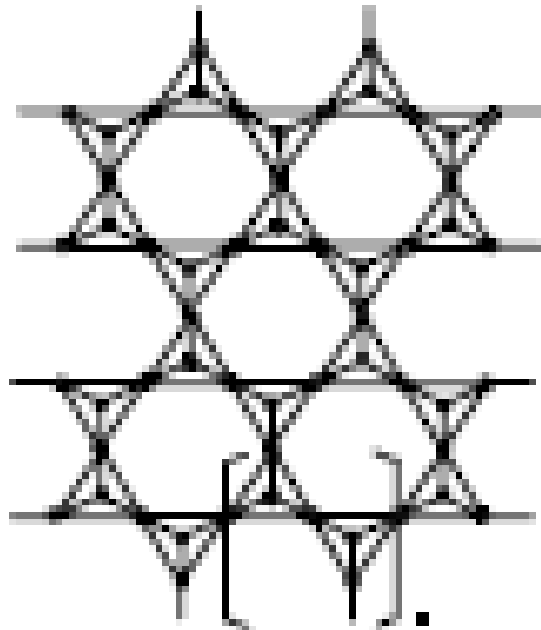
Double chain



Structure of silicates

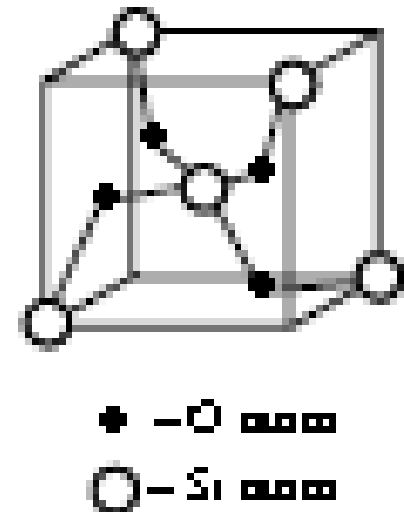
Sheet silicates (e.g., Talc)

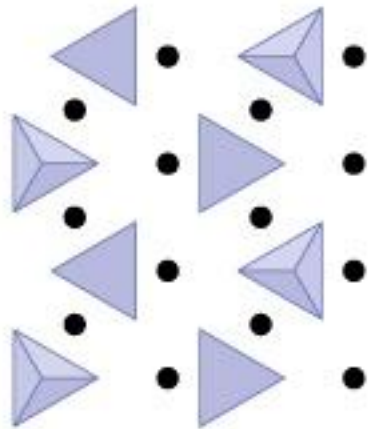
Three oxygen ions of each tetrahedra bond to adjacent tetrahedra



Frame work silicates (e.g., Quartz)

Each tetrahedra **share all** its oxygen ions



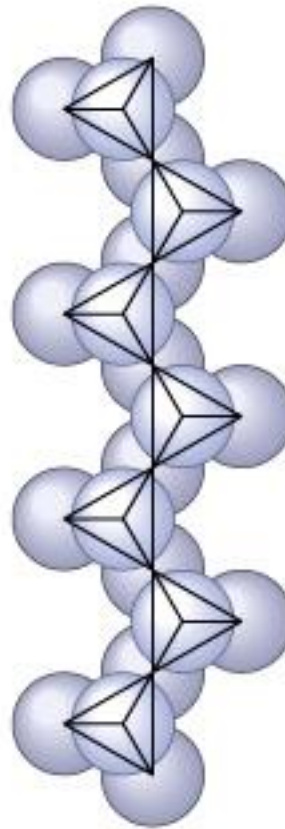


▲ Silica tetrahedron
apex toward you

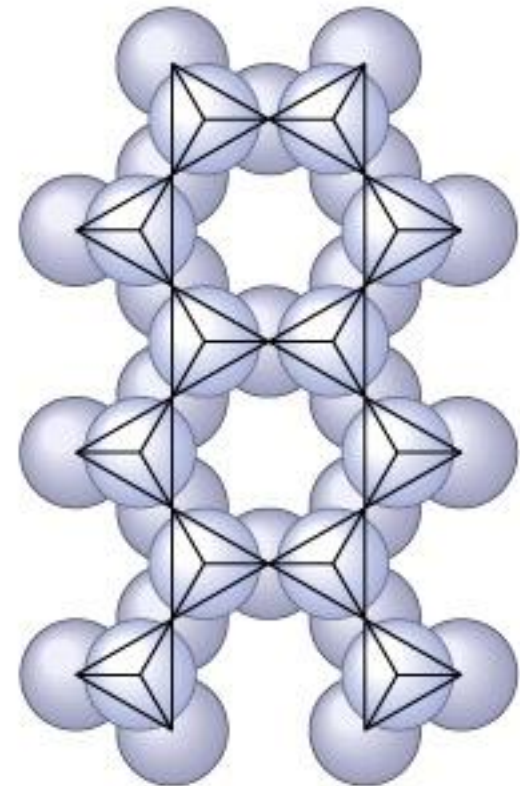
▼ Silica tetrahedron
apex away from
you

● Mg^{2+} or Fe^{2+}

(a) Isolated
tetrahedra
(example:
olivine)

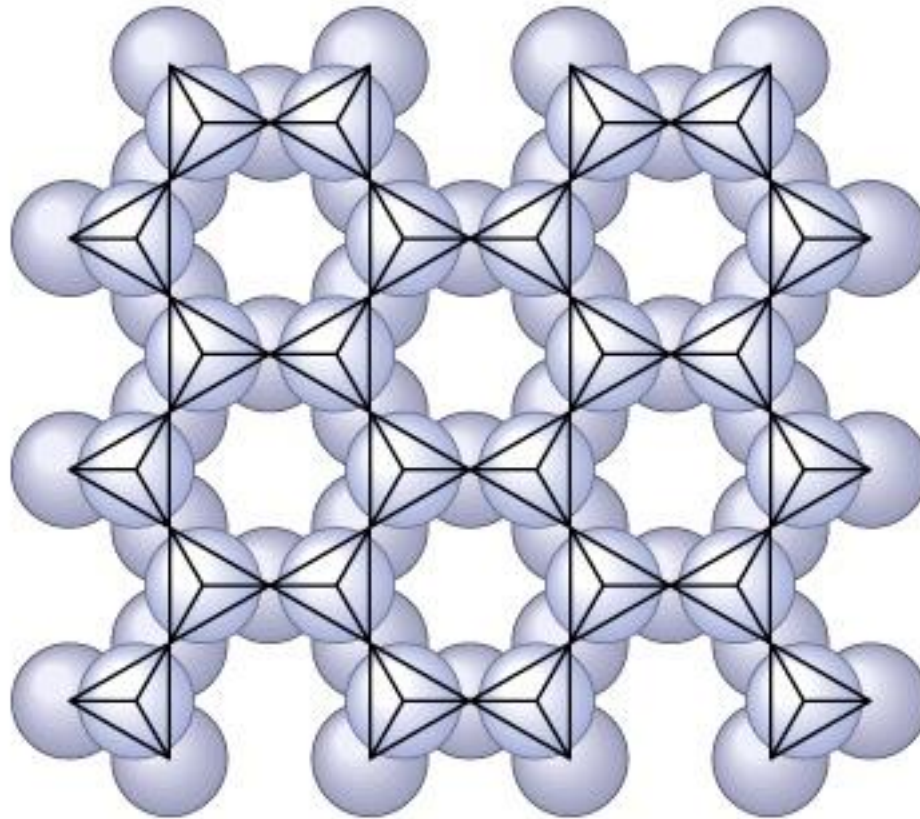


(b) Single
chain
(example:
pyroxene)



(c) Double
chain
(example:
amphibole)

Sheet Silicate (example: mica)



Silicate minerals



Silicate minerals



Non-silicate minerals



Important mineral groups

Name	Important constituents (other than O)
Olivine	Si, Fe, Mg
Pyroxene	Si, Fe, Mg, Ca
Amphibole	Si, Ca, Mg, Fe, Na, K
Micas	Si, Al, K, Fe, Mg
Feldspars	Si, Al, Ca, Na, K
Carbonates	C, Ca, Mg
Evaporites	K, Cl, Ca, S

Physical properties of Minerals

Mineral identification

Crystal form

Hardness

Cleavage

Fracture

Luster

Density

Color

Streak

Crystal form or habit

- The external morphology of crystals generally reflect the internal arrangement of their constituent atoms.
- This can be obscured, however, if the mineral crystallized in an environment that did not allow it to grow without significant interaction with other crystals (even of the same mineral).

Halite (cubic) and Quartz (hexagonal)



Hardness

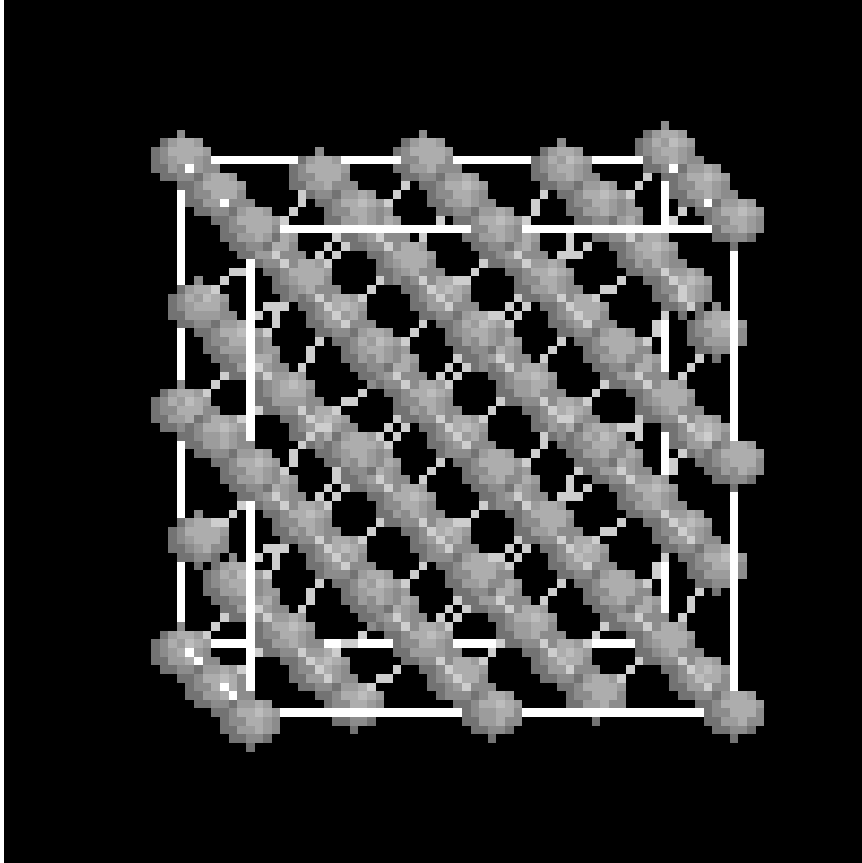
- How easy it is to scratch a mineral
- Mohs Scale of Hardness
- Relative scale consists of 10 minerals- ranked 1 (softest) to 10 (hardest)

**Table
2.2**

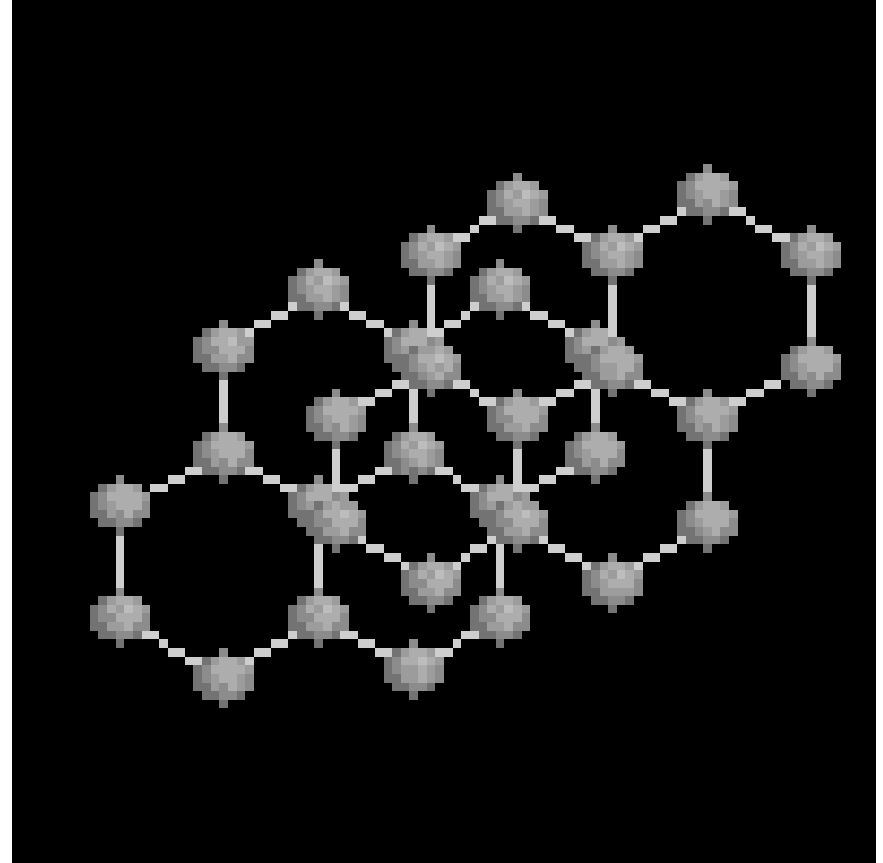
Mohs Scale of Hardness

Mineral	Scale Number	Common Objects
Talc	1	
Gypsum	2	— — — Fingernail
Calcite	3	— — — Copper coin
Fluorite	4	
Apatite	5	— — — Knife blade
Orthoclase	6	— — — Window glass
Quartz	7	— — — Steel file
Topaz	8	
Corundum	9	
Diamond	10	

Diamond vs. Graphite crystal structures



Hardness: 10



Hardness: 1-2

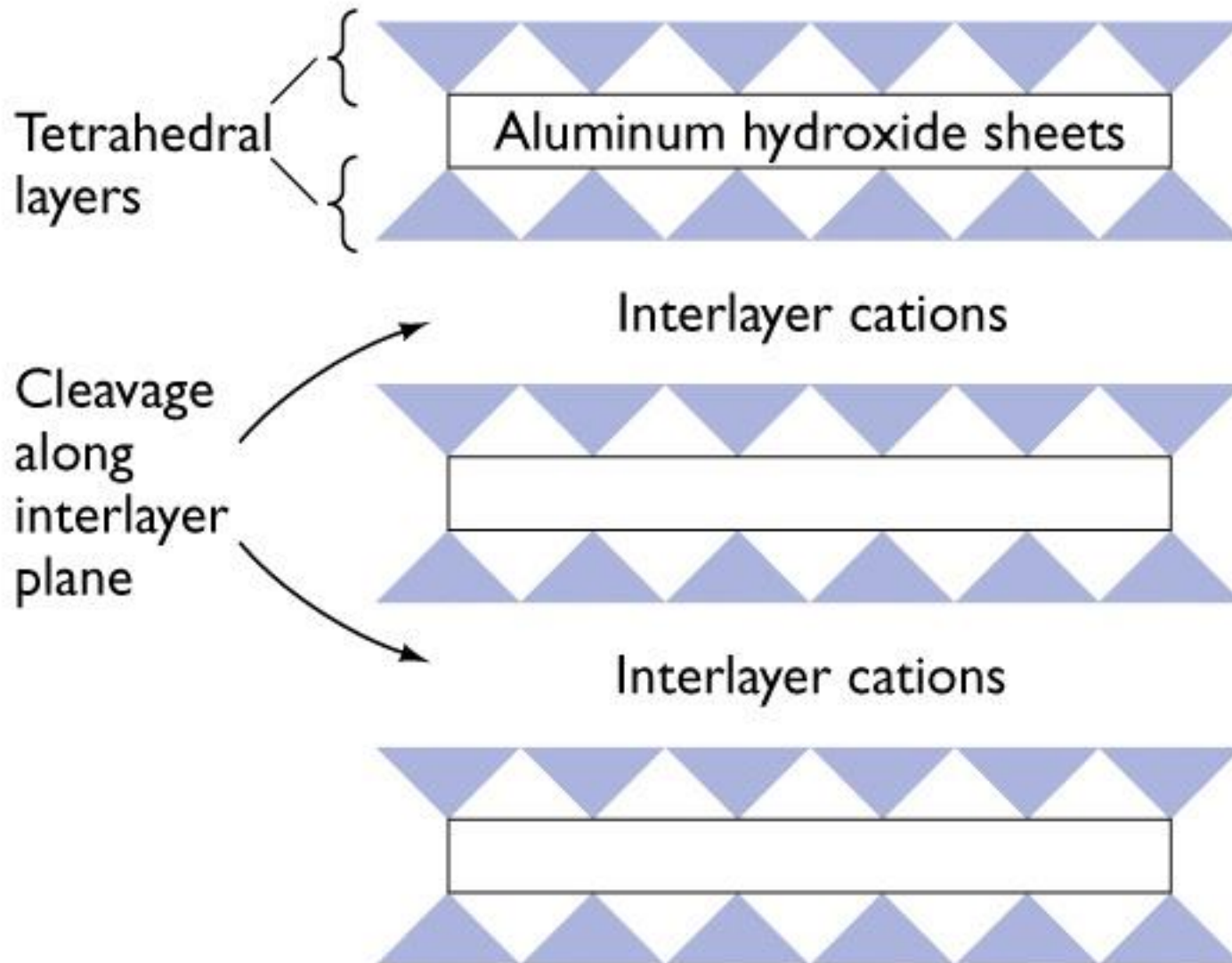
Cleavage

- The tendency of minerals to split along planar surfaces
- The term cleavage is also used to describe the **geometric pattern** produced by such breakage
- Cleavage varies inversely with bond strength; strong bond generally produce poor or no cleavage

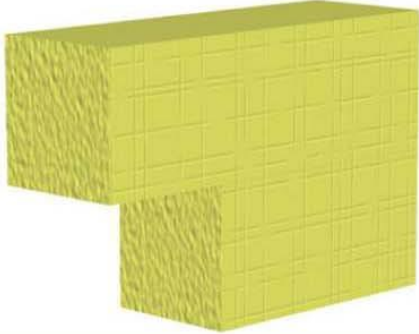
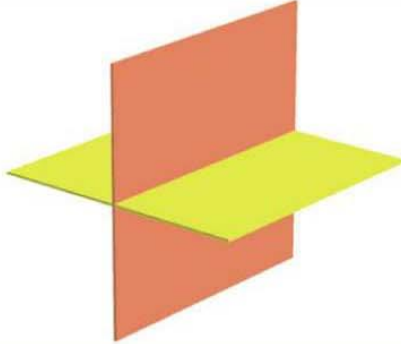
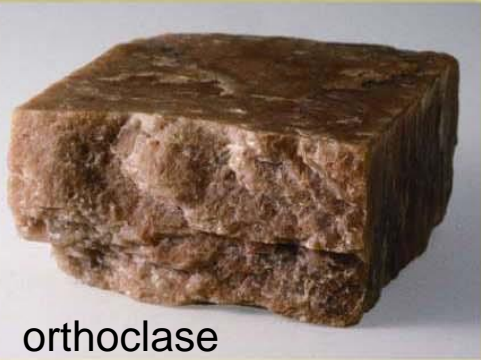

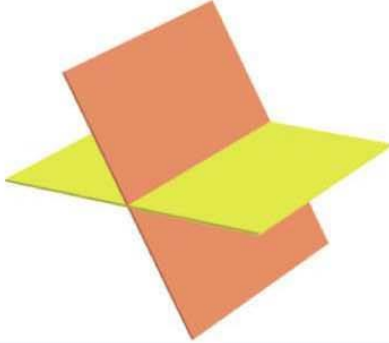

“Sheety” cleavage of mica



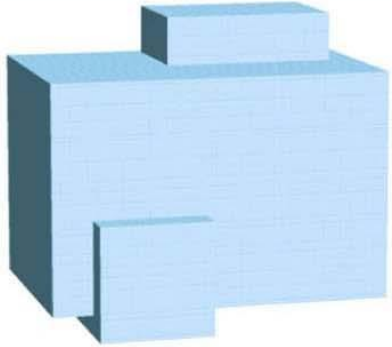
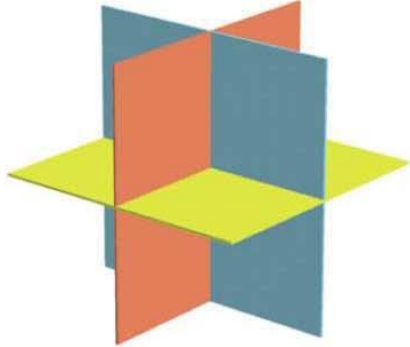

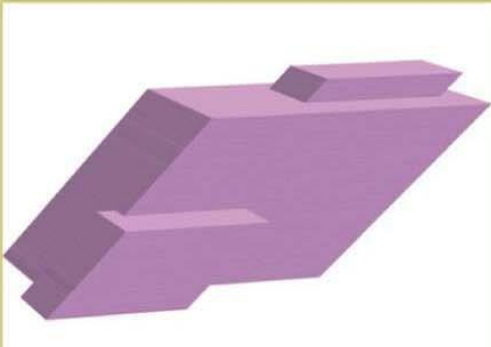
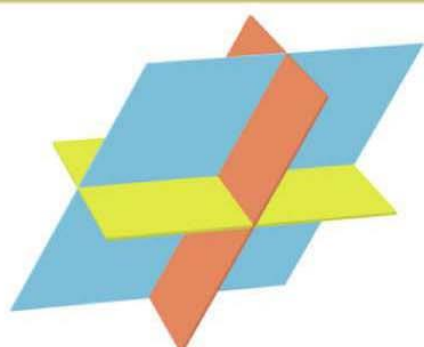

Atomic Structure of Micas



Comparison of cleavage and crystal faces

Number of Cleavage Directions	Sketch	Illustration of cleavage directions	Example
2 at 90°			 orthoclase
2 not at 90°			 amphibole

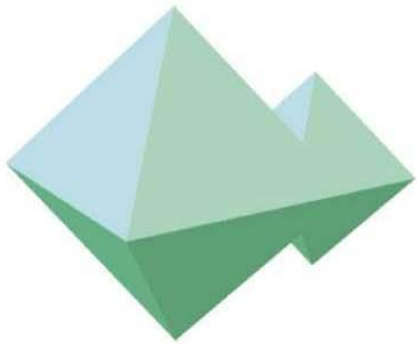
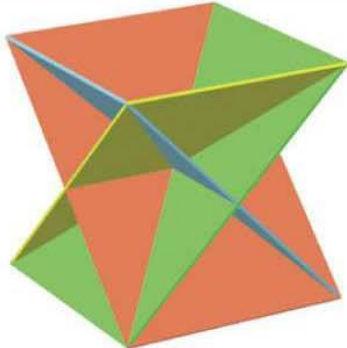

Cleavage (3 directions)

Number of Cleavage Directions	Sketch	Illustration of cleavage directions	Example
3 at 90°			 halite
			 calcite



**Rhombohedral cleavage of
calcite**

Cleavage (4 directions)

Number of Cleavage Directions	Sketch	Illustration of cleavage directions	Example
4			<p>fluorite</p> 

Fracture

- The tendency of crystals to break along irregular surfaces other than cleavages
- The fracture is related to how bond strength are distributed in direction
- Concoidal fracture: Showing smooth curved surfaces
- Fibrous or Splintery: Appearance like split wood

Fracture



Quartz



Chrysotile (a form of asbestos)



Actinolite

Luster

- The way the **surface of the mineral reflects light** give it a characteristic luster
- Luster is controlled by **kind of atoms present and their bonding** which affect the way light passes through or reflected

Luster

Table
2.3

Mineral Luster

<i>Metallic</i>	Strong reflections produced by opaque substances
<i>Vitreous</i>	Bright, as in glass
<i>Resinous</i>	Characteristic of resins, such as amber
<i>Greasy</i>	The appearance of being coated with an oily substance
<i>Pearly</i>	The whitish iridescence of such materials as pearl
<i>Silky</i>	The sheen of fibrous materials such as silk
<i>Adamantine</i>	The brilliant luster of diamond and similar minerals

Luster

*Metallic
example:
Galena*

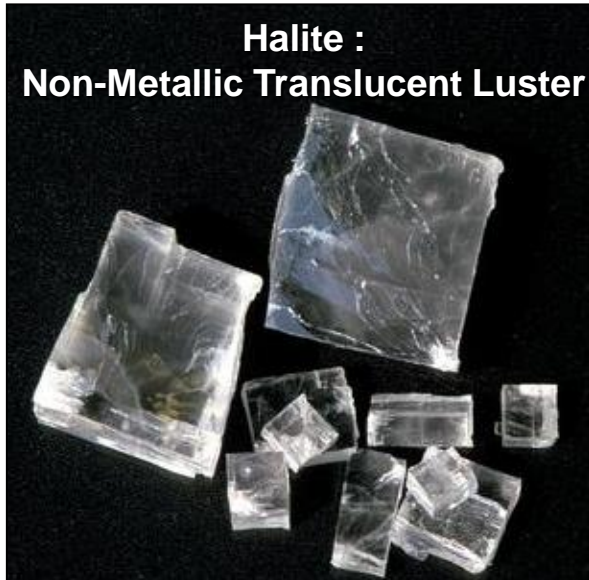


*Non-metallic
example:
Orthoclase*

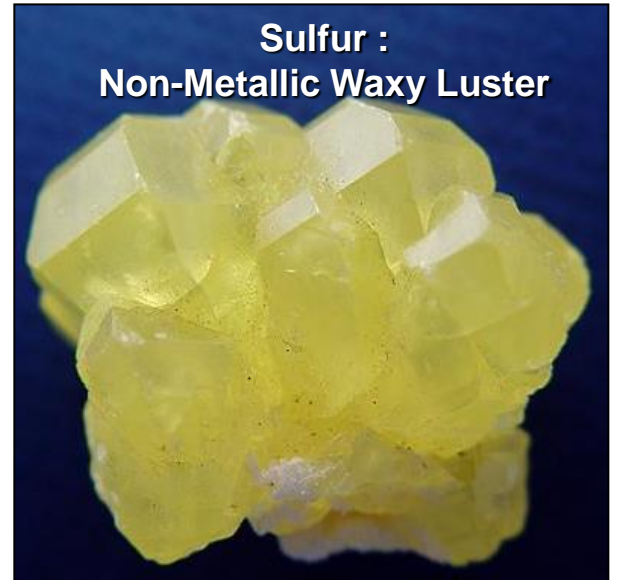


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Halite :
Non-Metallic Translucent Luster



Sulfur :
Non-Metallic Waxy Luster



Density and specific gravity

Density - Defined as the **mass divided by the volume** and normally designated by the Greek letter, rho, ρ .

mass/volume; SI units: **kg/m³ or kg m⁻³**, but geologists often **use g/cm³** as the unit of choice.

Specific Gravity - **Ratio of the mass of a substance** to the mass of an equal volume of water. S.G. is unitless.

Examples - quartz (SiO₂) has a S.G. of 2.65 while galena (PbS) has a S.G. of 7.5 and gold (Au) has a S.G. of 19.3.

Color

- Color arises due to **electronic transitions**, often of **trace** constituents, in the visible range of the EM spectrum.
e.g., quartz is found in a variety of colors.
- Color of a mineral may be **quite diagnostic for the trace element and coordination number of its bonding environment.**

Color



Milky quartz



Rosy quartz



Citrine

Color and density

Two broad categories are ferromagnesian and nonferromagnesian silicates.

Ferromagnesian silicates - dark color, density range from 3.2 - 3.6

- **Olivine** - high T, low silica rocks; comprises over 50% of upper mantle
- **Pyroxenes** - high T, low silica rocks
- **Amphiboles** - esp. hornblende; moderate T, higher silica rocks
- **Mica** - esp. biotite; moderate T, higher silica rocks
- **Garnet** - common metamorphic mineral

Color and density

Nonferromagnesian silicates - light color, density close to 2.7

Mica - esp. muscovite; moderate T, higher silica rocks

Feldspars - plagioclase and orthoclase; **most common mineral in crust**; form over a wide range of temperatures and melt compositions

Quartz - low T, high silica rocks; extremely stable at surface, hence it tends to be a major component in sedimentary rocks.

Clay - esp. kaolinite; different types found in different soils

Streak

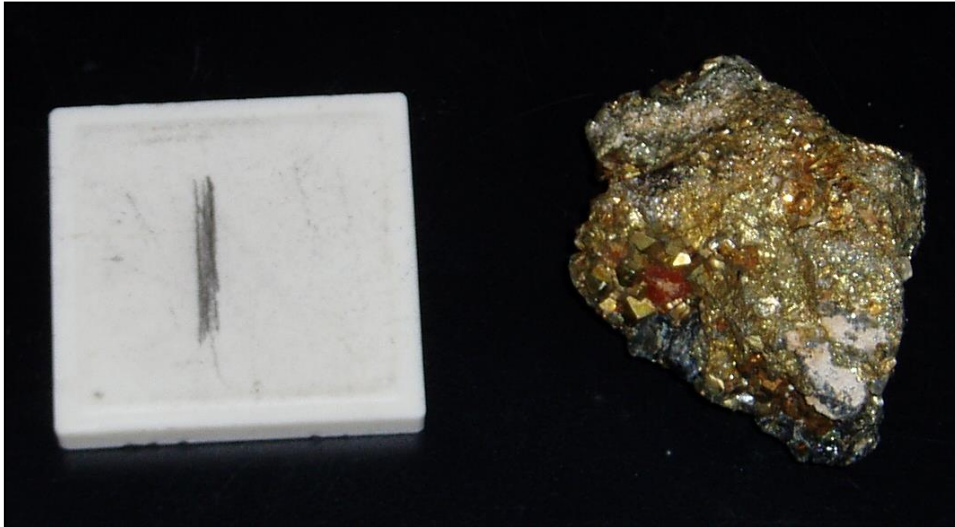
- Streak refers to the color of a mineral's powdered form left behind after it is scraped or rubbed across a porcelain streak plate.
- A mineral may appear one color and then produce a streak with a different color.
- A mineral's streak color is a more reliable identification characteristic than the minerals perceived surface color.

Streak



Hematite

Streak

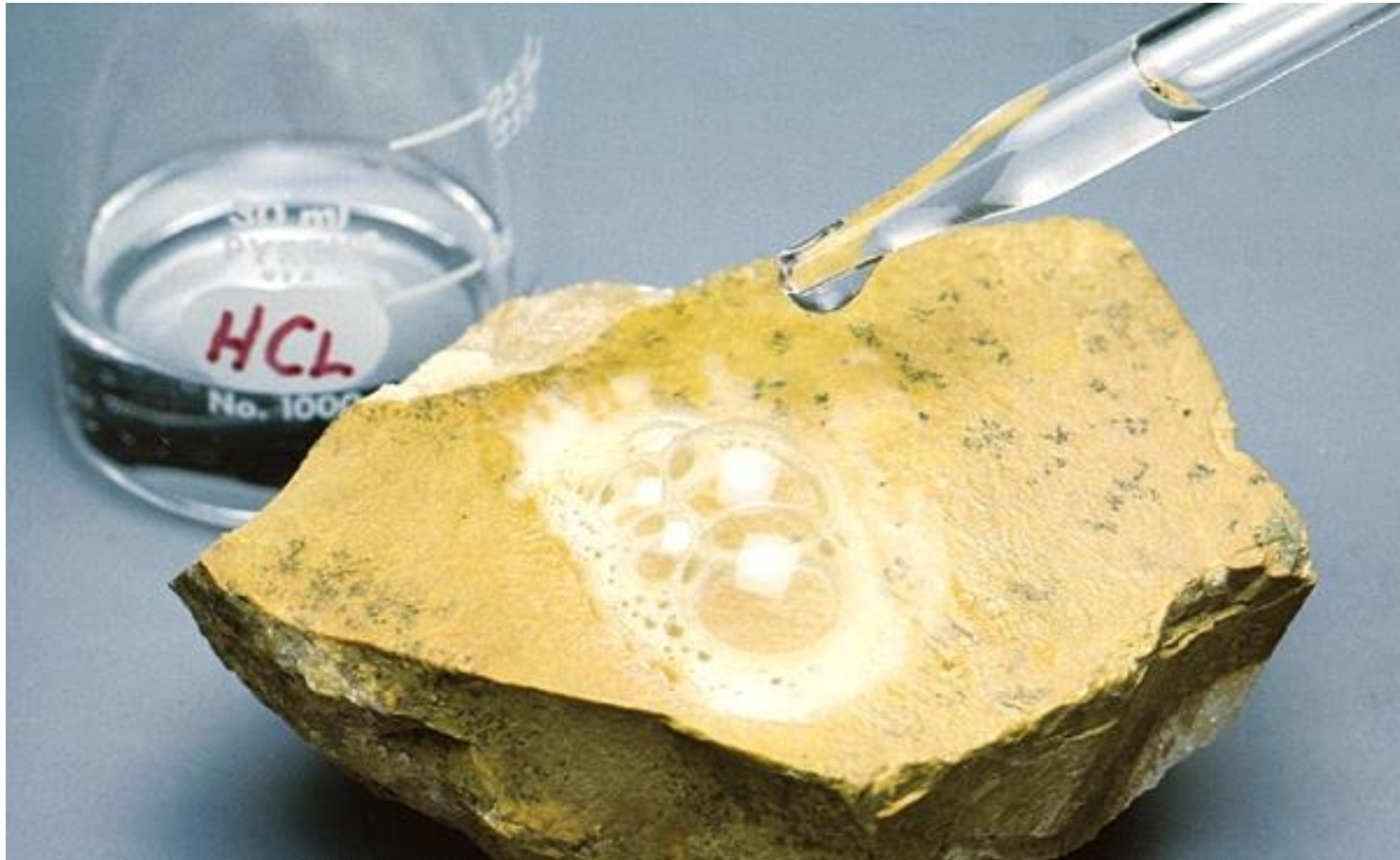


Mineral pyrite is gold in color, it leaves a grey “**pencil lead**” streak on the porcelain streak plate

Distinctive properties

- **reaction with hydrochloric acid** (calcite fizzes)
- **taste** (halite tastes salty)
- **feel** (talc feels soapy, graphite feels greasy)
- **magnetism** (magnetite attracts a magnet)
- **double refraction** (calcite when placed over printed material, letters appear doubled)
- **smell** (sulfur smells like rotten eggs)

Calcite passes the “acid test”



**Table
2.4**

Physical Properties of Minerals

Property	Relation to Composition and Crystal Structure
Hardness	Strong chemical bonds give high hardness. Covalently bonded minerals are generally harder than ionically bonded minerals.
Cleavage	Cleavage is poor if bond strength in crystal structure is high and is good if bond strength is low. Covalent bonds generally give poor or no cleavage; ionic bonds are weak and so give excellent cleavage.
Fracture	Type is related to distribution of bond strengths across irregular surfaces other than cleavage planes.
Luster	Tends to be glassy for ionically bonded crystals, more variable for covalently bonded crystals.
Color	Determined by kinds of atoms and trace impurities. Many ionically bonded crystals are colorless. Iron tends to color strongly.
Streak	Color of fine powder is more characteristic than that of massive mineral because of uniformly small size of grains.
Density	Depends on atomic weight of atoms and their closeness of packing in crystal structure. Iron minerals and metals have high density; covalently bonded minerals have more open packing and so have lower density.

Polymorphs

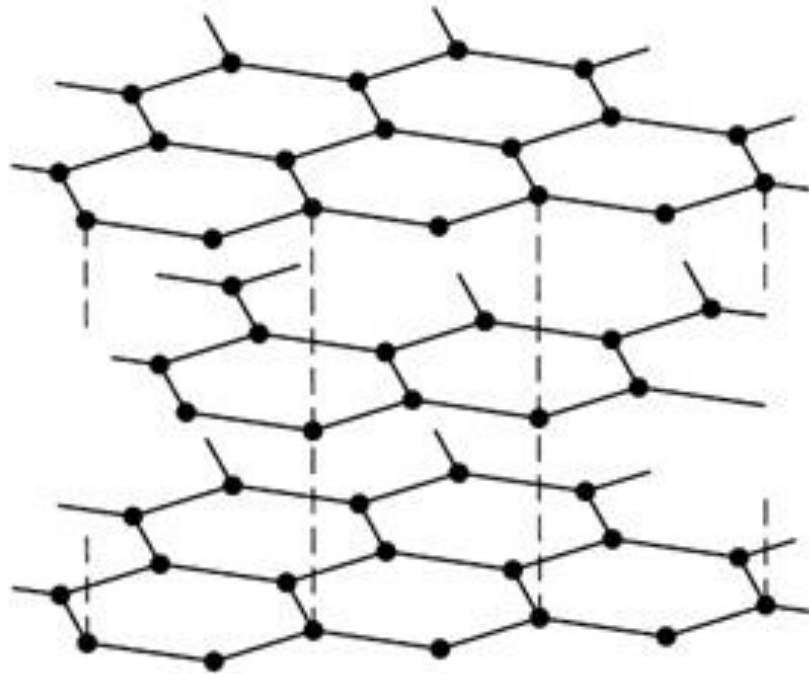
Minerals with the same chemical composition but different structure.

e.g., diamond and graphite

andalusite, kyanite, and sillimanite

Graphite

Atomic Structure



(a) Graphite

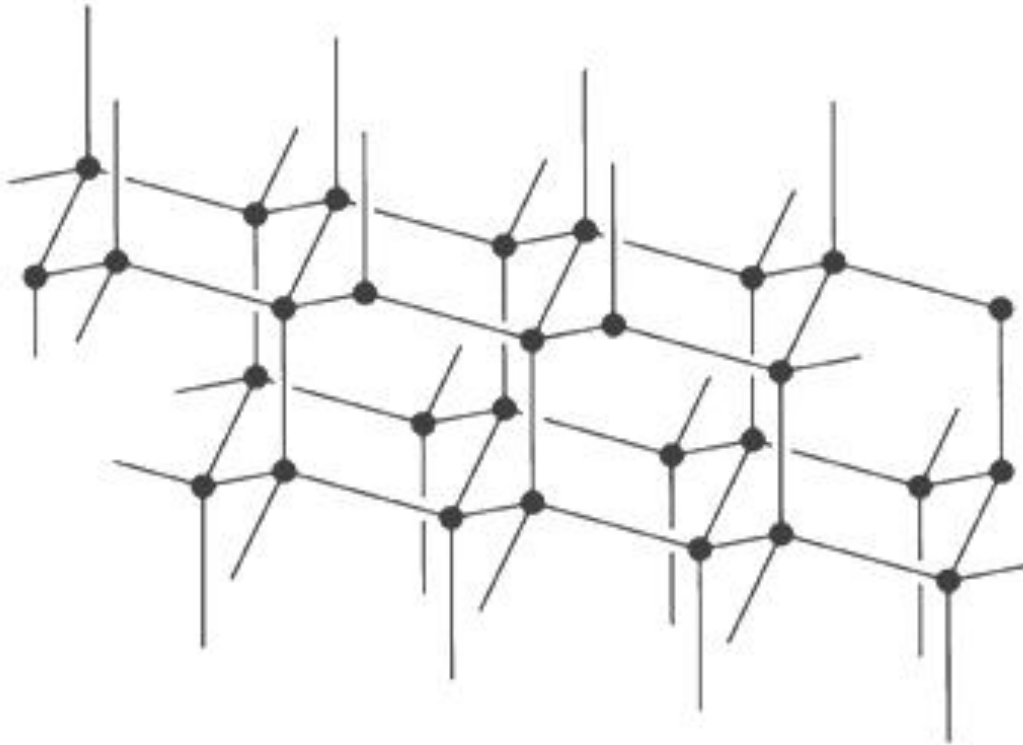
Crystal Form



Ken Lucas, Visuals Unlimited

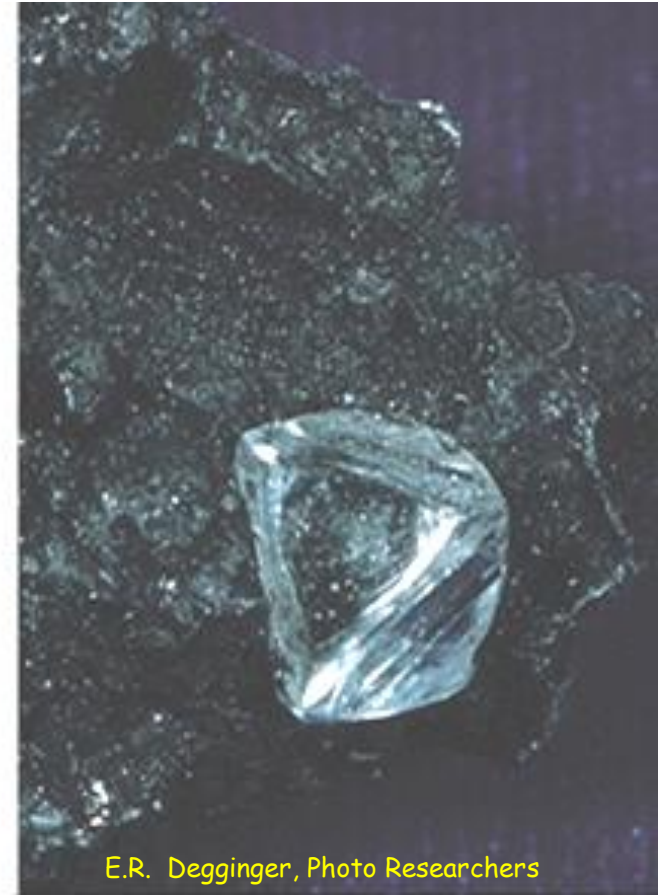
Diamond

Atomic Structure



Diamond

Crystal Form



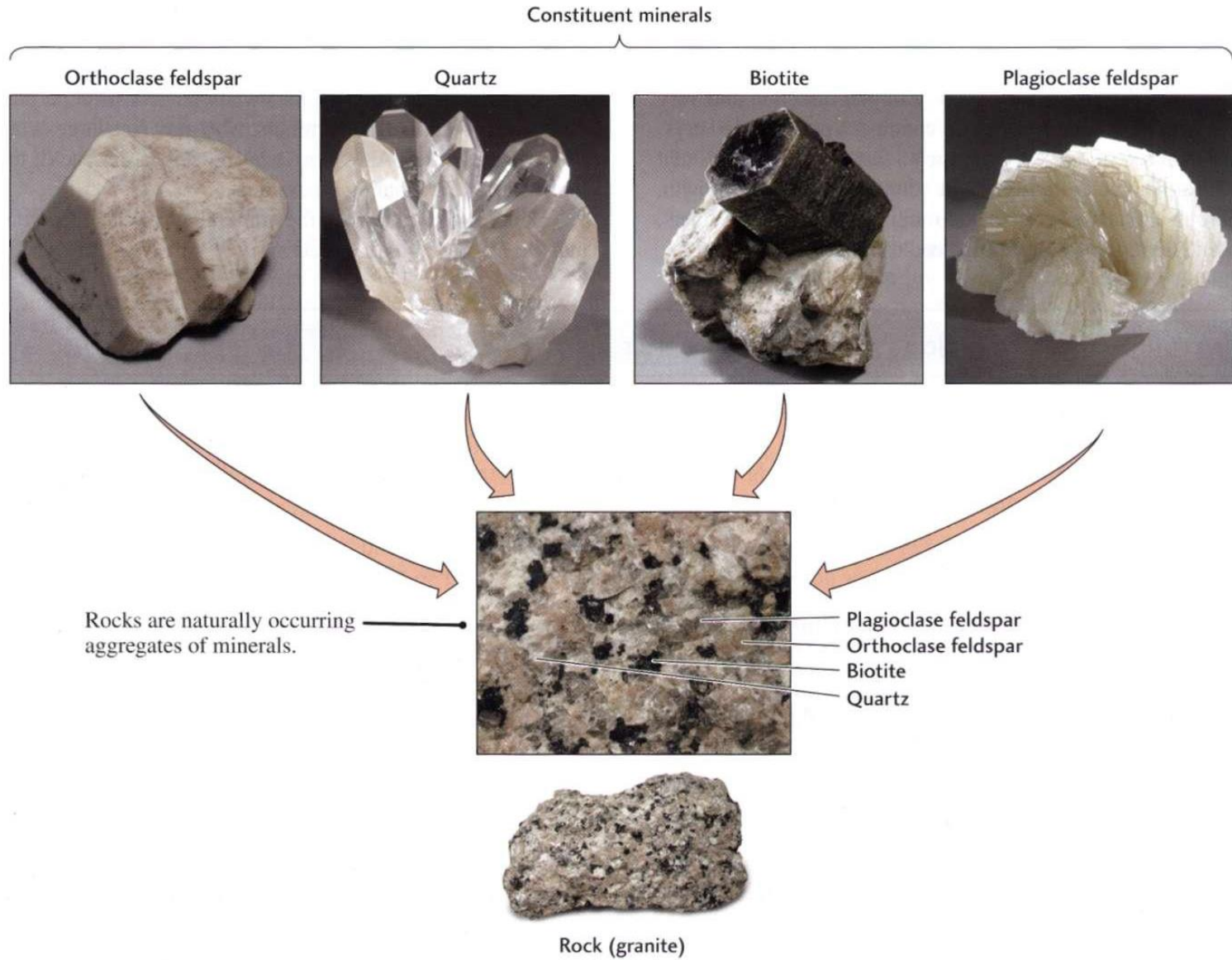
E.R. Degginger, Photo Researchers

(b)

Rocks

- A naturally occurring consolidated mixture of minerals or mineral-like substances
- Rocks can be also made up of non mineral matter (e.g., obsidian and coal)
- The identity of rock is determined partly by its mineral and partly by its texture.

Rocks



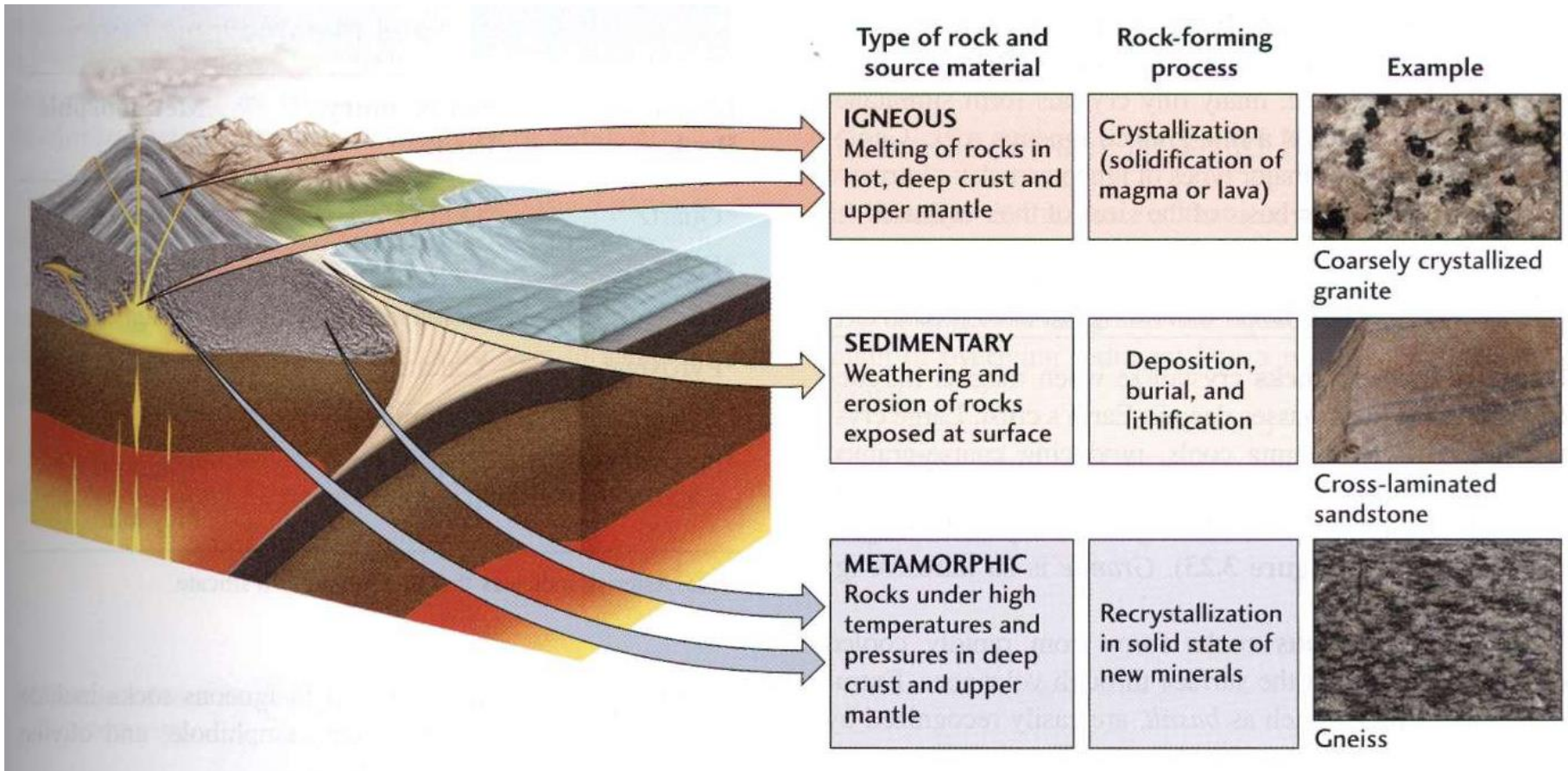
Texture

- Texture describes size and shapes of a rocks mineral crystals or grains.
- The grain large enough to be seen the rock is classified as **coarse** grained.
- The grain **not** large enough to be seen the rock is classified as **fine** grained.

Rocks

- Rocks formed by solidification of molten rock are called igneous rock
- Weathering and erosion of rocks exposed at the surface – sedimentary rocks
- Rocks formed under high pressure and temperature in deep crust and upper mantle is metamorphic rocks

Rocks



Rocks

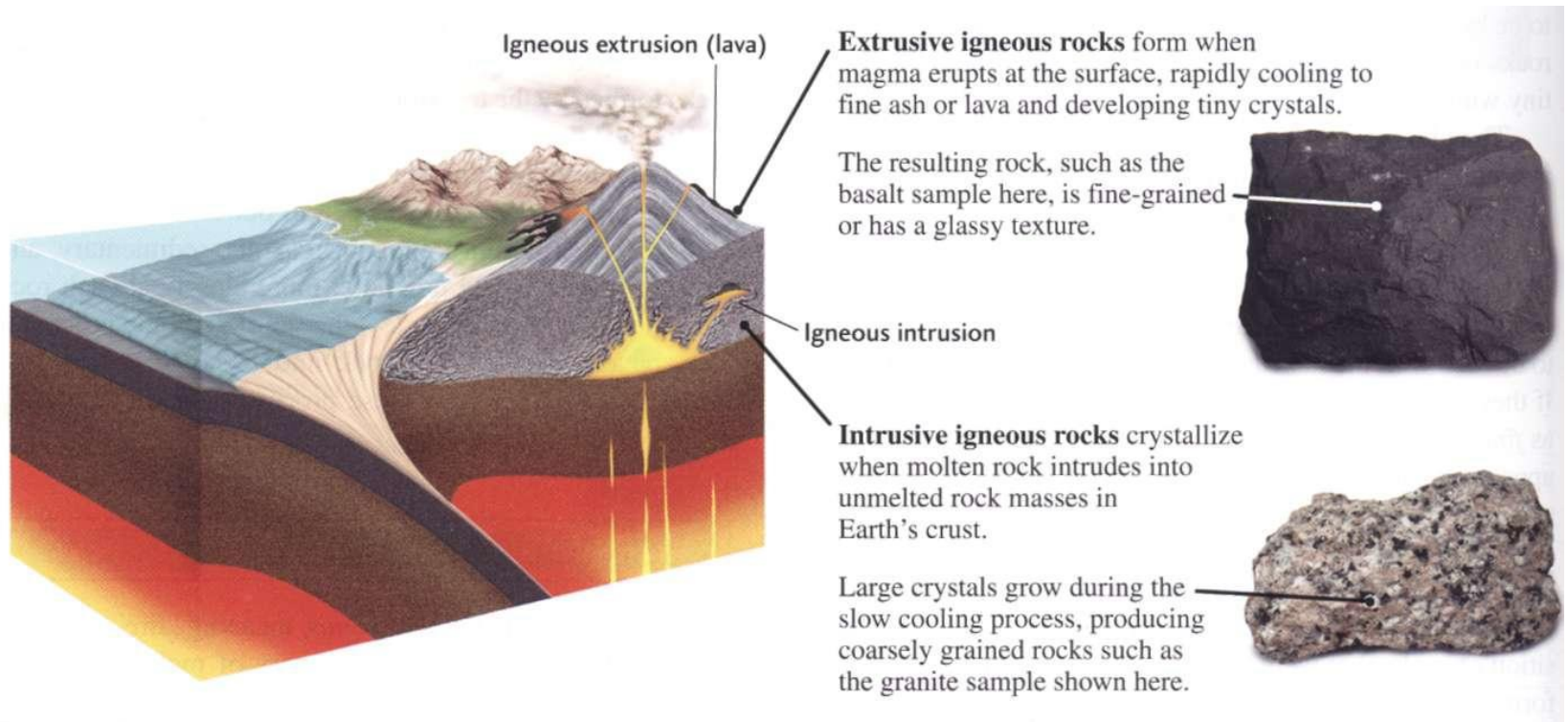
Table 3.5

Some Common Minerals
of Igneous, Sedimentary,
and Metamorphic Rocks

Igneous Rocks	Sedimentary Rocks	Metamorphic Rocks
*Quartz	*Quartz	*Quartz
*Feldspar	*Clay minerals	*Feldspar
*Mica	*Feldspar	*Mica
*Pyroxene	Calcite	*Garnet
*Amphibole	Dolomite	*Pyroxene
*Olivine	Gypsum	*Staurolite
	Halite	*Kyanite

Note: Asterisk indicates that the mineral is a silicate.

Igneous Rocks





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