Earth Materials – Minerals and Rocks

I) Minerals

<u>Topics:</u>

- **What are minerals?**
- **Characteristics of Minerals**
- **Types of Minerals**

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Minerals

(A) Definition:

-- naturally occurring

Amethysts in geode: minerals

-- inorganic solid

-- definitive chemical composition

-- orderly arrangement of atoms

Synthetic Ruby: not a mineral

1) Minerals

(A) Definition:

-- naturally occurring

-- inorganic solid

-- definitive chemical composition

-- orderly arrangement of atoms

Rock Salt (Halite)

Sugar: Not a mineral

Diamond

mineral

Pearl

not a mineral (organic)

(1) Minerals

(A) Definition:

-- naturally occurring

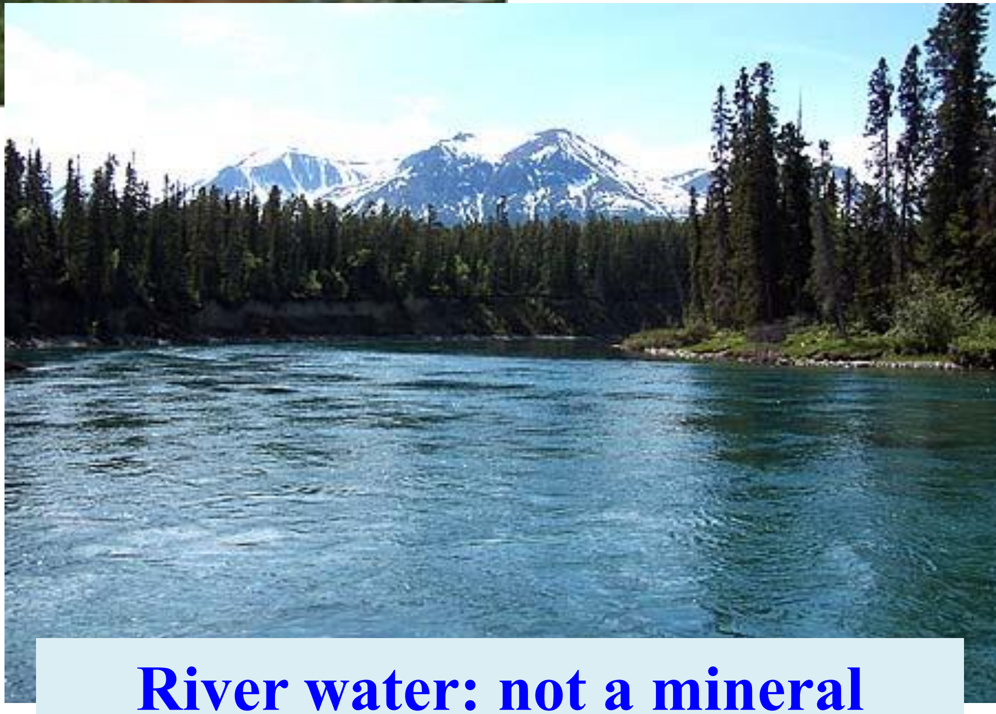
-- inorganic solid

Glacier ice

: a mineral

-- definitive chemical composition

-- orderly arrangement of atoms



River water: not a mineral

(A) Definition:

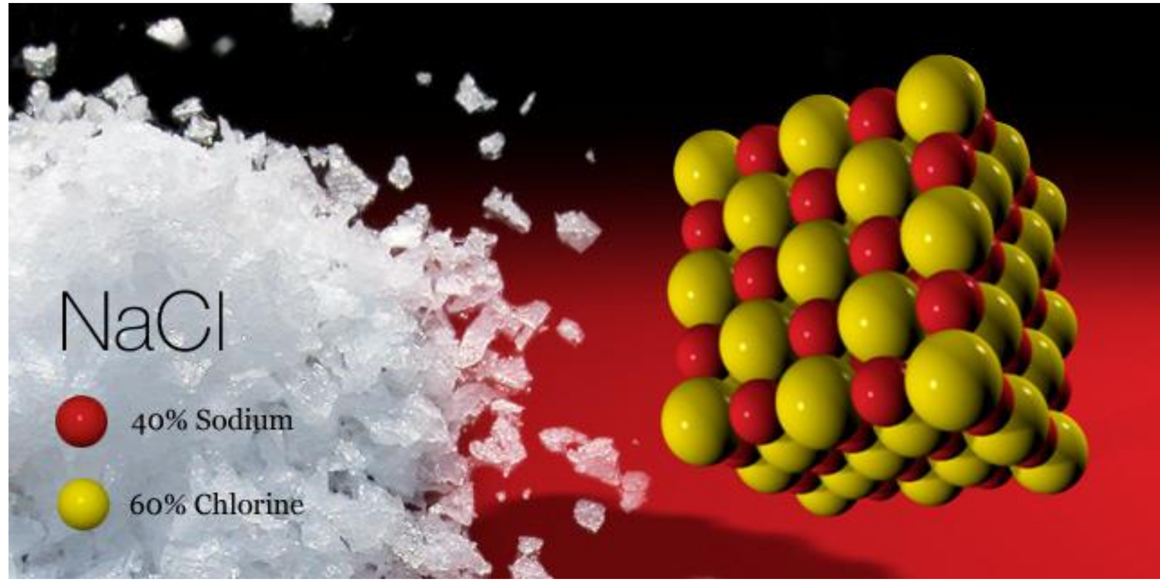
-- naturally occurring

-- inorganic solid

-- definitive chemical composition

-- orderly arrangement of atoms

NaCl : Halite



SiO_2 : Quartz

Gold (Au)

Graphite (C)

Mineral

(A) Definition:

-- naturally occurring

-- inorganic solid

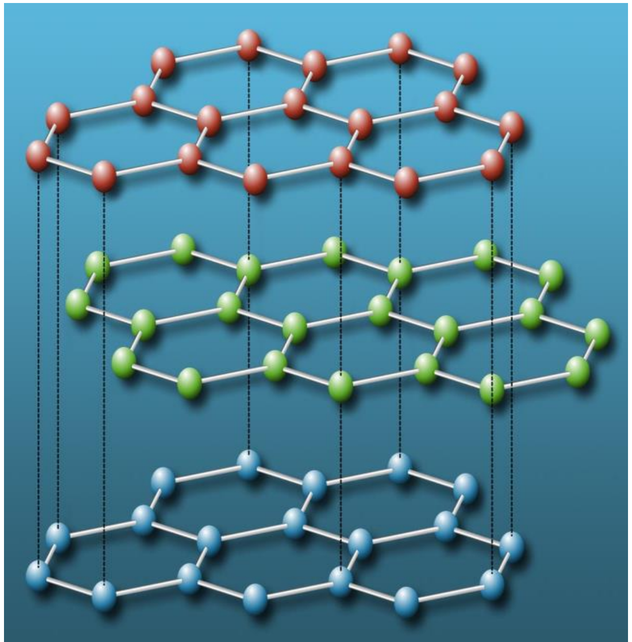
-- definitive chemical composition

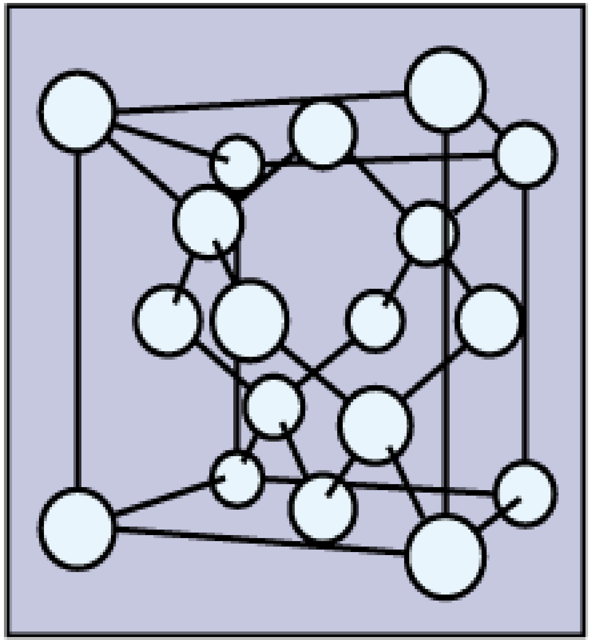
-- orderly arrangement of atoms

(Crystal Structure)

Graphite

Diamond





e.g.,

Graphite

Diamond

Both are made of Carbon

What are Minerals?

Definition:

- **naturally occurring**
- **inorganic solid**
- **definitive chemical composition**
- **orderly arrangement of atoms**

Which of the following contains minerals?

- A diamond ring
- Marble floor of a hotel
- Smectite powder to cure stomachache
- Your glasses
- Your pencil
- A coin you flipped up to decide if you should go for a class
- The powder that a gymnast uses to increase friction

Characteristics of Minerals

- Allow quick mineral identification.

e.g., Hardness - resistance to scratching

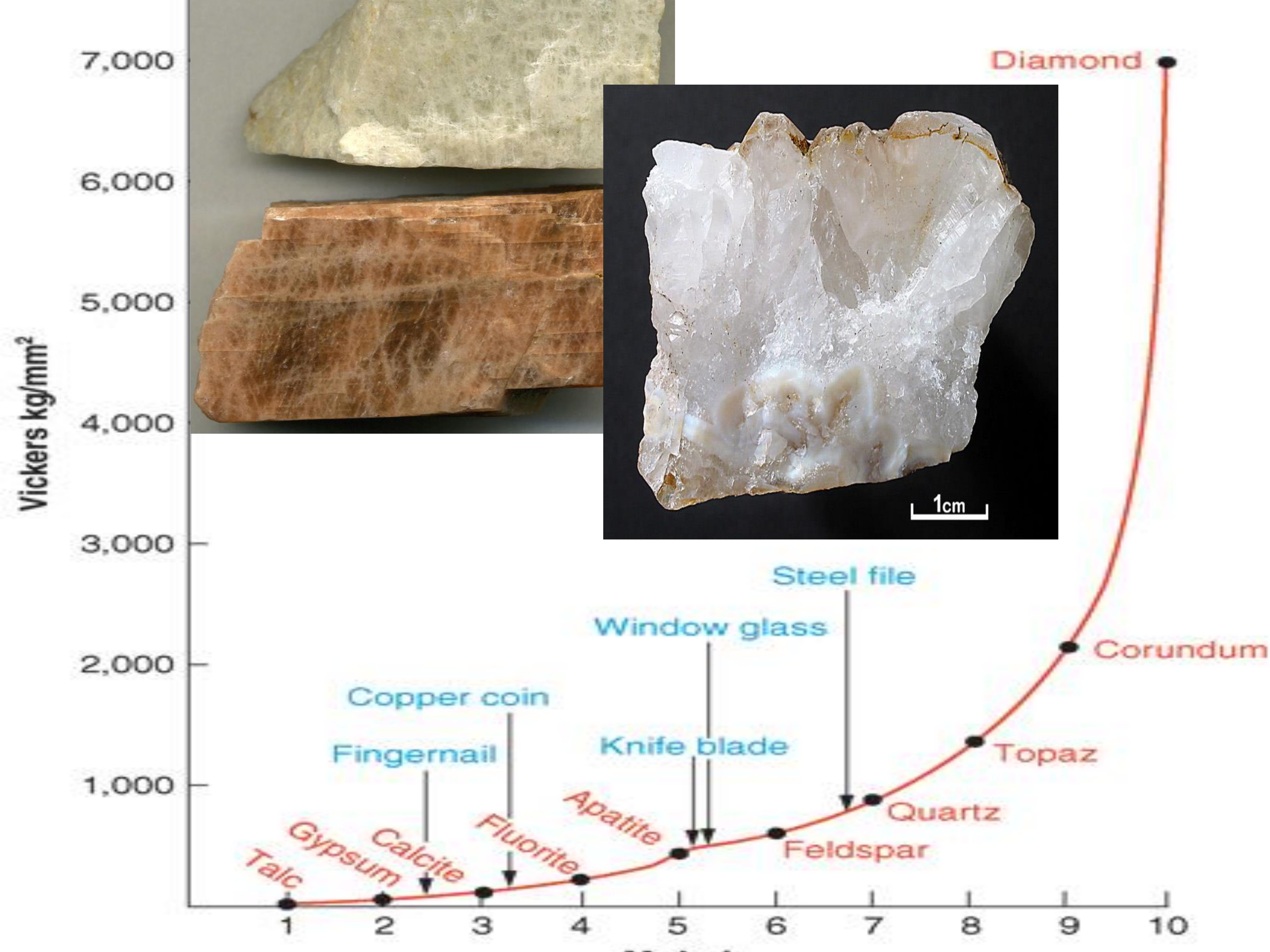
Talc is softest mineral (1 in Mohs' Hardness Scale)

Diamond is hardest (10 in Mohs' Hardness Scale)

Hardness

Photo © Parvinder Sethi

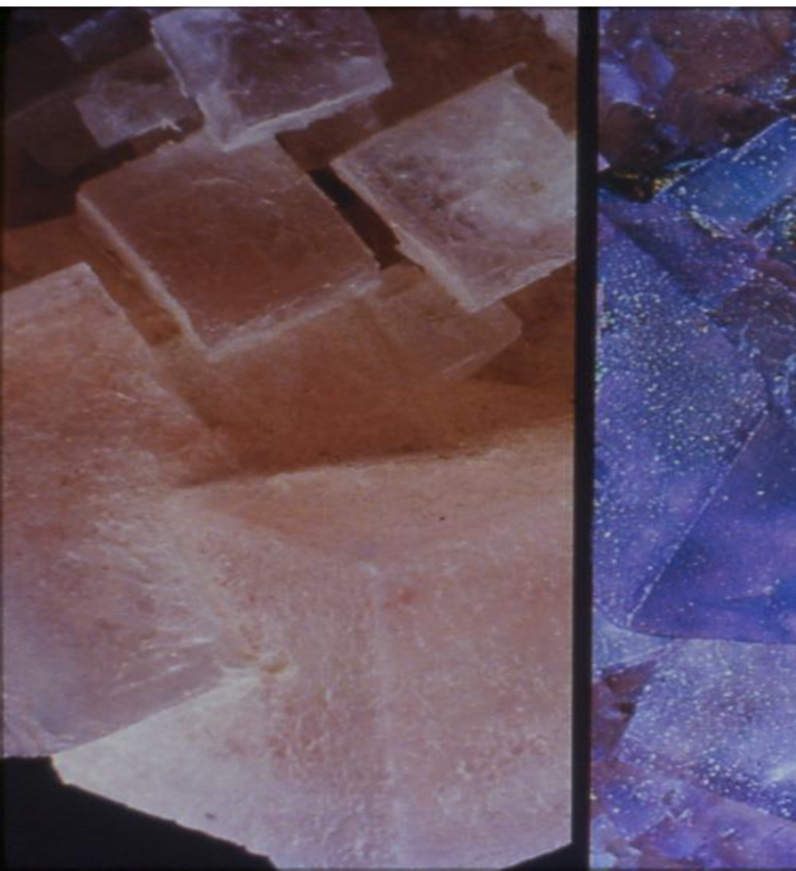
e.g., Gypsum: H < 2.5

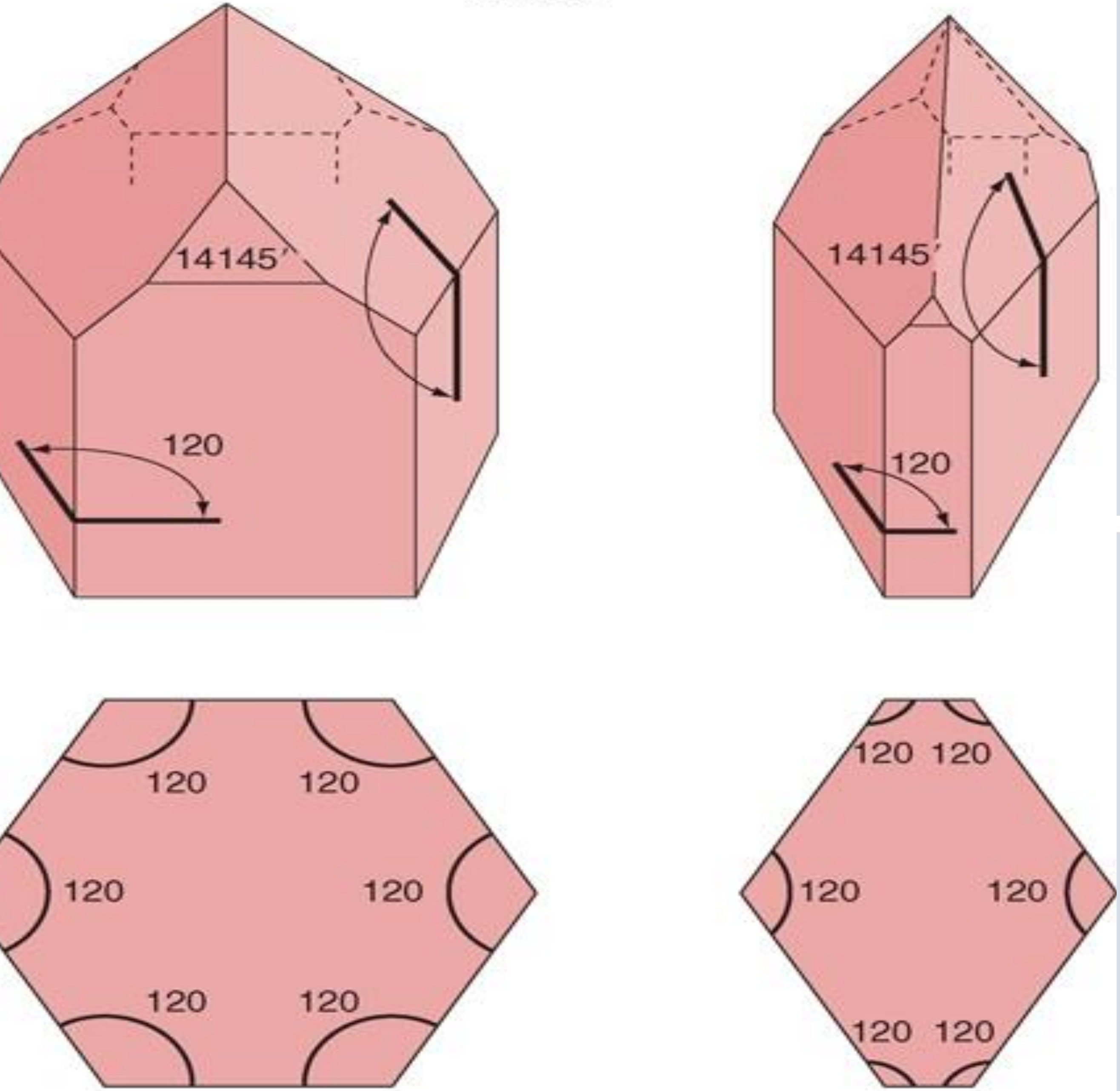

Vickers kg/mm²
7,000
6,000
5,000
4,000
3,000
2,000
1,000
1
2
3
4
5
6
7
8
9
10
Diamond
Corundum
Topaz
Quartz
Feldspar
Apatite
Fluorite
Calcite
Gypsum
Talc
Steel file
Window glass
Knife blade
Copper coin
Fingernail
1cm

Characteristics of Minerals

Crystal form

: planar surfaces form during crystal growth





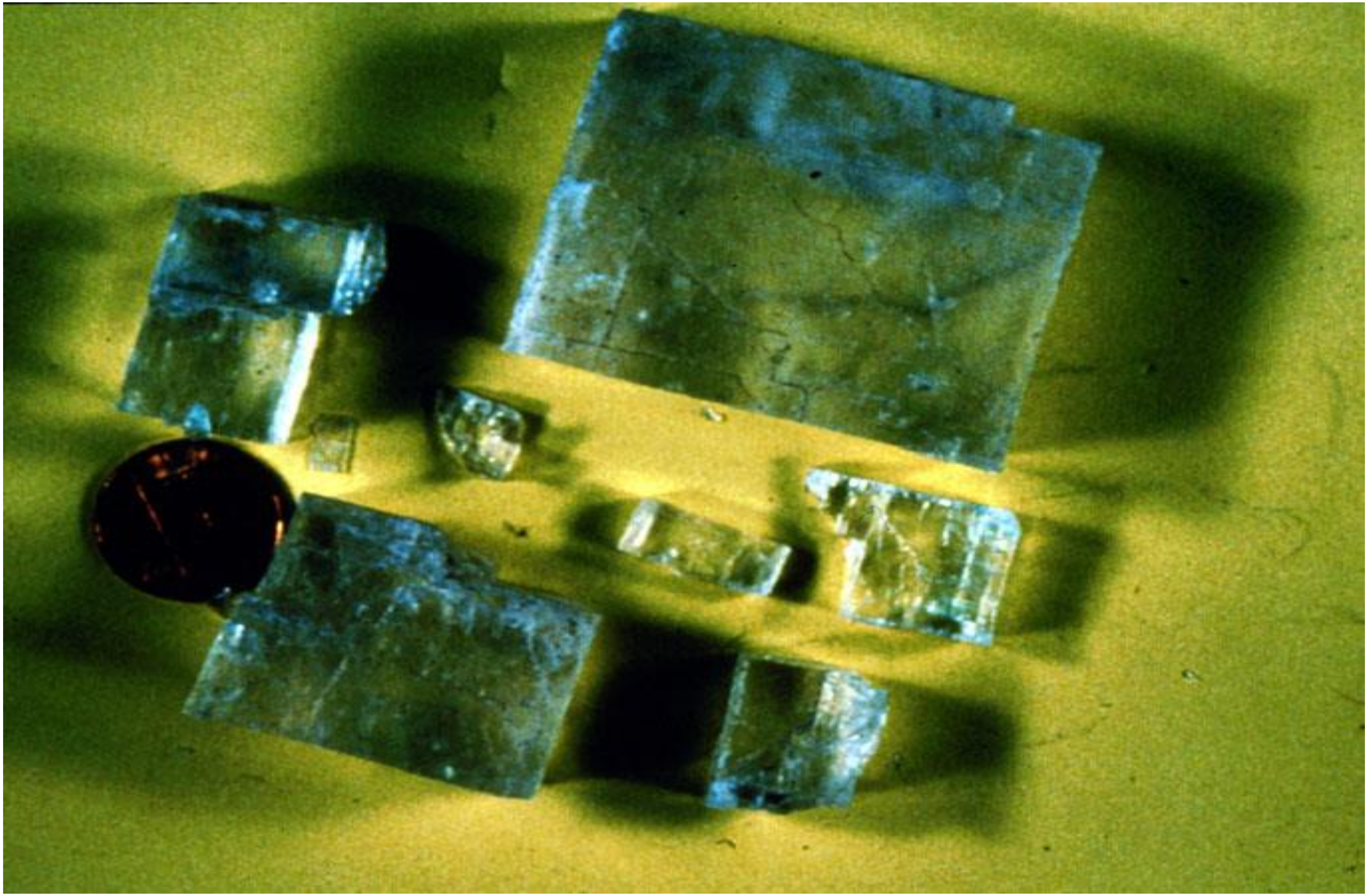
B

otos © Parvinder Sethi

Quartz

Photo © Parvinder Sethi

Halite: cubic crystal form



Specific Gravity

– density of mineral/density of water

Galena: PbS (7.6)

Quartz: SiO_2 (2.65)

Cleavage - breakable weak surface(s)

e.g., 1 direction of cleavage

2 sets of Cleavage
e.g., Amphibole

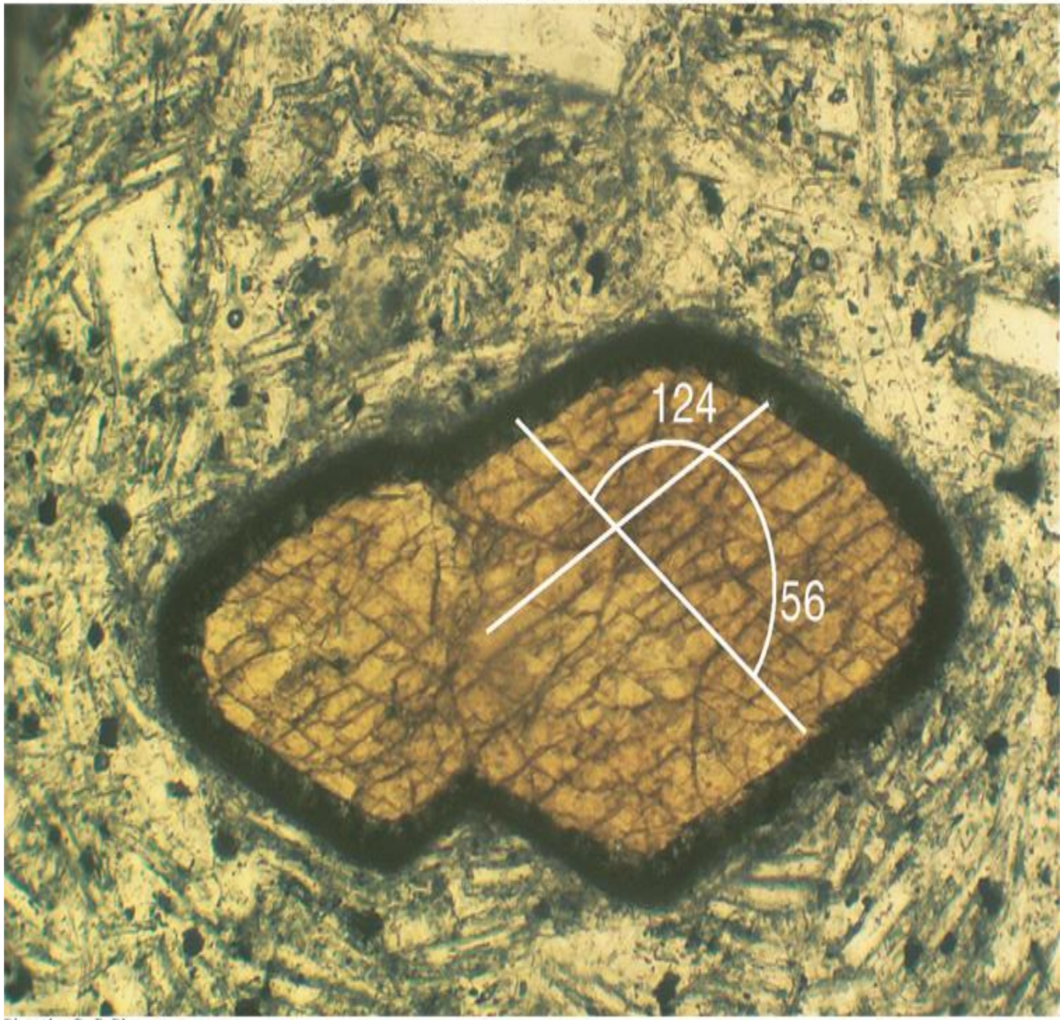
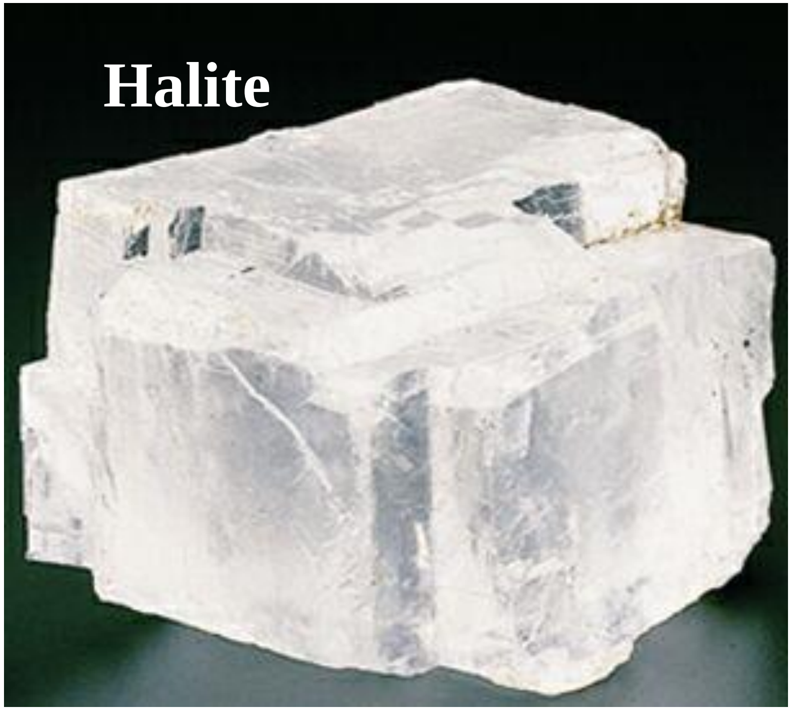
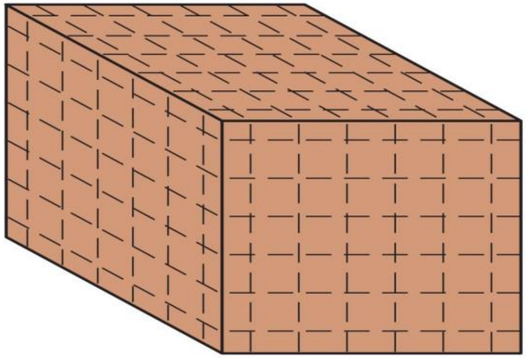


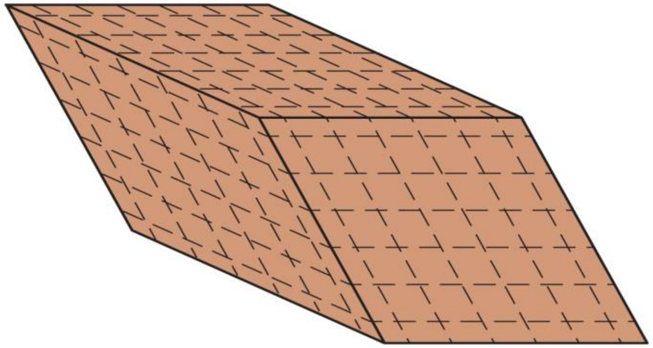
Photo by C. C. Plummer

e.g., 3 sets of cleavages



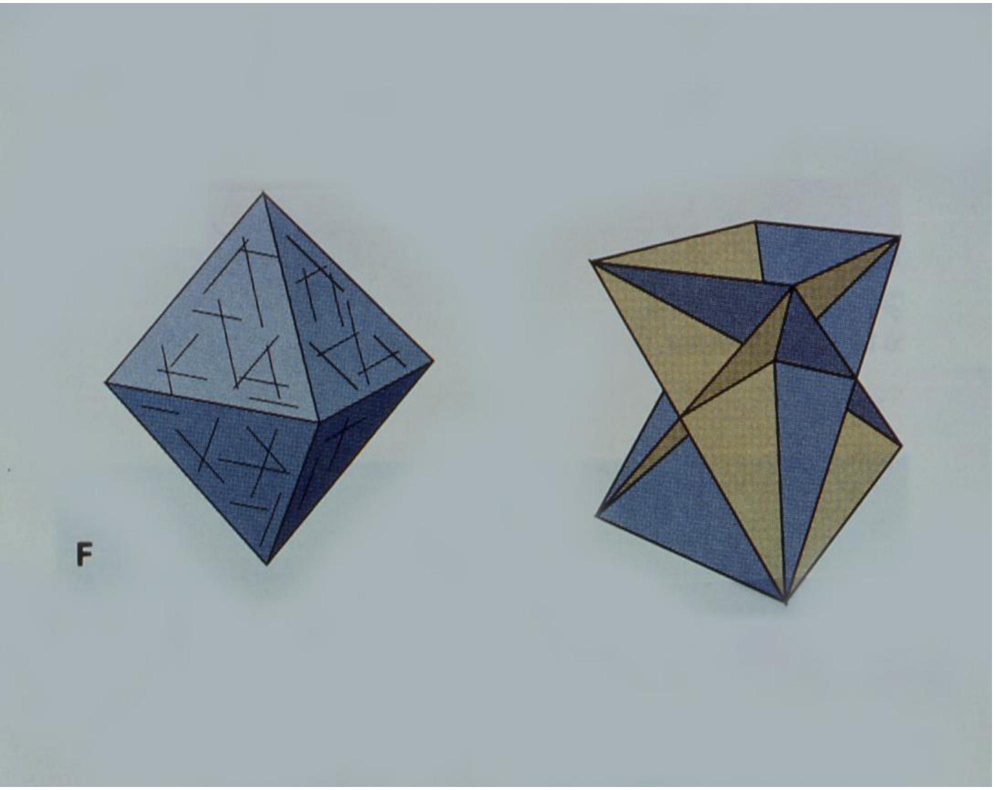


(d) Three directions of cleavage at right angles. Mineral examples: halite, galena



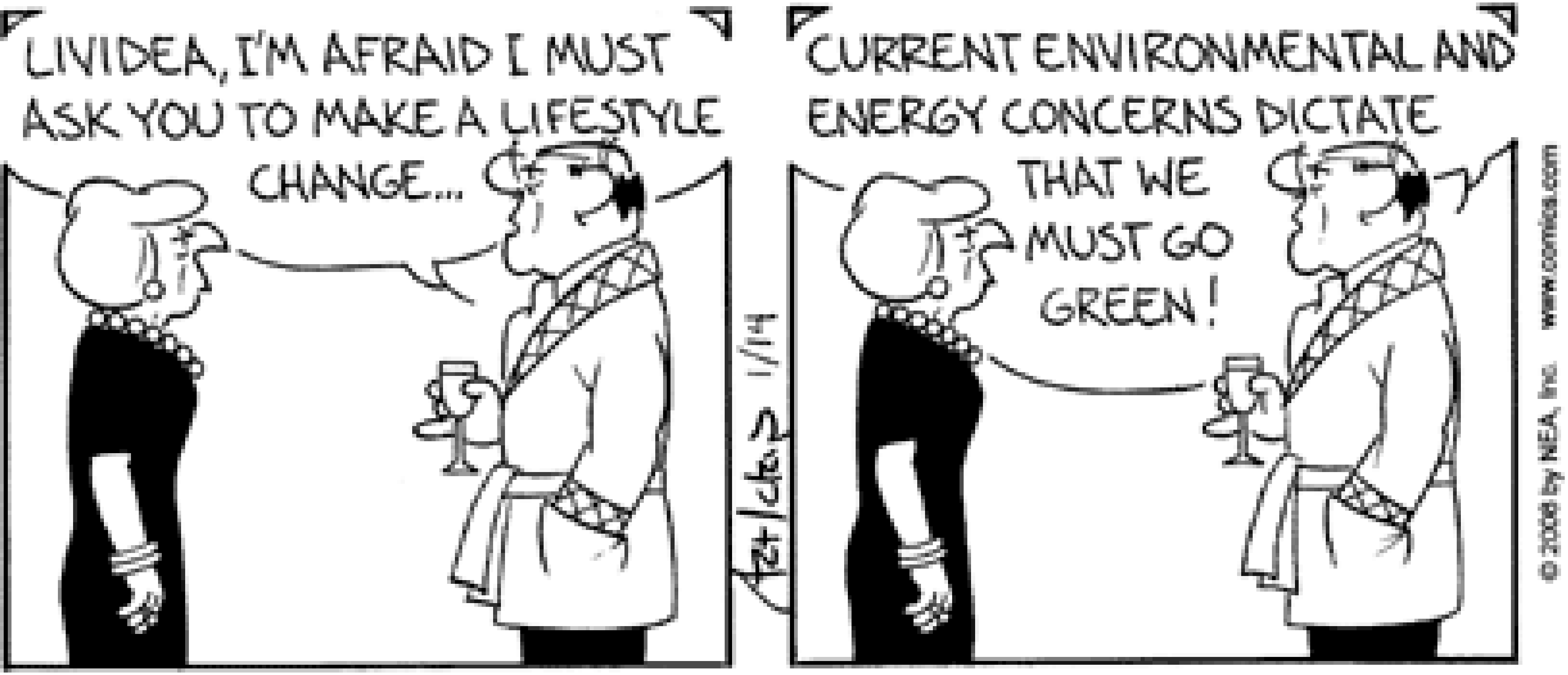
(e) Three directions of cleavage not at right angles. Mineral example: calcite

4 sets of cleavages



Color

Photo © Parvinder Sethi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CURRENT ENVIRONMENTAL AND ENERGY CONCERNS DICTATE THAT WE MUST GO GREEN!
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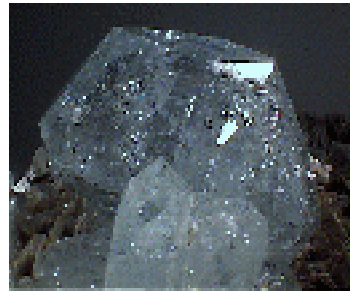
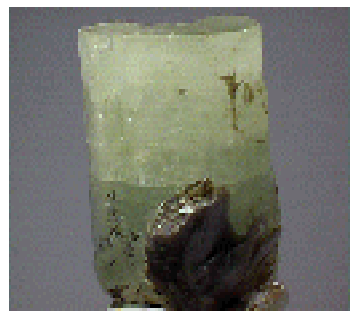
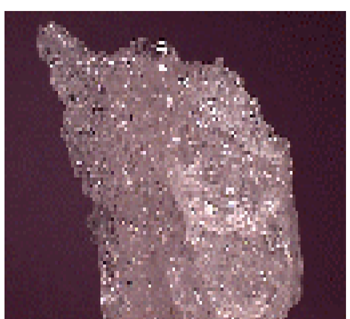
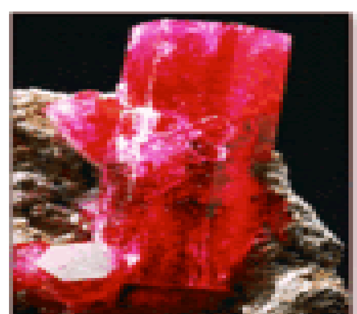
Emerald: Beryl with trace amounts of chromium

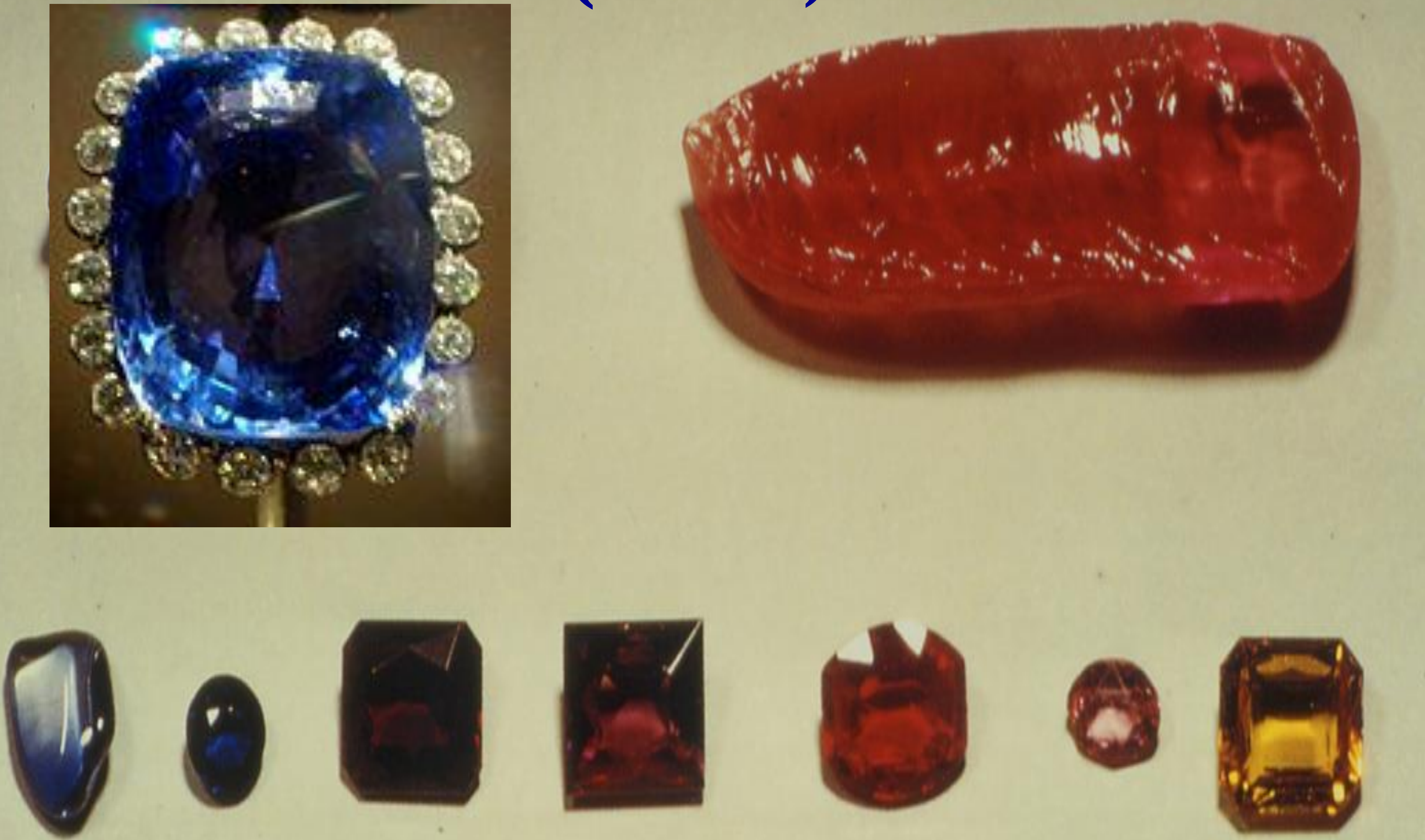
Beryl: $Be_3Al_2(SiO_3)_6$

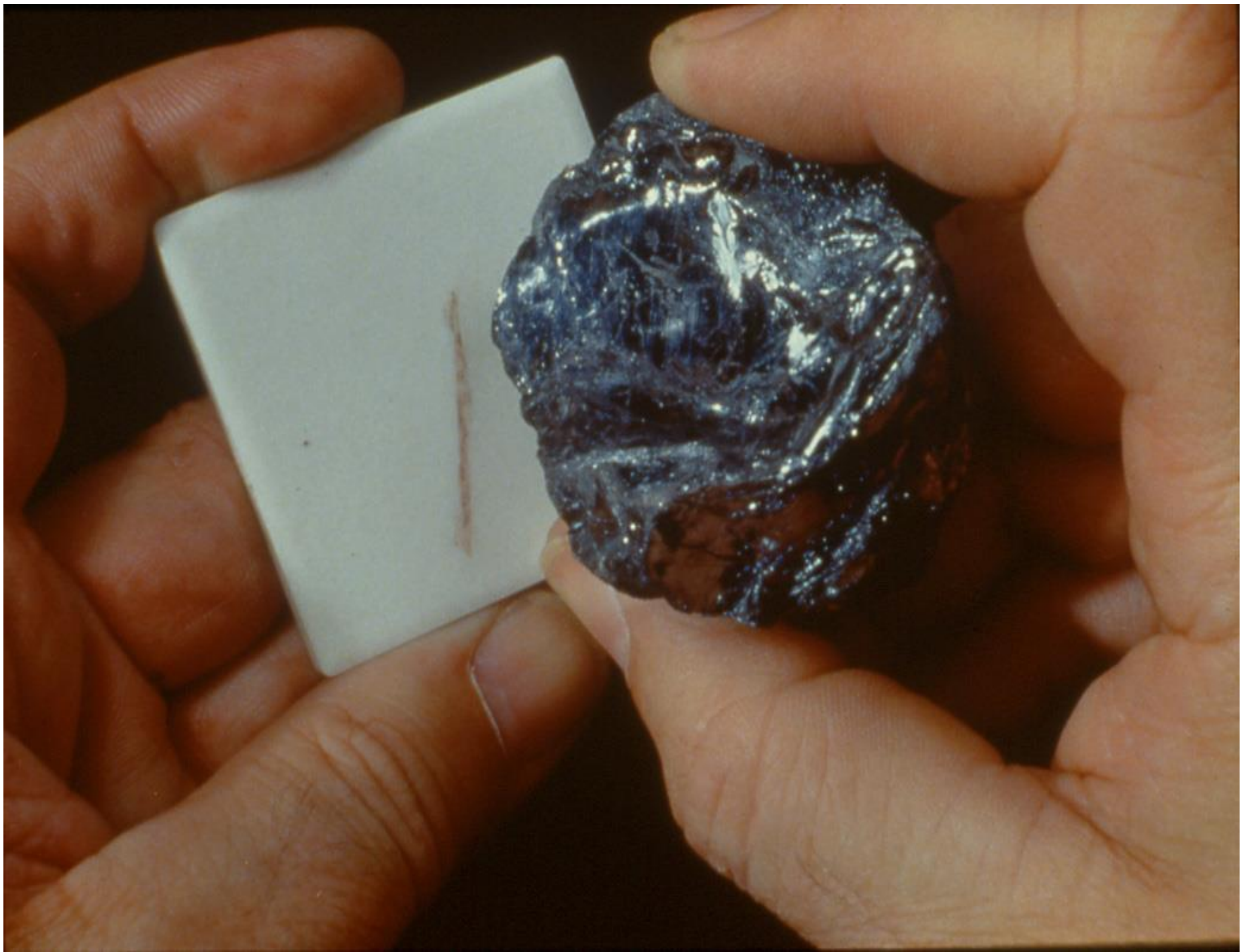




Corundum
(Al2O3)



Hematite

<u>streak</u> : color of mineral powder



Characteristics of Minerals:

luster

Metallic

Glassy

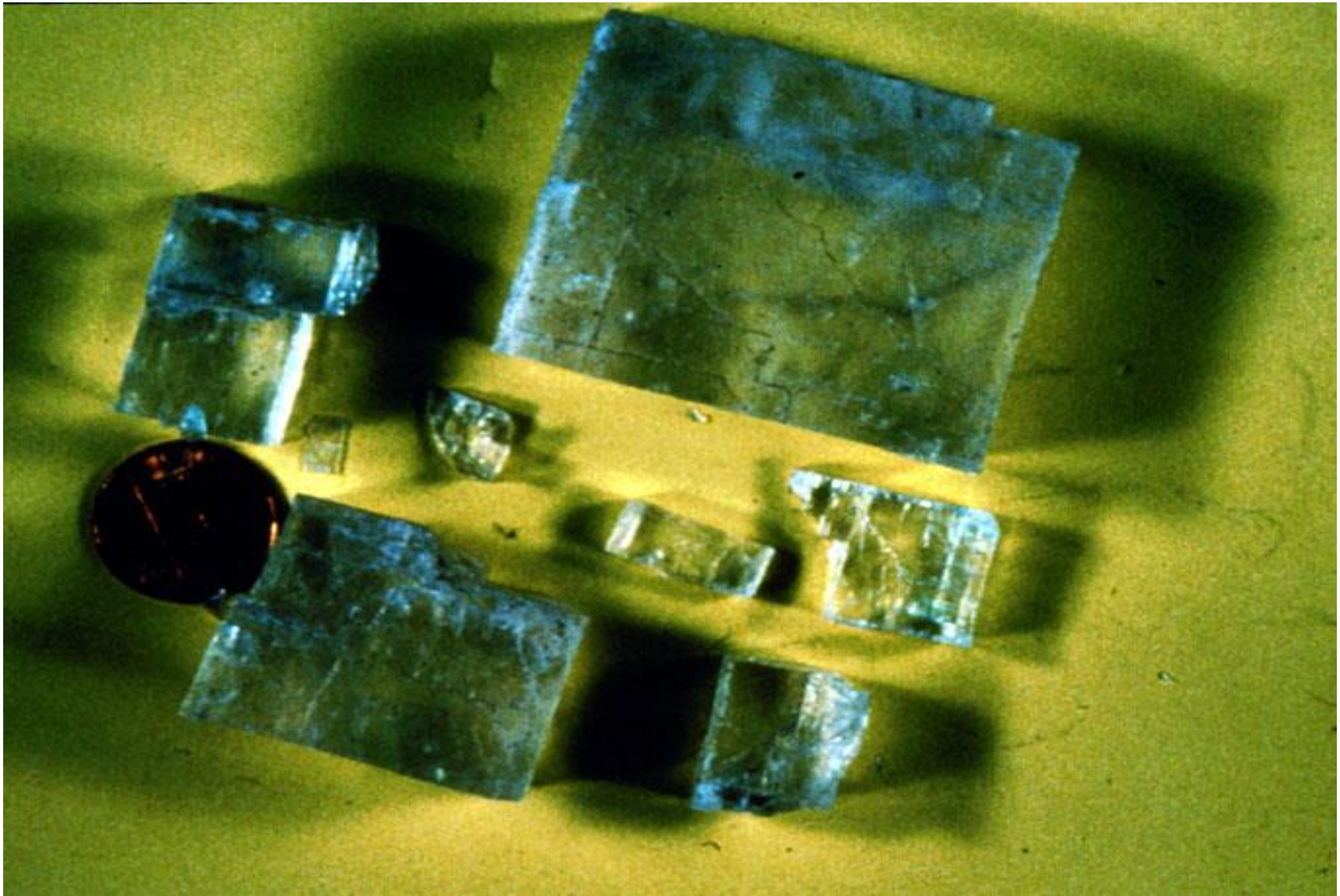
Earthy

Characteristics of Minerals:

Dissolve in acid: e.g., Calcite ($CaCO_3$)

Characteristics of Minerals

Taste salty: Halite



Characteristics of Minerals

Magnetic: e.g., Magnetite

What did the paper clip say to the magnet?

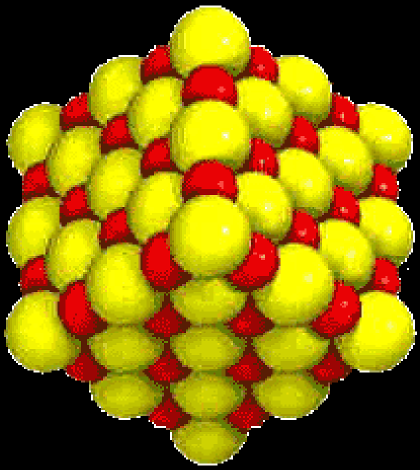
"I find you very attractive!"

Characteristics of minerals:

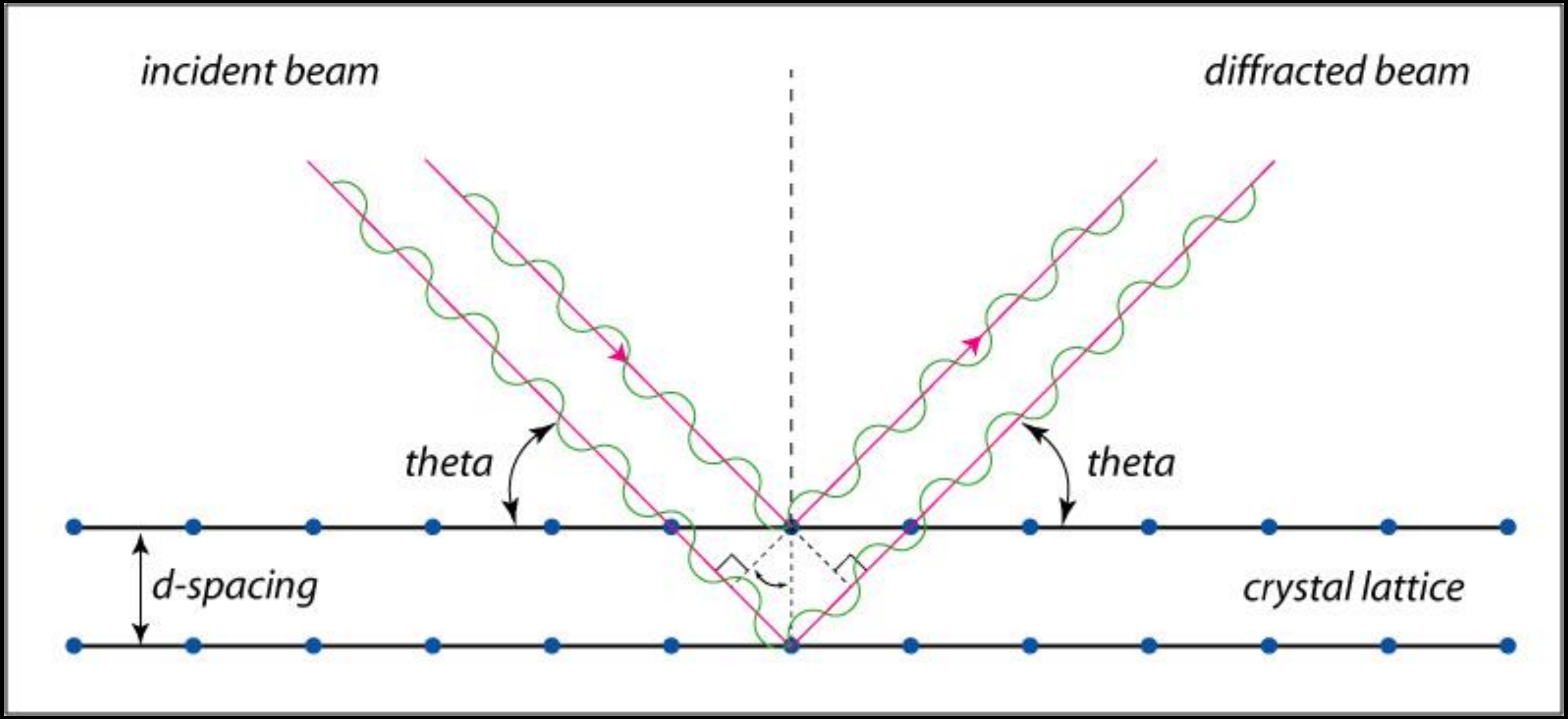
- Hardness
- Crystal form
- Specific gravity
- Cleavage
- Color
- Streak
- Luster
- Acid, taste, magnetic…..

What is X-Ray Diffraction??

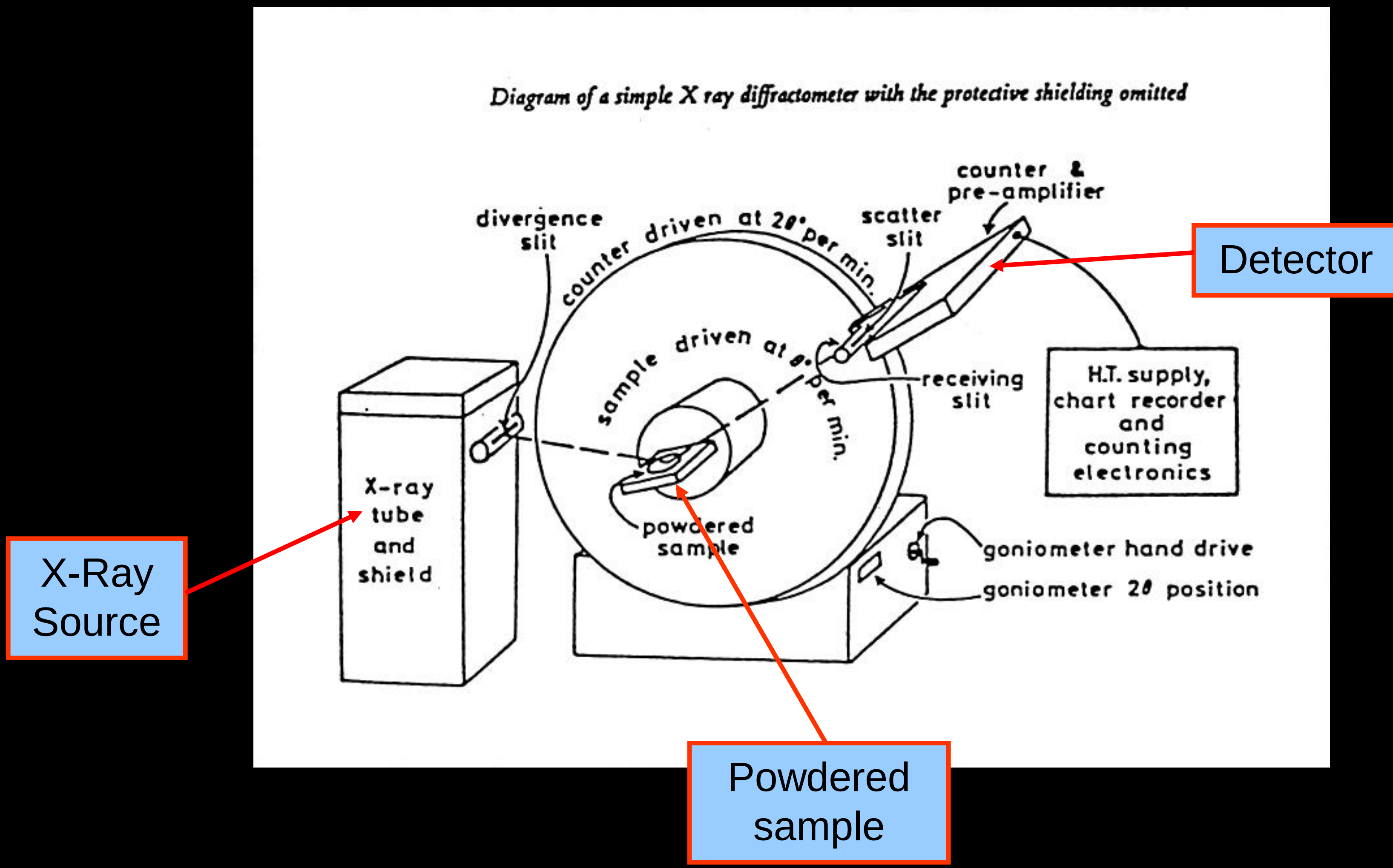
- Crystalline substances (e.g. minerals) consist of parallel rows of atoms separated by a ‘unique’ distance
- Simple Example:
  - Halite (Na and Cl)

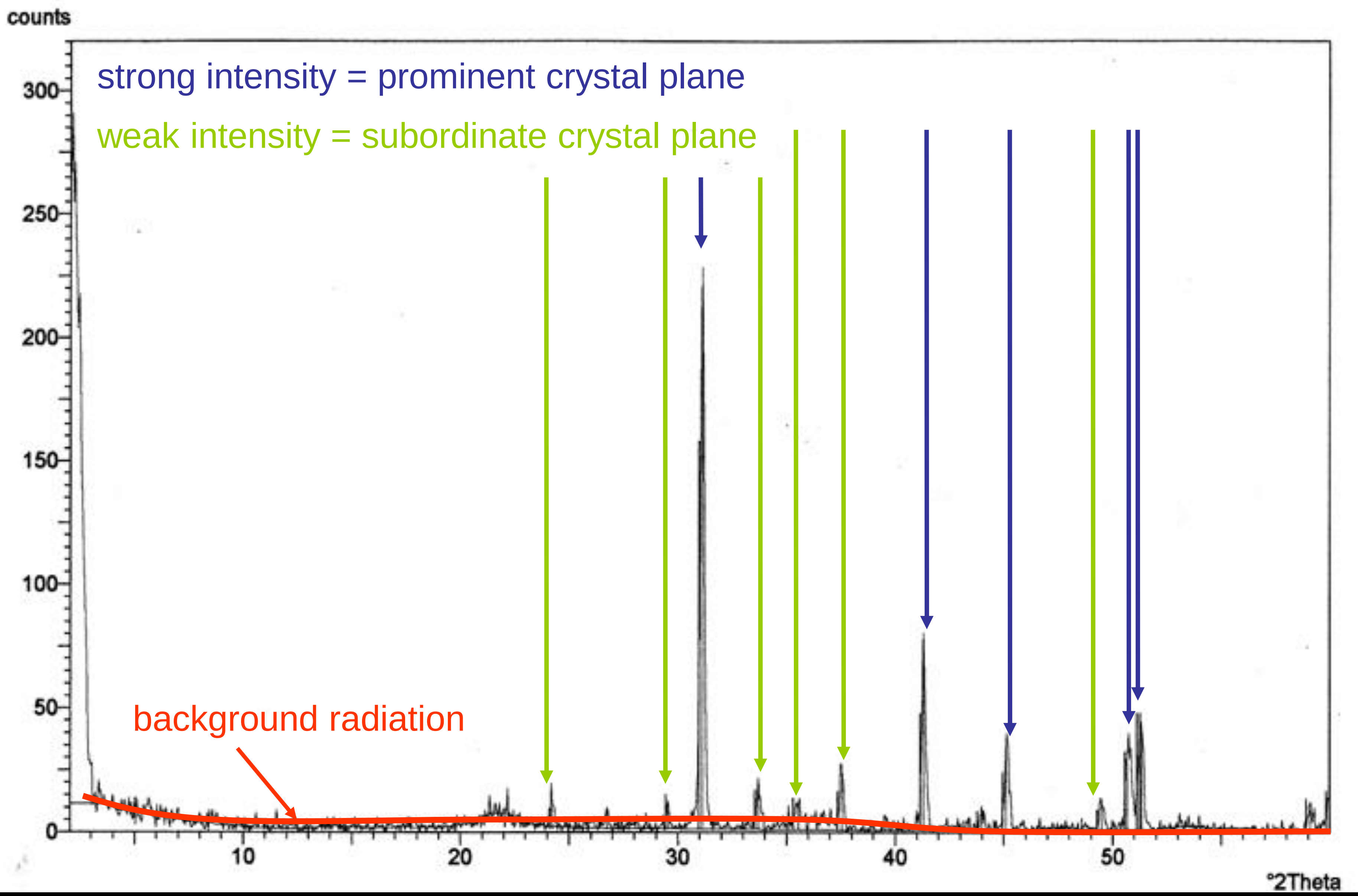


- Crystalline substances (e.g. minerals) consist of parallel rows of atoms separated by a ‘unique’ distance
- Diffraction occurs when radiation enters a crystalline substance and is scattered
- Direction and intensity of diffraction depends on orientation of crystal lattice with radiation

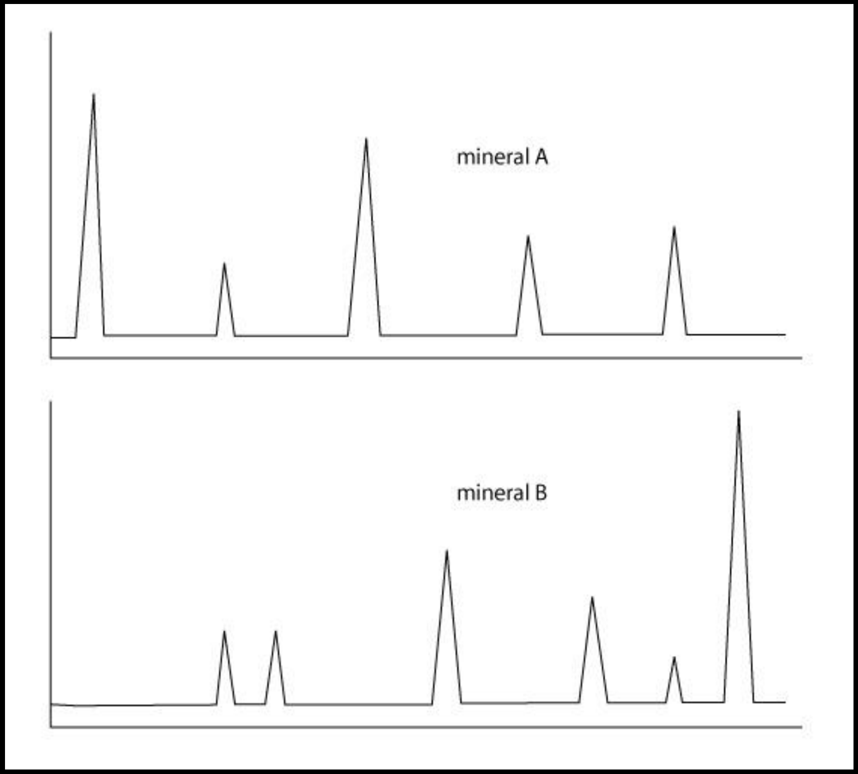


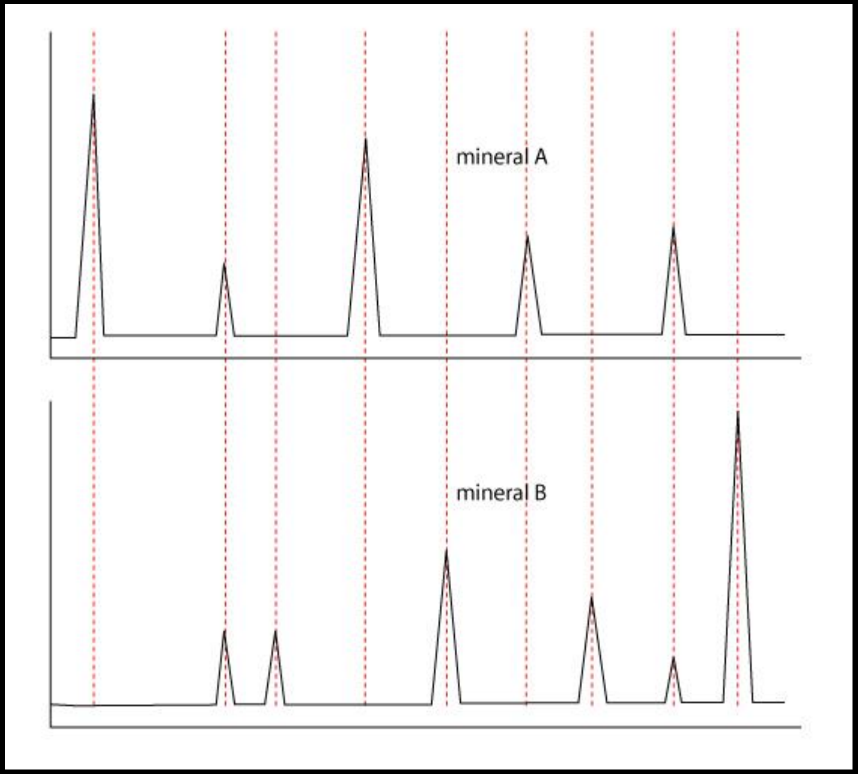
Schematic X-Ray Diffractometer




counts
300
250
200
150
100
50
0
strong intensity = prominent crystal plane
weak intensity = subordinate crystal plane
background radiation
10
20
30
40
50
°2Theta

Mixture of 2 Minerals





Applications of XRD

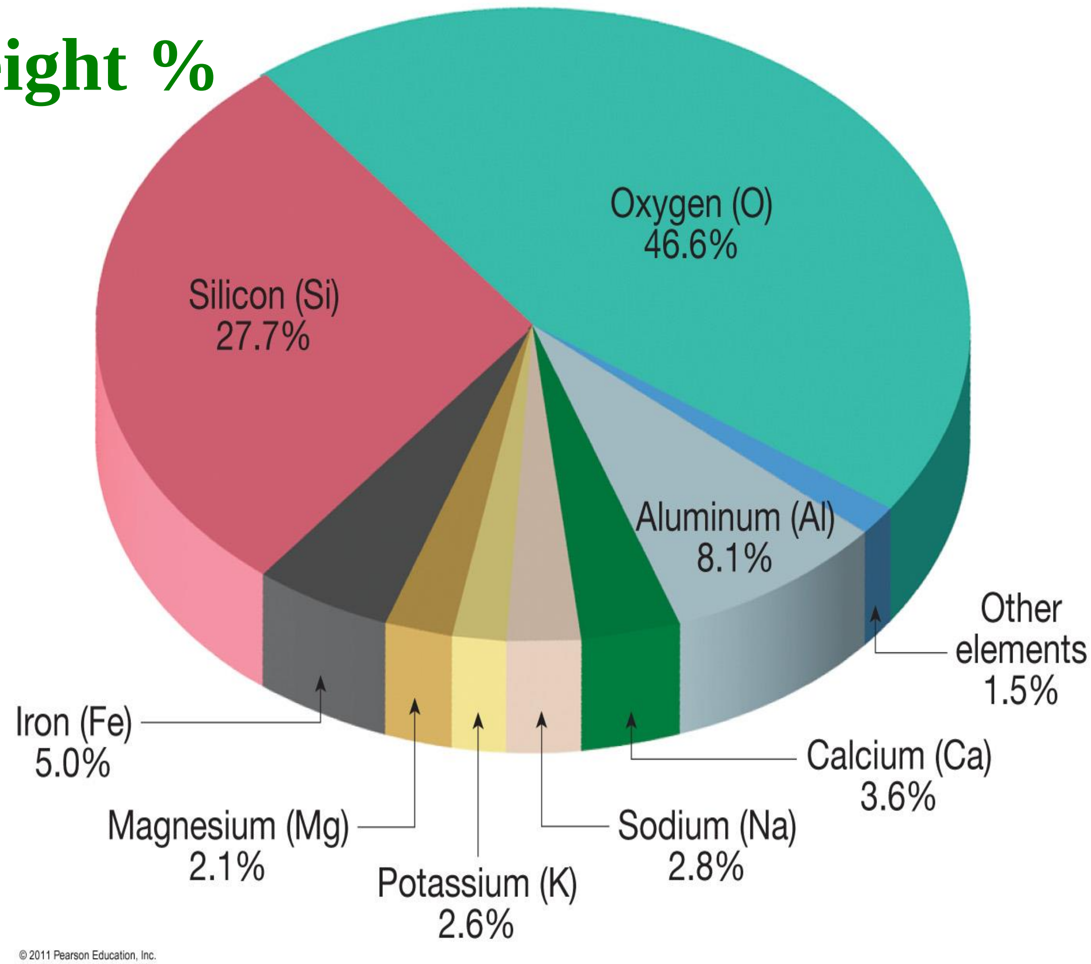
- Unknown mineral ID
- Solid solution ID (e.g. feldspars, olivine)
- Mixtures of minerals
- Clay analyses
- Zeolites
- Crystallographic applications
- Material Science

Types of Minerals

Most common minerals : <u>**Silicate minerals**</u>

- Contain **silicon + oxygen**

Weight %

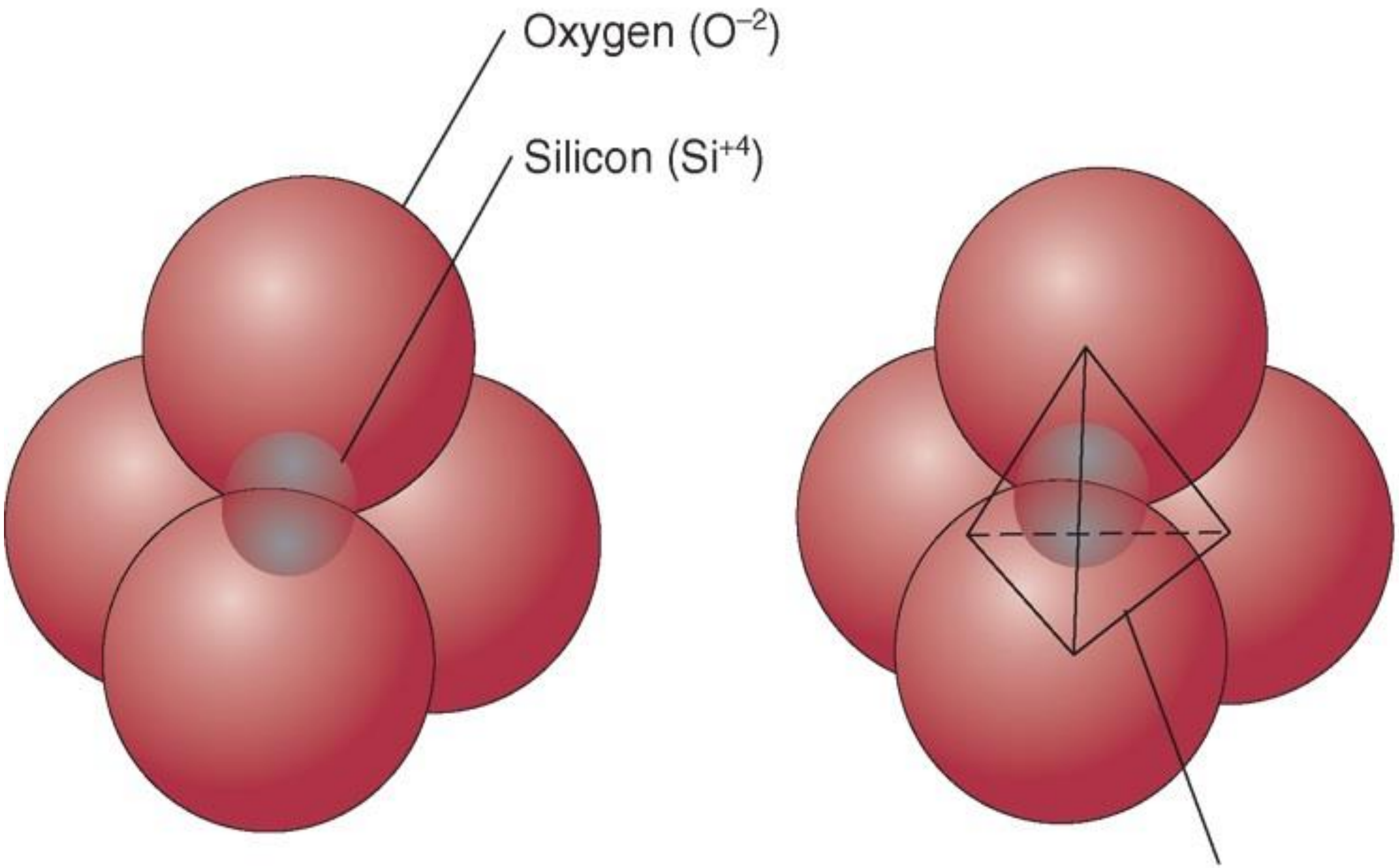


<u>**Crustal Abundance**</u>

<u>Element</u>	<u>Volume%</u>
O	~ 94
Si	~ 1
Al	~ 1

Silicate Minerals

building block: Silicate tetrahedron **$SiO_4^{\ 4-}$**

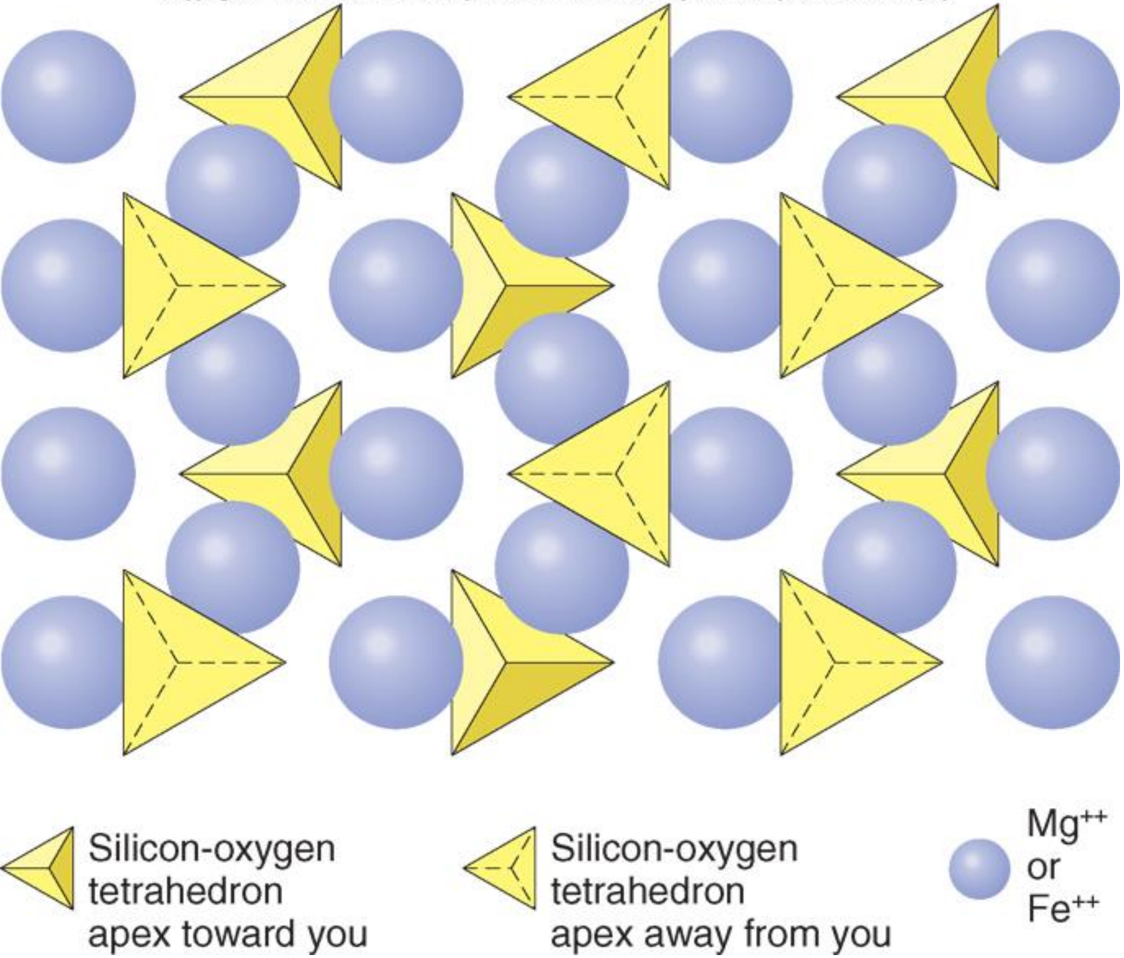


A Arrangement of atoms in silicon-oxygen tetrahedron

B Diagrammatic representation of a silicon-oxygen tetrahedron

Balance charge by:

a) adding cations



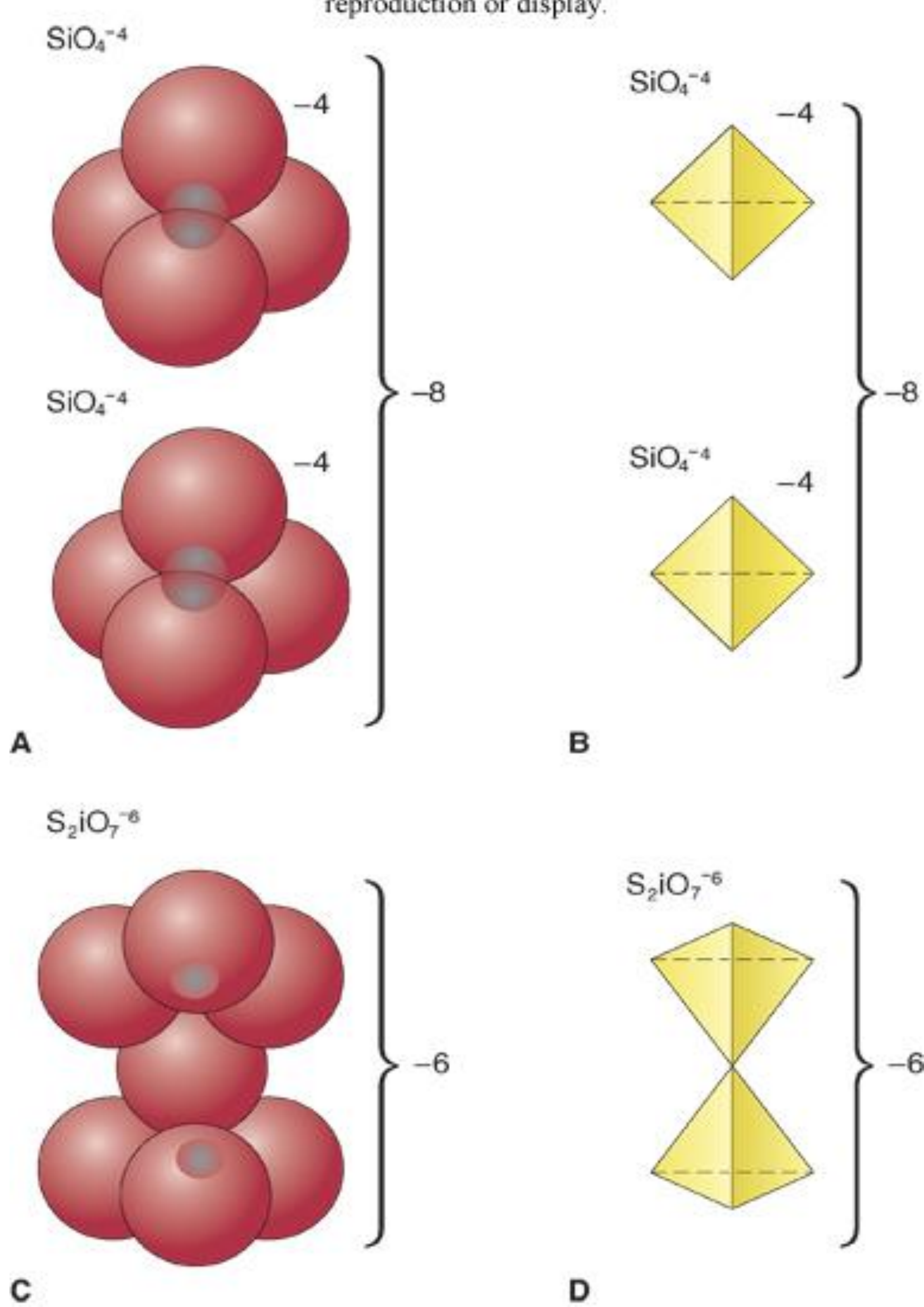
Olivine $(Mg, Fe)_2\ SiO_4$

no cleavage

Balance charge by:

a) adding cations

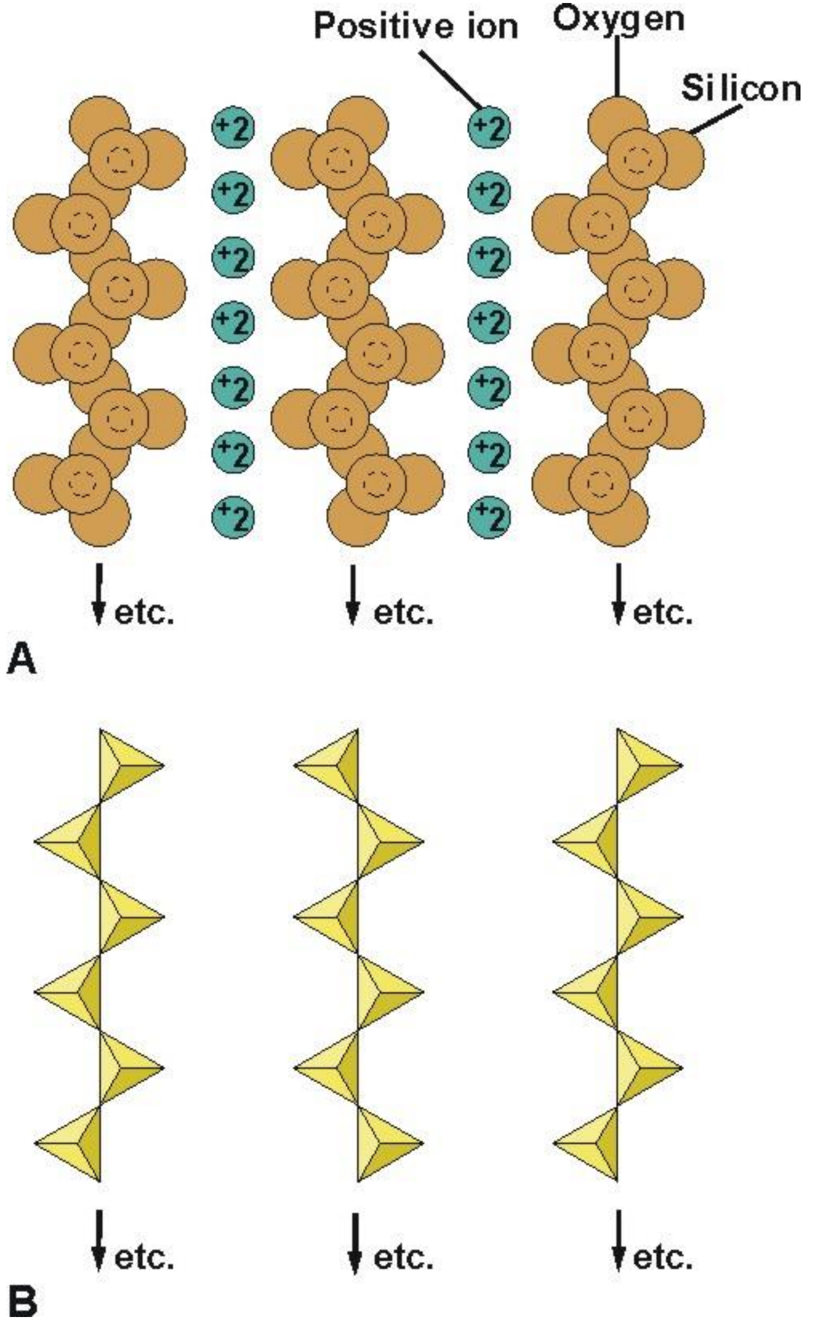
b) sharing oxygen anion with adjacent tetrahedron



Single Chain

e.g.,

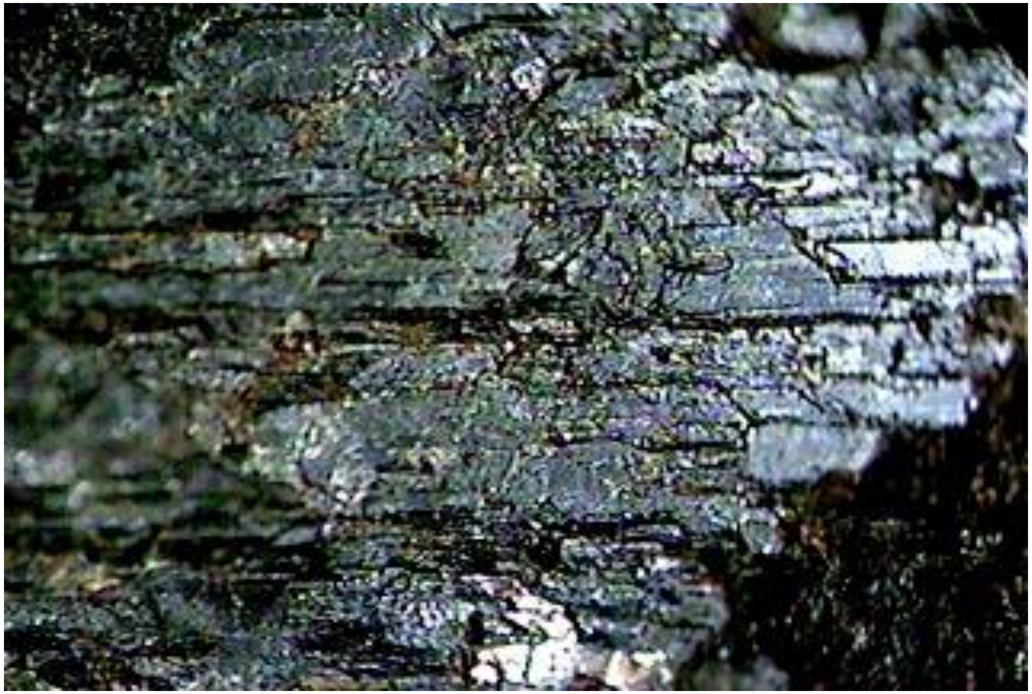
pyroxene

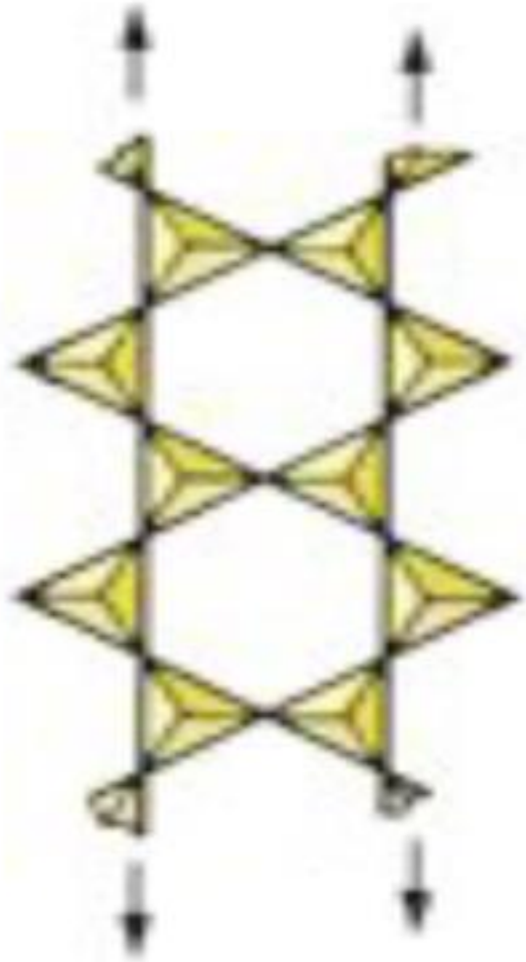


Double chain

e.g.,

Amphibole:

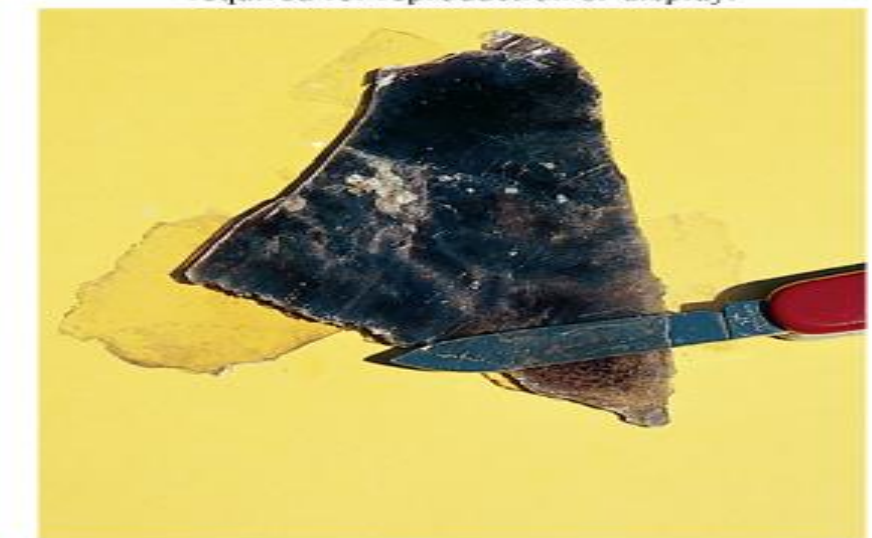




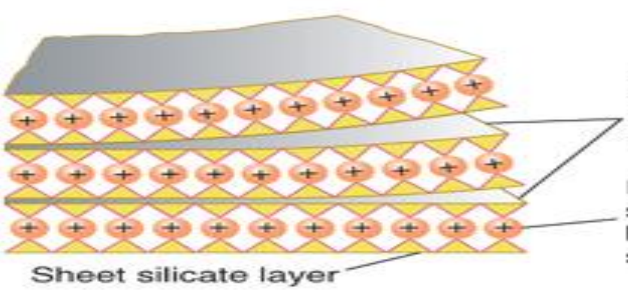
Sheet Silicate

e.g.,

Mica; Clay minerals

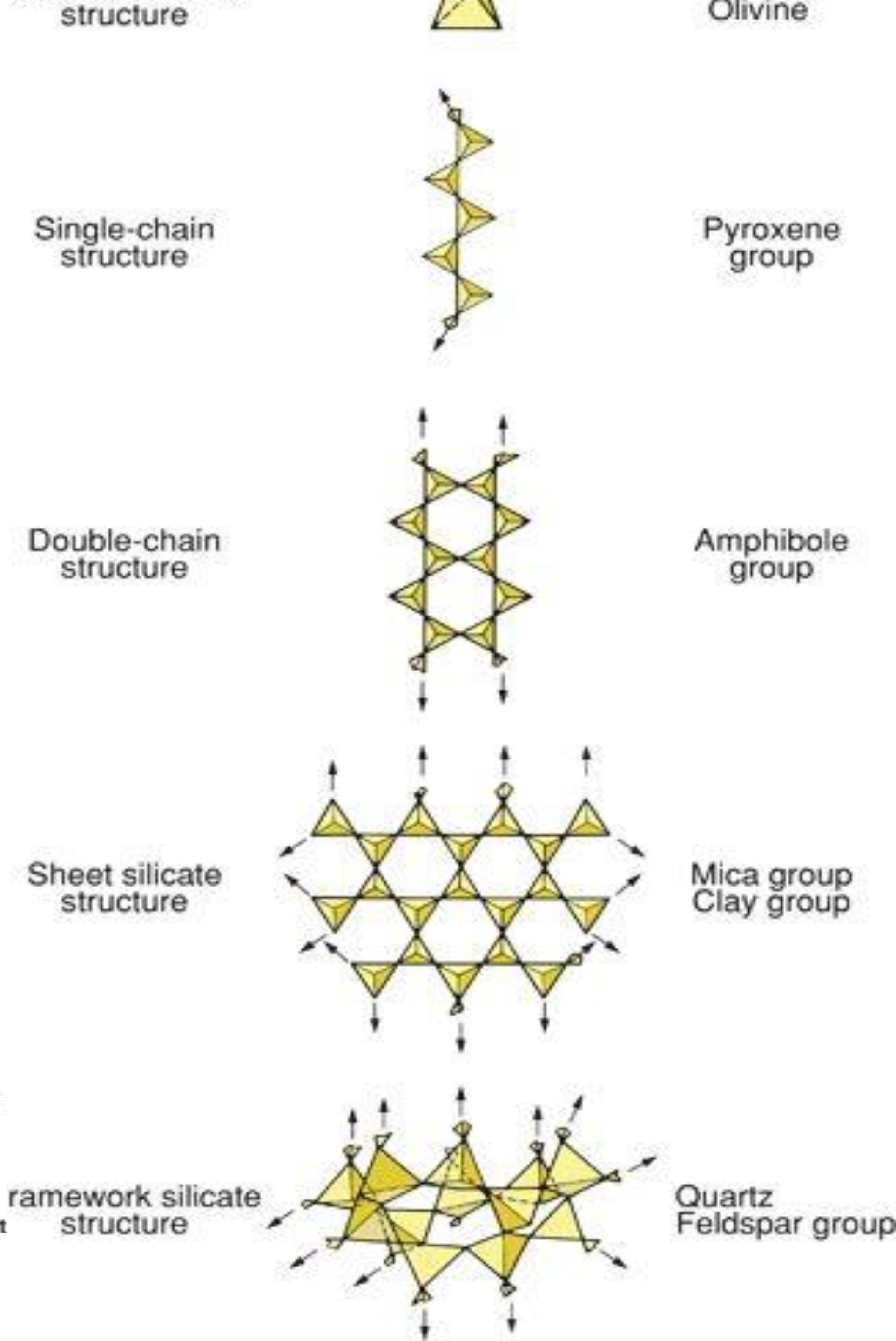


A



B

Photo by C. C. Plummer

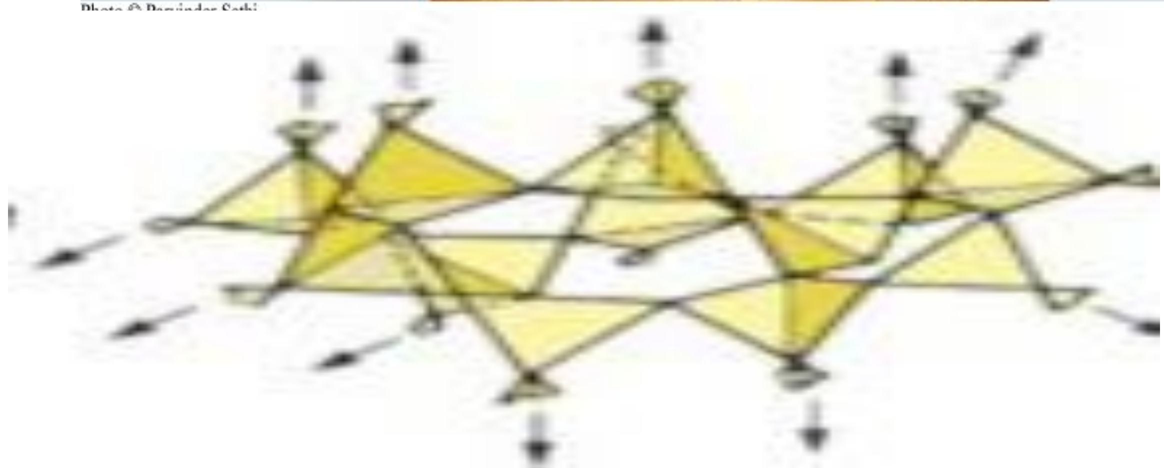


Framework Structure

e.g., Quartz (SiO2)

no cleavage

Conchoidal fracture



Silica tetrahedra can link together to form different crystal structures:

Olivine (Mg, Fe)$_2$ SiO$_4$

Pyroxene

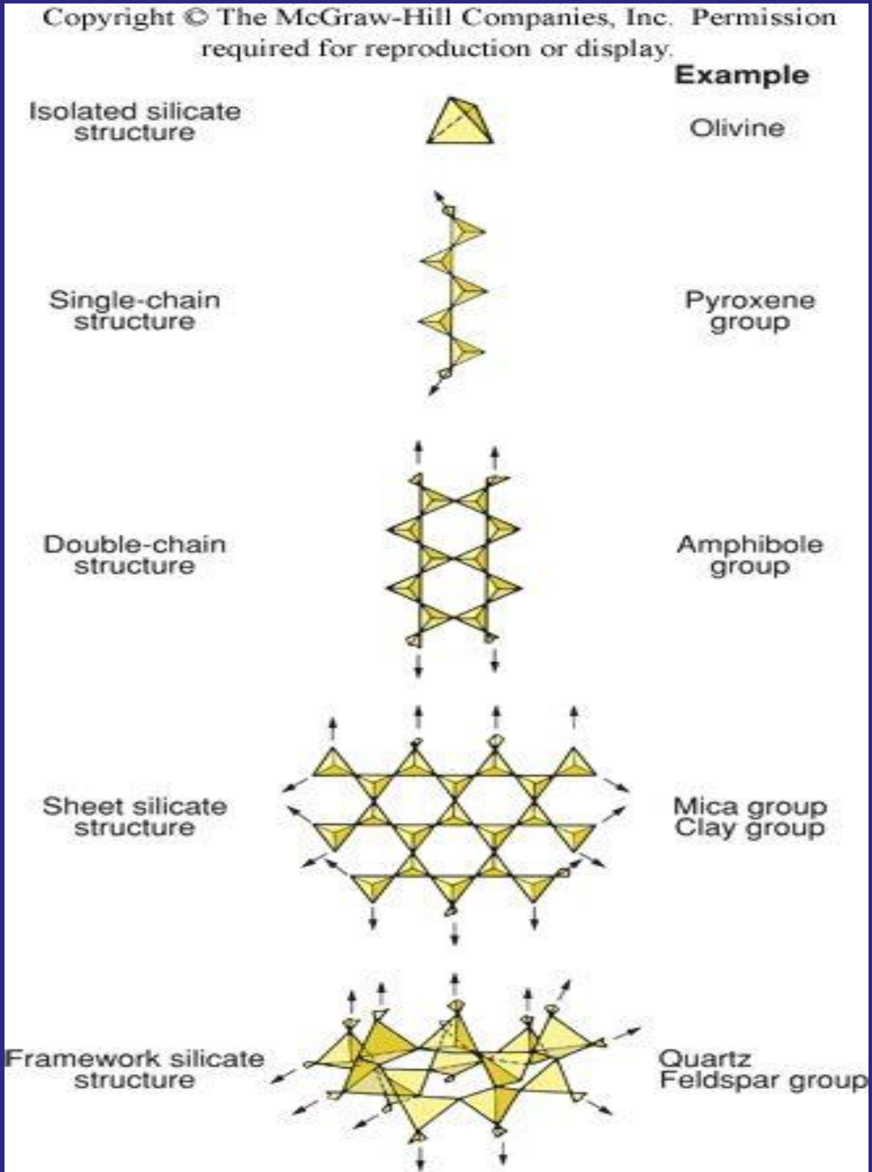
Amphibole

Mica

Clay mineral group

Feldspar

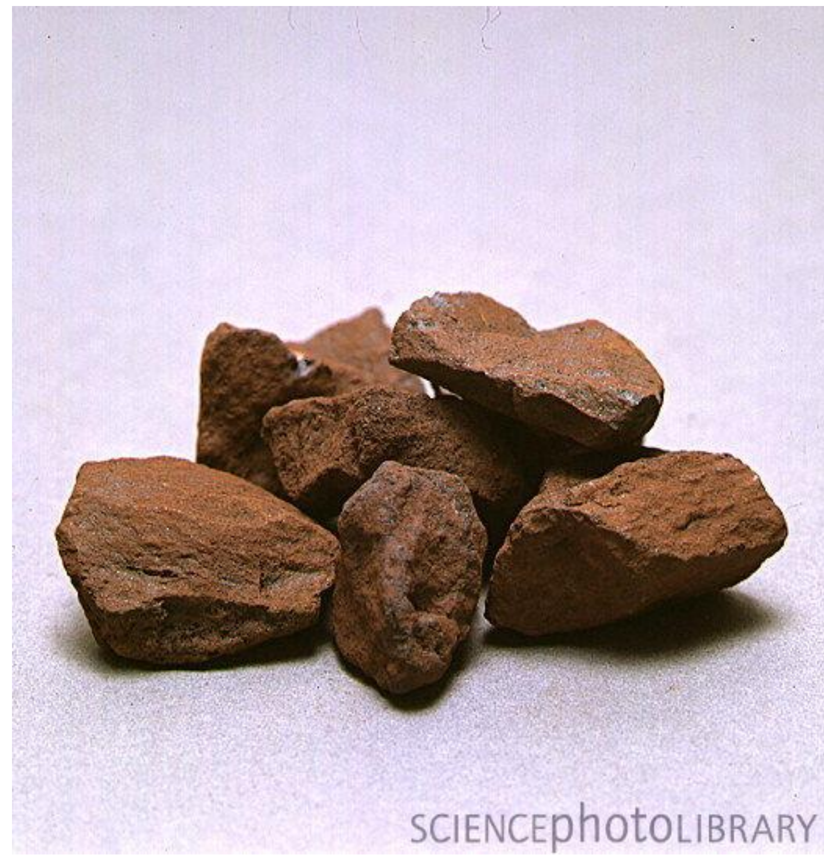
Quartz (SiO$_2$)



Other Mineral Groups

Oxides

Magnetite (Fe_3O_4) **Hematite (Fe_2O_3)**



Sulfides

e.g.,

Galena (PbS) **Pyrite (FeS_2)**

<u>**Carbonates**</u> - contain carbonate $(CO_3)^{2-}$

e.g.,

<u>**Calcite**</u> **($CaCO_3$)**

reacts with acid easily

$CaCO_3 + 2H^+$

$\rightarrow Ca^{2+} + CO_2(gas) + H_2O$

<u>Dolomite</u> ($CaMg(CO_3)_2$)

react with acid,

but not as easily

Evaporites

e.g.,

Halite (NaCl) **Gypsum ($CaSO_4$ $2H_2O$)**

Serpentinization: 0-500° C

REACTANTS (Mg end-members)		Mg:Si ratio	
Forsterite: (olivine)	Mg_2SiO_4	2 : 1	= ***Harzburgite***
Enstatite: (orthopyroxene)	$MgSiO_3$	1 : 1	*(depleted)*
Diopside: (clinopyroxene)	$CaMgSi_2O_6$		

PRODUCTS

Serpentine	$Mg_3Si_2O_5(OH)_4$	1.5 : 1
Brucite	$Mg(OH)_2$	
Talc	$Mg_3Si_4O_{10}(OH)_2$	0.75 : 1

Chlorite	$(Mg, Al, Fe)_3(Si, Al)_2O_5(OH)_4$	(analog to serpentine)
Smectite	$[(Ca,Na)(Al,Mg,Fe)]_3(Al,Si)_4O_{10}(OH)_2$	(analog to talc)

Serpentinization (hydration) Reactions

Olivine to Serpentine (+ Brucite):

$2Mg_2SiO_4 + 3H_2O = Mg_3Si_2O_5(OH)_4 + Mg(OH)_2$

Enstatite to Serpentine (+ Talc):

$6MgSiO_3 + 3H_2O = Mg_3Si_2O_5(OH)_4 + Mg_3Si_4O_{10}(OH)_2$

Olivine + Enstatite to Serpentine:

$Mg_2SiO_4 + MgSiO_3 + 2H_2O = Mg_3Si_2O_5(OH)_4$

Addition of ~10 mol% Fe produces Magnetite and H_2:

Fayalite (Fe end-member olivine): (Fe_3O_4 = Magnetite = FeO . Fe_2O_3)

$3Fe_2SiO_4 + 2H_2O = 2Fe_3O_4 + 3SiO_2(aq) + 2H_2$ $4\ Fe^{2+} + 2\ H_2O \rightarrow 4\ Fe^{3+} + 2\ O^{2-} + 2\ H_2$

Hydrocarbon production: $4H_2 + CO_2 = CH_4 + 2H_2O$ ***(Fischer-Tropsch rxn)***

(at high pH: $4H_2 + CO_3^{2-} = CH_4 + H_2O + 2OH^-$)

Origin of CH_4 on Earth via:

Biogenic processes:

--thermal breakdown of complex C compounds in buried organic matter *("**thermogenesis**")*

$$2\ \text{“}CH_2O\text{”} \Rightarrow CH_4 + CO_2$$

--microbial production *("**methanogenesis**")*

$$CO_2 + 4H_2 = CH_4 + 2H_2O$$

$$CH_3COOH \Rightarrow CH_4 + CO_2$$

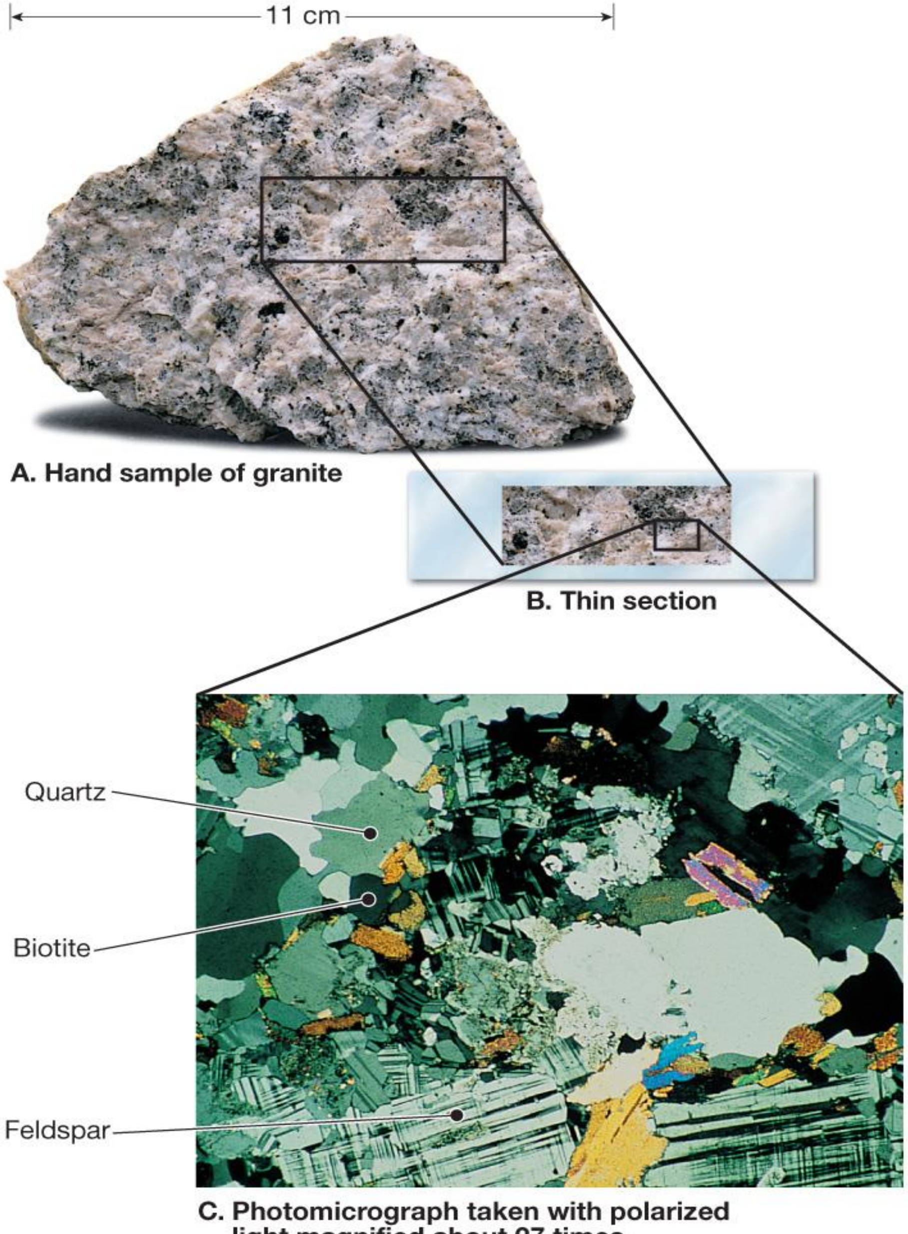
Abiogenic processes:

--outgassing of juvenile CH_4 from the mantle

--inorganic synthesis at high T (***Fischer-Tropsch rxn***)

Earth Materials – (II) Rocks

Rocks: solid, cohesive aggregates of minerals/debris

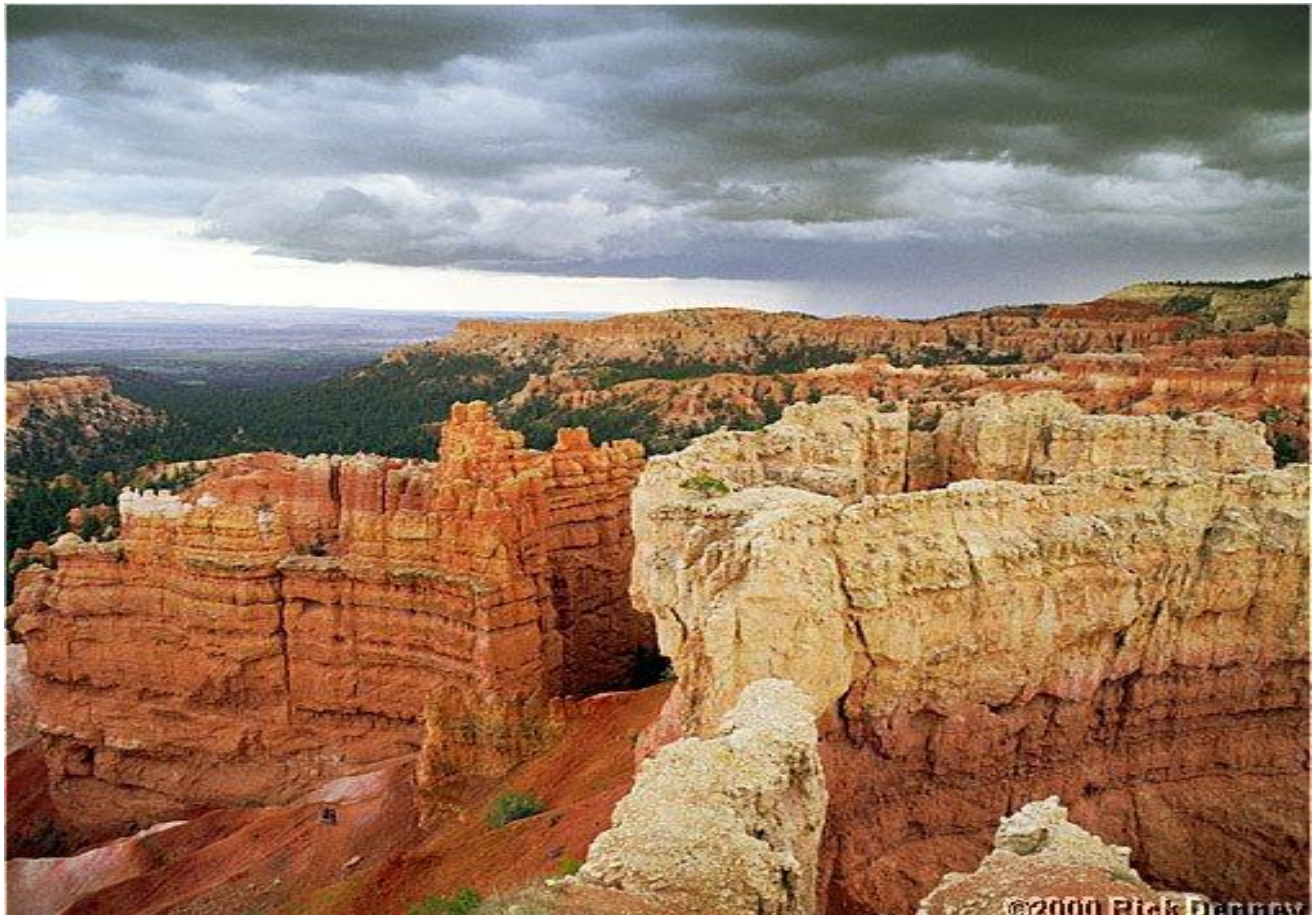


Rocks or minerals

- A round hard solid found in a river
- The bling bling stuff attached to a ring
- The marble floor of a hotel
- A flint that ancient solider used as a spear
- A shiny transparent flawless stone that Isaac Newton found at a seashore
- Coal

Classes of Rocks

1) <u>Sedimentary</u>-form by weathering of rocks, deposition of sediments, or precipitation at/near Earth's surface.

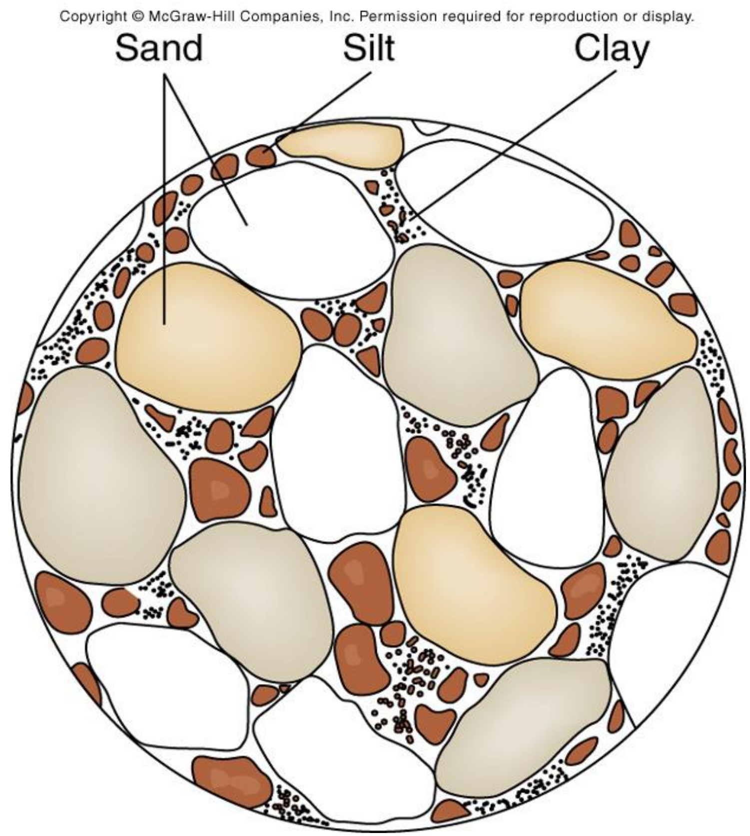


Typical feature: **horizontal layers (bedding)** formed by settling of grains in water

Rock Classification

1) <u>Sedimentary Rock</u>

-- <u>Clastic rocks</u>: composed of fragments of sediments/ shells/fossils

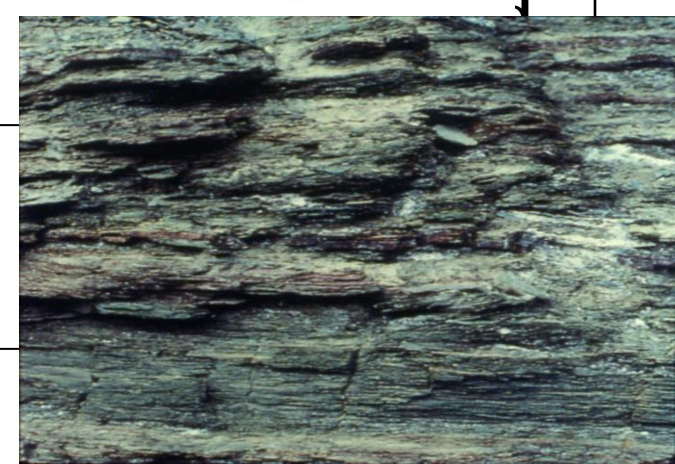


Sediment has been transported, deposited, & consolidated

Classified based on **grain size** and **shape**

Clastic sedimentary rocks

Conglomerate, Breccia	pebb
Sandstone	sand
Siltstone	silt (finer
Mudstone/shale	



Bioclastic Rocks

: form by cementation of skeletal remains

e.g., **Fossiliferous Limestone**

Chemical Sedimentary Rocks

: crystallization of dissolved ions directly from water due to changes in T, P, or chemistry of the water.

e.g., Rock Salt **Rock Gypsum**

Chemical Sedimentary Rocks: crystallization of dissolved ions directly from water due to changes in T, P, or chemistry of the water. **e.g., Crystalline Limestone**

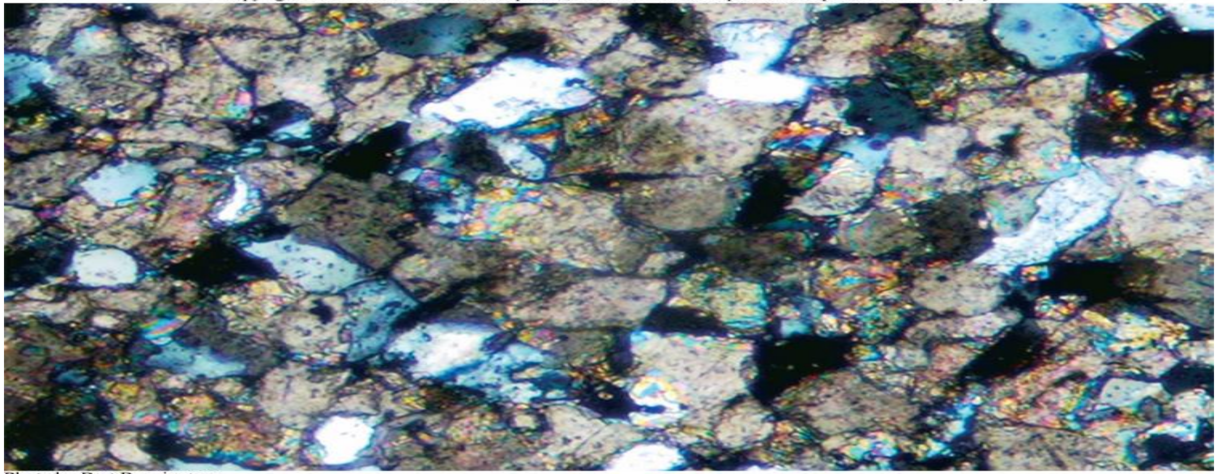
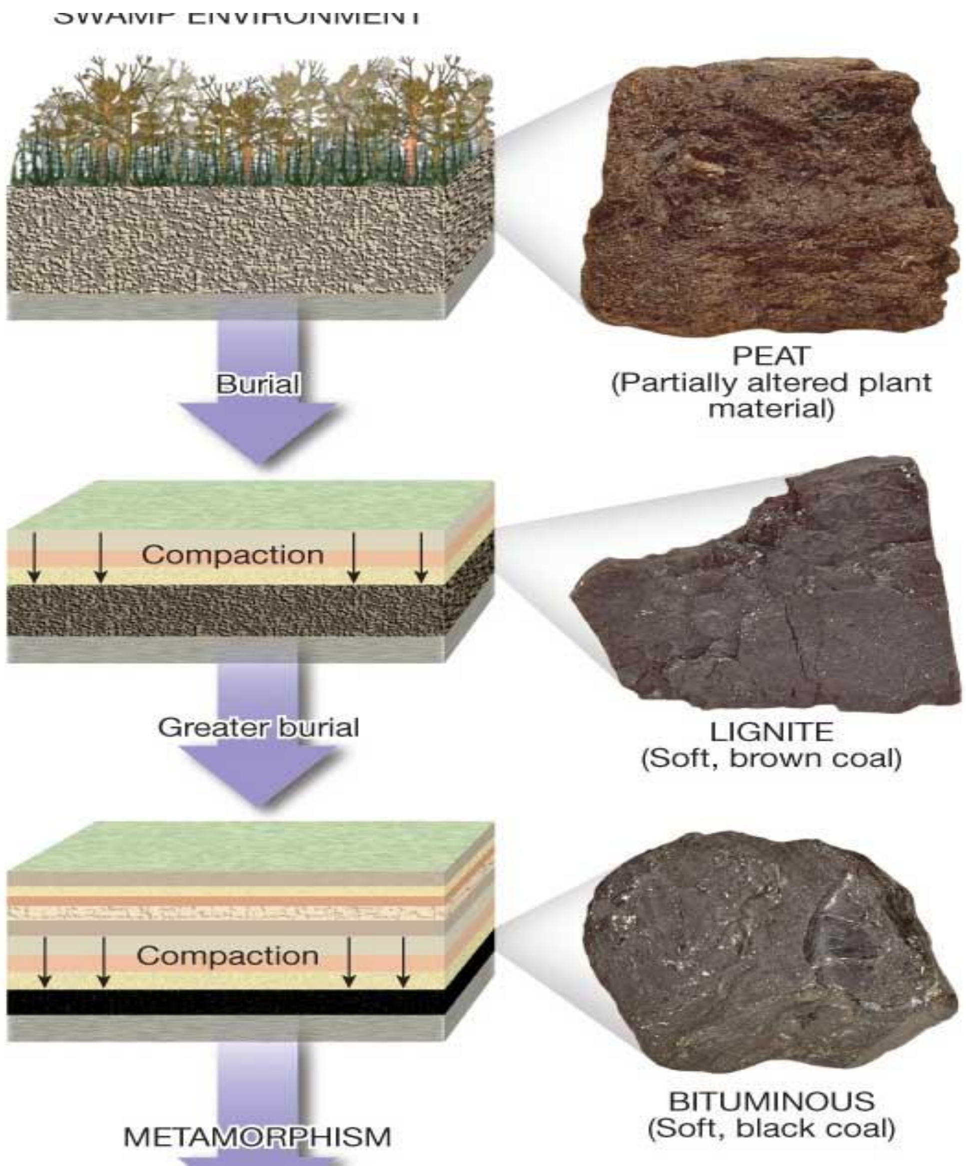


Photo by Bret Bennington

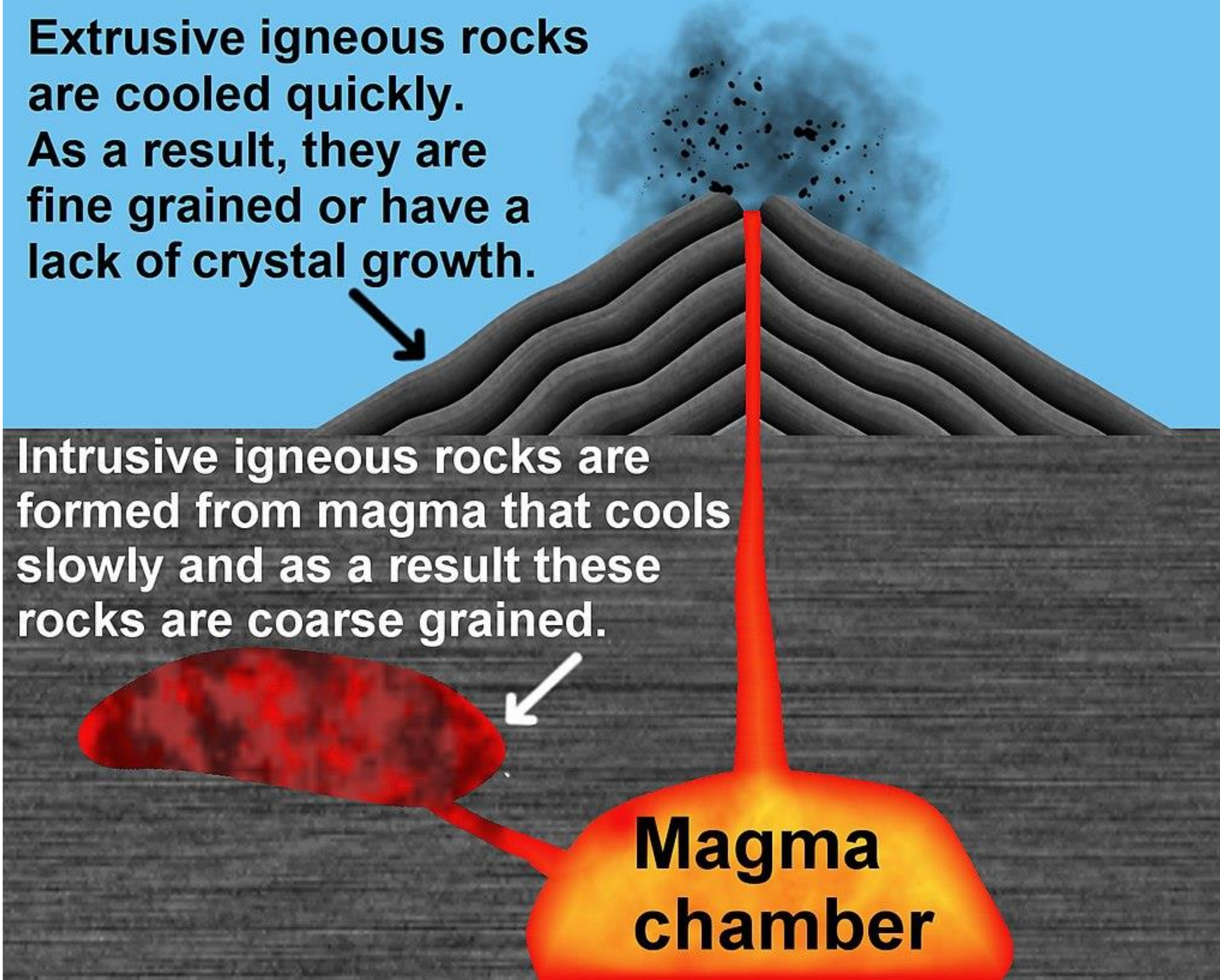
Organic Sedimentary Rocks

Coal: from compression of plant remains



Classes of Rocks

2) <u>Igneous</u> - form by cooling & solidification of hot molten rock


Extrusive igneous rocks are cooled quickly. As a result, they are fine grained or have a lack of crystal growth.
Intrusive igneous rocks are formed from magma that cools slowly and as a result these rocks are coarse grained.
Magma chamber

2) <u>**Igneous Rock**</u>- based on **grain size & composition**

Composition/Grain Size	*Coarse-grained* **Intrusive**	*Fine-grained or* mixed grains **Extrusive**
Silicic (light rock, SiO_2-rich, abundant quartz + feldspar) **felsic**	**Granite** (continental crust)	**Rhyolite**
Intermediate	Diorite	**Andesite**
Mafic (dark rock, less SiO_2, rich in Mg + Fe)	**Gabbro**	**Basalt** (oceanic crust)

Typical **texture**

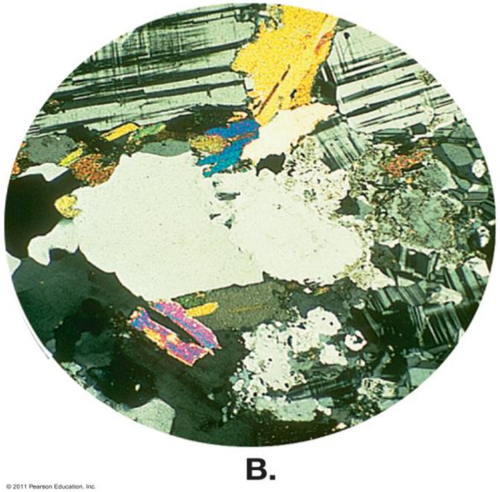
: interlocking grains,

fit together like jigsaw puzzle

B.

Rock Classification

1) **<u>Igneous Rock</u>**- classified by



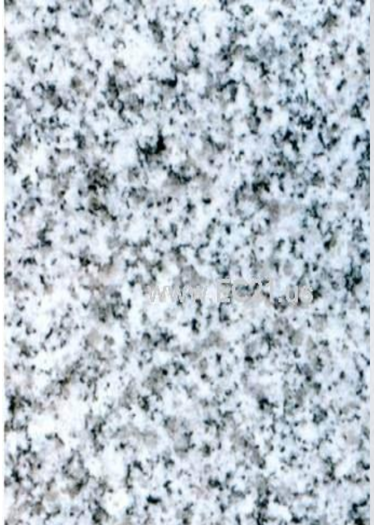
- **Grain size -** related to cooling rate.

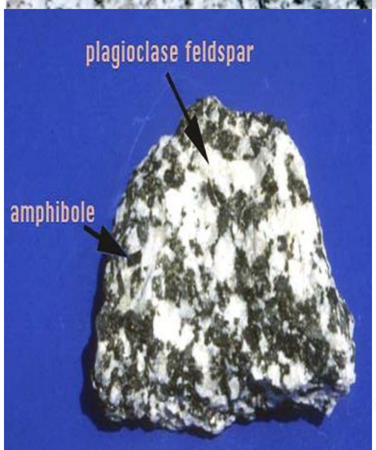
Lava cools quickly at Earth's **surface** (**<u>extrusive</u>** igneous rock), producing **small mineral grains (or mixed grain)**

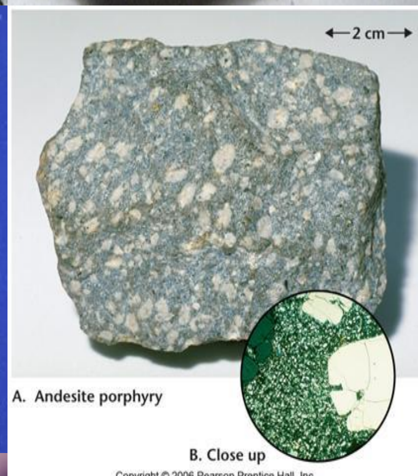
Magma cools slowly **deep** within Earth (**<u>intrusive</u>** igneous rock), producing large mineral grains

- **Composition -** indicated by minerals present; roughly by color of rock (% light vs. dark minerals)

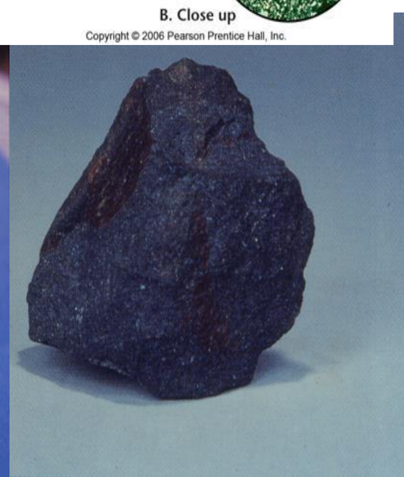
Typical **texture : interlocking grains, fit together like jigsaw puzzle**



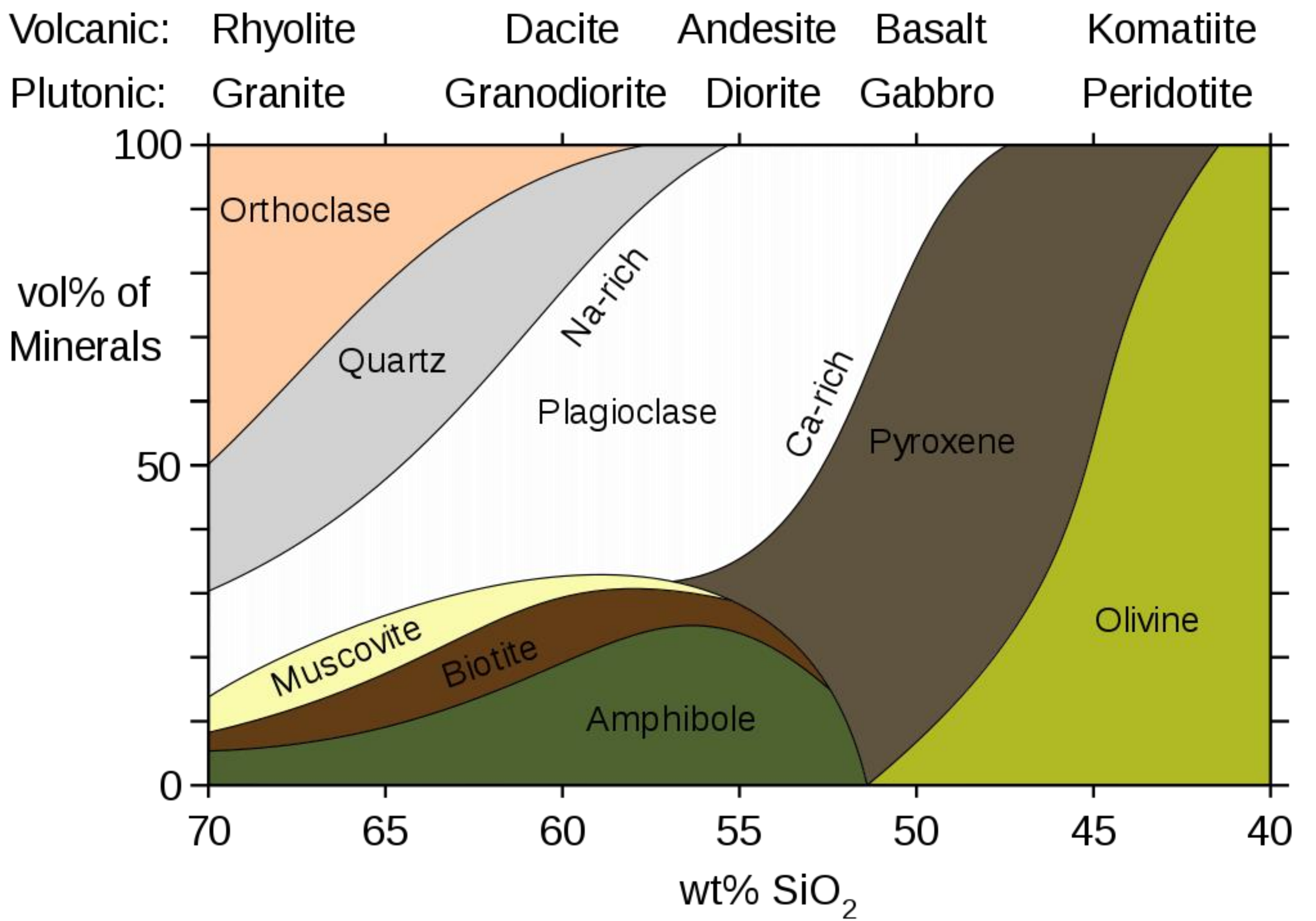


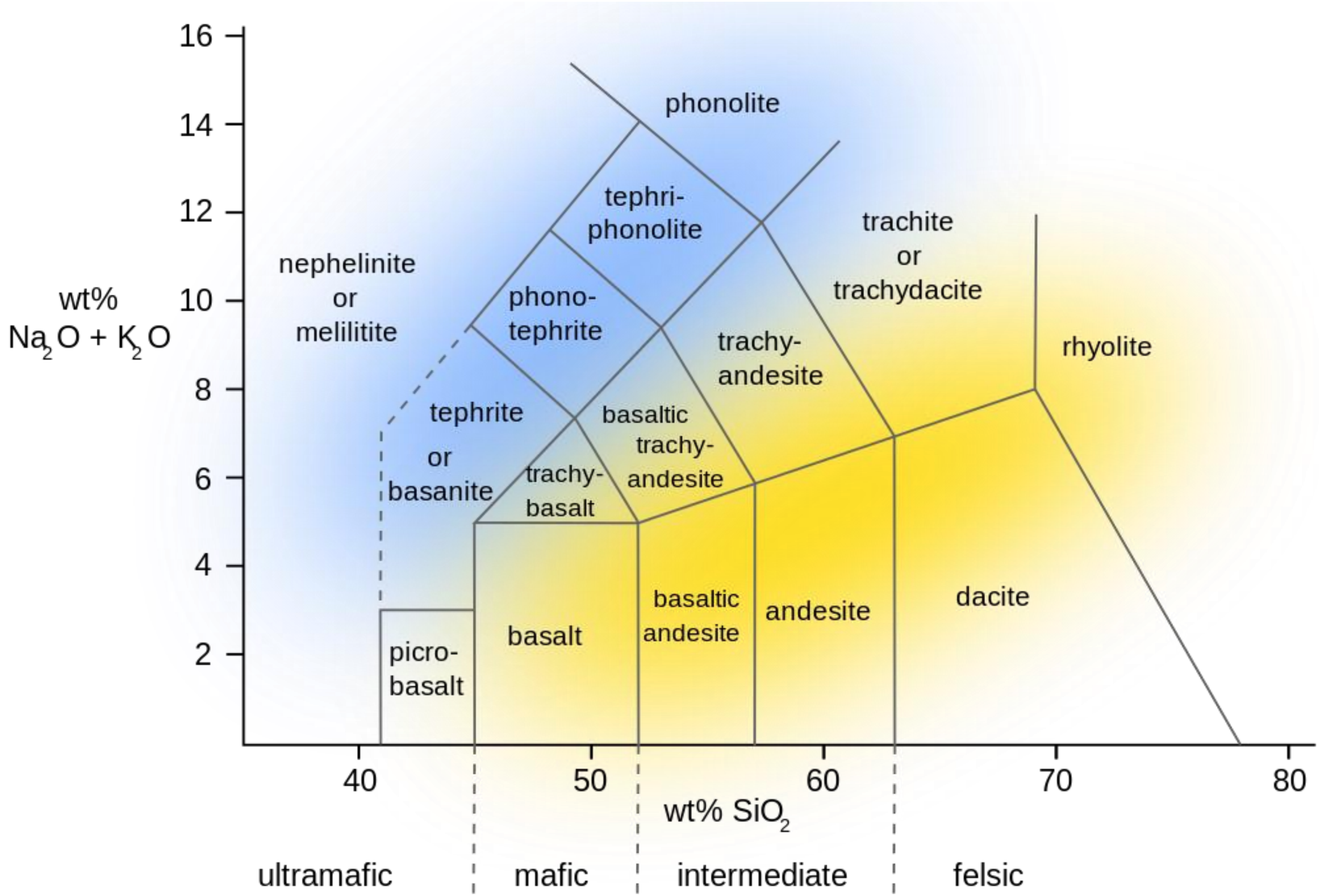


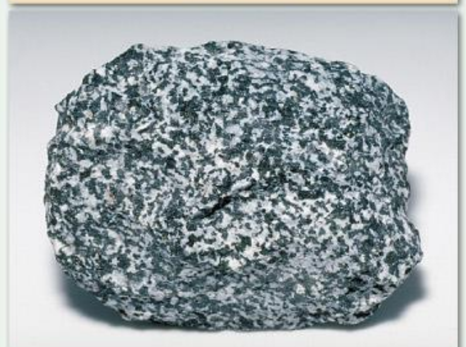
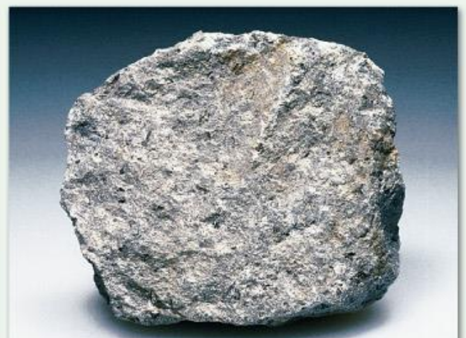
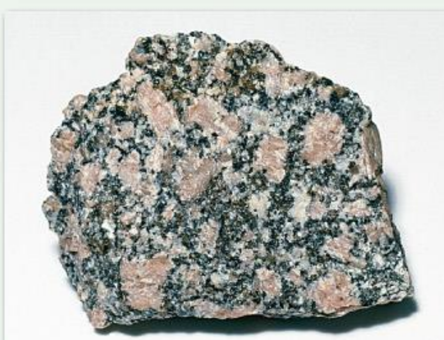
A. Andesite porphyry

arse-grained **Intrusive**	*Fine-grained* *Or* **Mixed grains** **Extrusive**
Granite tinental crust)	**Rhyolite**
Diorite	**Andesite**
Gabbro	**Basalt** (oceanic crust)


Volcanic:
Rhyolite
Dacite
Andesite
Basalt
Komatiite
Plutonic:
Granite
Granodiorite
Diorite
Gabbro
Peridotite
100
50
0
vol% of Minerals
Orthoclase
Quartz
Na-rich
Plagioclase
Ca-rich
Pyroxene
Olivine
Muscovite
Biotite
Amphibole
70
65
60
55
50
45
40
wt% SiO2


16
14
12
10
8
6
4
2
wt%
$Na_2O + K_2O$
40
50
60
70
80
wt% SiO_2
phonolite
tephri-
phonolite
trachite
or
trachydacite
nephelinite
or
melilitite
phono-
tephrite
trachy-
andesite
rhyolite
tephrite
or
basanite
basaltic
trachy-
andesite
trachy-
basalt
picro-
basalt
basalt
basaltic
andesite
andesite
dacite
ultramafic
mafic
intermediate
felsic

Texture	Composition		
	Felsic (Granitic)	**Intermediate** (Andesitic)	**Mafic** (Basaltic)
Phaneritic (course-grained)	 Granite	 Diorite	 Gabbro
Aphanitic (fine-grained)	 Rhyolite	 Andesite	 Basalt
Porphyritic	 Granite porphyry	 Andesite porphyry	 Basalt porphyry

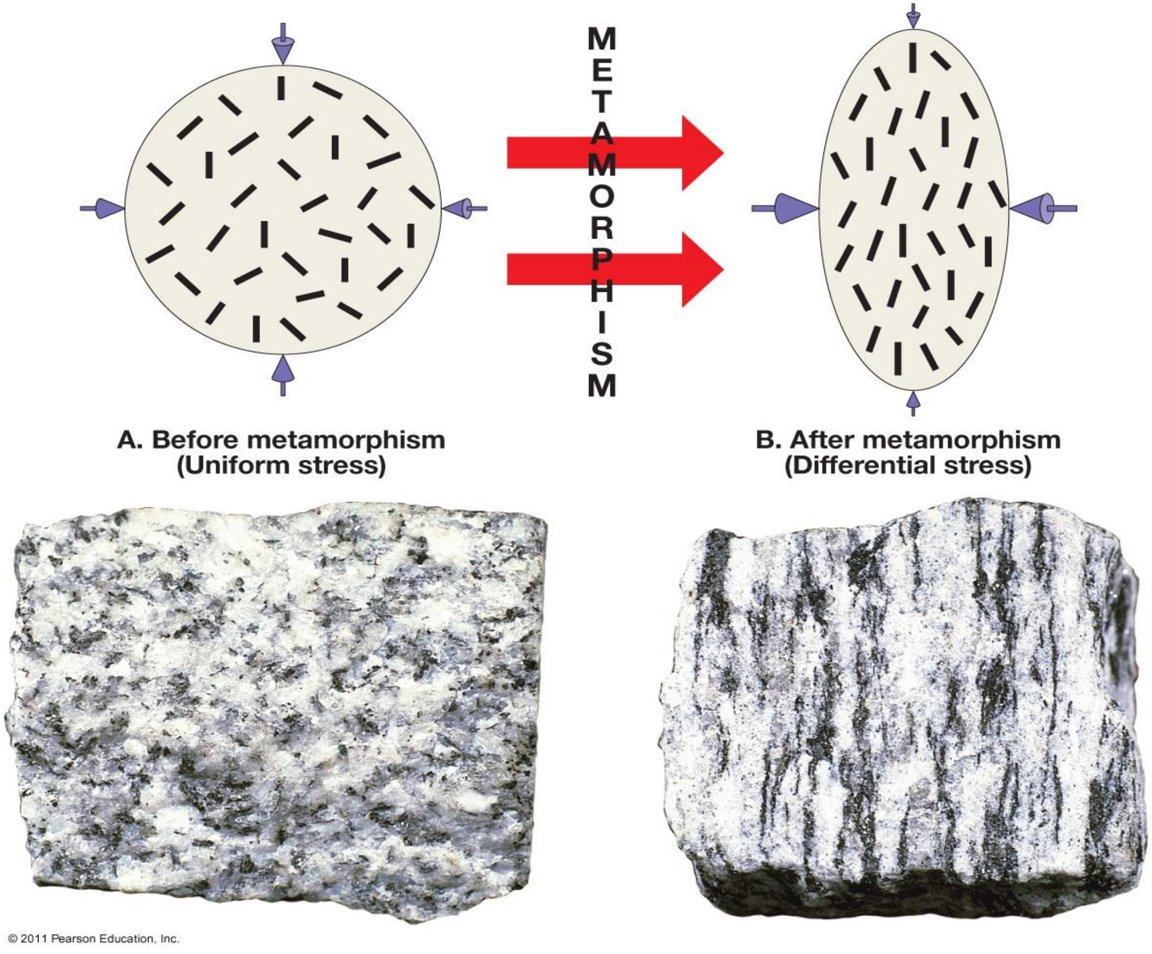
3) <u>Metamorphic</u> - form when pre-existing rock (**protolith**) changes shape/mineral content due to intense heat/stress.

Rock Classification

3) **<u>Metamorphic Rocks</u>** – classified according to presence or absence of foliation

Foliation: parallel alignment of minerals in metamorphic rock due to <u>intense stress</u> during metamorphism

Foliation



[**Animation: Foliation Processes**]

Foliated Metamorphic Rocks

Slate	Low grade metamorphism	rock cleavage
Schist	Intermediate grade	coarse aligned mica
Gneiss	High grade	Bands of light & dark minerals

Slate

-- low-grade metamorphism

-- fine grained

-- split along flat, parallel planes

(rock cleavage)

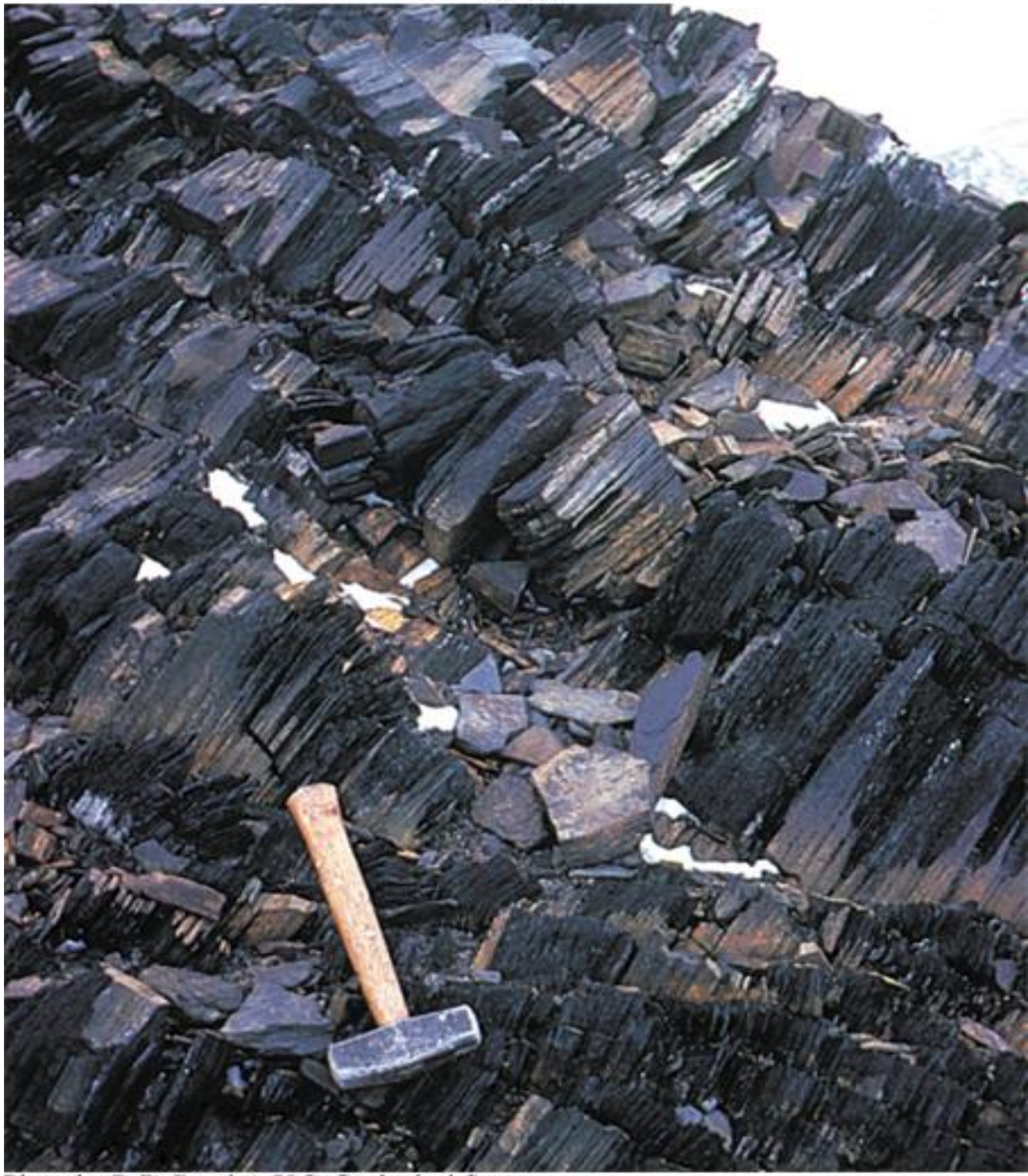


Photo by P. D. Rowley, U.S. Geological Survey

Schist

- intermediate grade metamorphism

- visible minerals

- silky, wavy surfaces

Photo by C. C. Plummer

Gneiss

-- high grade metamorphism

-- alternated bands of

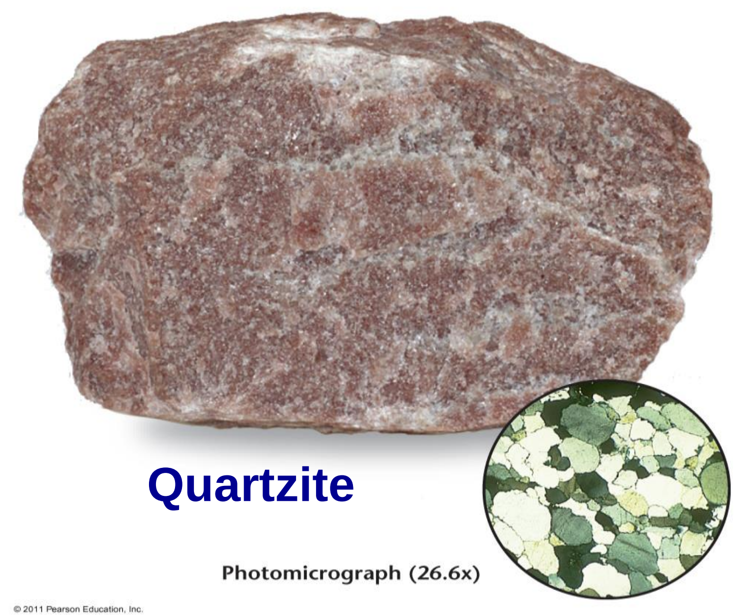
felsic (light)&mafic (dark)

minerals

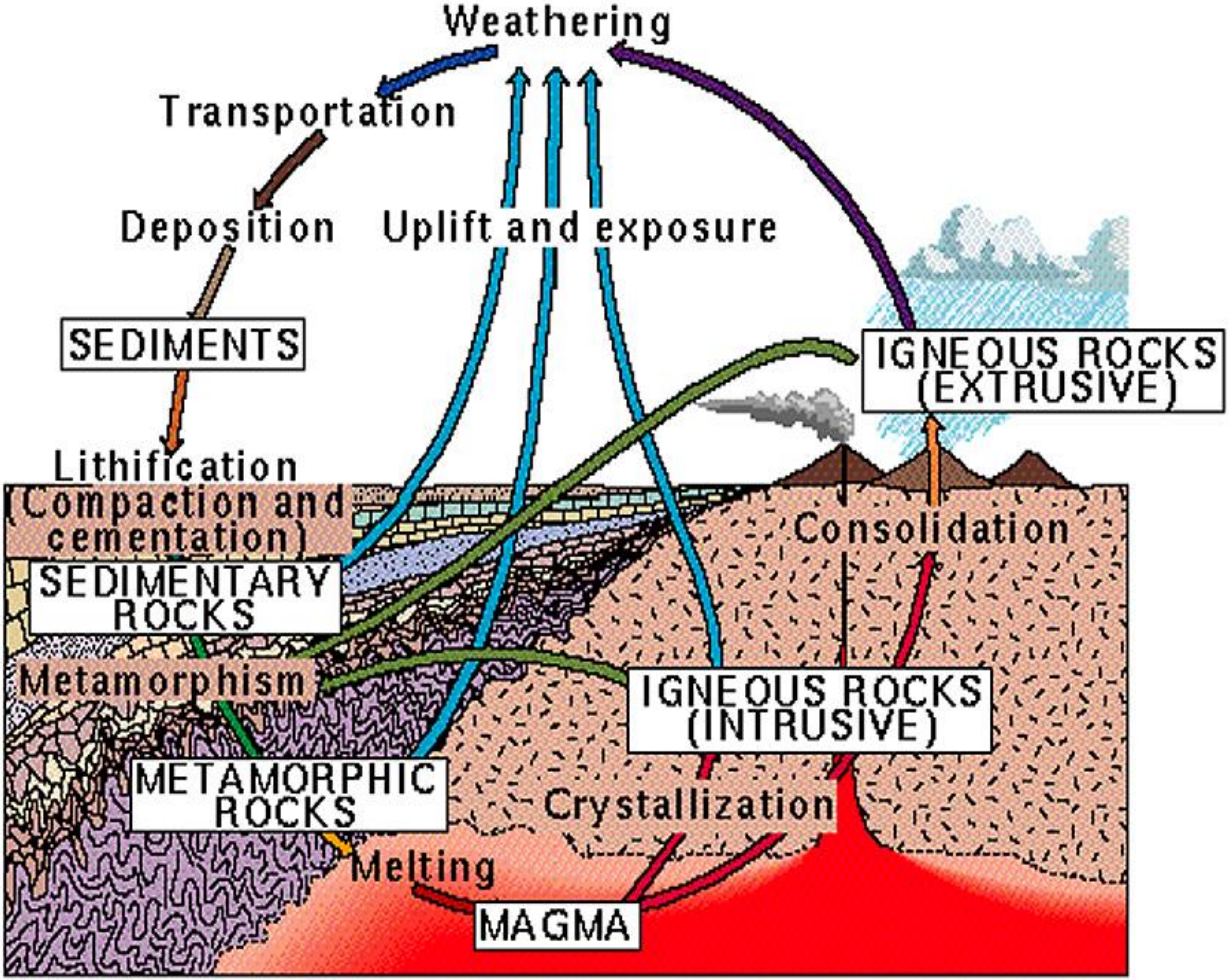
Non-foliated Metamorphic Rocks

Single mineral; or, **not been subjected to stress**

Marble (composed of calcite)	metamorphosed limestone
Quartzite (composed of quartz)	metamorphosed sandstone

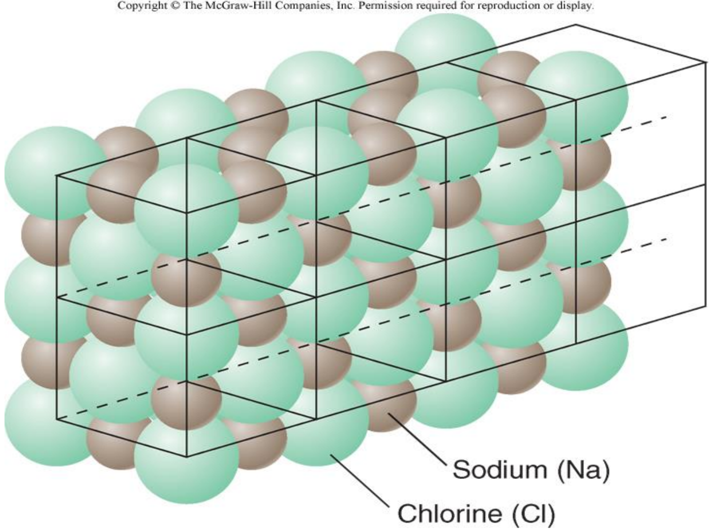


Jade, Jadeite and Nephrite



Weathering
Transportation
Deposition
Uplift and exposure
SEDIMENTS
IGNEOUS ROCKS
(EXTRUSIVE)
Lithification
(Compaction and
cementation)
Consolidation
SEDIMENTARY
ROCKS
Metamorphism
IGNEOUS ROCKS
(INTRUSIVE)
METAMORPHIC
ROCKS
Crystallization
Melting
MAGMA

Basic Chemistry



(A) Elements and Atoms

-- ***Element*** **:** a substance that can not be broken down into others substances

e.g., hydrogen, oxygen

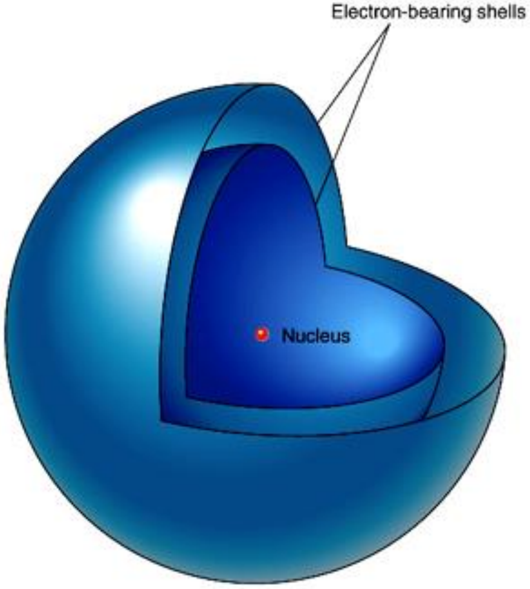
-- ***Atom*** **:** smallest particle of an element that retains the properties of that element

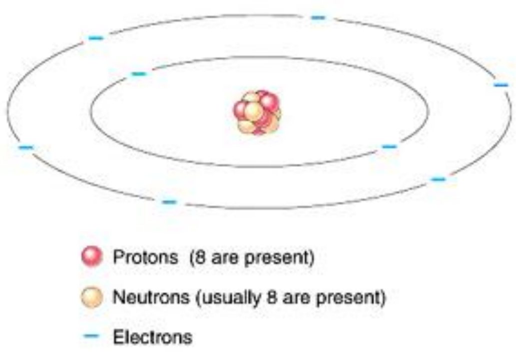
(Radius: 10^{-8} cm)

(B) Atomic Structure

- **Protons & neutrons** form the **nucleus** of an atom

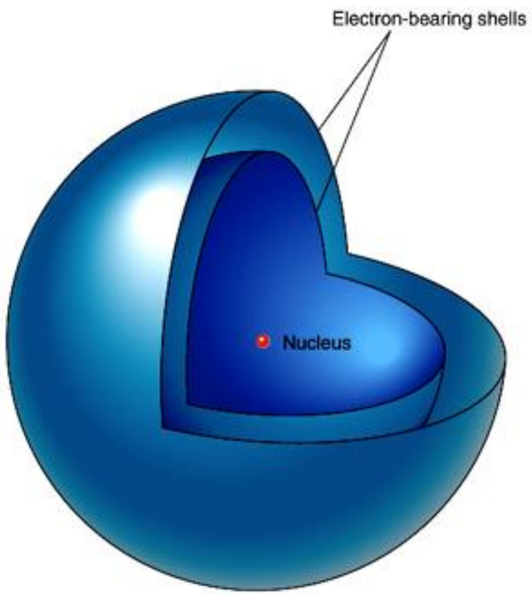
- represents tiny fraction of the volume at the center of an atom, but nearly all of the **mass**

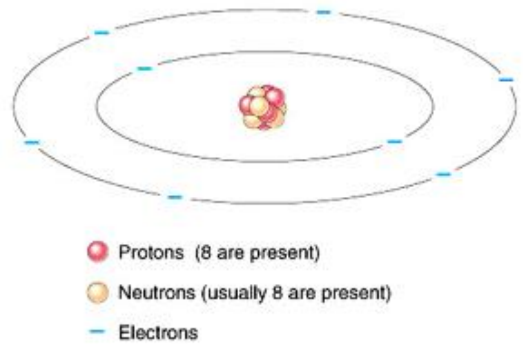




- **Electrons** orbit the nucleus in discrete *shells* or energy levels**.**

  - **electron shells** represent nearly all of the **volume** of an atom, but only a tiny fraction of the mass

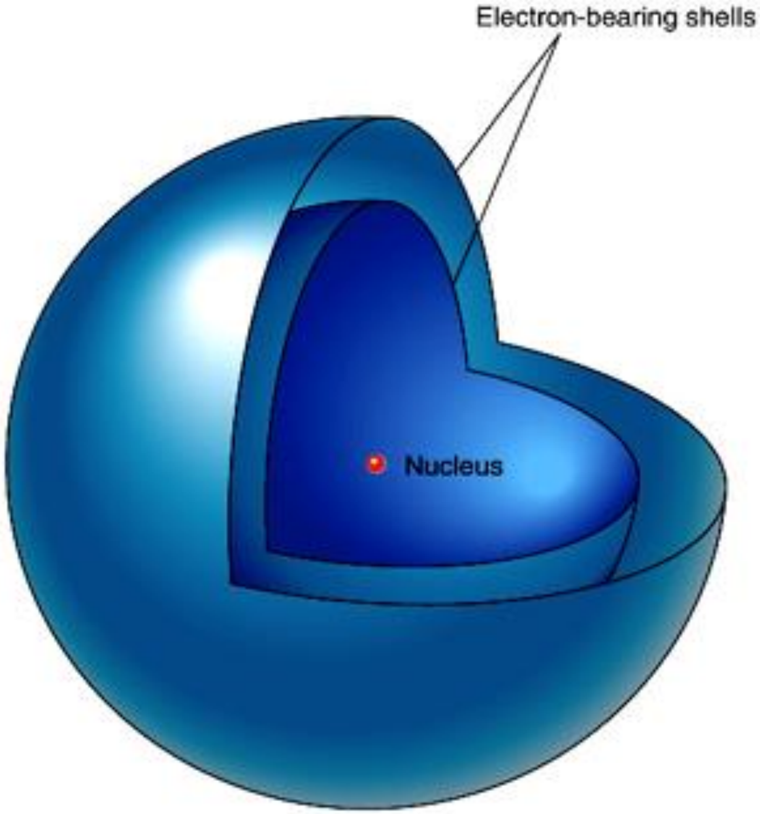




Protons
(positively charged)

Neutrons
(neutral)

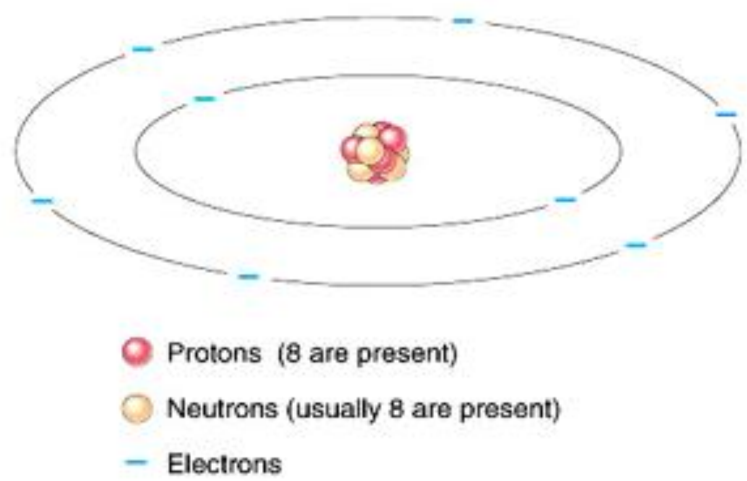
Electrons
(negatively charged)



Atomic Number

: number of protons

in each atom



e.g.,

Atomic Number	**Element**
1	**Hydrogen (H)**
6	**Carbon (C)**
8	**Oxygen (O)**
79	**Gold (Au)**

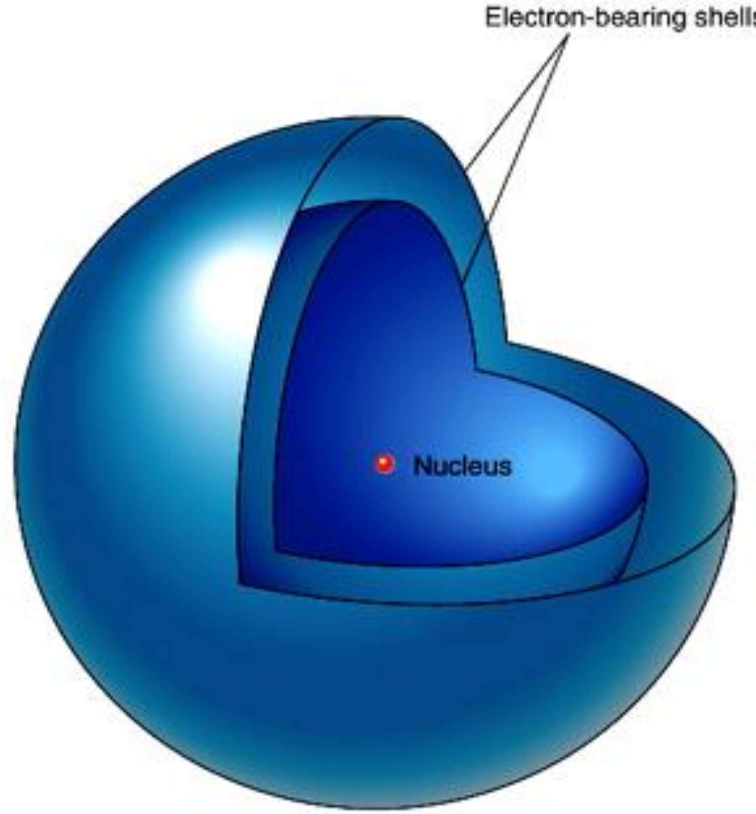
Atomic Mass Number

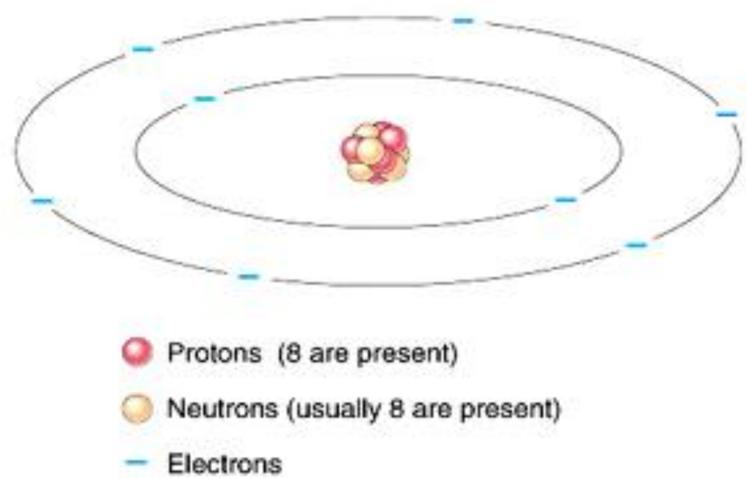
: total number of neutrons and protons

e.g., **oxygen**

# of N	Atomic Mass #
8	16
9	17
10	18

Atoms of an element with **different numbers of neutrons** are called **isotopes** e.g., ^{16}O, ^{17}O, ^{18}O





Isotopes

e.g.,

Carbon isotopes

^{12}C: 6 protons + 6 neutrons

^{13}C: 6 protons + 7 neutrons

^{14}C: 6 protons + 8 neutrons

Isotopes

- Isotopes may be either **stable** or **unstable**
  - ***Stable*** isotopes retain all of their protons and neutrons through time
  - Unstable or **radioactive** isotopes spontaneously lose subatomic particles from their nuclei over time

Ions:

atoms gain or lose electron(s) to form ions

lose electrons: **cation** (e.g., Na^+)

gain electrons : **anion** (e.g, Cl^-)

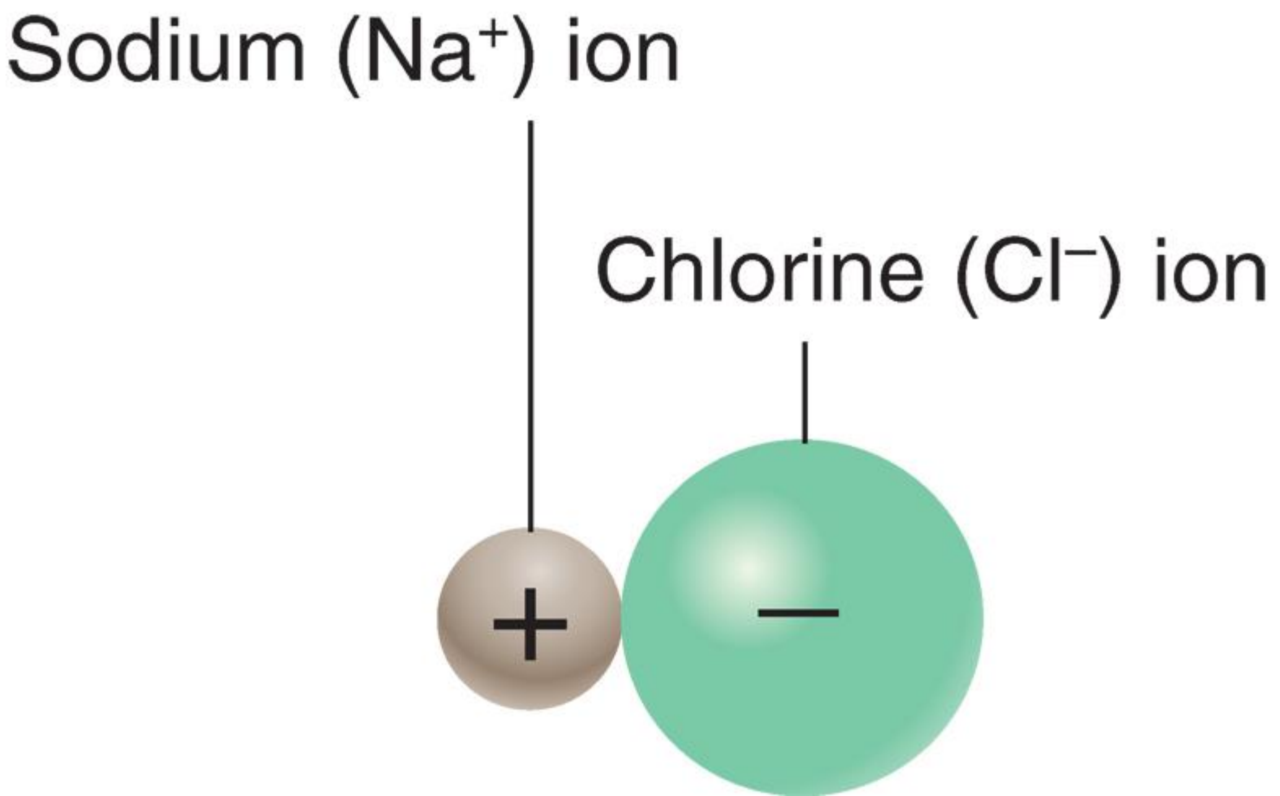
"magic numbers" (e.g., 2, 8)

-- most stable condition for each electron shell

(C) Chemical Bonds

-- Ionic bond

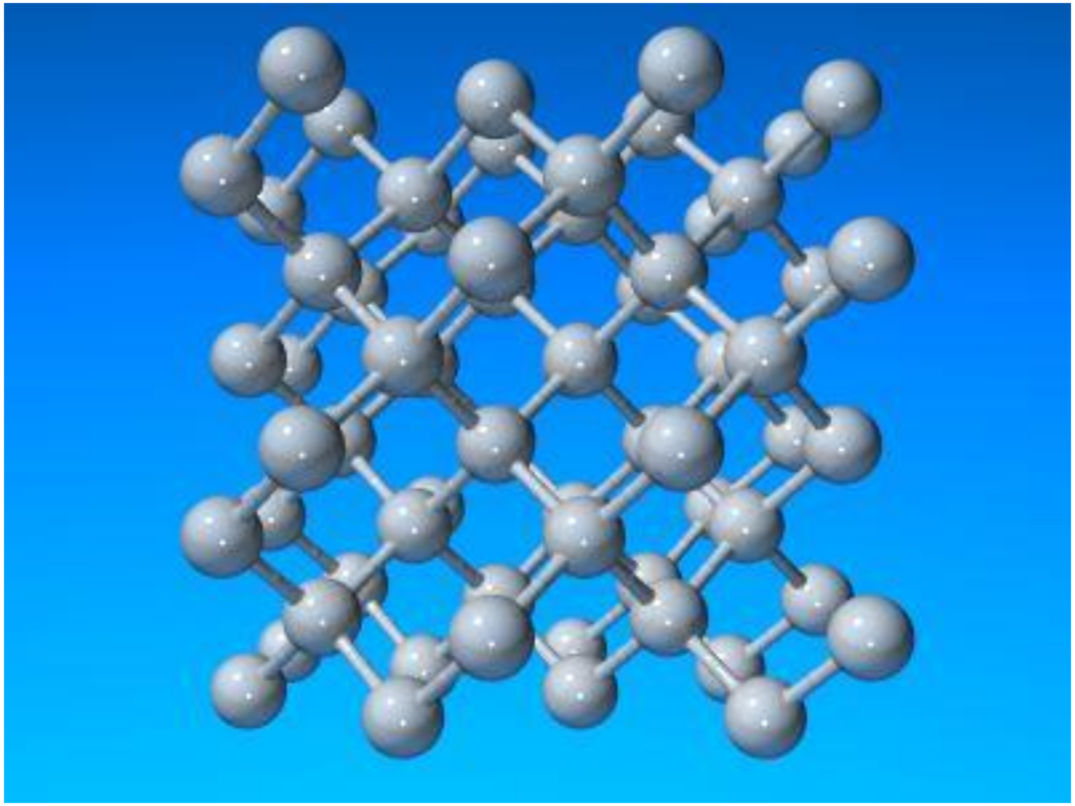
: electrons transfer completely from one atom to another



-- Covalent bond

: atoms share electrons in their outer shells, no net grain or loss

e.g., diamond (100% carbon)



-- Van der Waals bond

: weak residual electric static forces

e.g., bonding between graphite sheets