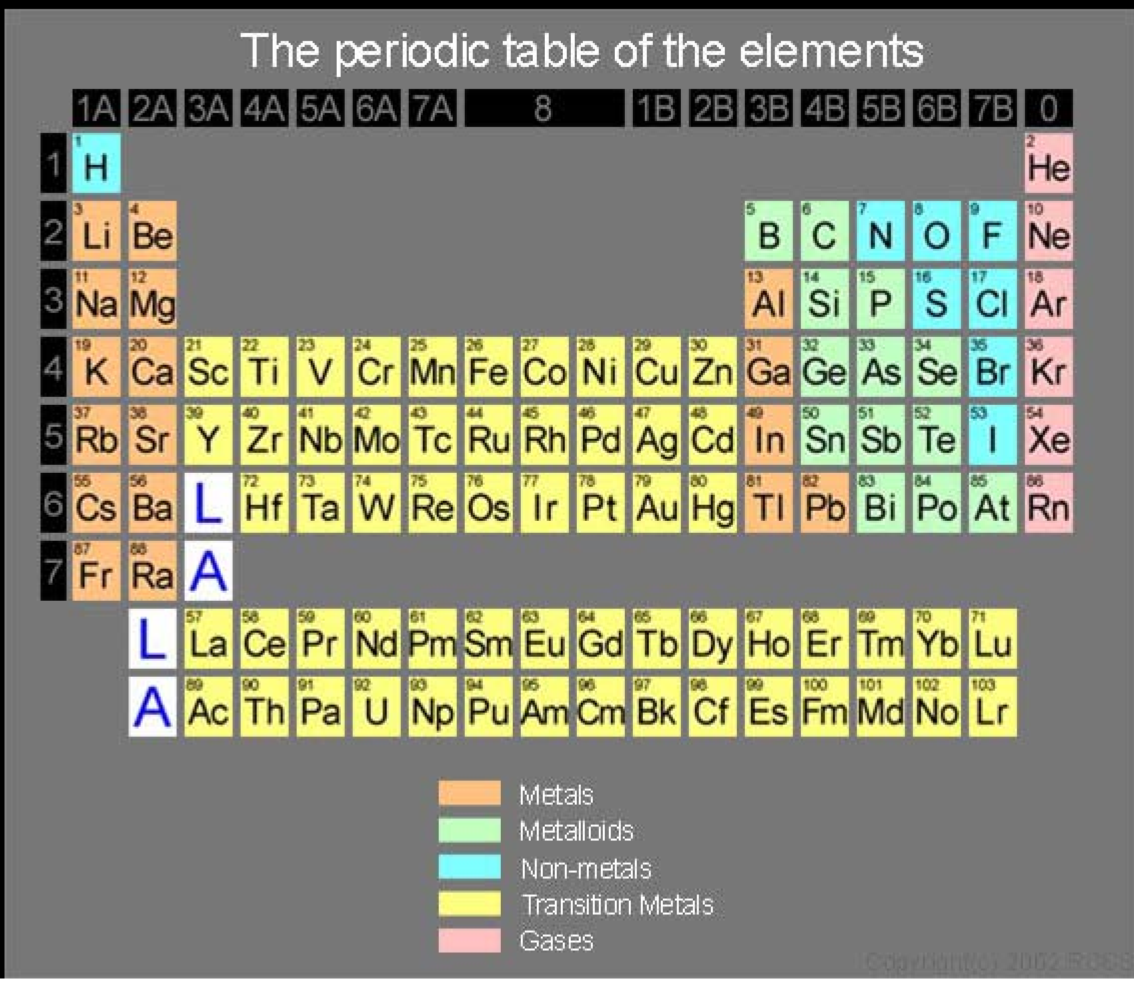
Dissipation of The Chemical Energy

First Stages

The Earth is Made Of . . . P 69

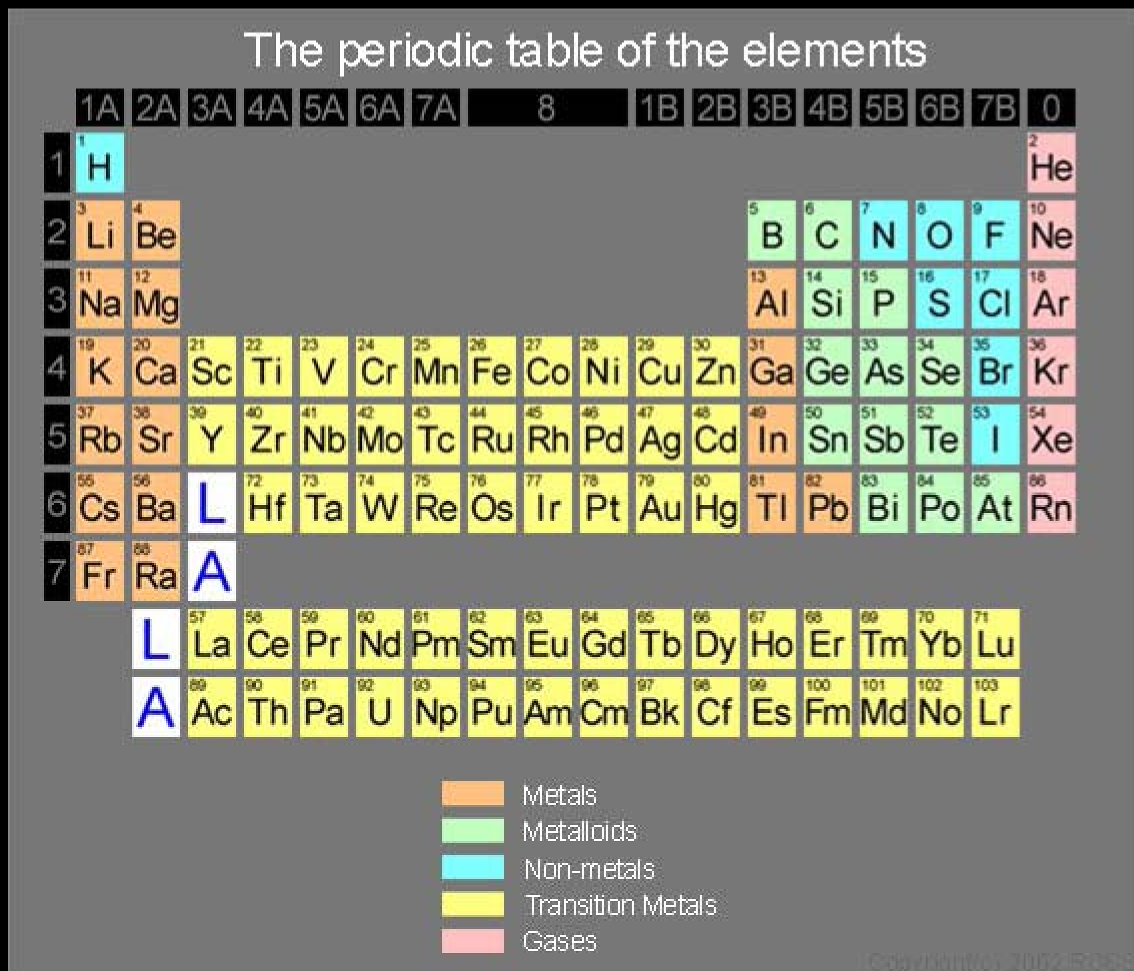
Question *Looking at the periodic table, and thinking about what you know already,*



Which elements do you think are the most abundant in the Earth's lithosphere?

THE EARTH IS MADE OF . . .

All 92 elements are found on Earth.



The Earth is Made Of . . .

All 92 elements are found on Earth.

But, most of these elements exist as compounds.

$NaCl$	**$CaCO_3$**	**SiO_4**	**$C_6H_{12}O_6$**
halite	*calcite*	*silica*	*sugar*

But, are there any major categories or divisions of compounds that make up the Earth?

The Earth is Made Of . . .

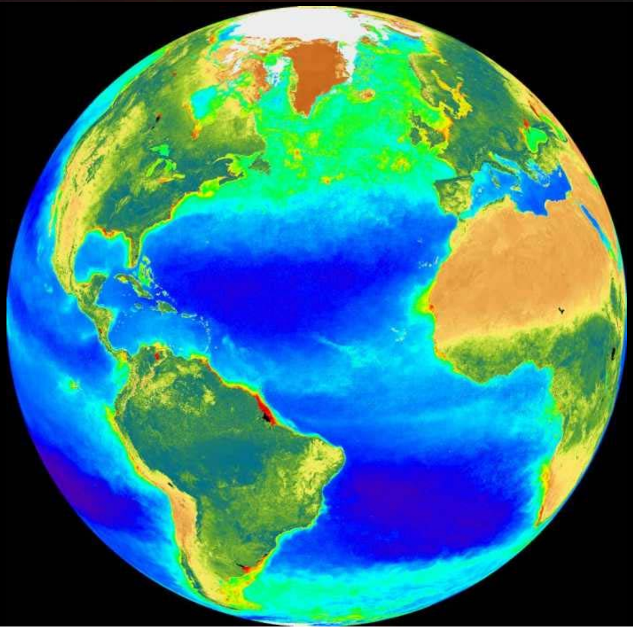
But, are there any major categories of compounds that make up the Earth?

- Atmosphere/Hydrosphere

N_2
O_2
CO_2

Oceans, rivers, lakes, etc.

H_2O



THE EARTH IS MADE OF . . .

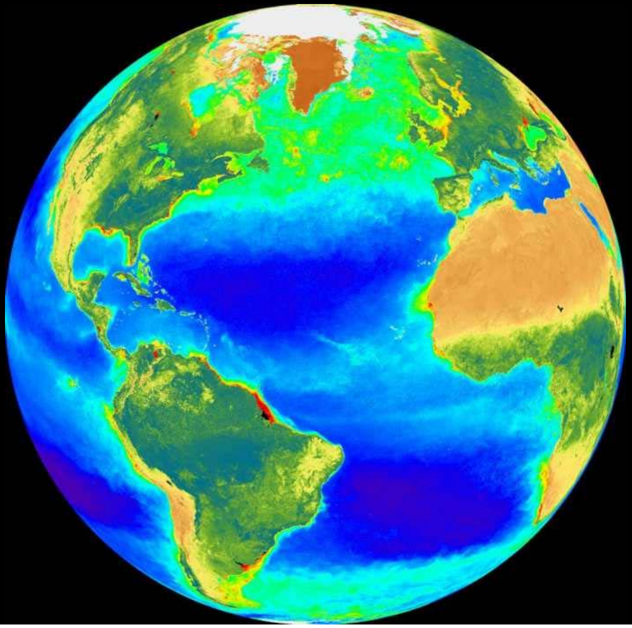
But, are there any major categories of compounds that make up the Earth?

- Atmosphere/Hydrosphere

N_2
O_2
CO_2

Oceans, rivers, lakes, etc.

H_2O

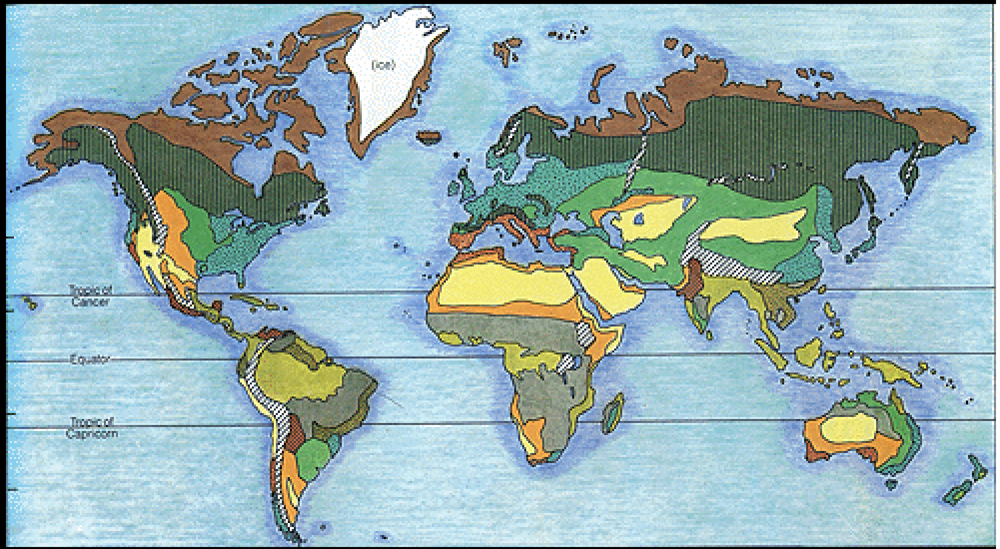


The Earth is Made Of . . .

But, are there any major categories of compounds that make up the Earth?

- **Biosphere**

The earth is a living planet



The distribution of different biomes on Earth

But, what is life made of?

C - carbon

H - hydrogen

N - nitrogen

In the form of amino acids, nucleic acids, fats, and sugars.

THE EARTH IS MADE OF . . .

But, are there any major categories of compounds that make up the Earth?

- Biosphere

The earth is a living planet

But, what is it made of?

C - carbon

H - hydrogen

N - nitrogen

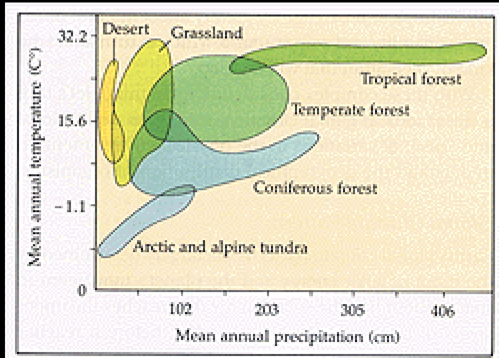


FIGURE 46.3
A climograph for some major North American biomes. The areas plotted here encompass the annual mean temperatures and precipitation occurring in some major North American biomes. The climograph provides only circumstantial evidence, however, that these factors are important in explaining the distribution of the biomes. The areas of overlap, for example, show that these variables alone are not sufficient to explain the observed distribution.

The distribution of different biomes on Earth

In the form of amino acids, nucleic acids, fats, and sugars.

The Earth is Made Of . . .

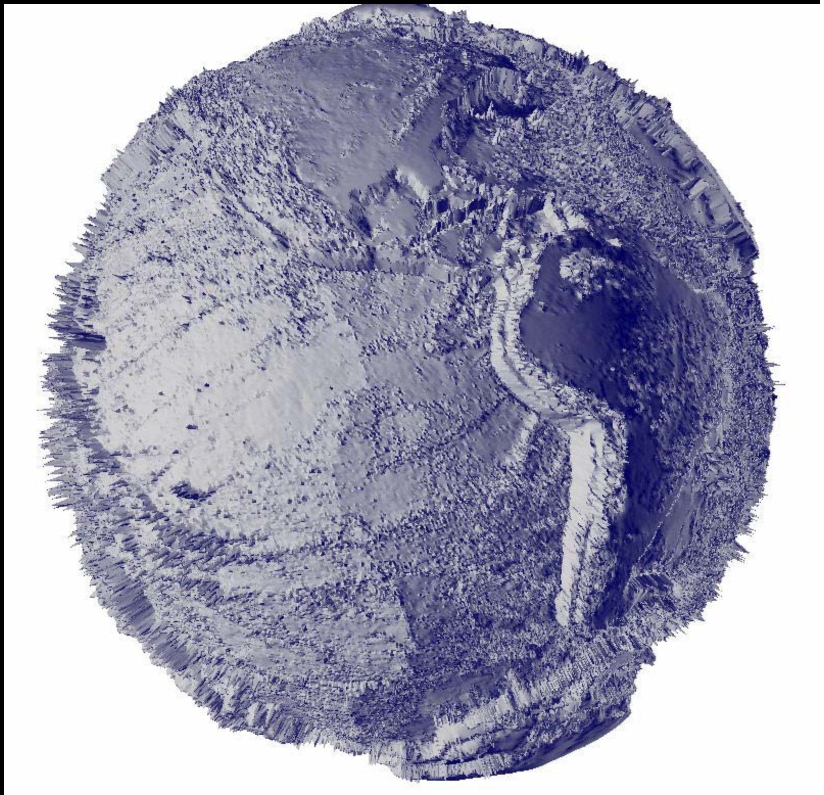
So far, between the atmosphere, hydrosphere, and biosphere, we have taken up only 4 or 5 of the 92 naturally occurring elements.

Where are the remaining 88?

They make up the

Lithosphere

The Solid Stuff of the Earth



http://www.reliefglobe.com/

The Earth is Made Of . . .

So . . . What is the lithosphere made of?

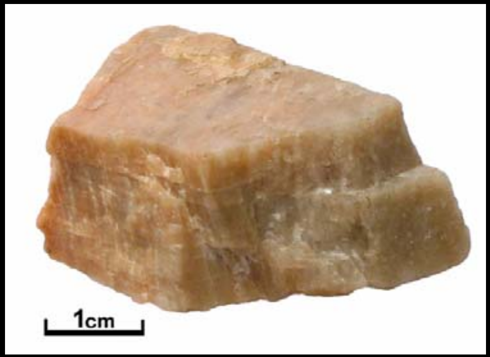
Well, lots of stuff.

Like rocks . . .

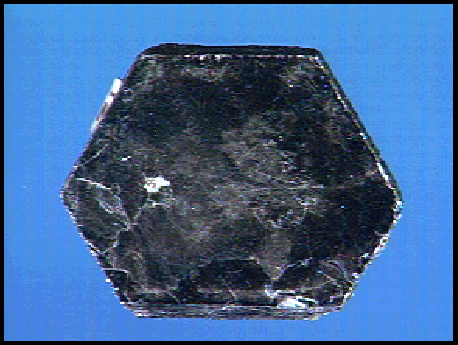
THE EARTH IS MADE OF . . .

So . . . What is the lithosphere made of?

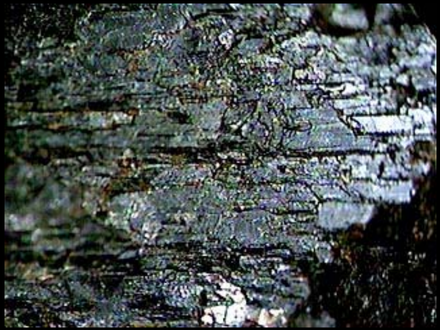
And the rocks are made of minerals, like . . .



orthoclase



biotite



amphibole

quartz

corundum

diamond

The Earth is Made Of . . .

So . . . What is the lithosphere made of?

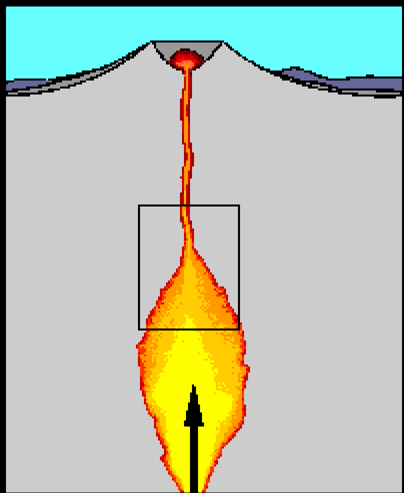
But minerals do not have to be bright and shiny.

But, of the 3000+ known minerals only about a dozen are abundant.

ROCK FORMING MINERALS

Magma

And the Igneous Rock Forming Minerals



Lava

~ 4.5 Ga ~ 4.5 Ga ~ 4.5 Ga

At ~4.5 Ga the Earth-Moon collision provided enough energy to melt them and begin their physical evolution.

~ 4.2 Ga ~ 4.2 Ga ~ 4.2 Ga

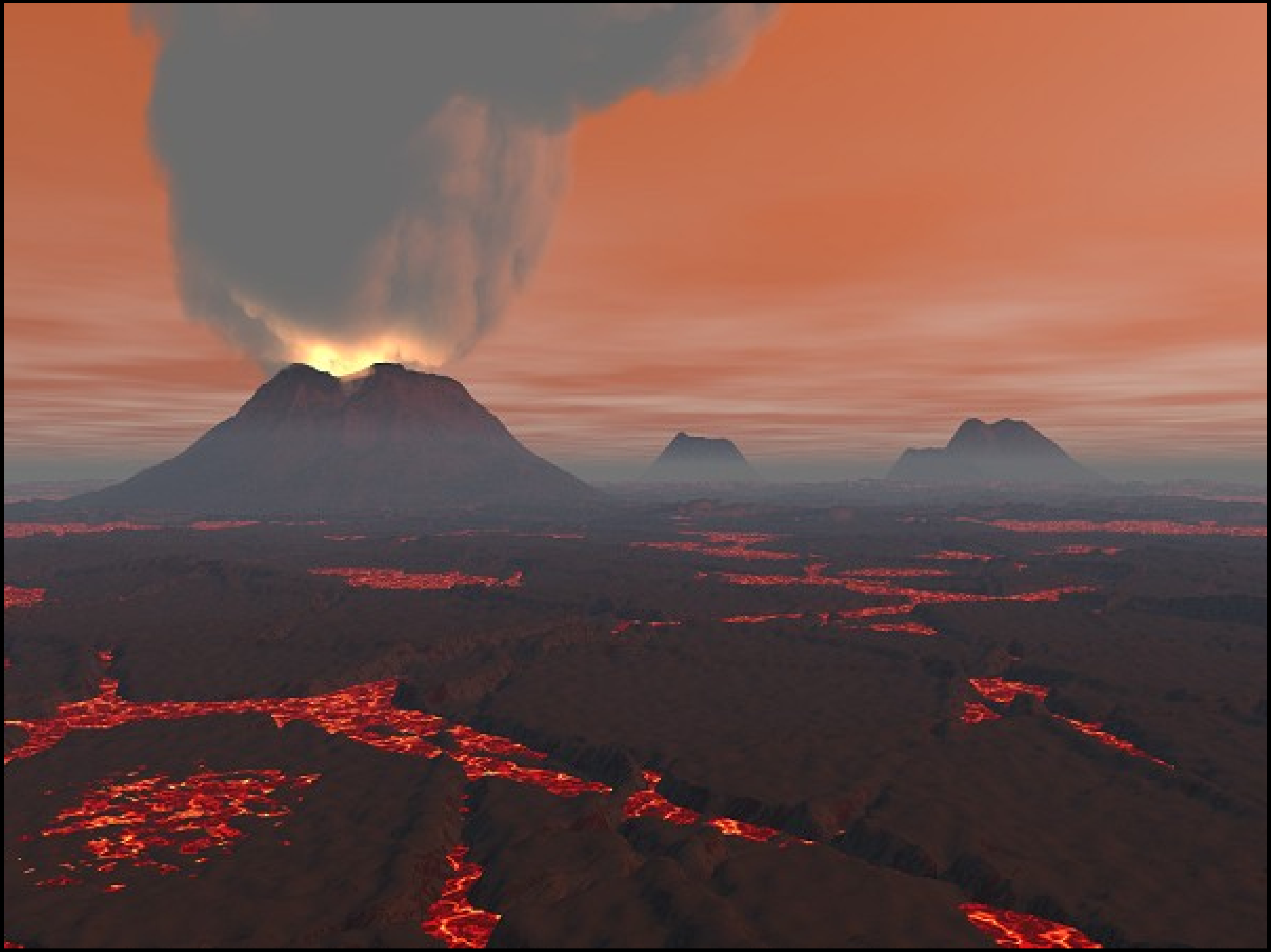
Earth About 4.2 billion years ago

Still molten hot, without water or life, being bombarded continuously by meteorites.

http://www.gps.caltech.edu/~mjwillis/research/bugbuster.html

~ 4.2 Ga ~ 4.2 Ga ~ 4.2 Ga

Infant Earth *The Earth as it may have appeared four+ billion years ago.*



http://www.arcadiastreet.com/cgvistas/earth_010.htm

P 76

Abundance of Elements That Form the Earth's Lithosphere

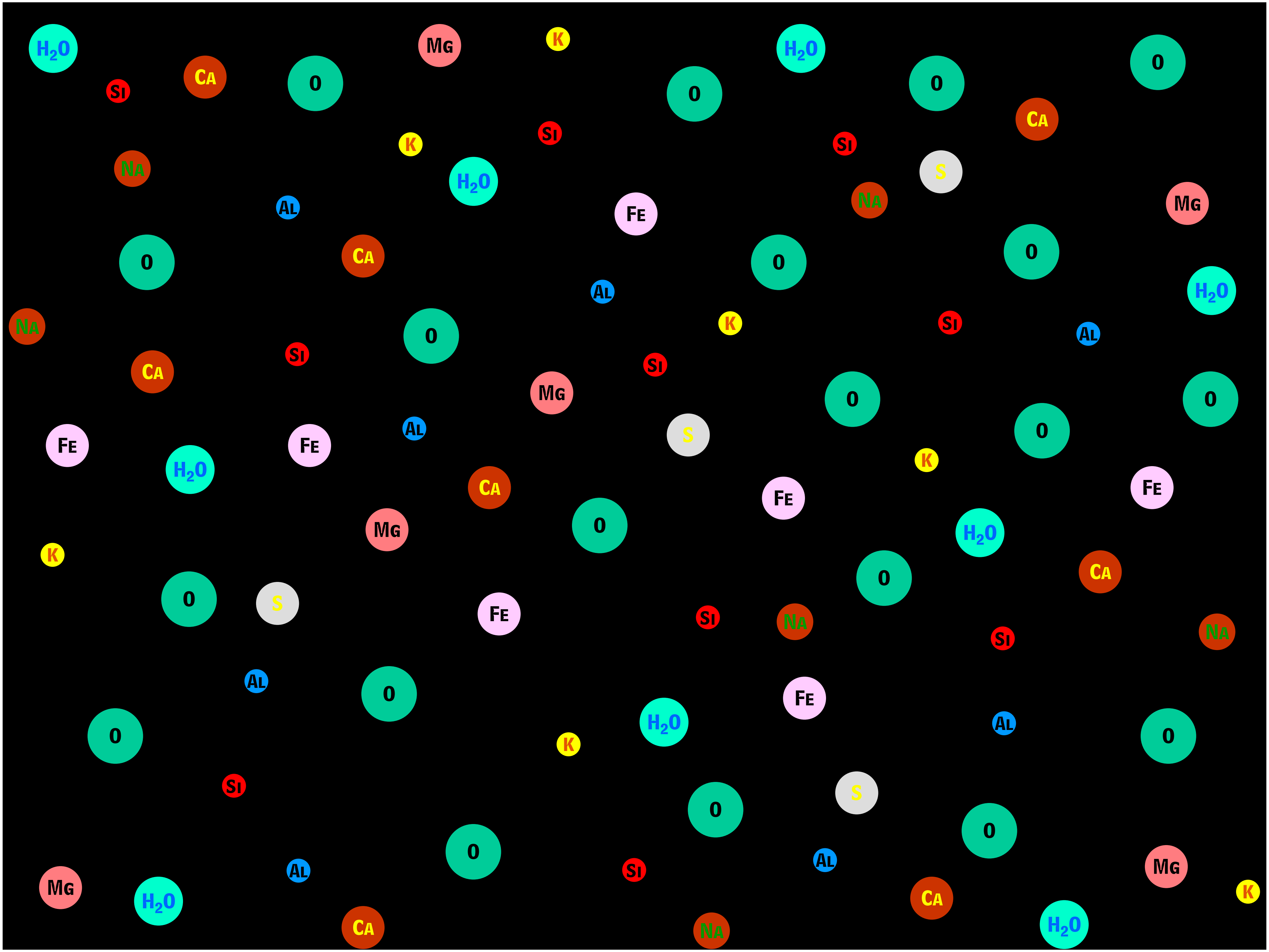
Element	Symbol	Atomic Number	Size (Angstroms)		Atomic Charge	Atomic Weight	Proportions in Earth	
			Atom	Ion			% Volume	% Weight
Oxygen	O	6	0.60	1.40	O^{--}	15.99	93.77	46.6
Silicon	Si	14	1.17	0.43	Si^{++++}	28.08	.86	27.72
Aluminum	Al	13	1.43	0.51	Al^{+++}	26.98	.47	8.13
Iron	Fe	26	1.24	0.74 0.64	Fe^{++} Fe^{+++}	55.87	.43	5.00
Calcium	Ca	20	1.96	0.99	Ca^{++}	40.08	1.03	3.60
Sodium	Na	11	1.86	0.97	Na^{+}	22.99	1.32	2.80
Potassium	K	19	2.31	1.35	K^{+}	39.09	1.83	2.59
Mag-nesium	Mg	12	1.60	.66	Mg^{++}	55.93	.30	1.10

Magma

14-1600°C

A Swirling Mass of Ionized Elements

And as the Temperature Drops These Cations and Anions Begin to Chemically Bond


K
Mg
H_2O
H_2O
O
Ca
O
O
Si
O
Ca
Si
K
Si
Na
S
H_2O
Na
Mg
Al
Fe
O
Ca
O
O
H_2O
Al
K
Si
Na
Al
O
Si
Si
Ca
Mg
O
O
Al
O
S
Fe
Fe
K
H_2O
Ca
Fe
Fe
O
Mg
H_2O
K
Ca
O
O
S
Fe
Si
Na
Na
Si
Al
O
Fe
H_2O
Al
O
O
K
Si
S
O
O
O
Al
Mg
Si
Al
Mg
K
Ca
H_2O
H_2O
Ca
Na

The Silica Tetrahedron And Covalent Bonding

P 70

Silicon has 4 valence electrons

Oxygen has 6 valence electrons

1st four in green

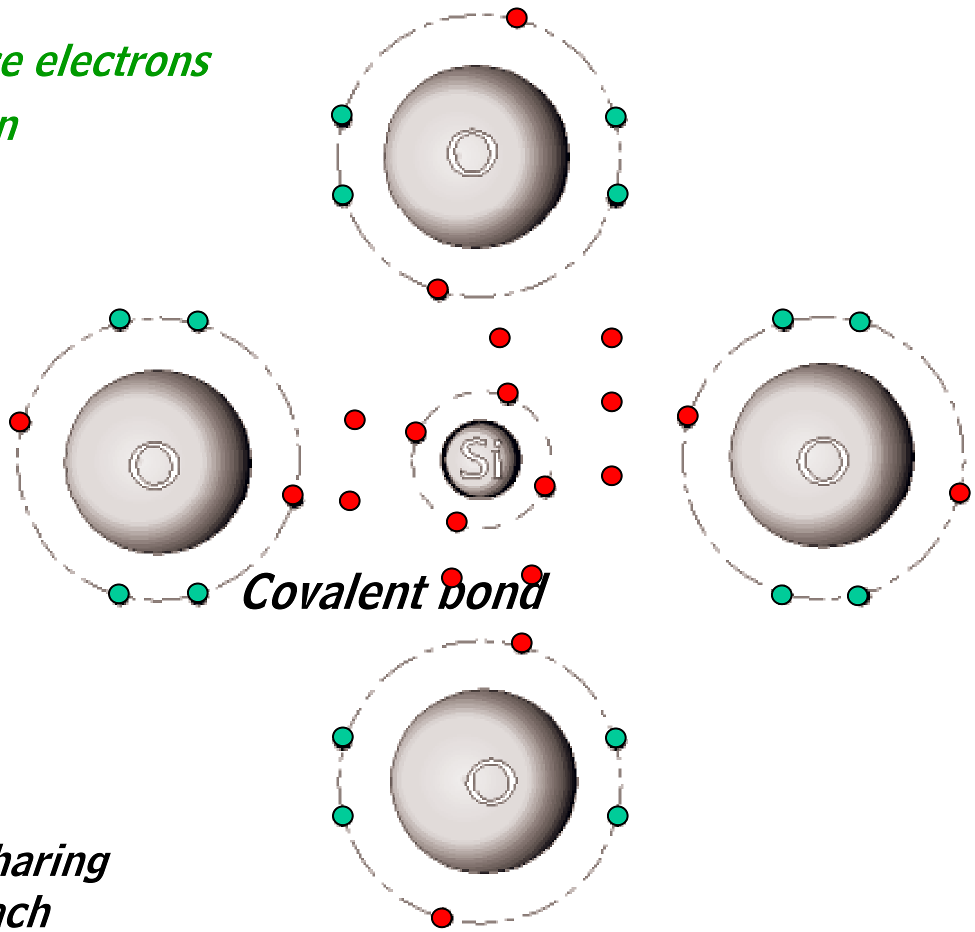
Last 2 in red

Same is true for other 3 oxygens

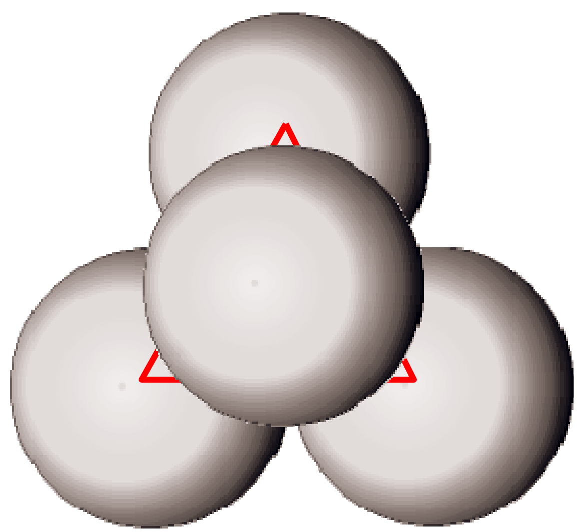
To satisfy the octet rule silicon must pick up 4 additional electrons.

(And oxygen 2)

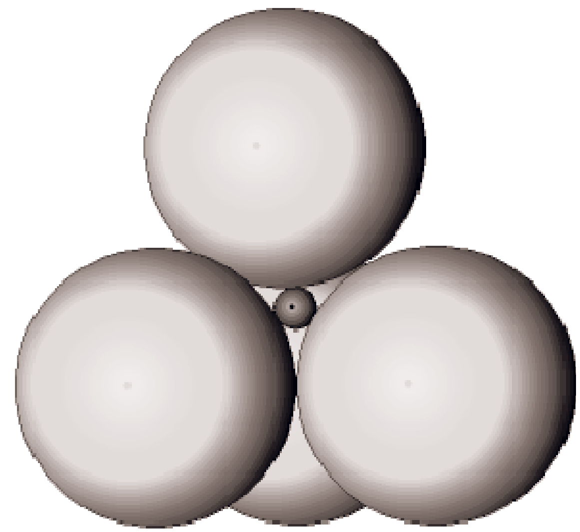
Silicon does so by sharing one electron with each oxgyen.



Geometry of The Silica Tetrahedron



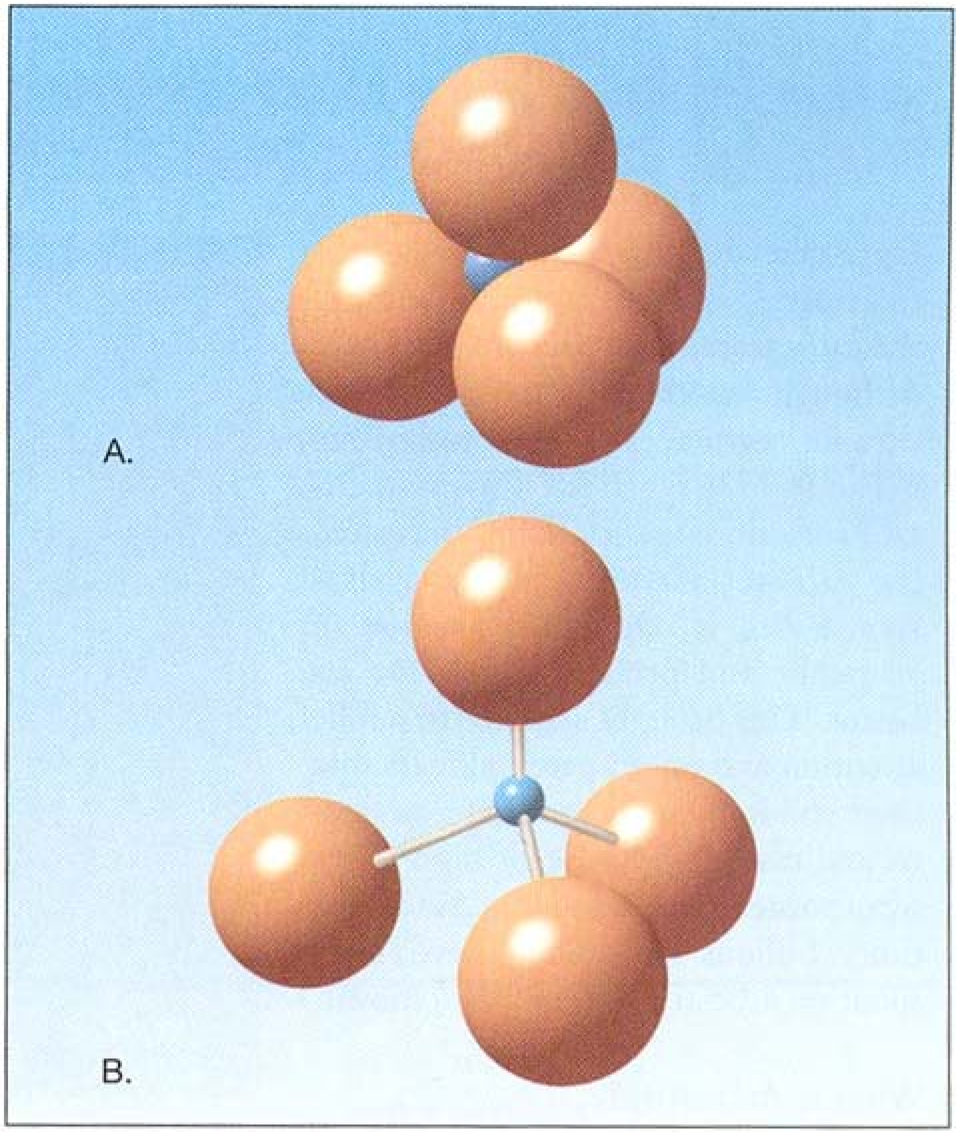
Top View

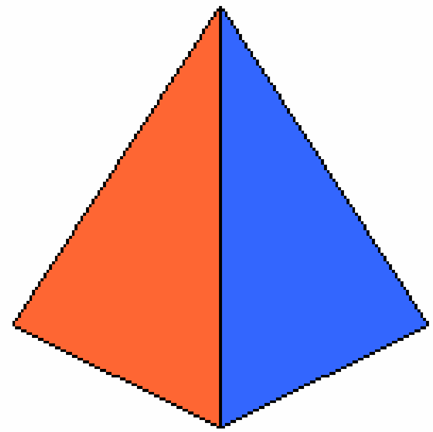


Side View

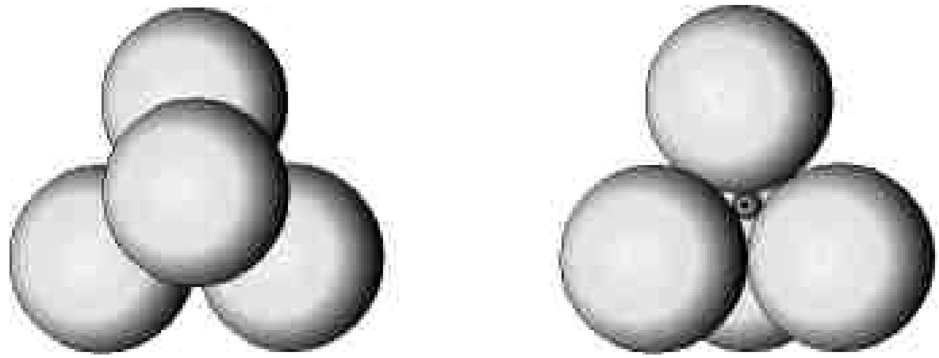
SiO_4^{-4}

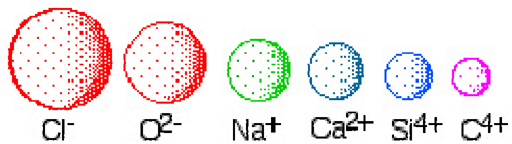
The Silica Tetrahedron



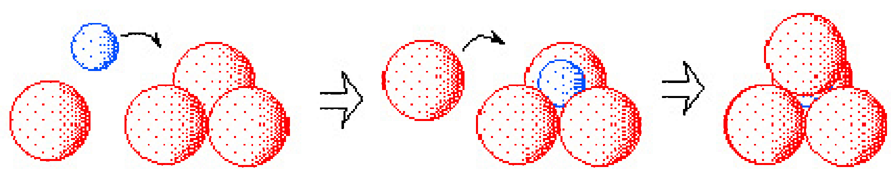


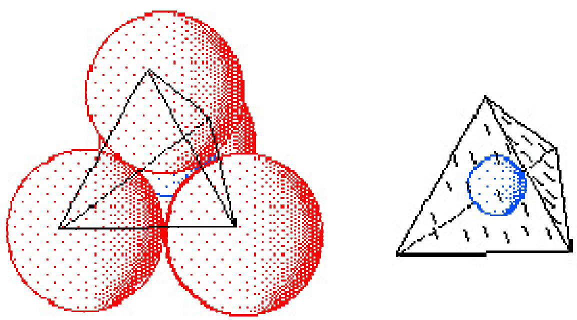
The Silica Tetrahedron





Constructing a single siilca tetrahedron:

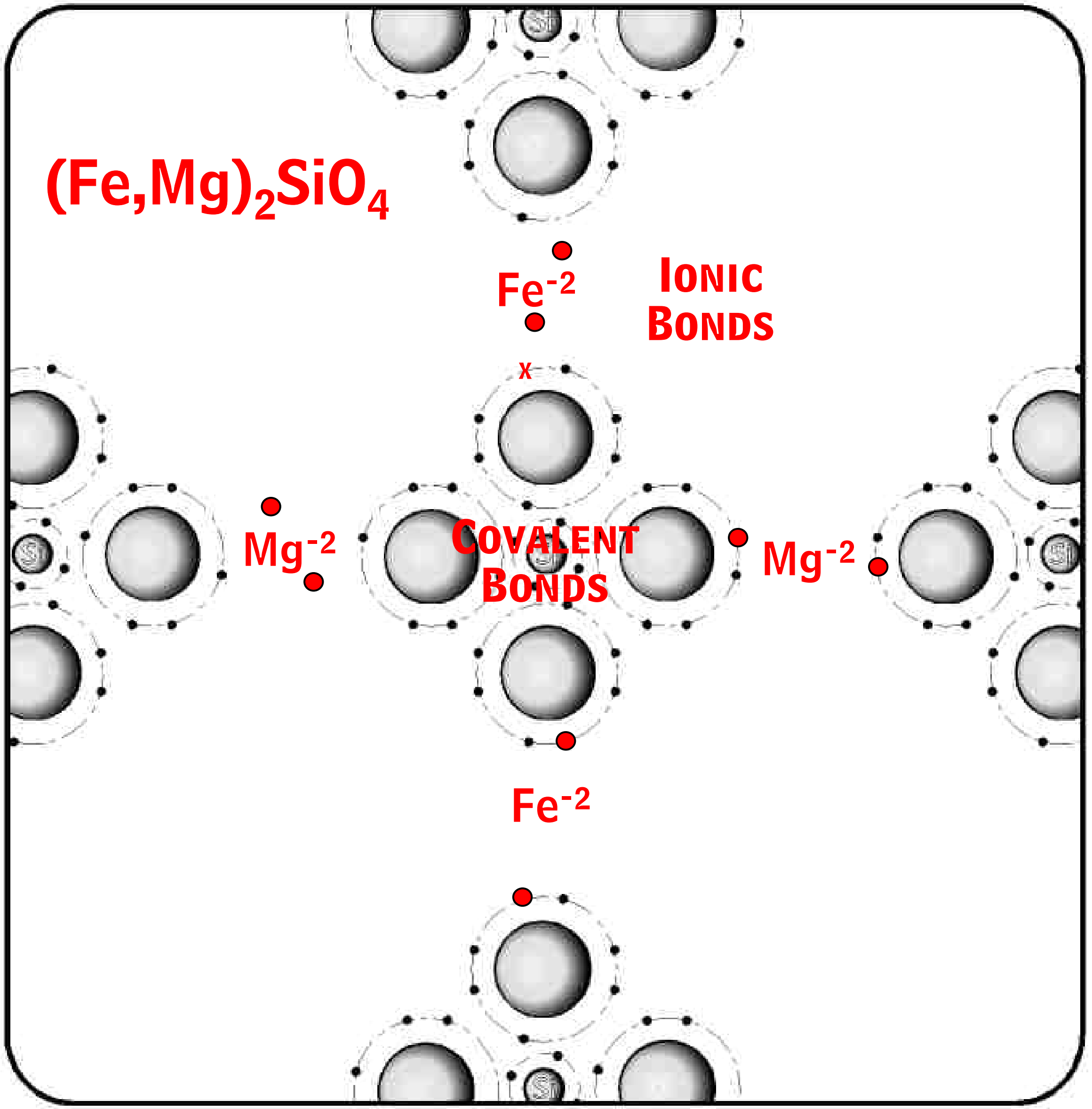




SiO_4^{4-}

OLIVINE

The first and Highest Temperature Forming

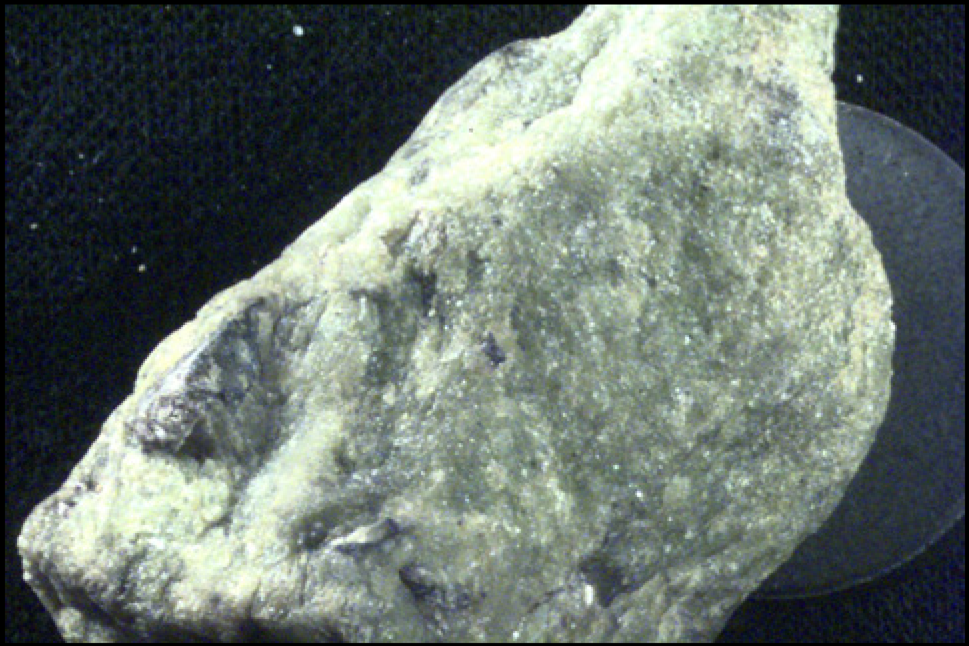


Olivine

The first and Highest Temperature Forming

Properties

- Crystals grows outward in all directions, from innumerable seeds scattered everywhere in the magma and so are granular shaped.
- Crystal structure has no planes of weakness so there is no cleavage.
- Olive green color (after olives) is distinctive.



The Reaction Principle

- Minerals (and rocks, and in fact everything else) are stable only under the conditions at which they form.
- Olivine forms at high temperatures, and is only stable at those temperatures.
- That is obvious if you raise the temperature – olivine will melt.
- Not quite so obvious if you lower the temperature . . . But . . . .

The Reaction Principle

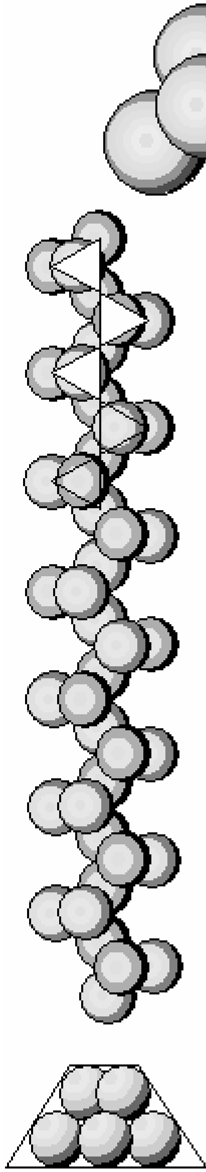
- In a cooling magma once the temperature falls below the stability range for olivine it reacts with the melt.
- That is it dissolves back into the melt and recrystallizes to form a crystal structure and mineral stable at the lower temperatures.

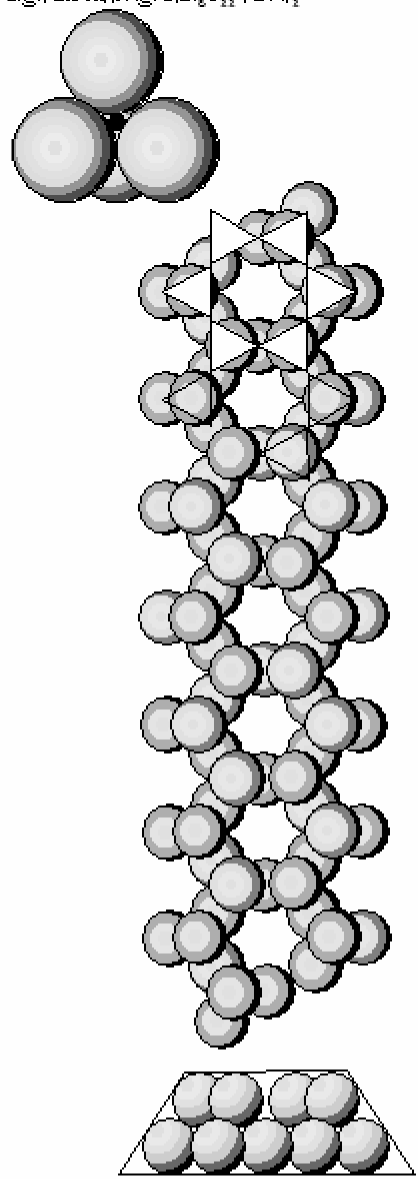
This is a fractionation process

The Mafic Minerals
Pyroxene and Amphibole

Pyroxene: Complex Silicates, e.g. $(CaNa)(MgFe)Si_2O_6$

Amphibole: Complex Silicates; e.g. $(CaNa)(MgFe)Si_8O_{22}$-$(OH)_2$



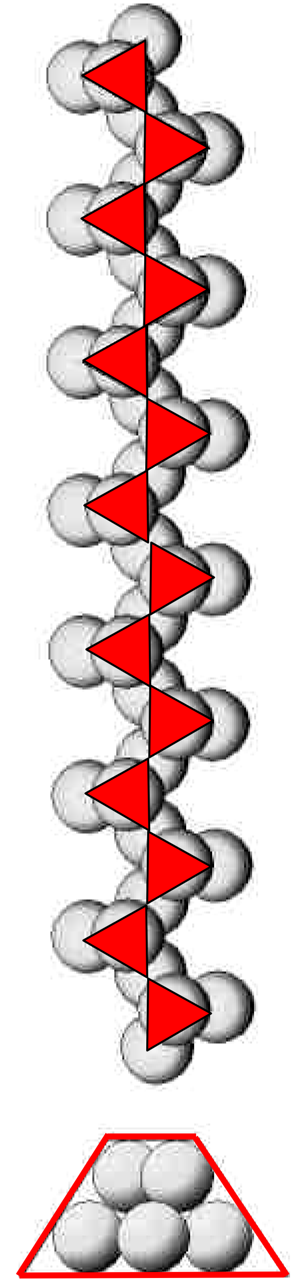


Pyroxene

Single Chain Silicates

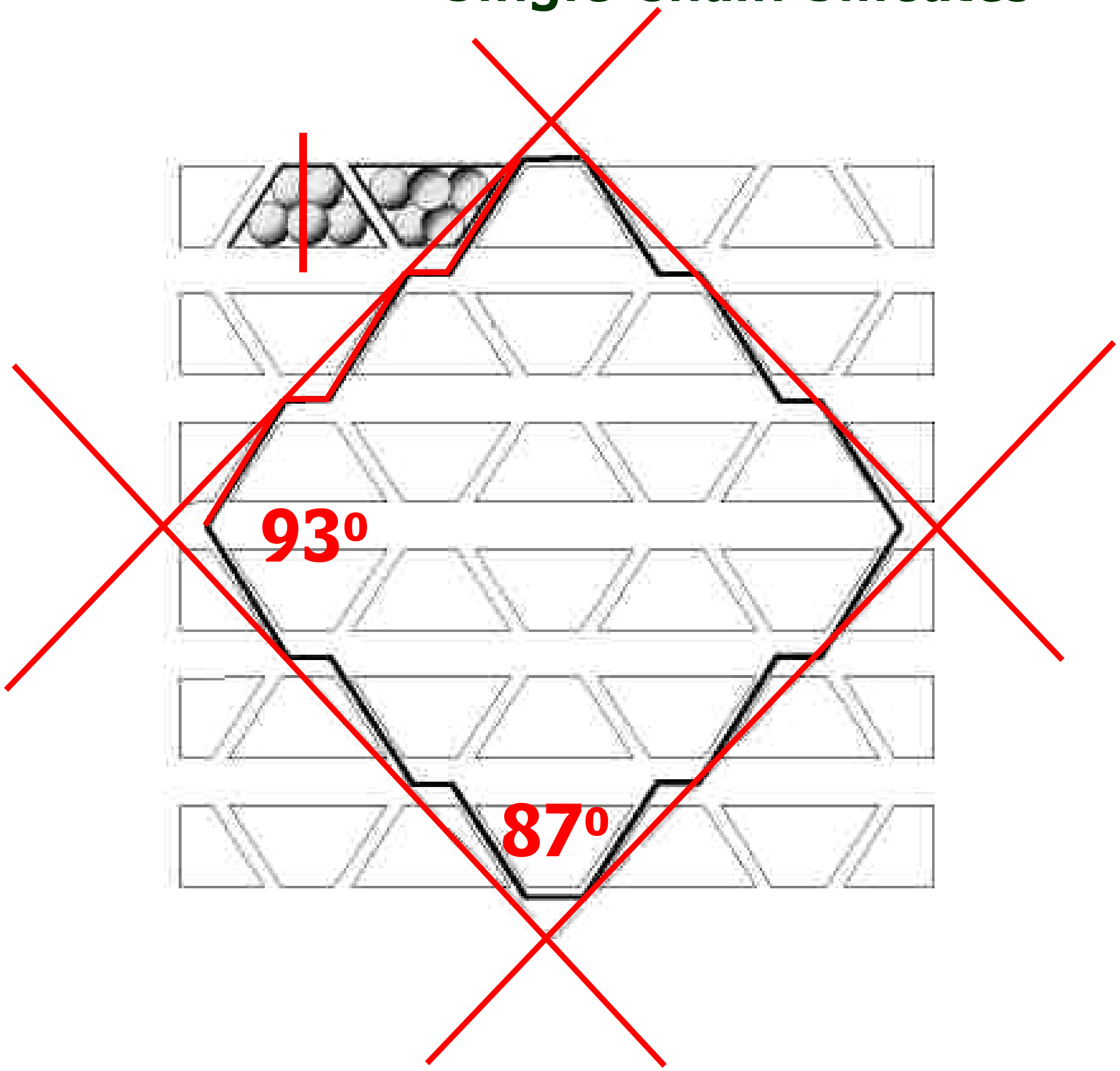
As the temperature in the melt declines isolated silica tetrahedra begin to join together – they polymerize.

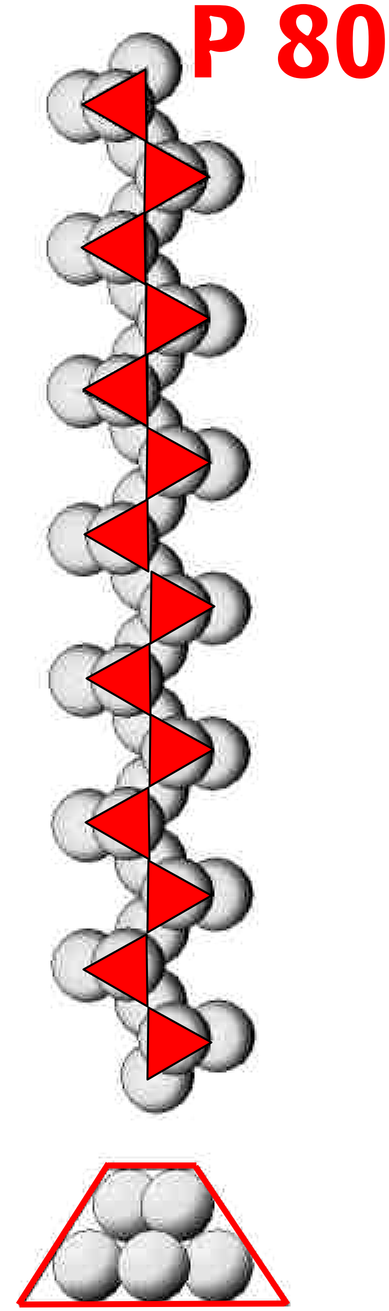
Polymerization - a chemical reaction in which two or more small molecules combine to form larger molecules that contain repeating structural units of the original molecules



PYROXENE

Single Chain Silicates





$(CaNa)(MgFe)Si_2O_6$

PYROXENE

The Second Highest Temperature Forming

Properties

- Single tetrahedra chains held together by Ca, Na, Fe, and Mg.
- Chain stacking creates an 87° and 93° prismatic cleavage with fracturing across third direction.
- Typically dull, dark, greenish-black.
- Crystals are often stubby

Pyroxene
The Second Highest Temperature Forming

Properties

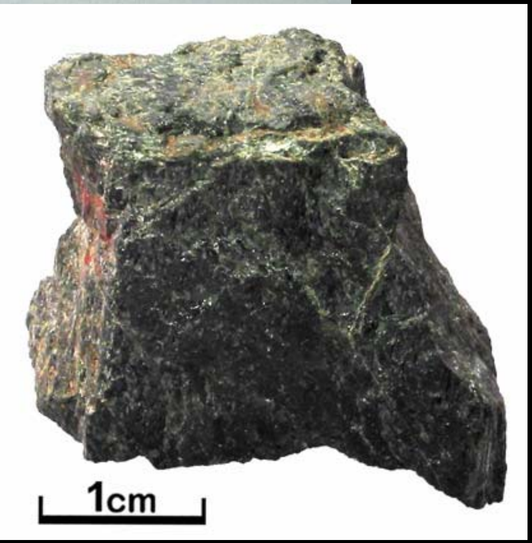
- Single tetrahedra chains held together by Ca, Na, Fe, and Mg.
- Chain stacking creates an 87° and 93° prismatic cleavage with fracturing across third direction.
- Typically dull, dark, greenish-black.
- Crystals are often stubby

Pyroxene

The Second Highest Temperature Forming

Properties

- Single tetrahedra chains held together by Ca, Na, Fe, and Mg.
- Chain stacking creates an 87° and 93° prismatic cleavage with fracturing across third direction.
- Typically dull, dark, greenish-black.
- Crystals are often stubby



Pyroxene

The Second Highest Temperature Forming

Properties

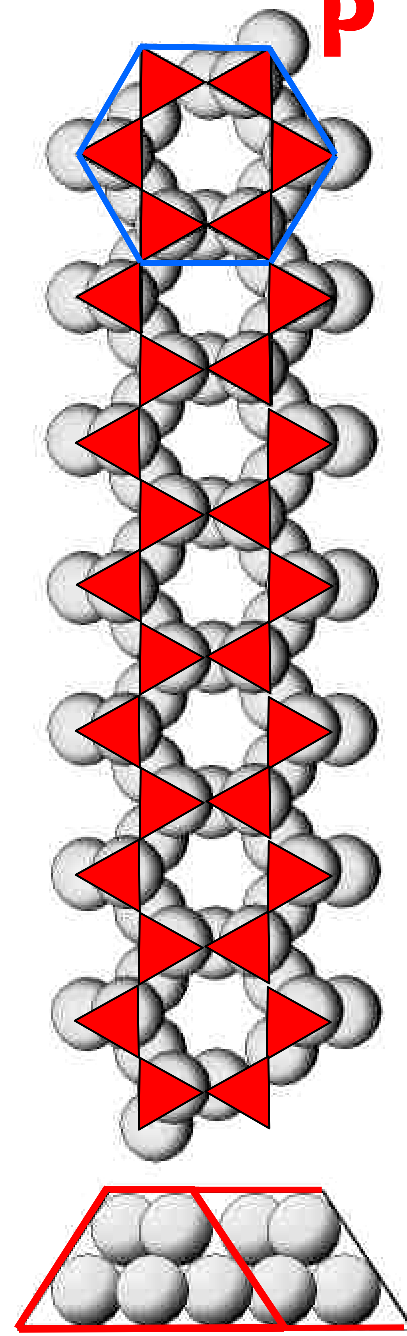
- Often pyroxene shows no cleavage at all.

AMPHIBOLE

Double Chain Silicates

P 79

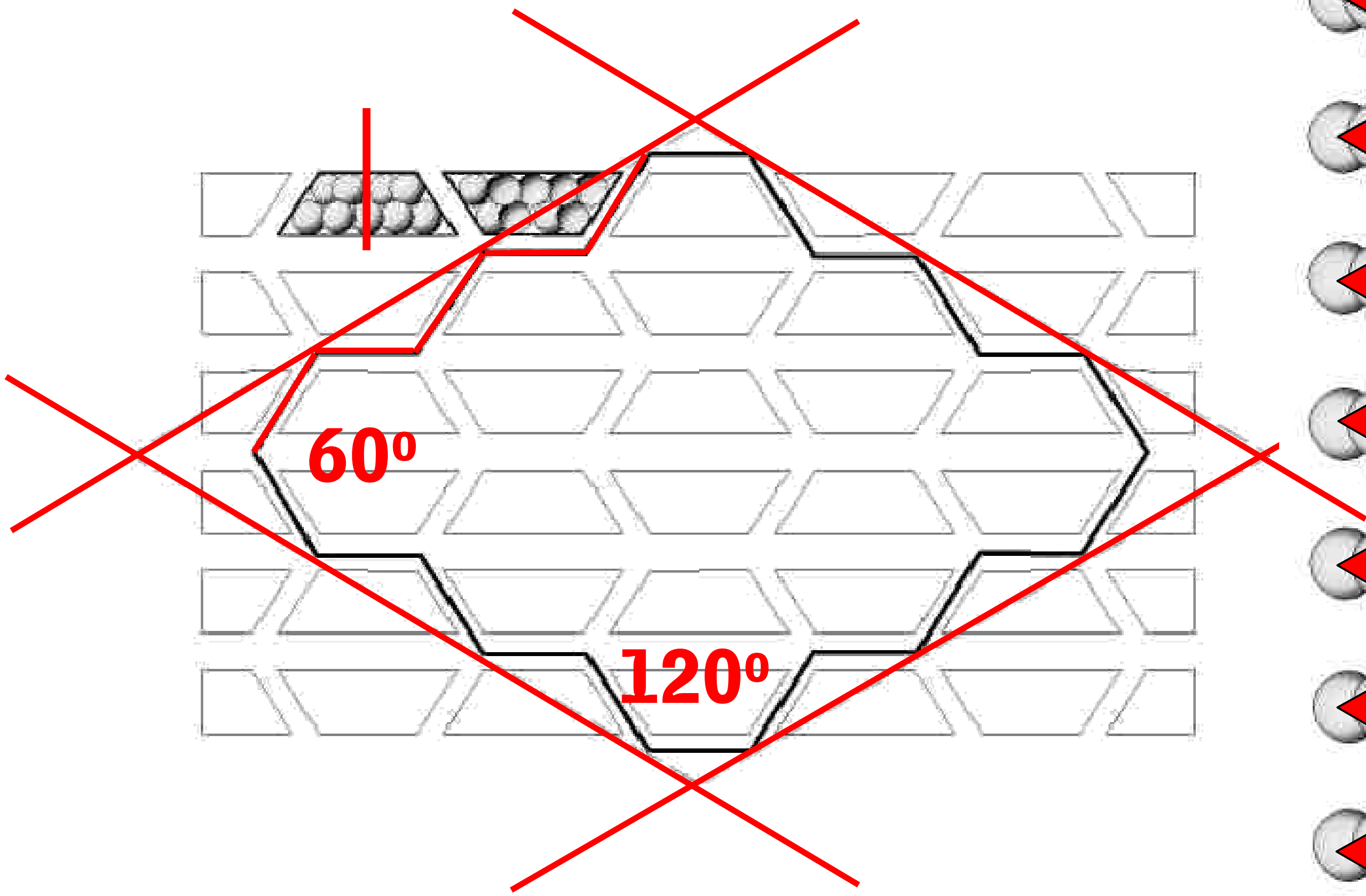
As the temperature in the melt declines even further the single chains of tetrahedra pyroxene react with the melt and join to form double chains.

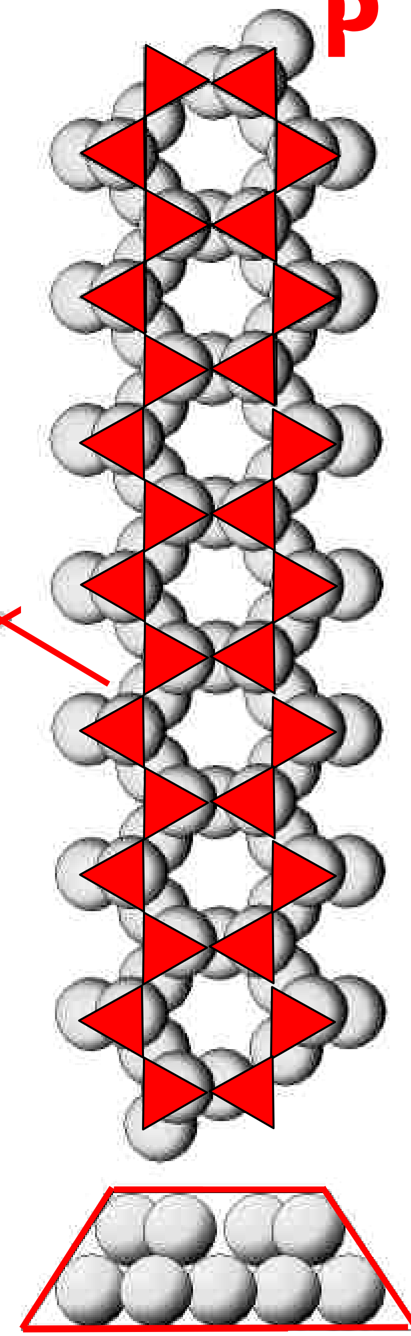


Amphibole

Double Chain Silicates

P 80



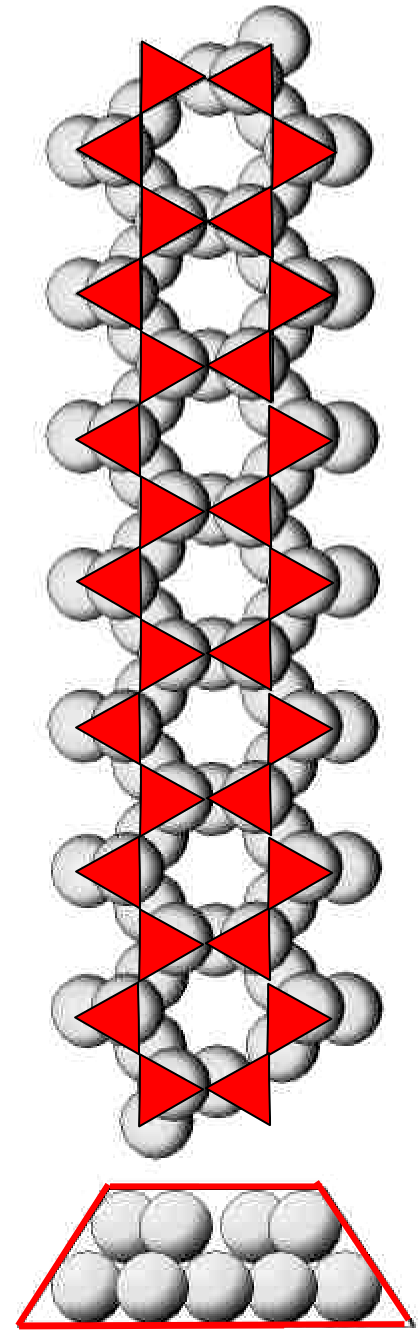


$(CaNa)(MgFe)Si_8O_{22} - (OH)_2$

Amphibole

Double Chain Silicates

As the temperature in the melt declines even further the single chains of tetrahedra pyroxene react with the melt and join to form double chains.



Amphibole

The Third Highest Temperature Forming

Properties

- Double tetrahedra chains held together by Ca, Na, Fe, and Mg.
- Chain stacking creates an 60° and 120° prismatic cleavage with fracturing across third direction.
- Typically shiny, black.
- Crystals are often elongate.
- Surface typically broken by lineations running length of crystal (these are the 60-120 cleavages coming to the surface.

Amphibole

The Third Highest Temperature Forming

Properties

- Double tetrahedra chains held together by Ca, Na, Fe, and Mg.
- Chain stacking creates an 60º and 120º prismatic cleavage with fracturing across third direction.
- Typically shiny, black.
- Crystals are often elongate.
- Surface typically broken by lineations running length of crystal (these are the 60-120 cleavages coming to the surface.

AMPHIBOLE

The Third Highest Temperature Forming

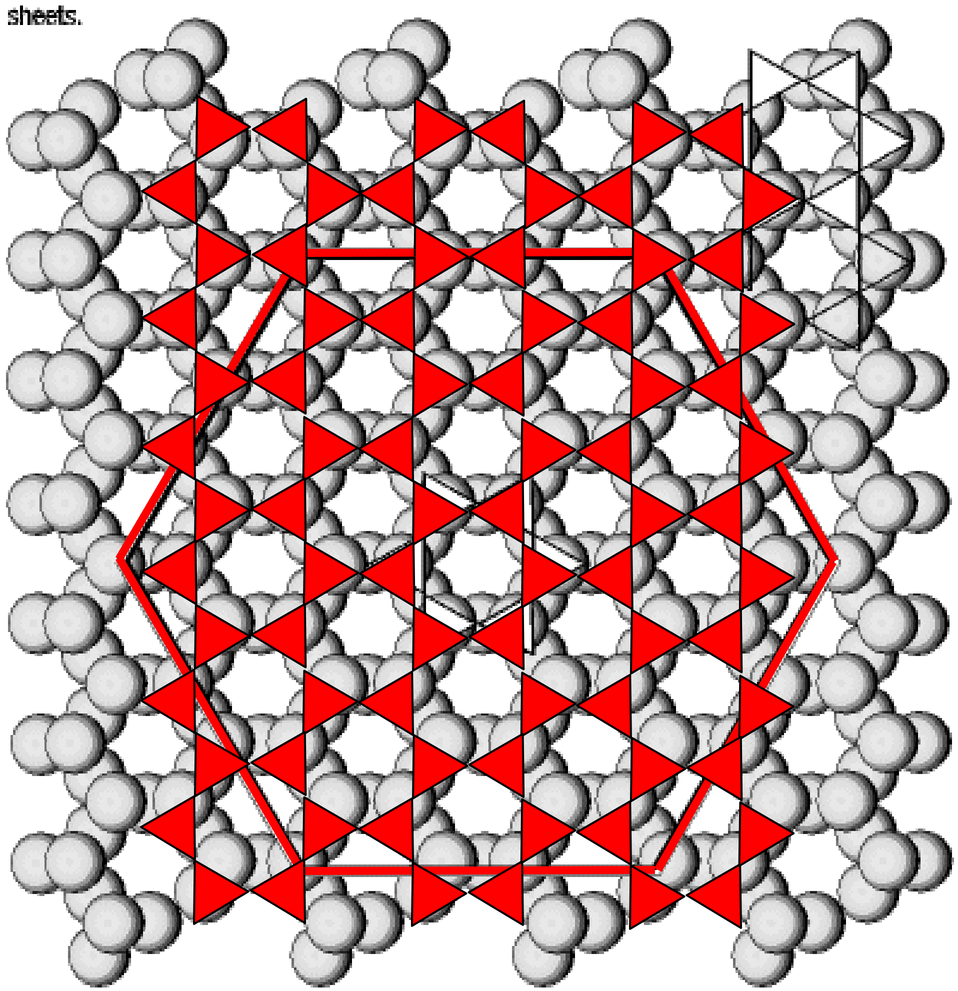
Properties

- Double tetrahedra chains held together by Ca, Na, Fe, and Mg.
- Chain stacking creates an 60° and 120° prismatic cleavage with fracturing across third direction.
- Typically shiny, black.
- Crystals are often elongate.
- Surface typically broken by lineations running length of crystal (these are the 60-120 cleavages coming to the surface.

Biotite

Sheet Silicates

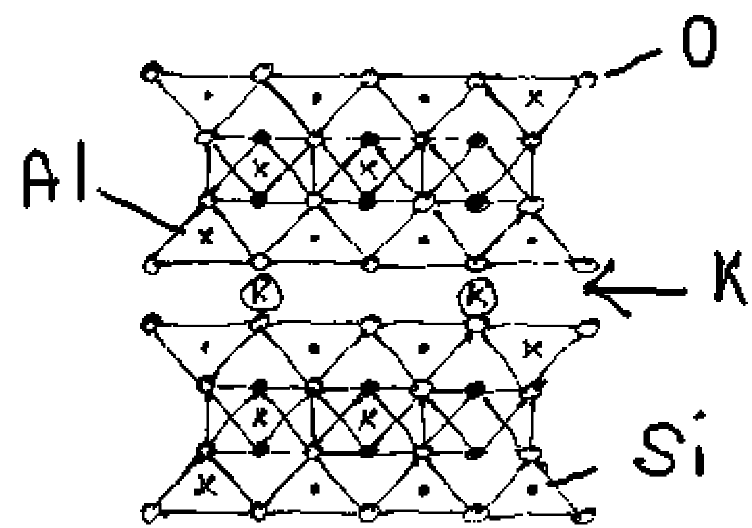
Now the double chains join together to form sheets.



Biotite

Sheet Silicates

Now the double chains join together to form sheets.

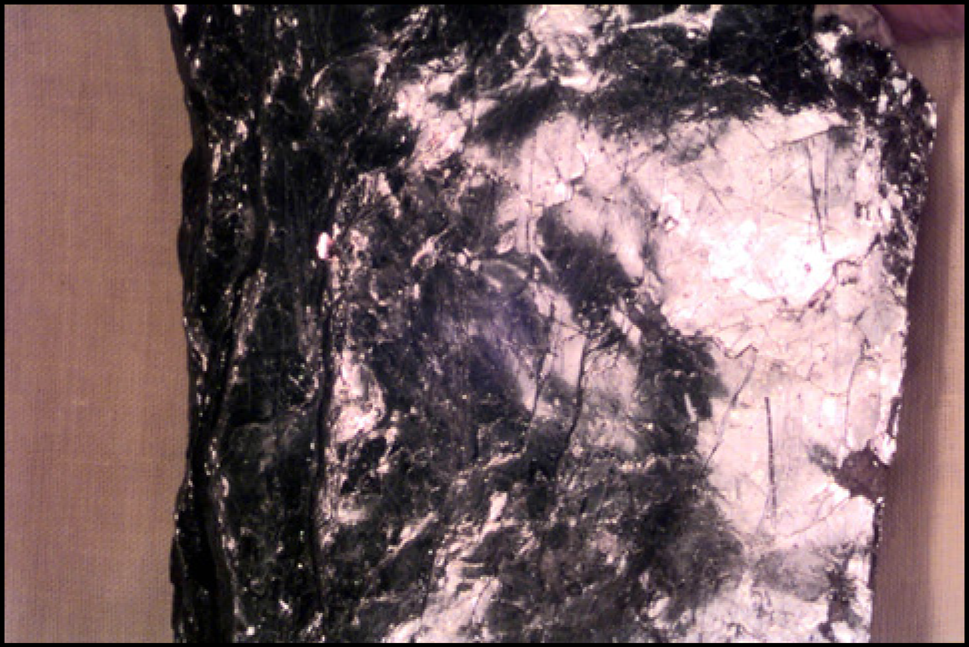


muscovite, a phyllosilicate

Biotite
Sheets of Tetrahedra

Properties

- Sheets of chains held together by Fe, Mg.
- Flat, slick smooth, black, very shiny cleavage faces.
- Sheets can be peeled away from each other by basal cleavage.



Biotite

Sheets of Tetrahedra

Properties

- Sheets of chains held together by Fe, Mg.
- Flat, slick smooth, black, very shiny cleavage faces.
- Sheets can be peeled away from each other by basal cleavage.

Biotite

Sheets of Tetrahedra

Properties

- Sheets of chains held together by Fe, Mg.
- Flat, slick smooth, black, very shiny cleavage faces.
- Even thin sheets remain black and opaque; light does not pass through them.
- Sheets can be peeled away from each other by basal cleavage.

Biotite
Sheets of Tetrahedra

Properties

- Sheets of chains held together by Fe, Mg.
- Flat, slick smooth, black, very shiny cleavage faces.
- Even thin sheets remain black and opaque; light does not pass through them.
- Sheets can be peeled away from each other by basal cleavage.

Muscovite

Sheets of Tetrahedra

Properties

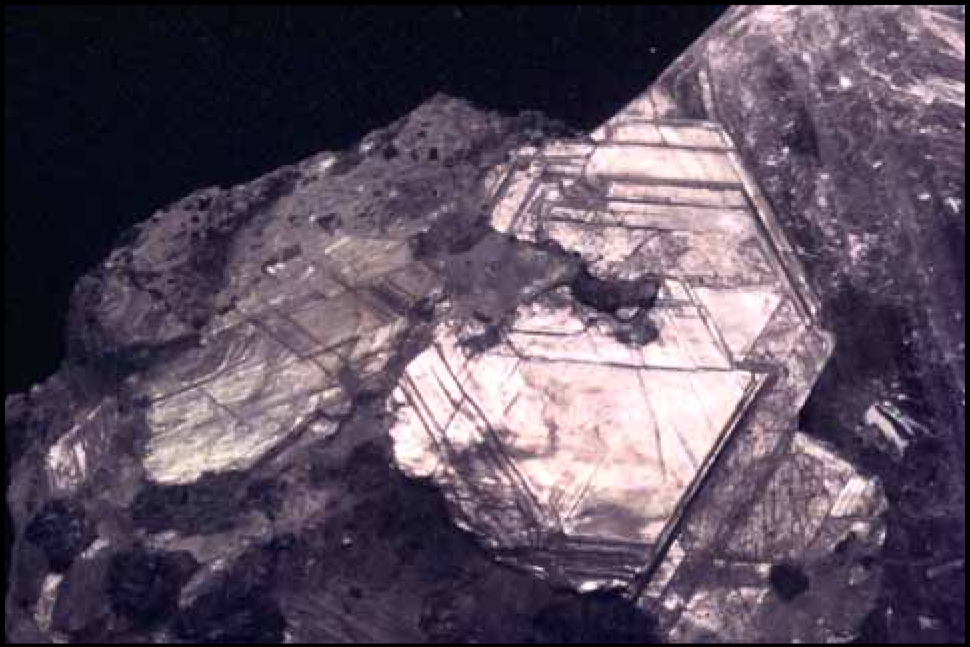
- Sheets of chains held together by potassium
- Flat, slick smooth, very shiny cleavage faces, but clear to brassy in color.
- Sheets are clear to translucent when thin.
- Sheets can be peeled away from each other by basal cleavage.

Muscovite

Sheets of Tetrahedra

Properties

- Sheets of chains held together by potassium
- Flat, slick smooth, very shiny cleavage faces, but clear to brassy in color.
- Sheets are clear to translucent when thin.
- Sheets can be peeled away from each other by basal cleavage.



Muscovite
Sheets of Tetrahedra

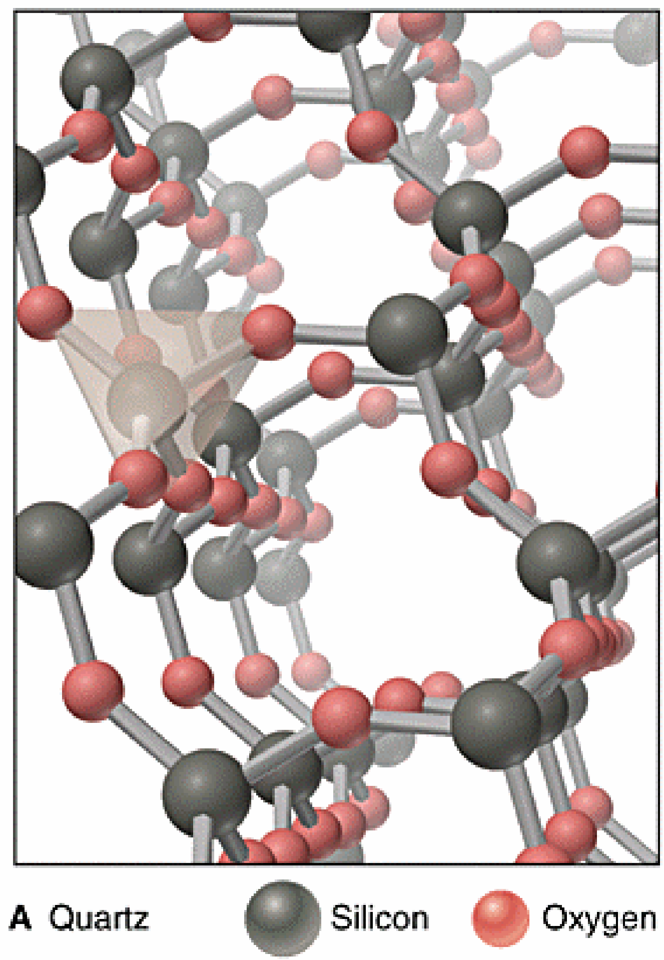
Properties

- Sheets of chains held together by potassium
- Flat, slick smooth, very shiny cleavage faces, but clear to brassy in color.
- Sheets are clear to translucent when thin.
- Sheets can be peeled away from each other by basal cleavage.

Quartz

Complete Framework of Silica Tetrahedrons

Now all the silica tetrahedra share their oxygens with other tetrahedra.



QUARTZ

Complete Framework of Tetrahedra

Properties

- Grows as six sided, doubly terminated (ends come to points) crystals when there is space to grow in.
- Crystal structure has no planes of weakness so there is no cleavage.
- Pure quartz is clear and glassy, but minor impurities produce a complete spectrum of color.
- Crystal faces typically have fine parallel ridges running at right angles to long axis of crystal.

QUARTZ

Complete Framework of Tetrahedra

Herkimer "Diamonds"

Properties

- Grows as six sided, doubly terminated (ends come to points) crystals when there is space to grow in.
- Crystal structure has no planes of weakness so there is no cleavage.
- Pure quartz is clear and glassy, but minor impurities produce a complete spectrum of color.
- Crystal faces typically have fine parallel ridges running at right angles to long axis of crystal.

QUARTZ

Complete Framework of Tetrahedra

Properties

- Grows as six sided, doubly terminated (ends come to points) crystals when there is space to grow in.
- Crystal structure has no planes of weakness so there is no cleavage.
- Pure quartz is clear and glassy, but minor impurities produce a complete spectrum of color.
- Crystal faces typically have fine parallel ridges running at right angles to long axis of crystal.

QUARTZ

Complete Framework of Tetrahedra

Properties

- Quartz that grows in enclosed spaces has a rough irregular surface showing no crystal form, although the atoms are still geometrically arranged inside.

- Quartz is the lowest temperature forming mineral. It crystallizes at about 570° centigrade.

FELDSPARS

Framework Silicates

Adding an alumina tetrahedron requires that the extra e- in the developing crystal be balanced by a cation of some sort.

We have three cations left to do this with.

Element	Symbol	Atomic Number	Size (Angstroms)		Atomic Charge	Atomic Weight	Proportions in Earth	
			Atom	Ion			% Volume	% Weight
Oxygen	O	6	0.60	1.40	O^{--}	15.99	93.77	46.6
Silicon	Si	14	1.17	0.43	Si^{++++}	28.08	.86	27.72
Aluminum	Al	13	1.43	0.51	Al^{+++}	26.98	.47	8.13
Iron	Fe	26	1.24	0.74 0.64	Fe^{++} Fe^{+++}	55.87	.43	5.00
Calcium	Ca	20	1.96	0.99	Ca^{++}	40.08	1.03	3.60
Sodium	Na	11	1.86	0.97	Na^{+}	22.99	1.32	2.80
Potassium	K	19	2.31	1.35	K^{+}	39.09	1.83	2.59
Mag-nesium	Mg	12	1.60	.66	Mg^{++}	55.93	.30	1.10

FELDSPARS

Framework Silicates

Aluminum is the third most abundant element in the lithosphere, and so far none of the minerals we have examined contain any of it.

But, aluminum helps form one of the most abundant, important, and widespread of any of the rock forming minerals.

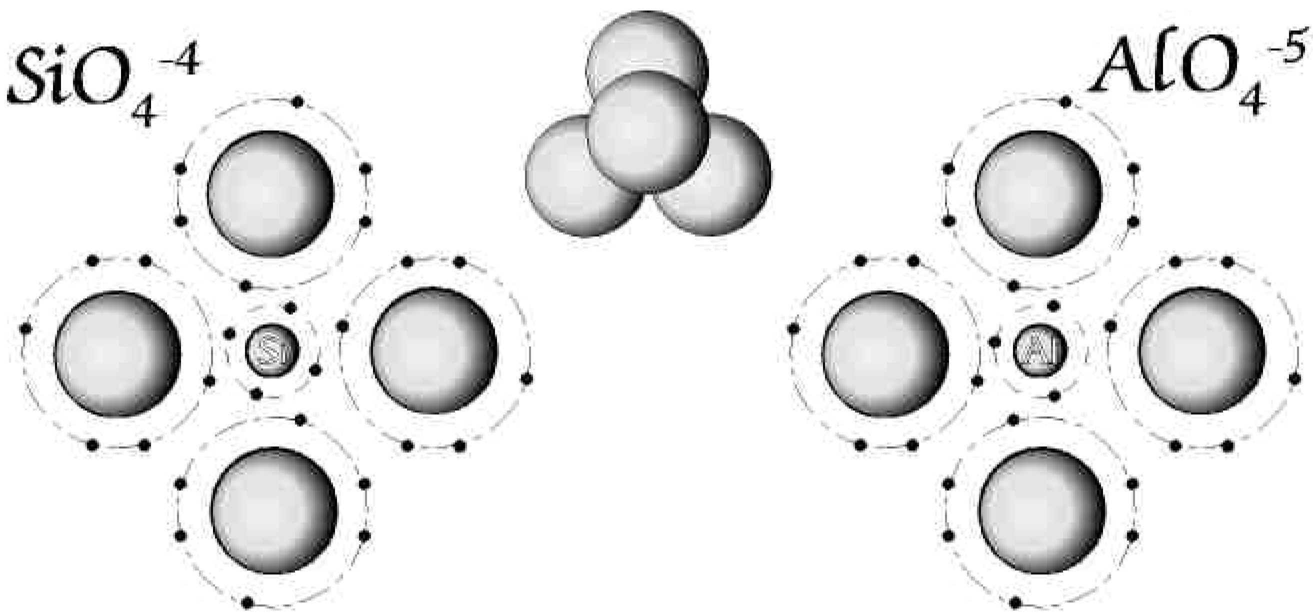
Element	Symbol	Atomic Number	Size (Angstroms)		Atomic Charge	Atomic Weight	Proportions in Earth	
			Atom	Ion			% Volume	% Weight
Oxygen	O	6	0.60	1.40	O^{--}	15.99		
Silicon	Si	14	1.17	0.43	Si^{++++}	28.08		
Aluminum	Al	13	1.43	0.51	Al^{+++}	26.98	.47	8.13
Iron	Fe	26	1.24	0.74 0.64	Fe^{++} Fe^{+++}	55.87		
Calcium	Ca	20	1.96	0.99	Ca^{++}	40.08		
Sodium	Na	11	1.86	0.97	Na^{+}	22.99		
Potassium	K	19	2.31	1.35	K^{+}	39.09		
Mag-nesium	Mg	12	1.60	.66	Mg^{++}	55.93		

FELDSPARS

Framework Silicates

Aluminum fits into this scheme primarily because it is about the same size as the silica atom.

This means that aluminum can substitute for silica, and in the process form an aluminum tetrahedron.



Of course, it can't be just that simple.

FELDSPARS

Framework Silicates

Adding a silica tetrahedron changes the charge balance in the crystal that must be adjusted for.

Silica Tetrahedron

(4 oxygen)(each needs 2 e-) = total 8 e- needed

(1 silicon)(has 4 e-) = total 4 e- to bond with oxygen

---

4 e- needed to balance SiO_4

Alumina Tetrahedron

(4 oxygen)(each needs 2 e-) = total 8 e- needed

(1 aluminum)(has 3 e-) = total 3 e- to bond with oxygen

---

5 e- needed to balance SiO_4

FELDSPARS

Framework Silicates

Adding an alumina tetrahedron requires that the extra e- in the developing crystal be balanced by a cation of some sort.

We have three cations left to do this with.

Element	Symbol	Atomic Number	Size (Angstroms)		Atomic Charge	Atomic Weight	Proportions in Earth	
			Atom	Ion			% Volume	% Weight
Oxygen	O	6	0.60	1.40	O^{--}	15.99	93.77	46.6
Silicon	Si	14	1.17	0.43	Si^{++++}	28.08	.86	27.72
Aluminum	Al	13	1.43	0.51	Al^{+++}	26.98	.47	8.13
Iron	Fe	26	1.24	0.74 0.64	Fe^{++} Fe^{+++}	55.87	.43	5.00
Calcium	Ca	20	1.96	0.99	Ca^{++}	40.08	1.03	3.60
Sodium	Na	11	1.86	0.97	Na^{+}	22.99	1.32	2.80
Potassium	K	19	2.31	1.35	K^{+}	39.09	1.83	2.59
Mag-nesium	Mg	12	1.60	.66	Mg^{++}	55.93	.30	1.10

Feldspars

Framework Silicates

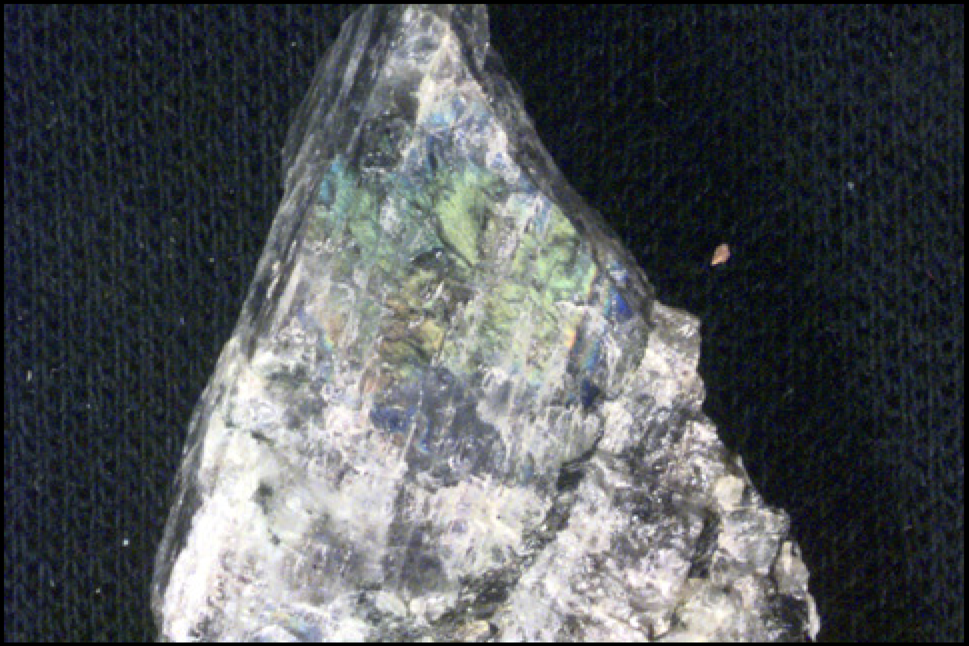
Constructing the Feldspar Minerals

Feldspar	Formula	Cation Charge	Cation Size	Substitutions
Orthoclase	**$KAlSi_3O_8$**	**K^{+1}**	**1.33 A**	*Charges ok, but sizes differences too large for substitution*
Sodium Plagioclase	**$NaAlSi_3O_8$**	**Na^{+1}**	**0.95 A**	*Sizes ok, but charges must be balanced from substitution.*
Calcium Plagioclase	**$CaAl_2Si_2O_8$**	**Ca^{+2}**	**0.99 A**	*Done with Al and Si tetrahedra substitutions.*

Calcium Plagionclase Feldspar
Framework Silicates

Properties

- Prismatic (2 directions of cleavage) at right angles.
- Fractures in the third direction
- Iridescent dark gray color.
- Striations (fine parallel grooves like on a record)
- Tends to be translusent.



Calcium Plagionclase Feldspar
Framework Silicates

Properties

- Prismatic (2 directions of cleavage) at right angles.
- Fractures in the third direction
- Iridescent dark gray color.
- Striations (fine parallel grooves like on a record)
- Tends to be translucent.

Sodium Plagionclase Feldspar

Framework Silicates

Properties

- Prismatic (2 directions of cleavage) at right angles.
- Fractures in the third direction
- White color
- Striations (fine parallel grooves like on a record)
- Tends to be translucent.

Sodium Plagionclase Feldspar

Framework Silicates

Properties

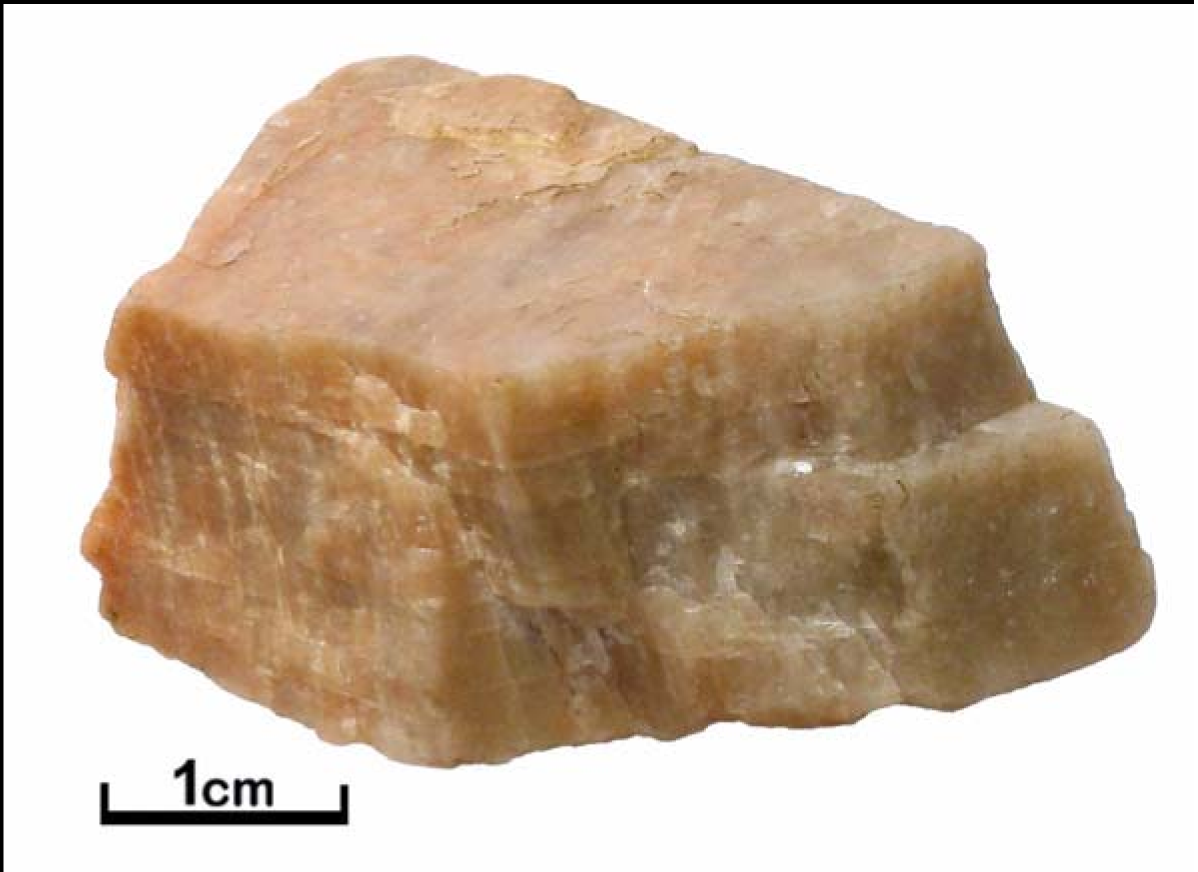
- Prismatic (2 directions of cleavage) at right angles.
- Fractures in the third direction
- White color
- Striations (fine parallel grooves like on a record)
- Tends to be translucent.

Orthoclase Feldspar (K-spar)

Framework Silicates

Properties

- Prismatic (2 directions of cleavage) at right angles.
- Fractures in the third direction
- Pink to greenish to white.
- Tends to be opaque.



Orthoclase Feldspar (K-spar)

Framework Silicates

Properties

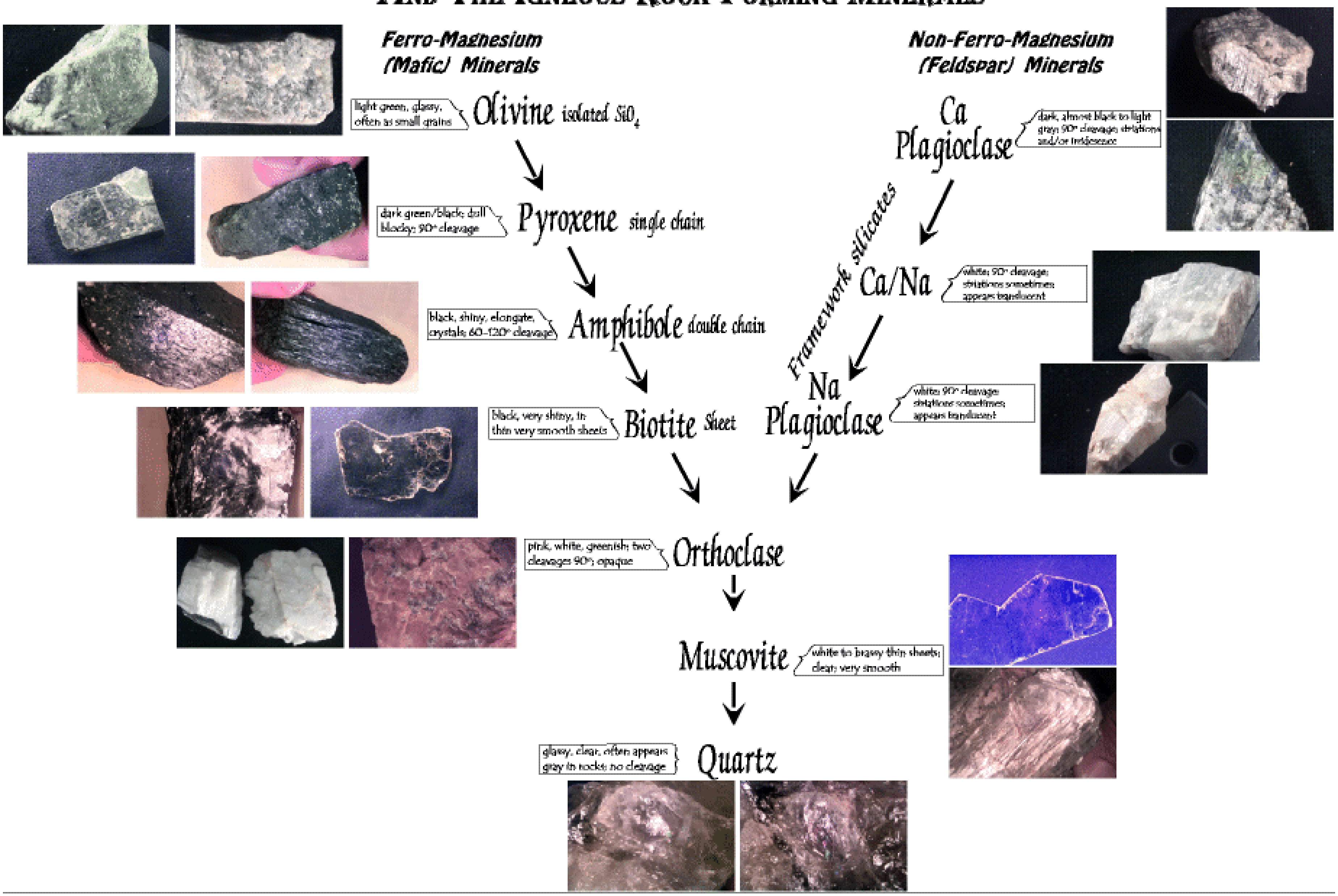
- Prismatic (2 directions of cleavage) at right angles.
- Fractures in the third direction
- Pink to greenish to white.
- Tends to be opaque.

Orthoclase Feldspar (K-spar)

Framework Silicates

Properties

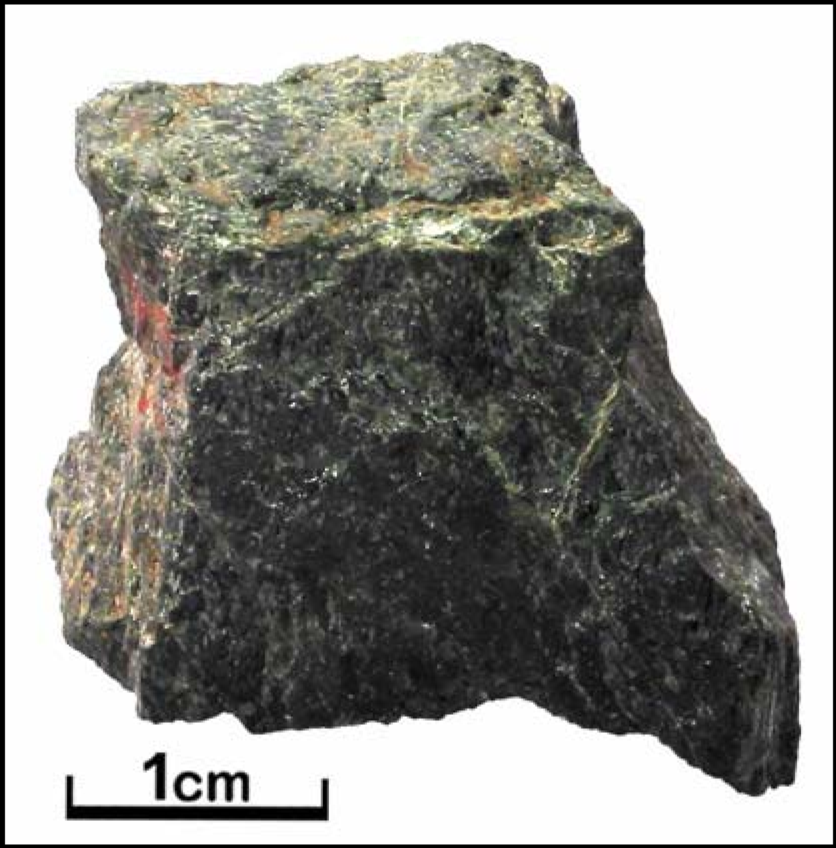
Bowen's Reaction Series
And The Igneous Rock Forming Minerals



A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals



A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the
8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the
8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the
8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals

A Random Sampling of the 8 Rock Forming Minerals