Minerals and Rocks

Rocks are assemblages of minerals.

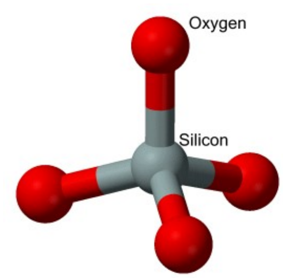
Minerals are naturally occurring, crystalline, solid compounds (or solutions in crystalline solid form). Minerals form and decompose under conditions governed by rules of chemistry and physics. These rules are expected to be the same on other planets. As such, an understanding of and ability to identify minerals is critically important to an astronaut geologist.

There are a staggering variety of minerals, each with a variety of different forms. Happily, there is a pretty small number of common ones and most of them are of one major type: Silicates.

Composition of the earth's crust

Element	Wt%	Atomic%	Volume%
O	46.60	62.55	~94
Si	27.72	21.22	~6
Al	8.13	6.47	
Fe	5.00	1.92	
Ca	3.63	1.94	
Na	2.83	2.34	
K	2.59	1.42	
Mg	2.09	1.84	
Total	98.59	100.00	100

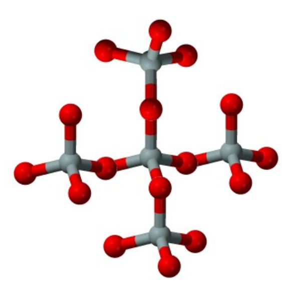
92% of the earth's crust is composed of silicate minerals.



Silica

The basic structure of silicate minerals is the silica tetrahedron: SiO_4^{4-}:
Each oxygen carries a negative one charge.

Pure silica is made of silica tetrahedra that are joined together to make a 3-D framework. Each silica tetrahedron is joined to its 4 nearest neighbours by sharing the oxygens at the vertices of the tetrahedra. Each oxygen is bonded to two silicons, and each silicon is bonded to 4 oxygens.



The overall ratio is: SiO_2

The molecule extends out in all directions so that each silica crystal forms a single macro-molecule.

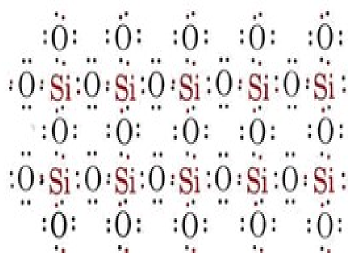
All of the oxygens are fully bonded, so the molecule has a neutral charge.

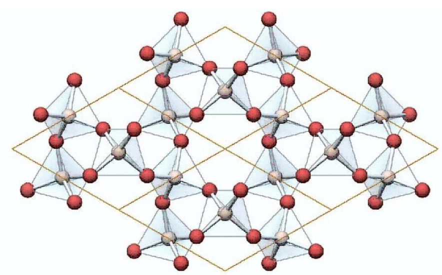
Other atoms and bonding arrangements finish off the edges of the crystal.

A common form of pure silica is quartz. Keep in mind that each crystal piece in the photo to the right is made up of a single molecule of covalently bonded, alternating oxygen and silicon in a three-dimensional matrix.

There are four types of silicate minerals with four different ways in which the silica tetrahedra are attached to each other.

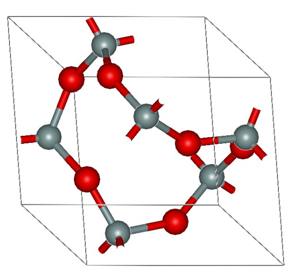
<u>1) Tectosilicates:</u> Framework Silicates
3-D macro-molecules.



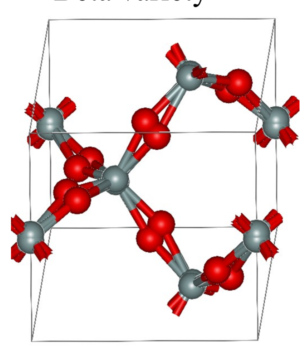


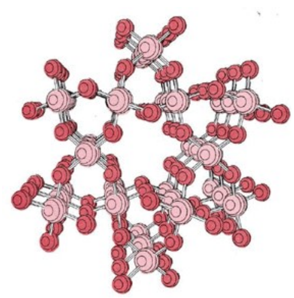
Quartz (12% of the crust)

Alpha variety



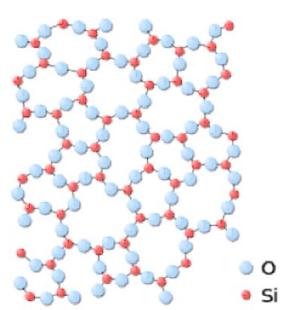
Beta variety





Lots of void spaces within the molecular structure give quartz a lower density than many silicate minerals.

2D view of the 3D framework in silica glass. This also is a macro-molecular structure, but less well organised at an atomic level. Modern glass has other components in it, besides silica.

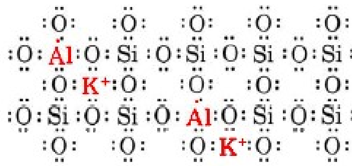


Feldspars

These are silica framework molecules in which a set ratio of silicon atoms are substituted with aluminum atoms. The name is German for "field crystal."

Since aluminum has one fewer electrons than silicon, an additional metal atom must be squeezed into the gaps between the tetrahedra to provide the additional electron.

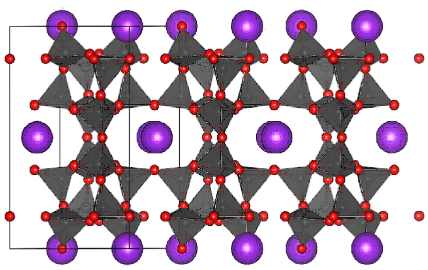
The mineral still forms a macromolecular lattice, just slightly more complex. The distortion in the lattice structure caused by the other metal ions produces the cleavage planes of weakness.



Orthoclase Feldspar (12% of the crust)

$KAlSi_3O_8$

1 aluminum tetrahedron for each 3 silica tetrahedra. So, could be written as: $K(AlO_2)(SiO_2)_3$



Orthoclase usually has a characteristic salmon-pink colour and, like all feldspars, it has two cleavage planes at right angles.

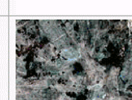
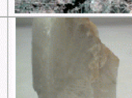
Plagioclase Feldspars: (39% of the crust)

Solid Solution from: $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$

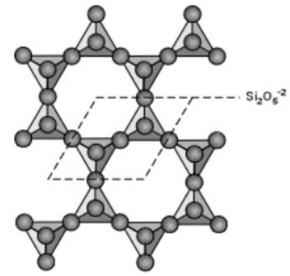
$Na(AlO_2)(SiO_2)_3$ and $Ca(AlO_2)_2(SiO_2)_2$

Similar to orthoclase, but with a grey colour. The two pure end-members of the solution series are rare.

Plagioclase minerals and their compositions

Name	% $CaAl_2Si_2O_8$	% $NaAlSi_3O_8$	Image
Anorthite	90–100	10–0	
Bytownite	70–90	30–10	
Labradorite	50–70	50–30	
Andesine	30–50	70–50	
Oligoclase	10–30	90–70	
Albite	0–10	100–90	

Phyllosilicates: Sheet Silicates



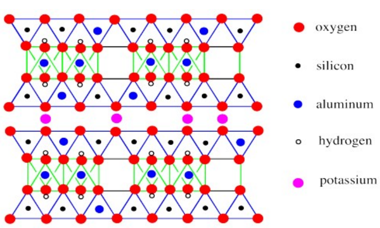
Each silica tetrahedron is bonded to three others.
This leaves one half-bonded 1- charged oxygen per tetrahedron.
The charged oxygen requires a positive metal ion to balance charges.

The basic formula ratio is $Si_2O_5^{2-}$

The sheet-like structure that develops is a 2-D macromolecule.
This produces one excellent cleavage plane.

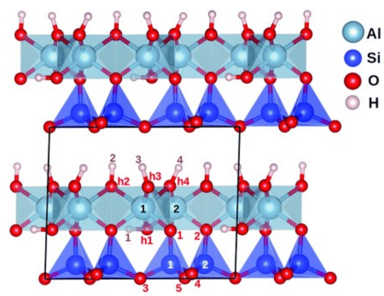
micas (5% of crust) and
non-hydrophilic

Muscovite



clay minerals (5% of crust)
-OH groups make them hydrophilic

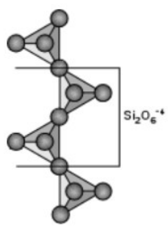
Kaolinite



Inosilicates: Chain Silicates (16 % of the crust)

Essentially 1-D macromolecules.
These minerals tend to be more dense than tectosilicates or phyllosilicates and the long chains stack together like spaghetti strands with much less void space. The proportion of heavy metals is greater than that in tectosilicates and phyllosilicates and the silica content is less.

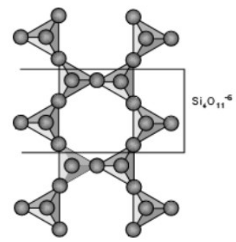
Single Chain Silicates: $Si_2O_6^{4-}$
Pyroxenes (11%)



Augite
$(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$

There are two tetrahedra in the unit cell. Two oxygens are shared outside of the cell and 1 is shared within. Thus, there are 4 oxygens not shared, so the charge is 4-.

Double Chain Silicates: $Si_4O_{11}^{6-}$
Amphiboles (5%)



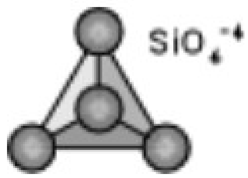
Hornblende
$(Ca,Na)_{2-3}(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH,F)_2$

There are 4 tetrahedra in the unit cell. 4 oxygens are shared with other cells and 3 are shared within the cell. This leaves 6 unshared oxygens, thus the 6- charge.

Nesosilicates: Isolated Silica Tetrahedra

SiO_4^{4-}

Olivines (<3% of the crust)



$(Mg^{+2}, Fe^{+2})_2SiO_4$

Even greater densities as the tetrahedra can pack closely together when free of their interconnections. The minerals also have low silica and high heavy metal content.

Garnet

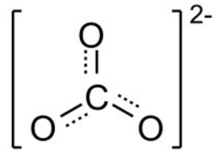
$X_3Y_2(SiO_4)_3$

X = 2+ ions: Ca, Mg, Fe, Mn
Y = 3+ ions: Al, Fe, Cr

Non-Silicate Mineral Groups
(<8% of the crust in total)

Carbonates
Sulfates
Halides
Oxides
Phosphates
Sulfides
Hydroxides
Elements

Carbonates



Flat, rather than tetrahedral.

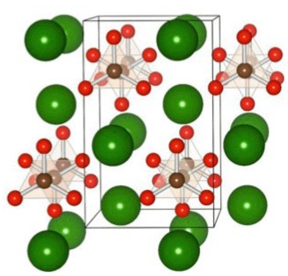
Forms ionic substances rather than polymerizing to make macromolecules.

Can be produced by both inorganic and organic processes.

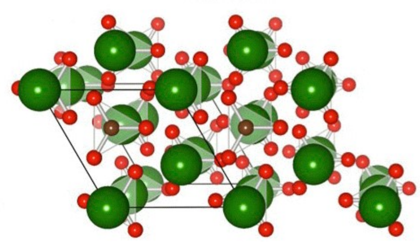
$$H_2O + CO_2 \longrightarrow H_2CO_3$$
$$H_2O + H_2CO_3 \longrightarrow HCO_3^{1-} + H_3O^+$$
$$H_2O + HCO_3^{1-} \longrightarrow CO_3^{2-} + H_3O^+$$

Calcium Carbonate

Aragonite



Calcite



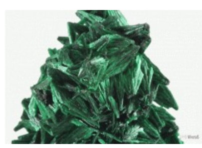
Dolomite
$MgCa(CO_3)_2$

Distinguished from calcite and aragonite by visibly reacting with 10% HCl only when powdered.

Siderite
$FeCO_3$

Rhodochrosite
$MnCO_3$

Malachite
$Cu_2CO_3(OH)_2$



Azurite
$Cu_3(CO_3)_2(OH)_2$

Sulfates

Gypsum
$CaSO_4 \cdot 2H_2O$

Usually the first mineral to start precipitating when sea water evaporates.

Halides

Halite
$NaCl$

Fluorite
CaF_2

Oxides

Hematite
Fe_2O_3

Magnetite
Fe_3O_4

($FeO + Fe_2O_3$)

<-- hematite with powdery surface

Corundum

Al_2O_3
Includes sapphire and ruby

Phosphates

Apatite
$Ca_{10}(PO_4)_6(OH,F,Cl)_2$

Sulfides

Pyrite
FeS_2

Galena
PbS

Hydroxides

Gibbsite
$Al(OH)_3$

Limonite
$FeO(OH) \bullet nH_2O$