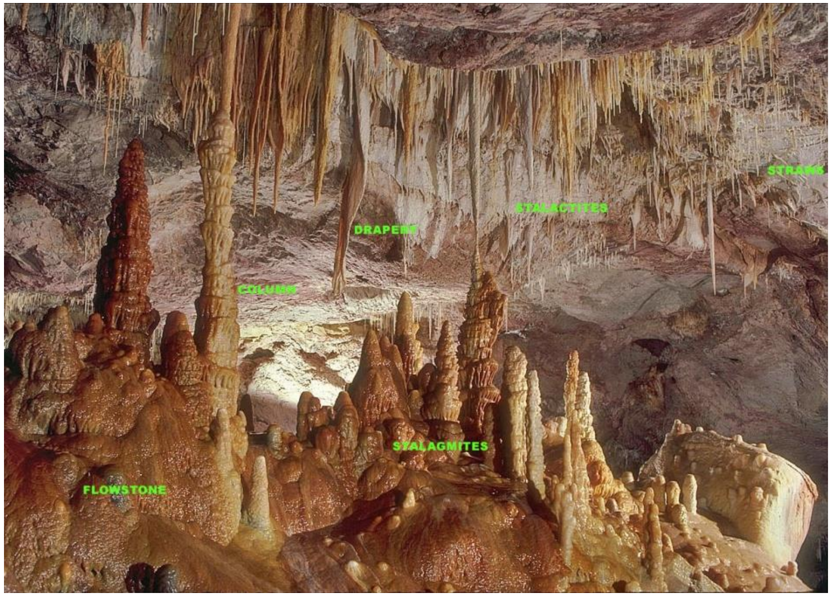
IDC 203: INTRODUCTION TO EARTH SCIENCES



Outline

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

Minerals: building blocks of rocks

Breck P. Kent

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 (H_2O I 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	cations	charge
O	-2	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

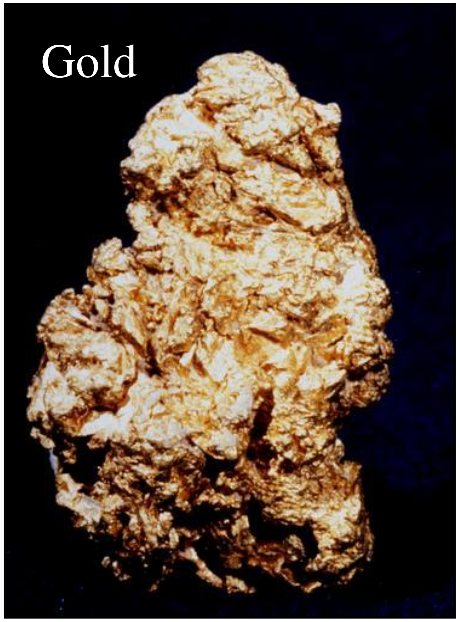
Table 21 Some Chemical Classes of Minerals

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.

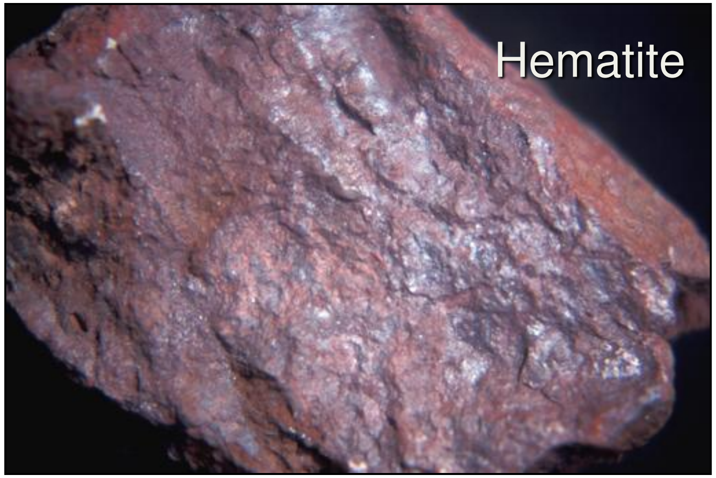
- Some examples are: Gold (Au), Silver (Ag), Copper (Cu), Iron (Fe), Diamonds (C), Graphite (C), and Platinum (Pt)



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)



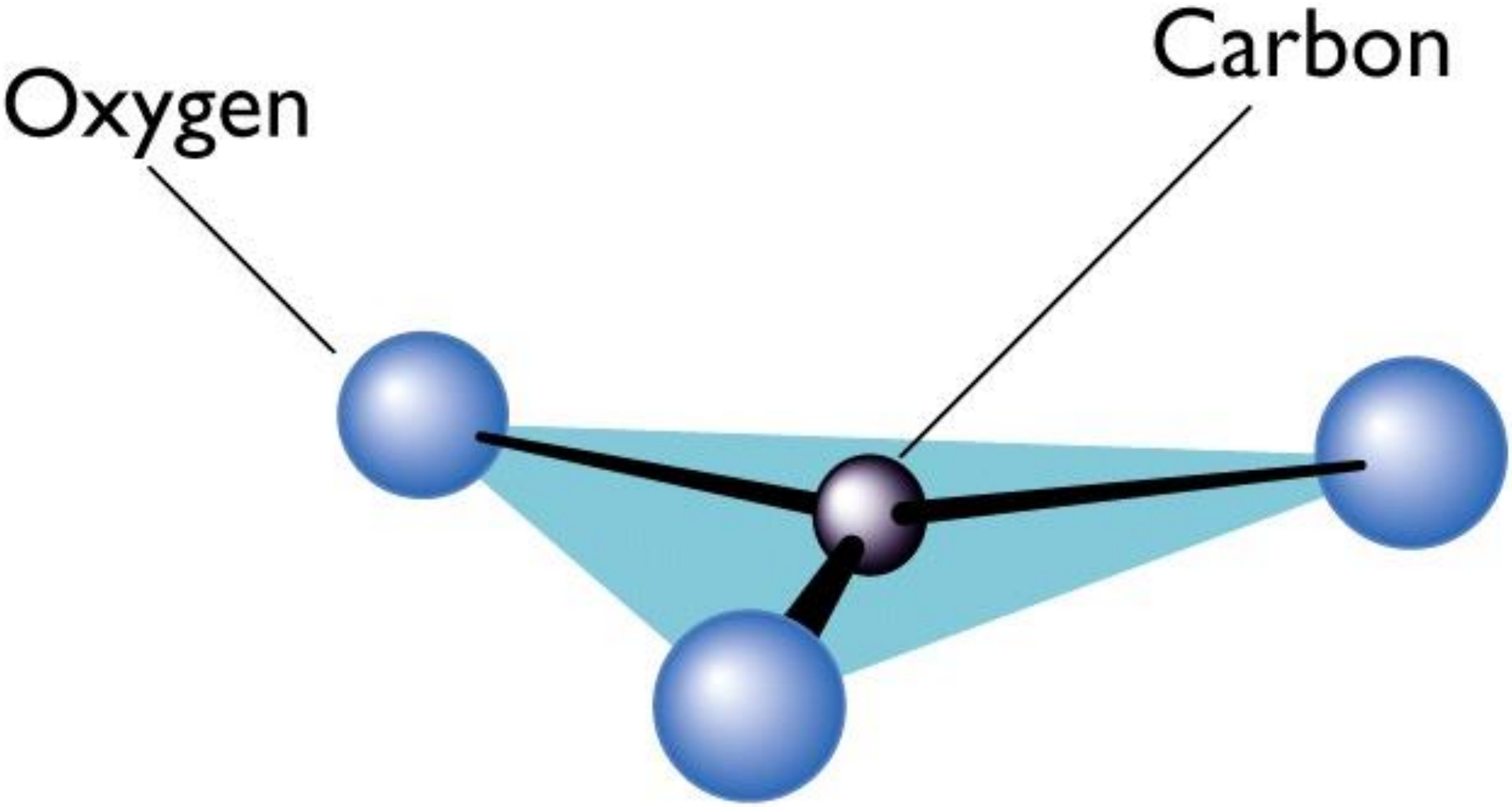
Carbonates

- 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 $CaMg(CO_3)_2$ (calcium/magnesium carbonate).

Dolomite

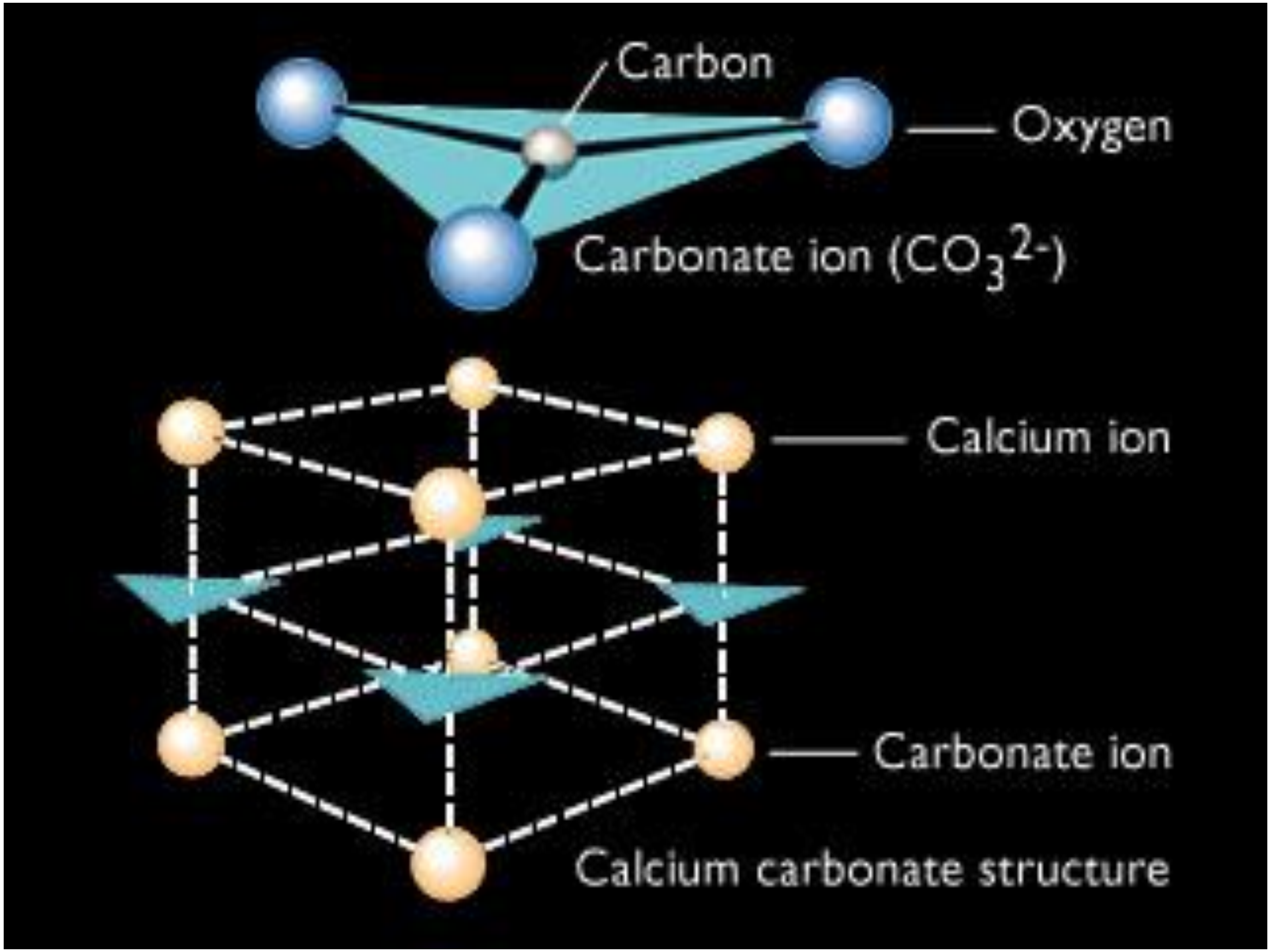
Calcite

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 Flourite (CaF_2).**

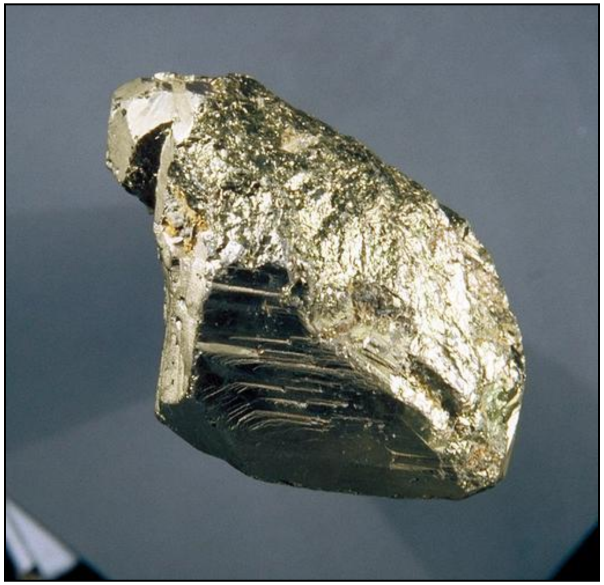
Halite

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) an 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 a anhydrous sulfate and Gypsum ($CaSO_4 \cdot 2H_2O$) is an example of a sulfate.**

Silicates

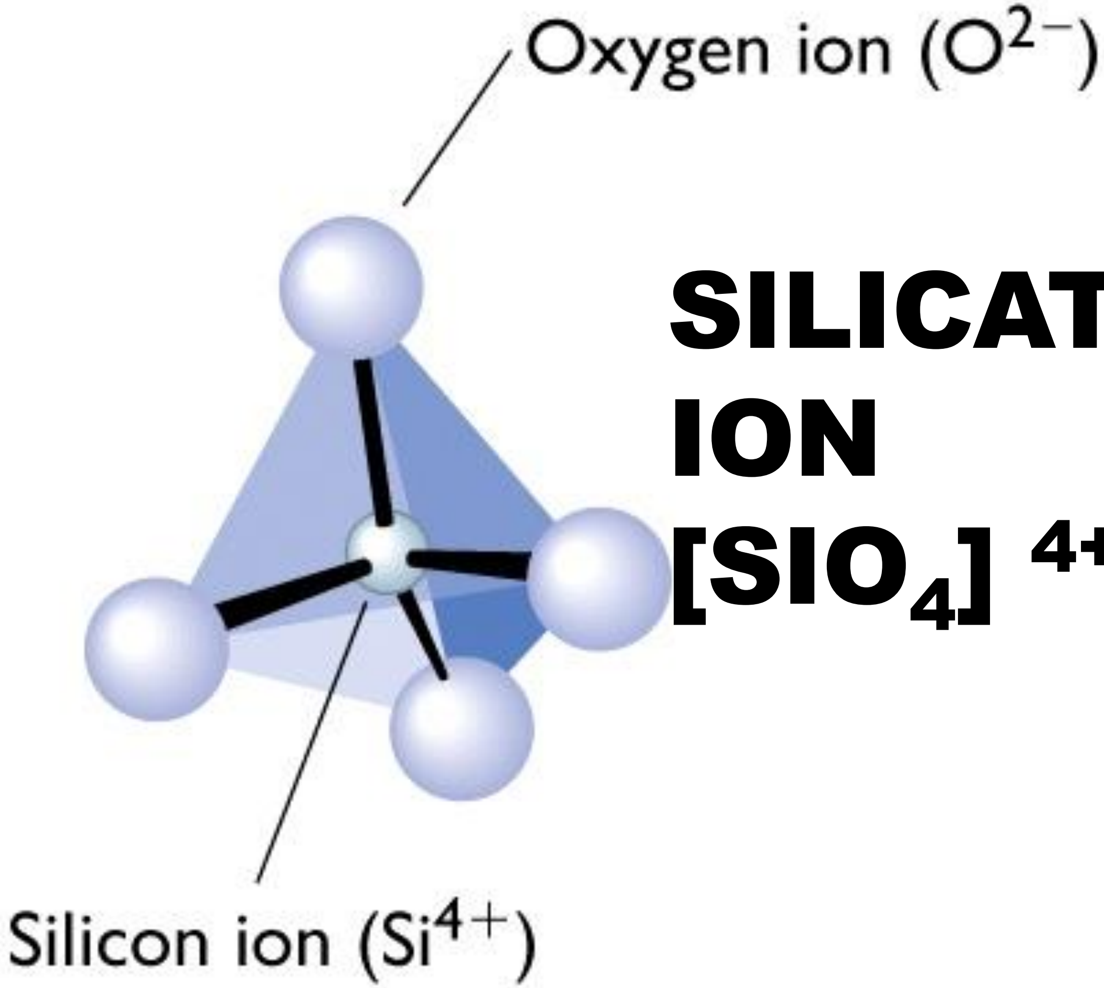
- **Silicates comprise the majority of minerals in the Earth's crust and upper mantle. Over 25% of all minerals are included in this group, with over 40% of those accounting for the most common and abundant minerals.**

- **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



(a)

SILICATE ION $[SIO_4]^{4+}$

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

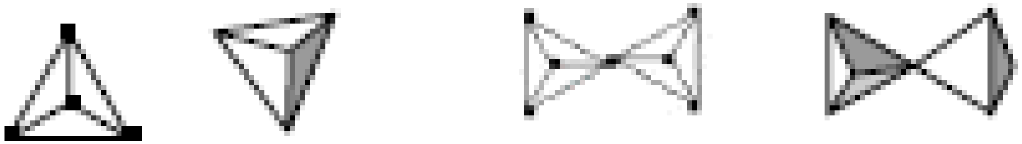
- Ferromagnesian silicates contain iron or magnesium ions joined to the silicate structure. They are darker and have a heavier specific gravity than non-ferromagnesian silicate minerals.
- Ferromagnesians include minerals such as olivine, pyroxene, hornblende, and biotite
- Non-ferromagnesians include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

Structure of silicates

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

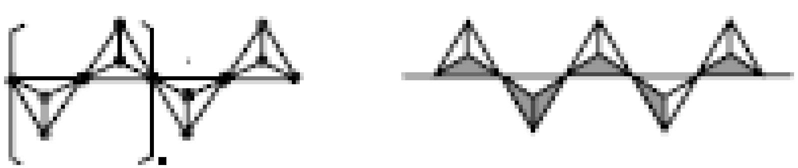
Structure of silicates

- **Isolated tetrahedrons (e.g., Olivine)**

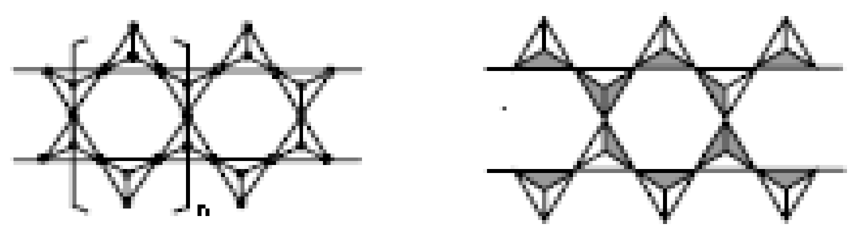


Structure of silicates

- 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

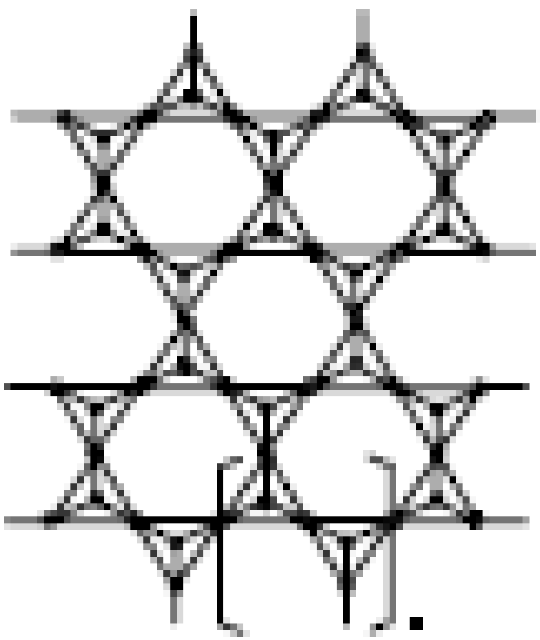


Double chain

Structure of silicates

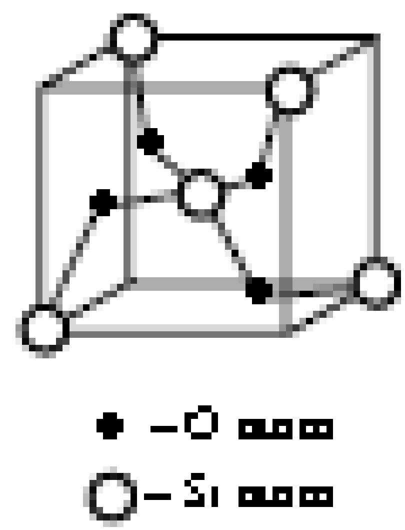
Sheet silicates (e.g., Talc)

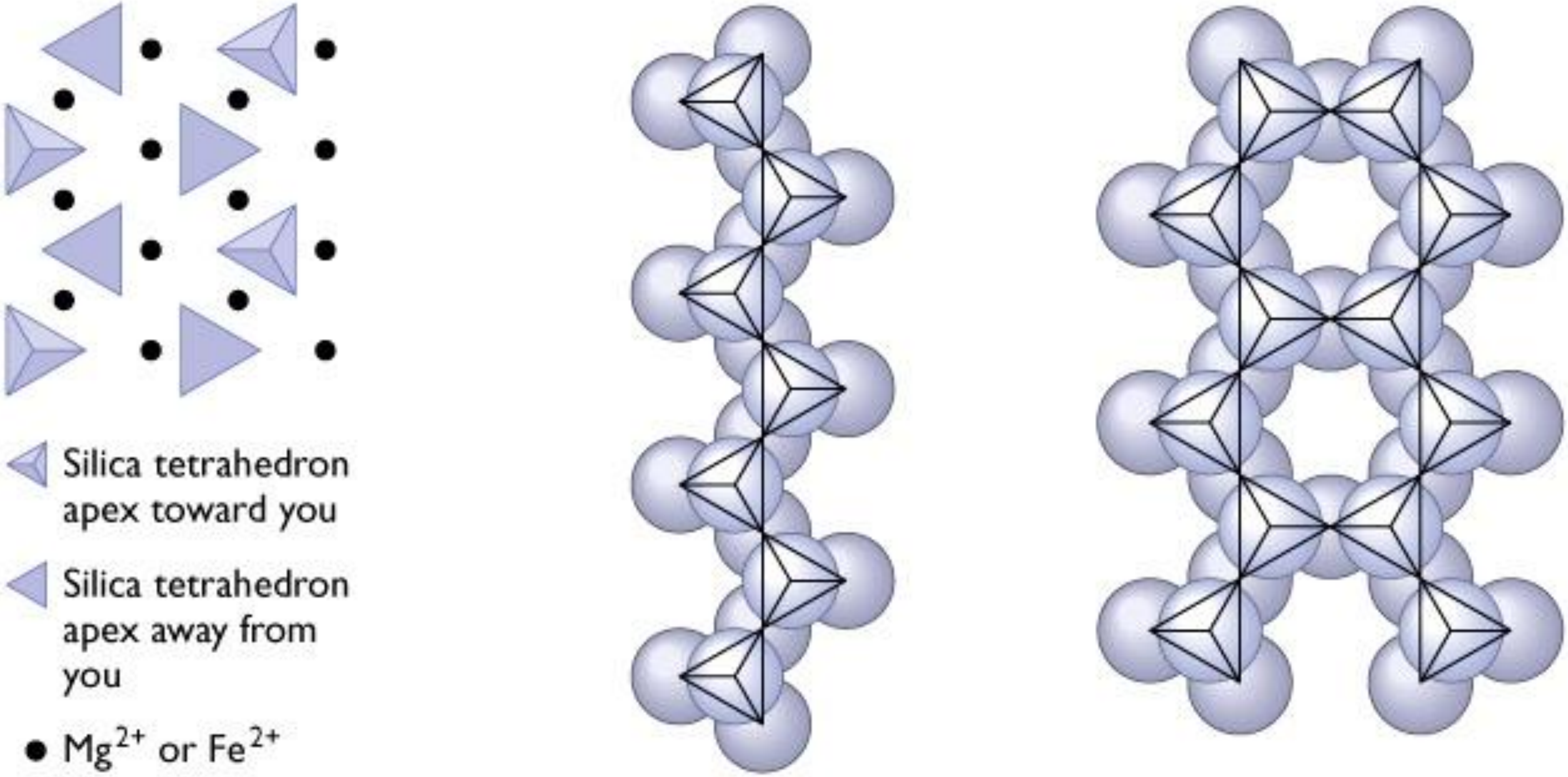
Three oxygen ions of each tetrahedra bond to adjacent tetrahedra



Frame work silicates (e.g., Quartz)

Each tetrahedra share all its oxygen ions



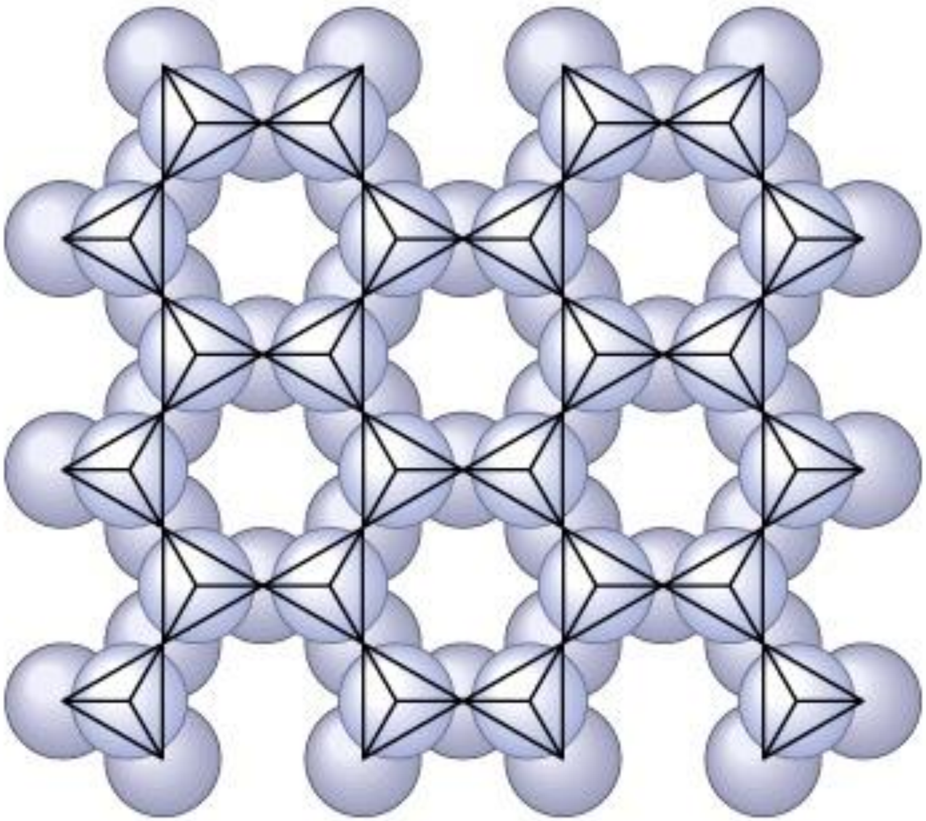


(a) Isolated tetrahedra (example: olivine)

(b) Single chain (example: pyroxene)

(c) Double chain (example: amphibole)

Sheet Silicate
(example: mica)



Silicate minerals

Silicate minerals

Chip Clark

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

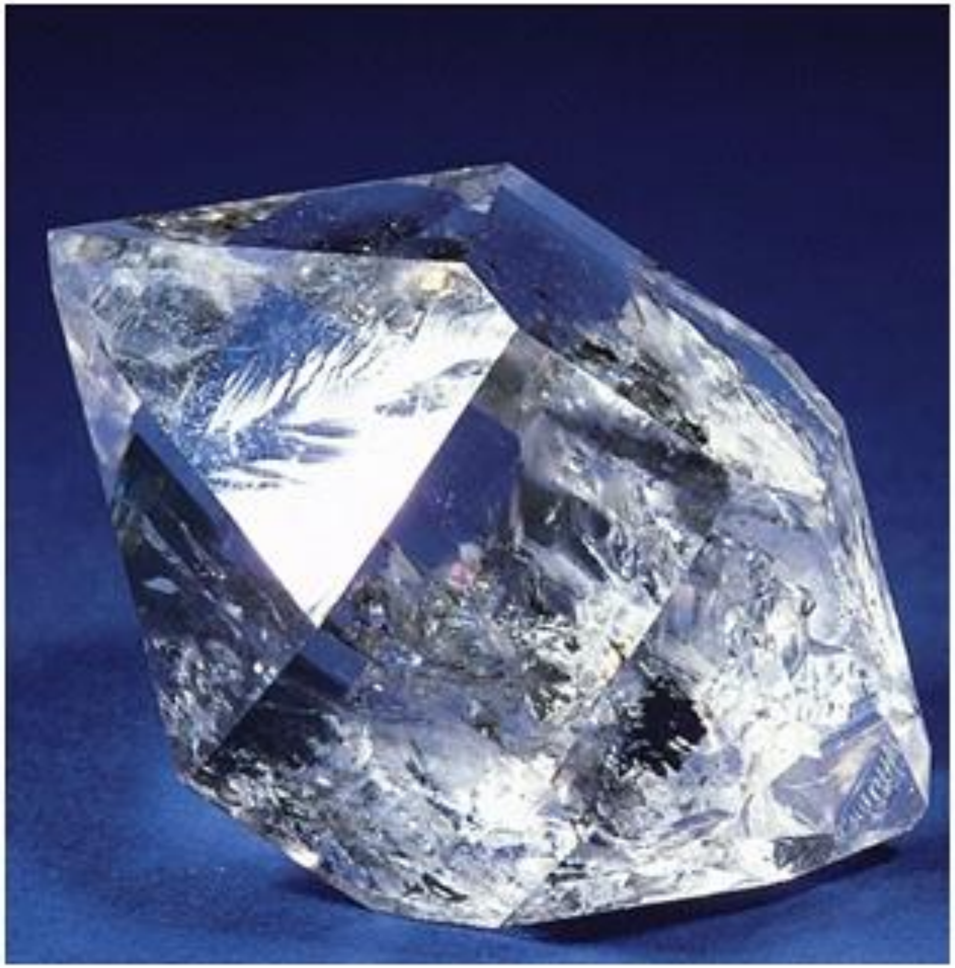
Streak

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

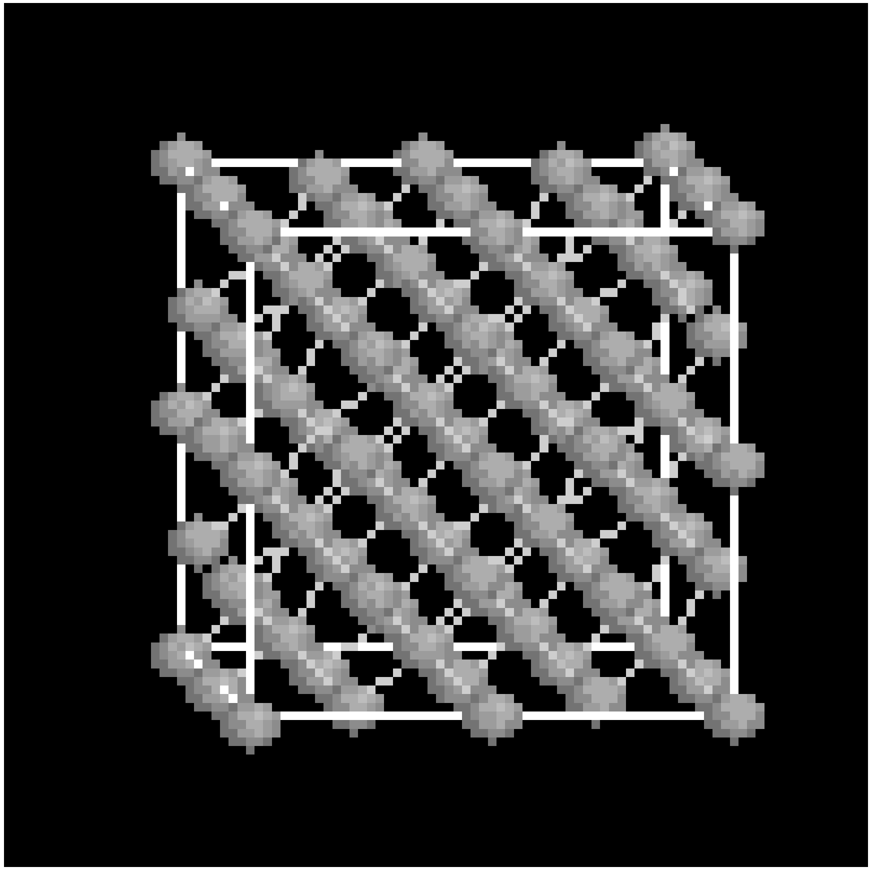
- Relative scale consists of 10 minerals- ranked 1 (softest) to 10 (hardest)

Table 2.2

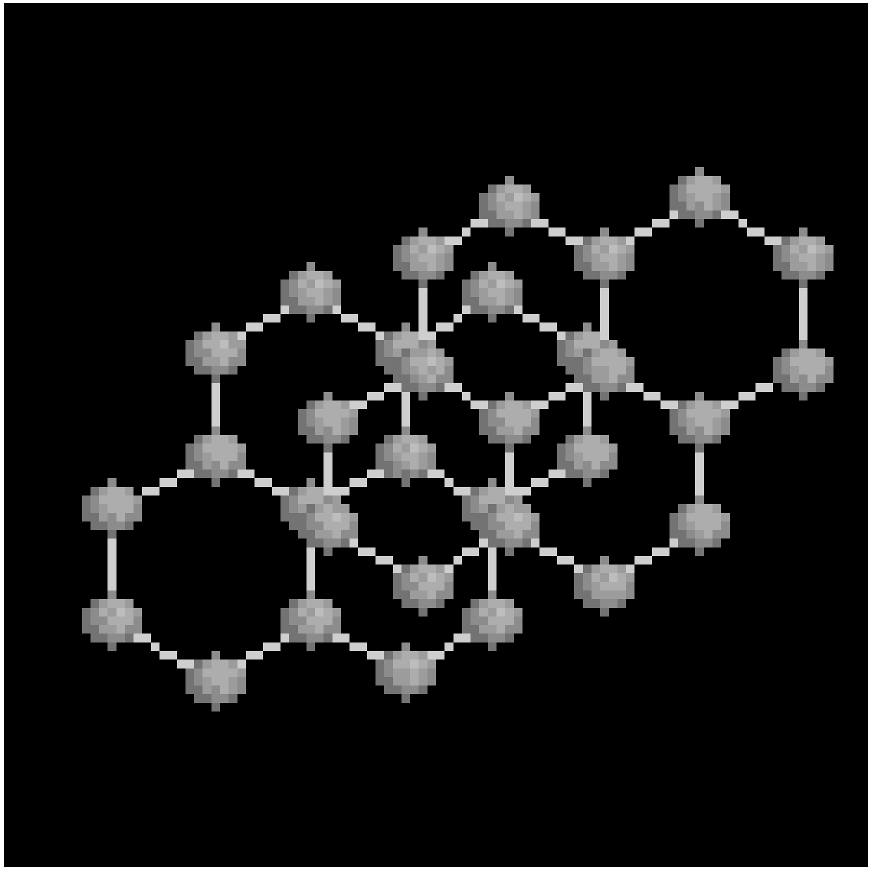
Mohs Scale of Hardness

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

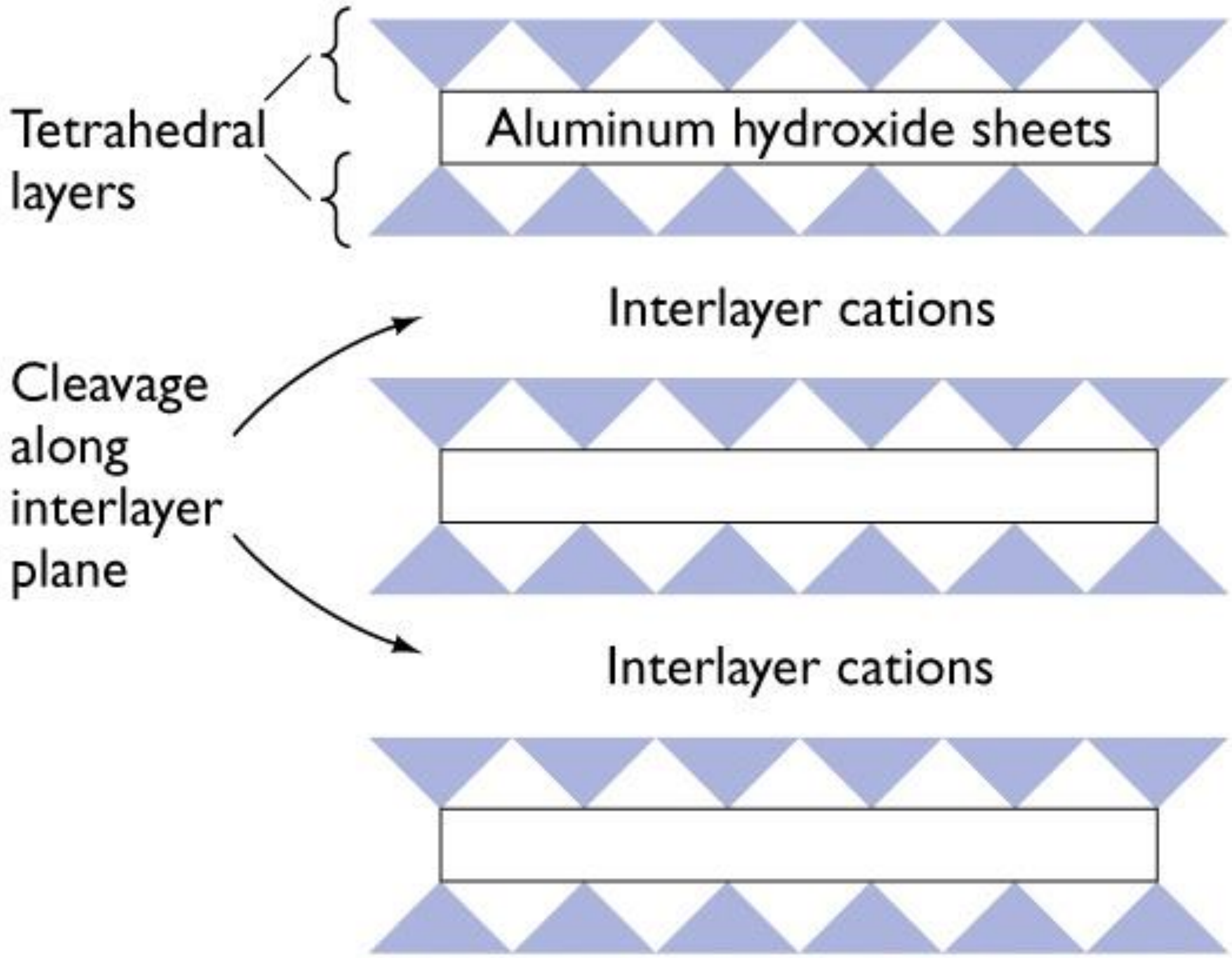
•The tendency of minerals to split along planar surfaces

•The term cleavage is also used to describe the **geometric pattern** produced by such breakage

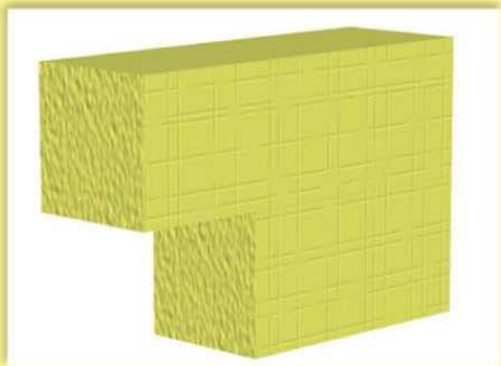
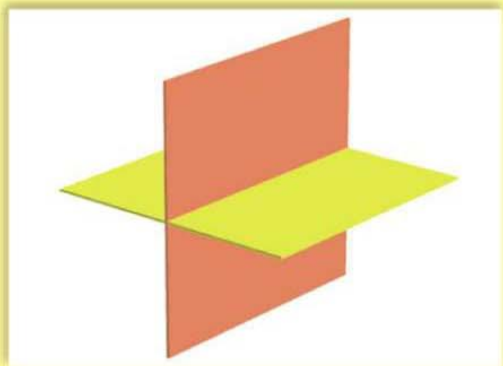
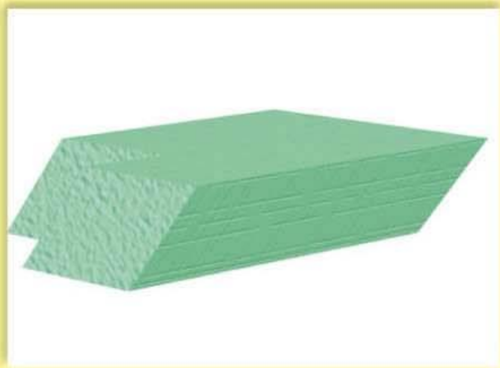
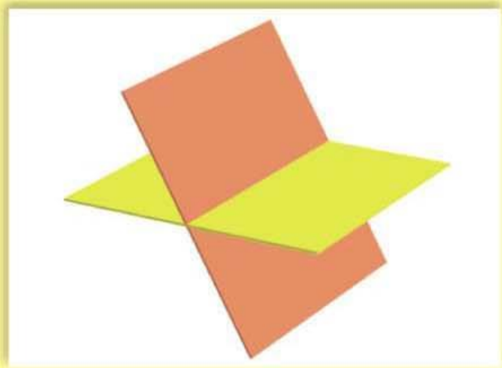
•Cleavage varies inversely with bond strength; strong bond generally produce poor or no cleavage

“Sheety” cleavage of mica

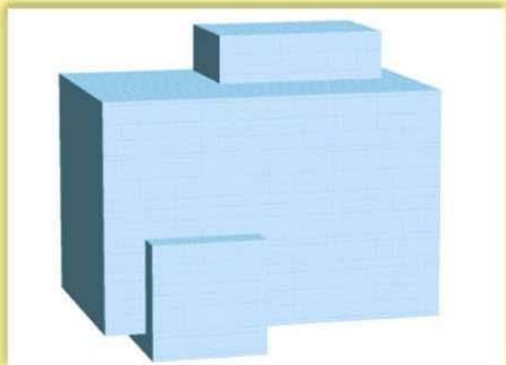
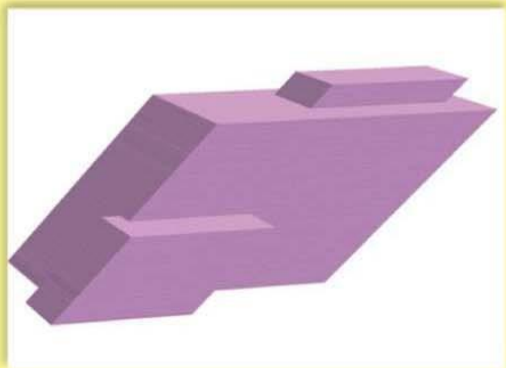
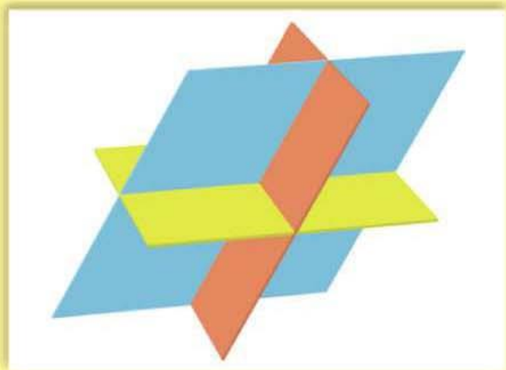
Atomic Structure of Micas



Comparison of cleavage and crystal faces

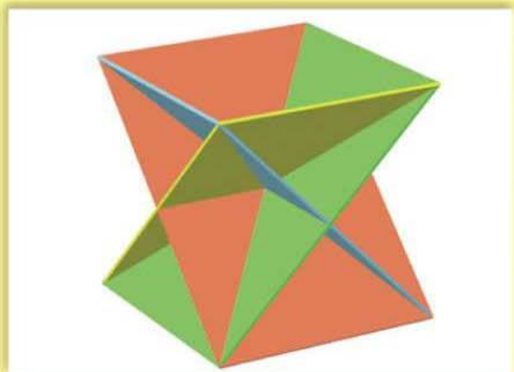
Number of Cleavage Directions	Sketch	Illustration of cleavage directions	Example
2 at 90°			 orthoclase
2 not at 90°			 amphibole

Cleavage (3 directions)

Number of Cleavage Directions	Sketch	Illustration of cleavage directions	Example
3 at 90°			
3 not at 90°			

Rhomboidal cleavage of calcite

Cleavage (4 directions)

Number of Cleavage Directions	Sketch	Illustration of cleavage directions	Example
4			

Fracture

- The tendency of crystals to break along irregular surfaces other than clevages
- 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

Chrysotile (a form of asbestos)

Quartz

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

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

Luster

Metallic example:
Galena

Non-metallic example:
Orthoclase

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/m^3 or $kg\ m^{-3}$, but geologists often use g/cm^3 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 (SiO_2) 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

Rosy quartz

Milky 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

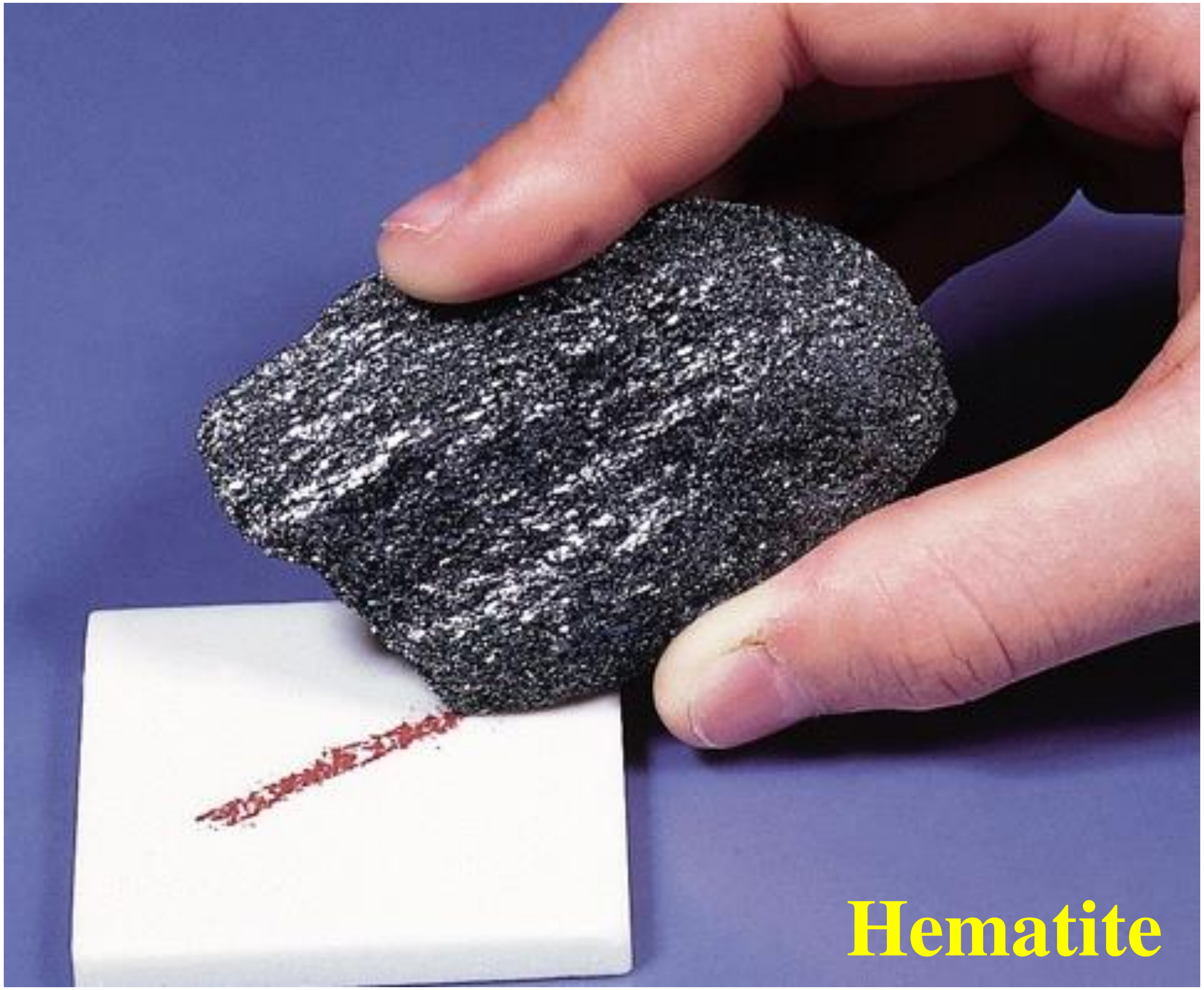
Quartz - low T, high silica rocks; extremely stable at surface, hence it tends to be a major component in sedimentary rocks.

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

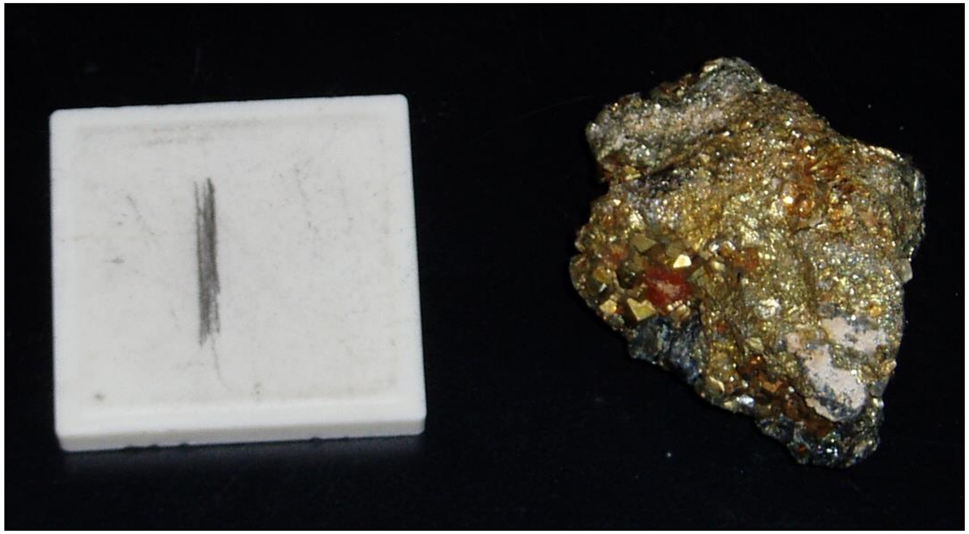
Streak

- 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



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"

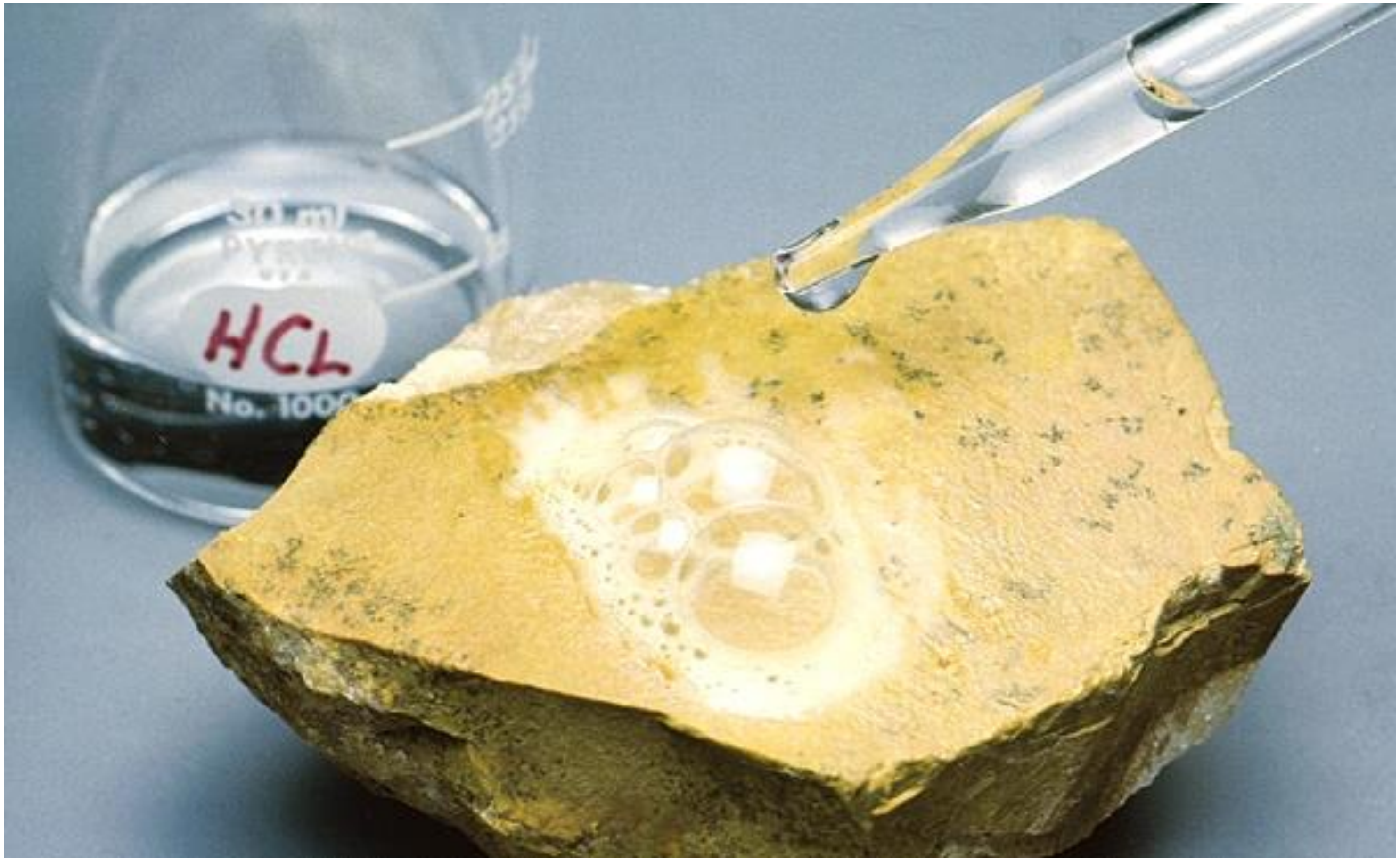


Table 2.4

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.

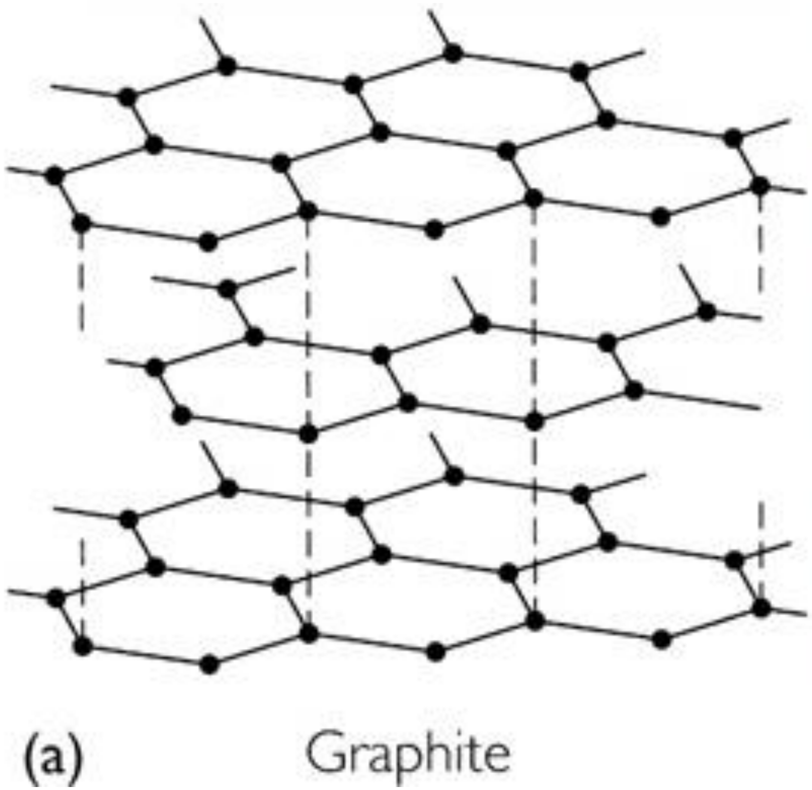
e.g., diamond and graphite

andalusite, kyanite, and sillimanite

Graphite

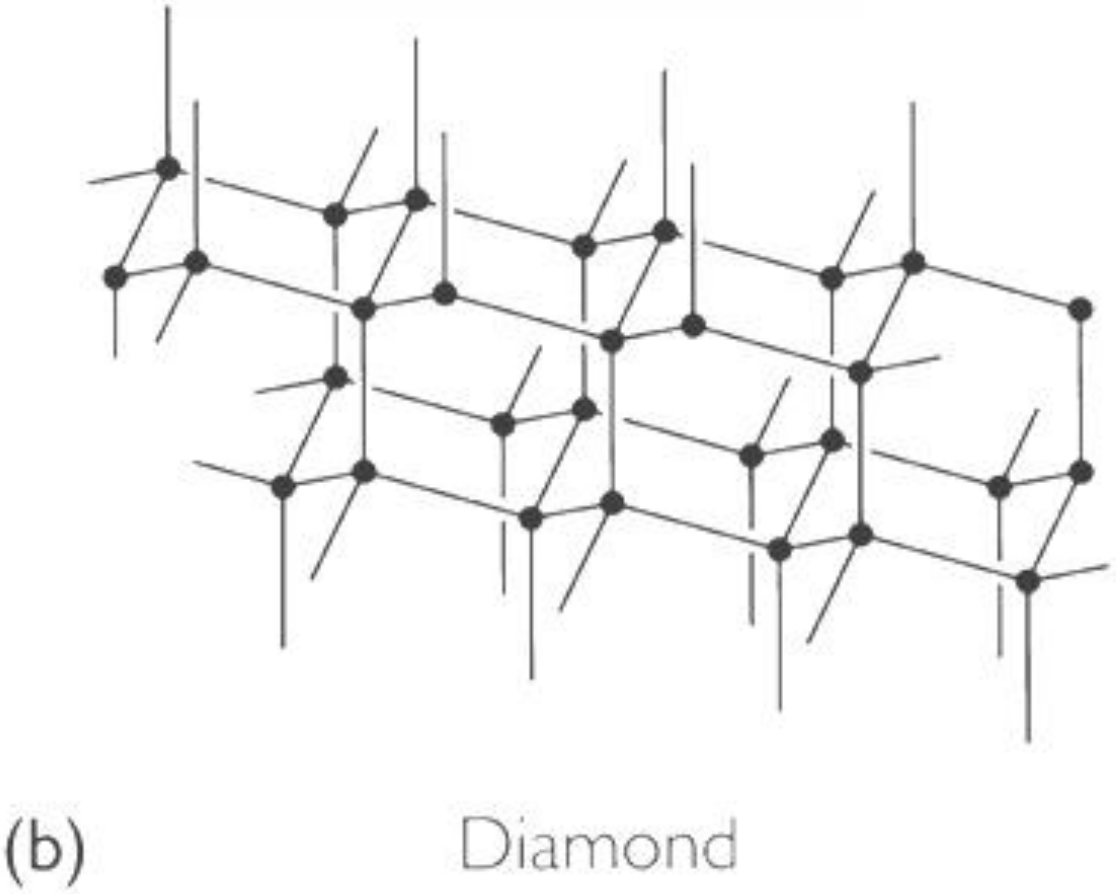
Atomic Structure

Crystal Form



Diamond

Atomic Structure



Crystal Form

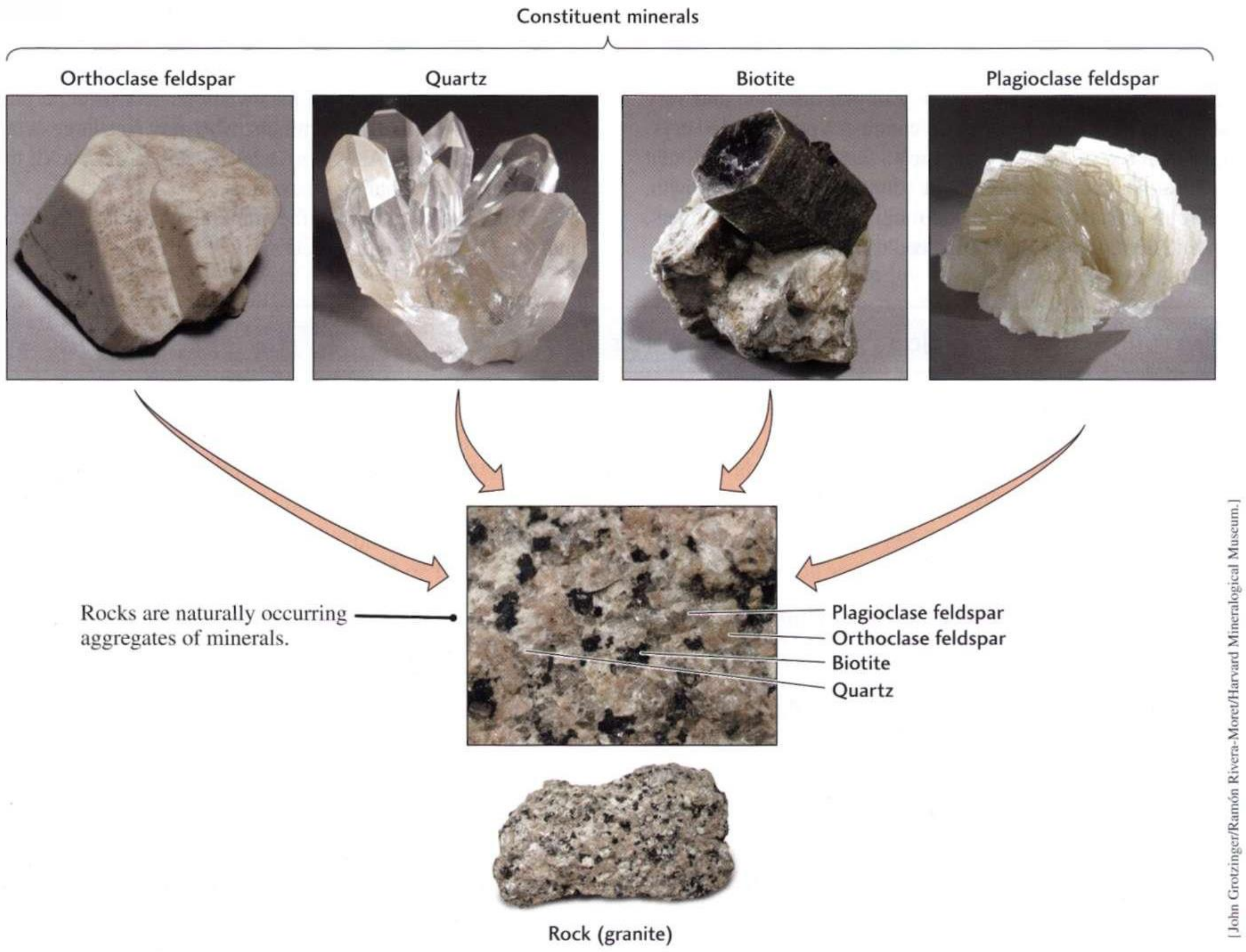
Rocks

•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


Constituent minerals
Orthoclase feldspar
Quartz
Biotite
Plagioclase feldspar
Rocks are naturally occurring aggregates of minerals.
Plagioclase feldspar
Orthoclase feldspar
Biotite
Quartz
Rock (granite)
[John Grotzinger/Ramón Rivera-Moret/Harvard Mineralogical Museum.]

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.

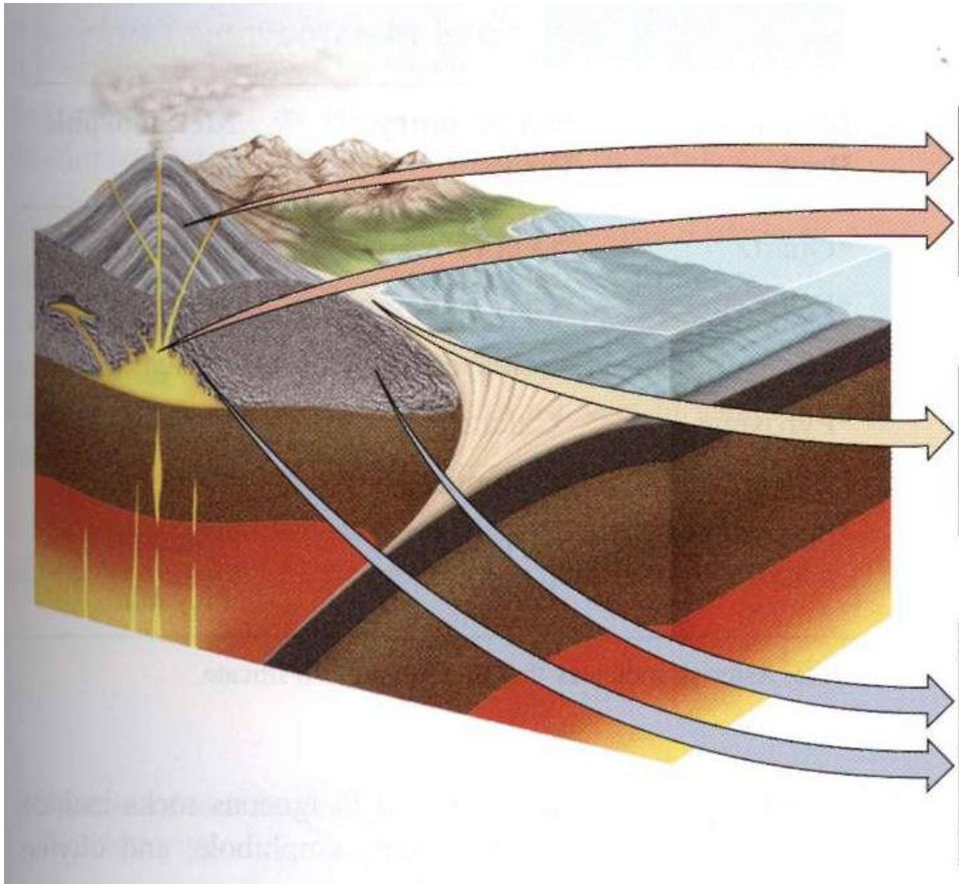
Rocks

- 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



Type of rock and source material	Rock-forming process	Example
IGNEOUS Melting of rocks in hot, deep crust and upper mantle	Crystallization (solidification of magma or lava)	 Coarsely crystallized granite
SEDIMENTARY Weathering and erosion of rocks exposed at surface	Deposition, burial, and lithification	 Cross-laminated sandstone
METAMORPHIC Rocks under high temperatures and pressures in deep crust and upper mantle	Recrystallization in solid state of new minerals	 Gneiss

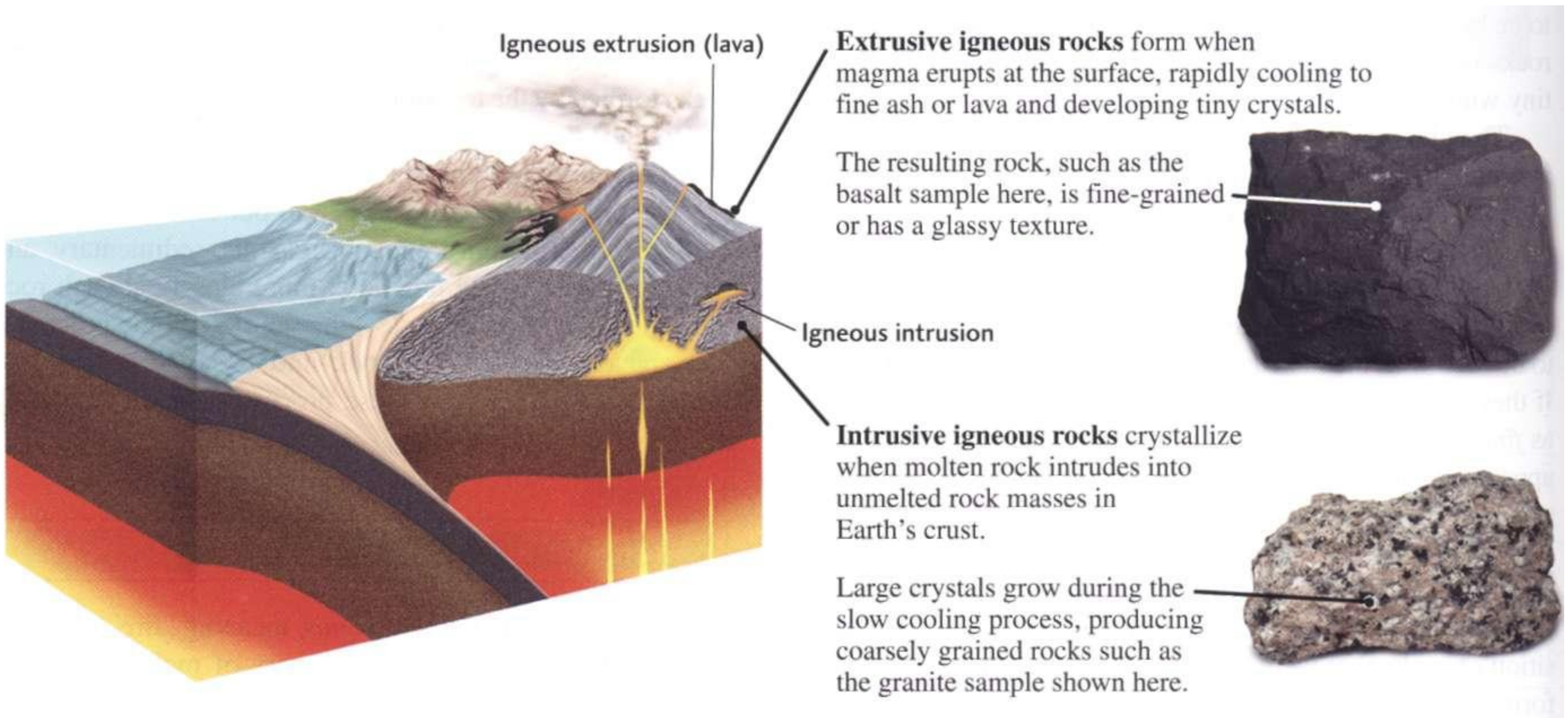
Rocks

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



IDC 203: INTRODUCTION TO EARTH SCIENCES