

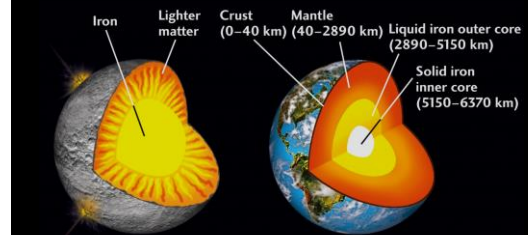
## Matter and Minerals (Part 2)

- Average Abundances of Elements in Earth's Crust
- Silicate Minerals
- Silicate Structures
- Nonsilicate Minerals
- Economic Uses
- Gemstones



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## Differentiation of Early Earth



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## Average Abundances of Elements in Earth's Crust



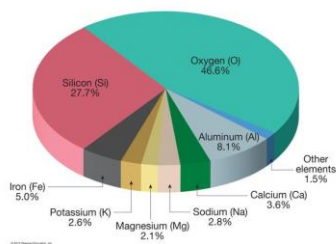
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## Minerals Are Subdivided Into Two Major Categories



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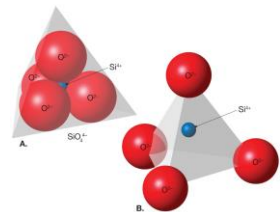
## Silicate Minerals



- Silicate minerals are comprised of the two most abundant elements in Earth's crust, silicon and oxygen
- More than 800 silicate minerals are known
- Silicate minerals account for 92% of Earth's crust








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## Silicon-Oxygen Tetrahedron



- Silicate minerals are comprised of Silicon-Oxygen Tetrahedra
- Silicon ion ( $\text{Si}^{4+}$ ) is surrounded by four oxygen ions ( $\text{O}^{2-}$ ) and represented by the formula ( $\text{SiO}_4$ )<sup>4-</sup>
- General formula for silicates:  
( $\text{SiO}_4$ )<sup>4-</sup> ± cations ( $\text{Mg}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ )


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Mineral/Formula	Cleavage	Silicate Structure	Example
Isolated group ( $\text{Mg, Fe, SiO}_2$ )	None	Single tetrahedron	
Pyroxene group ( $\text{Mg, Fe, SiO}_2$ )	Two planes at 90°	Single chain	
Amphibole group ( $\text{Ca, Mg, Fe, SiO}_2, \text{OH}_2$ )	Two planes at 60° and 120°	Double chain	
Quartz ( $\text{SiO}_2$ )	One plane	Sheet	
Mica ( $\text{K, Al, Si, OH}_2$ )	One plane	Sheet	
Phyllosilicate ( $\text{Al, Si, OH}_2$ )	Two planes at 90°	Two-dimensional framework	
Granite ( $\text{SiO}_2$ )	None	Three-dimensional framework	

### Silicate Mineral Groups

Silicate minerals are subdivided into different groups based on the internal arrangement of silicon-oxygen tetrahedra

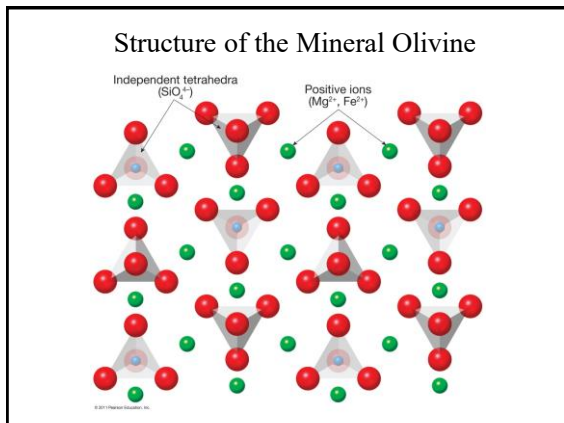
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Mineral/Formula	Cleavage	Silicate Structure	Example
Olivine ( $\text{Mg, Fe, SiO}_2$ )	None	Single tetrahedron	

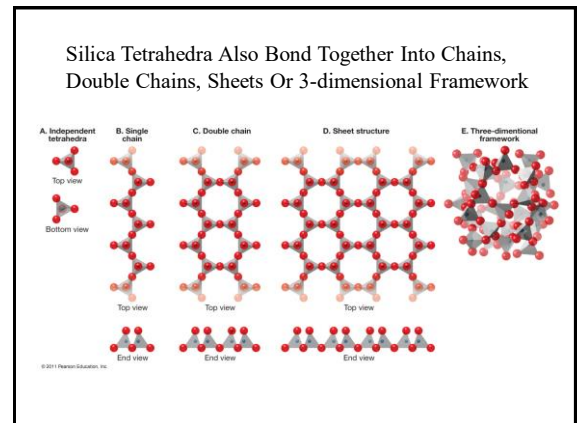
### Silicate Structures: Independent Tetrahedron

Cations link together individual tetrahedra in the crystal structure

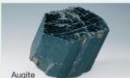

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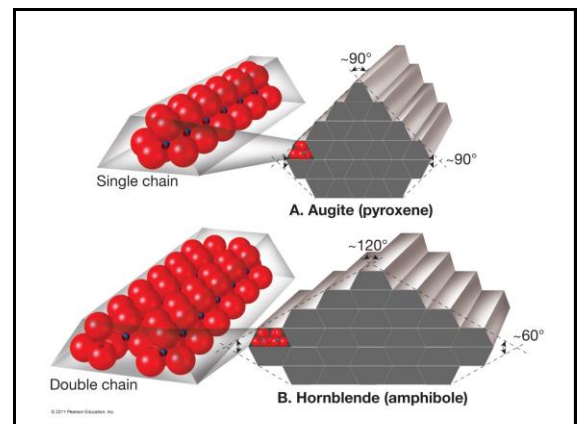


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Pyroxene group (Augite) ( $\text{Mg, Fe, SiO}_2$ )	Two planes at right angles	Single chains	
Amphibole group (Hornblende) $\text{Ca}_2(\text{Fe, Mg})_7\text{Si}_8\text{O}_{22}(\text{OH})_2$	Two planes at 60° and 120°	Double chains	

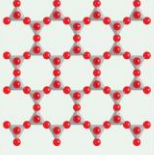


### Silicate Structures: Single And Double Chains of Tetrahedra

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## Silicate Structures: Sheets of Tetrahedra

	Mineral/Formula	Cleavage	Silicate Structure	Example
Micas	Biotite $\text{K(Mg,Fe)AlSi}_3\text{O}_{10}(\text{OH})_2$	One plane		 
	Muscovite $\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{OH})_2$			

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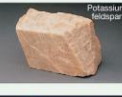

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## Micas Are Examples of Sheet Silicates



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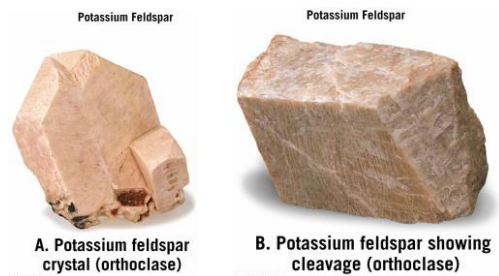
## Silicate Structures: Framework Silicates Comprised of Three-Dimensional Networks of Tetrahedra

	Mineral/Formula	Cleavage	Silicate Structure	Example
Feldspars	Potassium feldspar (Orthoclase) $\text{KAlSi}_3\text{O}_8$	Two planes at 90°		
	Plagioclase $(\text{Ca,Na})\text{AlSi}_3\text{O}_8$			
	Quartz $\text{SiO}_2$	None		

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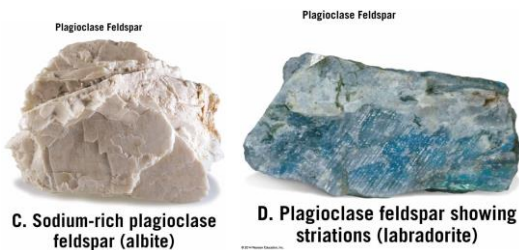
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## Feldspars Are Examples of Framework Silicates



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## Plagioclase Feldspar With Striations



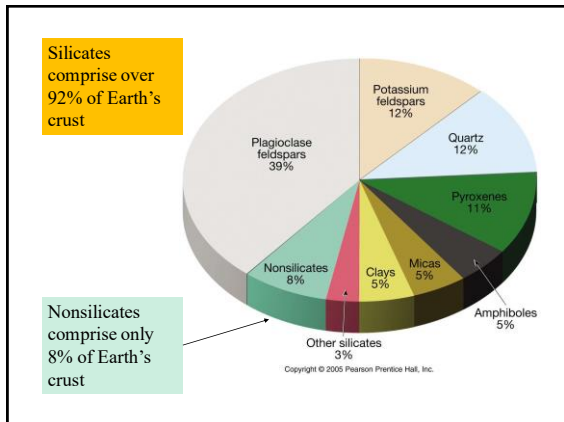
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Quartz Is A  
Common  
Framework  
Silicate



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### Nonsilicate Minerals

- Nonsilicate minerals do not have silicon in their chemical formula
- Many occur as economic ore deposits such as lead, zinc, copper, and mercury
- Some nonsilicates are used in construction material such as portland cement and plaster
- Other nonsilicates are utilized for/as drilling mud, fertilizer, electrical conductors, sulfad drugs, photography, and jewelry

Mineral Group	Mineral Name	Chemical Formula	Common Nonsilicate Mineral Groups	Examples
Carbonates	Calcite	$\text{CaCO}_3$	Carbonates	Marble, Limestone
Sulfates	Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	Sulfates	Plaster, Gypsum
Halides	Halite	$\text{NaCl}$	Halides	Rock Salt
Oxides	Hematite	$\text{Fe}_2\text{O}_3$	Oxides	Iron Ore
Sulfides	Pyrrite	$\text{FeS}_2$	Sulfides	Pyrite, Sulfur
Phosphates	Apatite	$\text{Ca}_5(\text{PO}_4)_3(\text{OH})$	Phosphates	Fertilizer
Nitrides	Silicon Nitride	$\text{Si}_3\text{N}_4$	Nitrides	Refractory
Organics	Opal	$\text{SiO}_2 \cdot n\text{H}_2\text{O}$	Organics	Jewelry

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### Carbonates

- Basic unit is the  $(\text{CO}_3)^{2-}$  complex
- There are different carbonate minerals depending on which cation is attached to the carbonate complex:

$$(\text{CO}_3)^{2-} + \text{cations}$$

- Two important carbonates:
  - Calcite  $[\text{CaCO}_3]$
  - Dolomite  $[\text{CaMg}(\text{CO}_3)_2]$

Calcite

Dolomite

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### Calcite Exhibits Double Refraction And Reacts With Dilute HCl

Refract

Double Refraction

Double R

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### Uses For Carbonate Minerals

Calcite  $\text{CaCO}_3$

Siderite  $\text{FeCO}_3$

Azurite  $\text{Cu}_3(\text{CO}_3)_2(\text{OH})_2$

Magnesite  $\text{MgCO}_3$

Dolomite  $(\text{Ca,Mg})\text{CO}_3$

Malachite  $\text{Cu}_2\text{CO}_3(\text{OH})_2$

Calcite  $\text{CaCO}_3$  Portland cement, lime

Dolomite  $\text{CaMg}(\text{CO}_3)_2$  Portland cement, lime

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### Oxides

- Cations are bonded to oxygen

$$\text{O}^{2-} + \text{cations}$$

- Two important oxides:
  - Hematite  $(\text{Fe}_2\text{O}_3)$
  - Magnetite  $(\text{Fe}_3\text{O}_4)$


Hematite

Magnetite

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**Some Economic Uses for Oxides**



**Hematite**  
 $\text{Fe}_2\text{O}_3$   
Iron ore minerals

**Magnetite**  
 $\text{Fe}_3\text{O}_4$   
Iron ore minerals

**Limonite**  
 $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$   
Iron ore minerals

**Corundum**  
 $\text{Al}_2\text{O}_3$   
Abrasives and gemstones

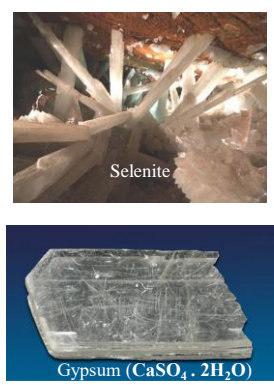
**Bauxite**  
 $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$   
Aluminum ore

Hematite	$\text{Fe}_2\text{O}_3$	Ore of iron, pigment
Magnetite	$\text{Fe}_3\text{O}_4$	Ore of iron
Corundum	$\text{Al}_2\text{O}_3$	Gemstone, abrasive
Ice	$\text{H}_2\text{O}$	Solid form of water

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**Sulfates**

- Sulfur is present as the sulfate ion ( $\text{SO}_4$ )<sup>2-</sup>
- ( $\text{SO}_4$ )<sup>2-</sup> + cations
- Two important sulfates:
  - Anhydrite ( $\text{CaSO}_4$ )
  - Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ )



**Selenite**

**Gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ )**

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**Uses For Sulfate Minerals**



**Anhydrite**  
 $\text{CaSO}_4$

**Gypsum**  
 $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

**Barite**  
 $\text{BaSO}_4$


**Celestite**  
 $\text{SrSO}_4$

Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	Plaster
Anhydrite	$\text{CaSO}_4$	Plaster
Barite	$\text{BaSO}_4$	Drilling mud

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**Sulfides**

- Many important ore deposits exist as sulfides
- $\text{S}^{2-}$  + cations
- Two important sulfides:
  - Pyrite ( $\text{FeS}_2$ )
  - Galena ( $\text{PbS}$ )




**Pyrite ( $\text{FeS}_2$ )**

**Galena ( $\text{PbS}$ )**

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**Sulfide Mineral Uses**



**Galena**  
 $\text{PbS}$

**Chalcopyrite**  
 $\text{CuFeS}_2$

**Sphalerite**  
 $\text{ZnS}$

**Molybdenite**  
 $\text{MoS}_2$

**Pyrite**  
 $\text{FeS}_2$

**Bornite**  
 $\text{Cu}_5\text{FeS}_4$

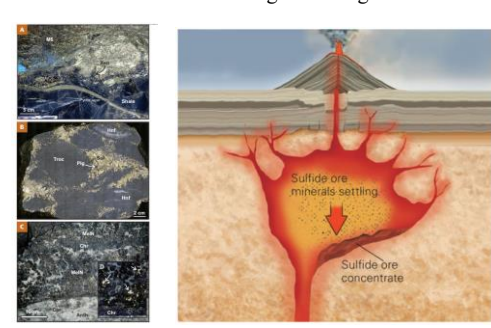
**Arsenopyrite**  
 $\text{FeAsS}$

**Stibnite**  
 $\text{Sb}_2\text{S}_3$

Galena	$\text{PbS}$	Ore of lead
Sphalerite	$\text{ZnS}$	Ore of zinc
Pyrite	$\text{FeS}_2$	Sulfuric acid production
Chalcopyrite	$\text{CuFeS}_2$	Ore of copper
Cinnabar	$\text{HgS}$	Ore of mercury

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**Sulfide Ore Minerals Settling In A Magma Chamber**



**Sulfide ore minerals settling**

**Sulfide ore concentrate**

Barnes et al. (2017)

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[illegible]

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Volcanogenic massive sulfide ore deposit at Kidd Mine, Ontario, Canada, formed 2.7 billion years ago on an ancient seafloor

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# Halides

- Generally form ionic bonds
- Some precipitate from salty water (seawater)
- Important halides:
  - Halite (NaCl)
  - Sylvite (KCl)
  - Fluorite (CaF<sub>2</sub>)



Halite (NaCl)




Sylvite (KCl)



Fluorite (CaF<sub>2</sub>)

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## Some Economic Uses For Halides




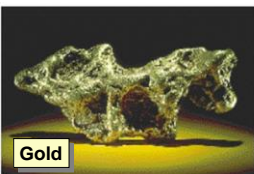

Four mineral samples are shown in a row. From left to right: a white, lustrous, irregularly shaped mineral; a cluster of small, translucent, pinkish-purple crystals; a cluster of yellowish, translucent, cubic crystals; and a reddish-orange, irregularly shaped mineral.

<b>Cryolite</b> $\text{Na}_3\text{AlF}_6$	<b>Fluorite</b> $\text{CaF}_2$	<b>Halite</b> $\text{NaCl}$	<b>Sylvite</b> <b>(KCl)</b>
--	-----------------------------------	--------------------------------	--------------------------------

Halite	$\text{NaCl}$	Common salt
Fluorite	$\text{CaF}_2$	Used in steelmaking
Sylvite	KCl	Fertilizer


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- Native Element Minerals are composed of only one element:
  - Graphite (C)
  - Diamond (C)
  - Copper (Cu)
  - Gold (Au)
  - Sulfur (S)




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## Native Element Uses




**Sulfur (S)**




**Diamond (C)**




**Graphite (C)**




**Gold (Au)**



**Silver (Ag)**



**Copper (Cu)**

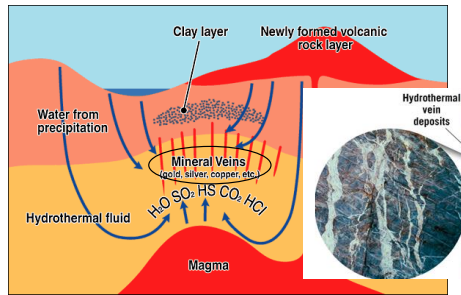


**Platinum (Pt)**

Gold	Au	Trade, jewelry
Copper	Cu	Electrical conductor
Diamond	C	Gemstone, abrasive
Sulfur	S	Sulfa drugs, chemicals
Graphite	C	Pencil lead, dry lubricant
Silver	Ag	Jewelry, photography
Platinum	Pt	Catalyst

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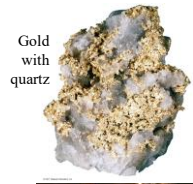
### Many Native Element Minerals Deposited In Veins Associated With Hydrothermal Fluids And Magma



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Native silver in hydrothermal vein



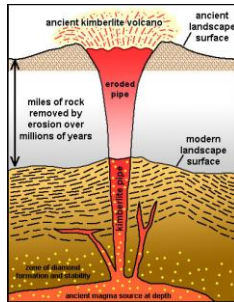
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### Diamonds From Kimberlite Pipes



Kimberlite pipes of South Africa contain diamonds originating at depths of at least 150 km (90 miles)



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Beryl Crystals



Australian Sapphires

Table 3.A Important Gemstones		
Gem	Mineral Name	Prized Hues
<b>Precious</b>		
Diamond	Diamond	Colorless, yellows
Emerald	Beryl	Greens
Opal	Opal	Brilliant hues
Ruby	Corundum	Reds
Sapphire	Corundum	Blues
<b>Semiprecious</b>		
Alexandrite	Chrysoberyl	Variable
Amethyst	Quartz	Purples
Cat's-eye	Chrysoberyl	Yellows
Chalcedony	Quartz (agate)	Banded
Citrine	Quartz	Yellows
Garnet	Garnet	Reds, greens
Jade	Jadeite or nephrite	Greens
Moonstone	Feldspar	Transparent blues
Peridot	Olivine	Olive greens
Smoky quartz	Quartz	Browns
Spinel	Spinel	Reds
Topaz	Topaz	Purples, reds
Tourmaline	Tourmaline	Reds, blue-greens
Turquoise	Turquoise	Blues
Zircon	Zircon	Reds

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