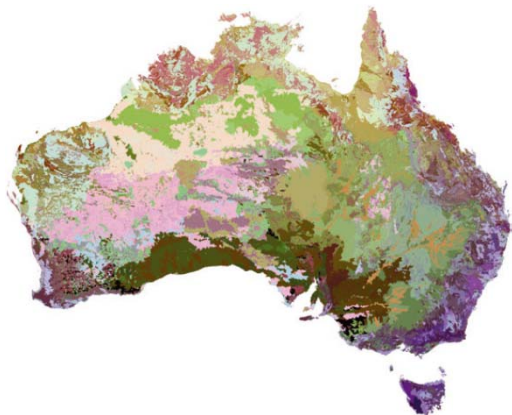


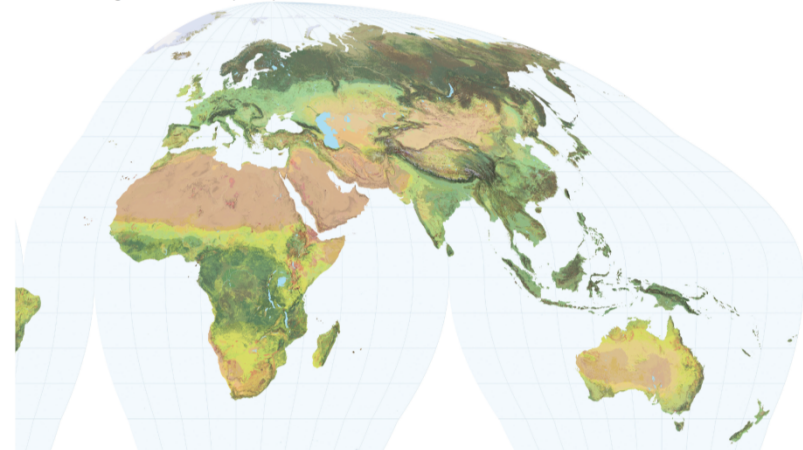


# Guest Lecture: Introduction to earth science

Dr Ian D Hollingsworth, CDU Adjunct, HESSE



Global Ecological Land Units (ELUs)





1. Soils

2. Rocks

3. Minerals

4. Practical



- Early soil classification was based on geology
- Rock mineralogy and structure influence soil formation

Aim to be able to:

1. Interpret geological mapping
2. Identify broad rock types



**$S=f(c, l, o, p) t_r$  ecological factor model**

- Soil type or property
- CLimate
- Organisms
- Relief or topography
- Parent material
- Time

**$l, v, a, s = f(S_0, l, t \dots) t_r$**

- **l** – ecosystem property such as carbon
- **v** – vegetation property such as biomass, diversity
- **a** – any property of animals such as work done
- **s** – any property of the soil such as pH, texture
- **S<sub>0</sub>** – state of the soil at time zero (**t<sub>0</sub>**)
- **l** – influxes such as organisms, sediment, rainfall
- **t** – time stretching forward from point **t<sub>0</sub>**

**DSM SCORPAN –  $S=f(s, c, o, r, p, t, \dots)$  pedometric model,**

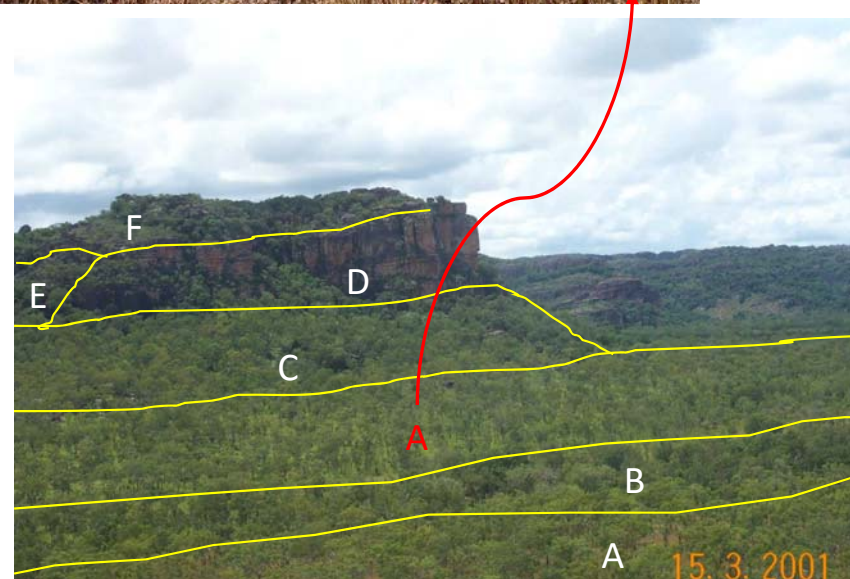
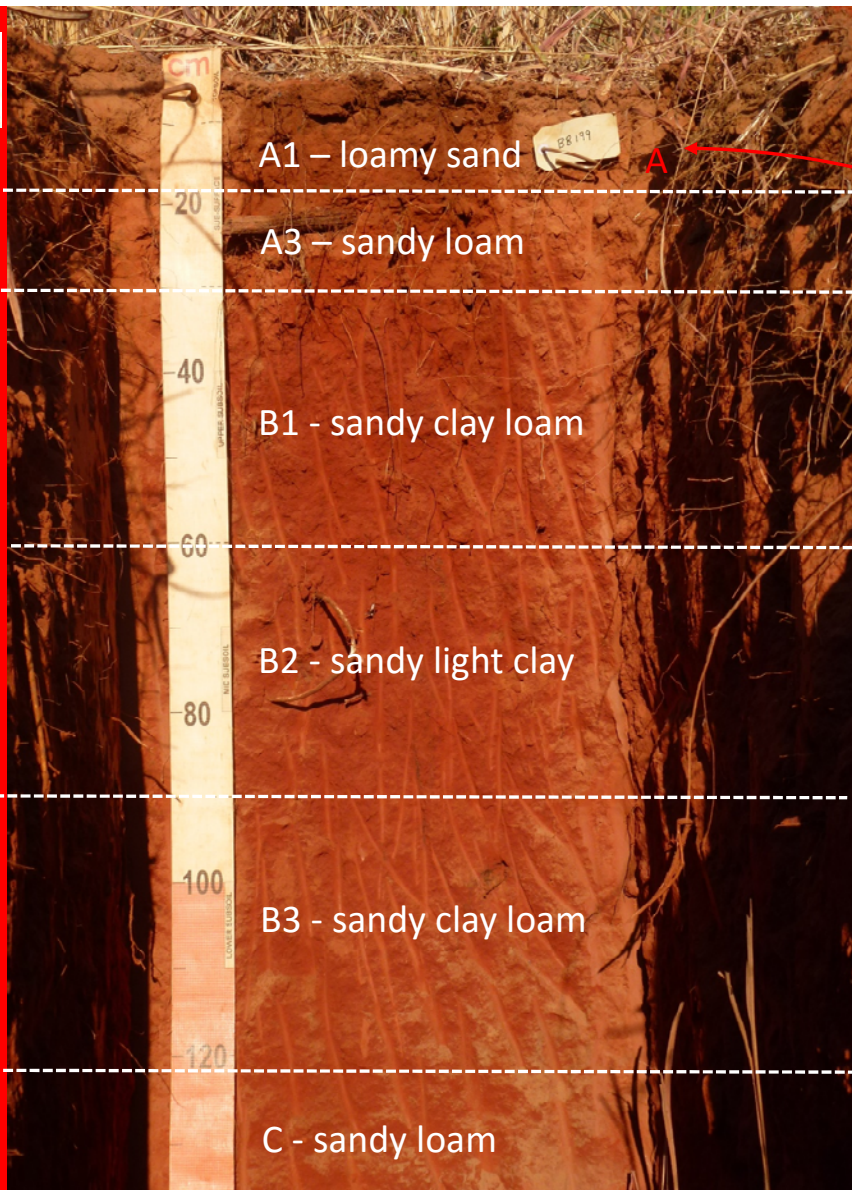
- Soil classes or attributes to be modelled
- **s**, previously measured soil property

**Land unit framework –  $L=f(s, c, o, r, p, t, \dots)$**

- Include biogeographic regionalisation and global land unit as aggregators
- Include vegetation community classification as a predictor
- Include a detailed working description of the sampling design
- Identify the minimum area that can be reliably identified



# Soils – soil description





Rocks are aggregates of minerals, which have a geological past.

Rocks can be conveniently grouped into:

**Igneous rocks – solidified molten rock material**

Metamorphic rocks – igneous and sedimentary rock altered by temperature and pressure

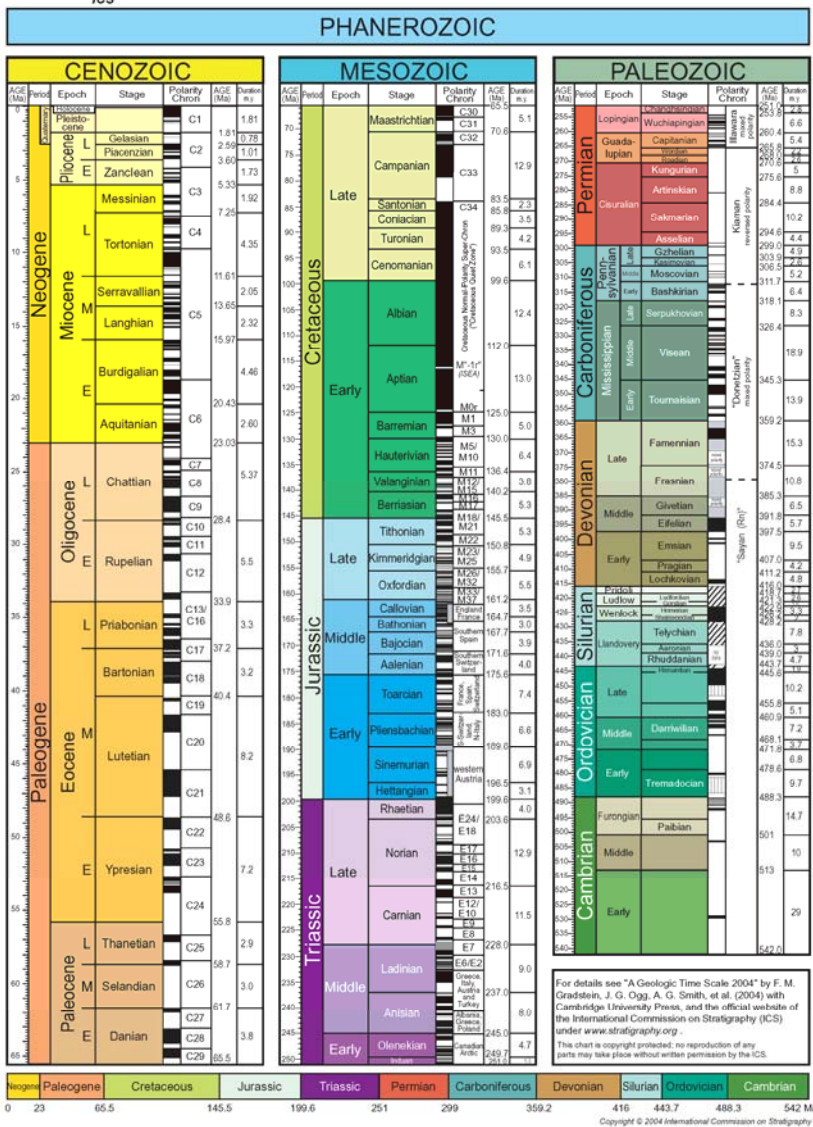
Sedimentary rocks – chemical, wind and water accumulation of disaggregated rock material at the earth's surface

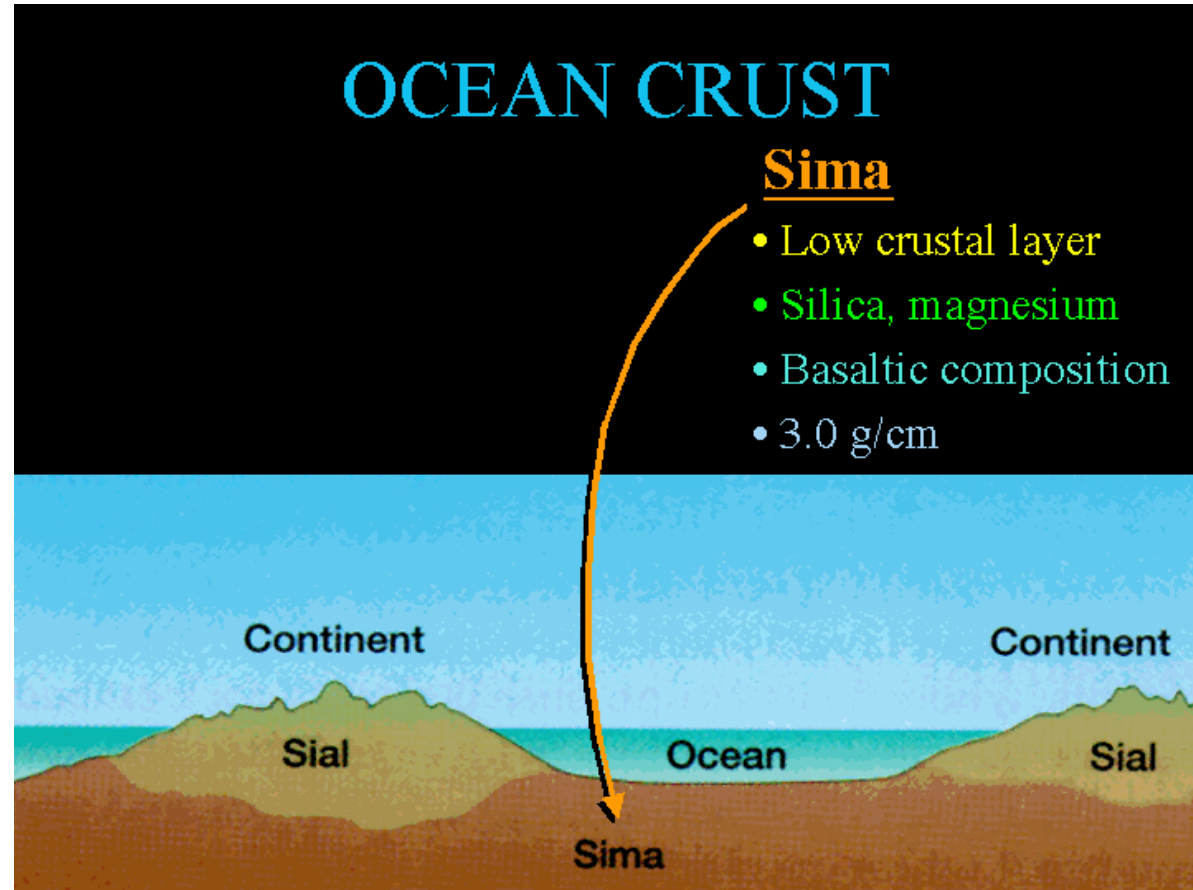
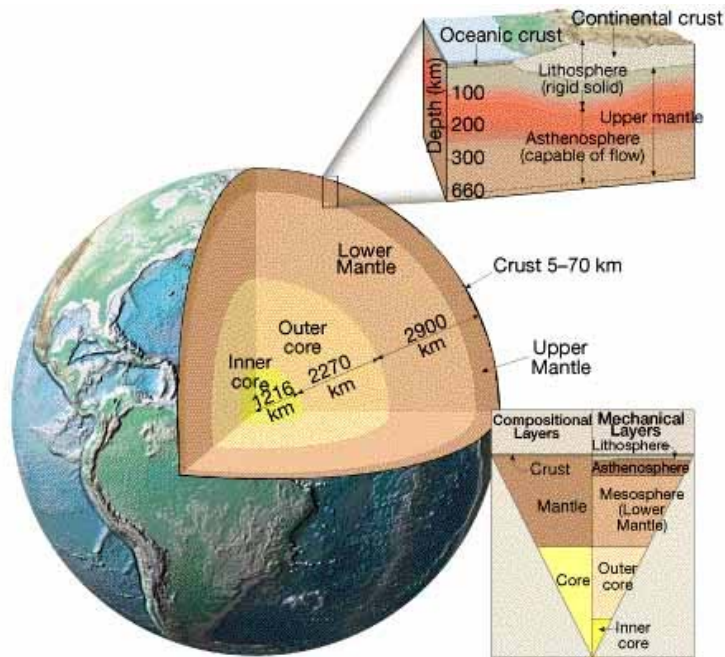


# Rocks – Geological time scale



## GEOLOGIC TIME SCALE



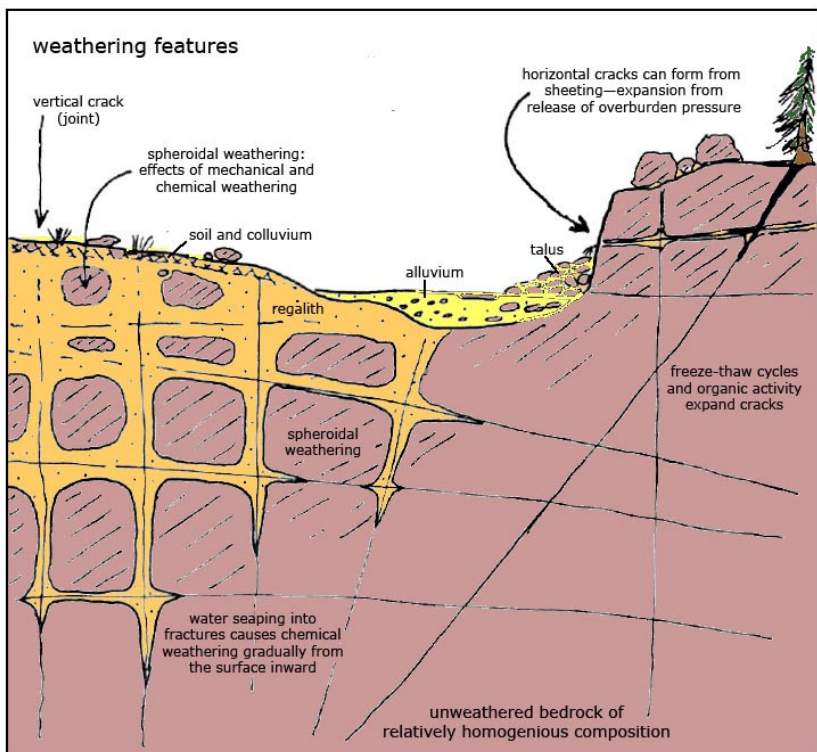


CONTINENTAL CRUST – SIAL Silicon and Aluminium based (light coloured Felsic) minerals

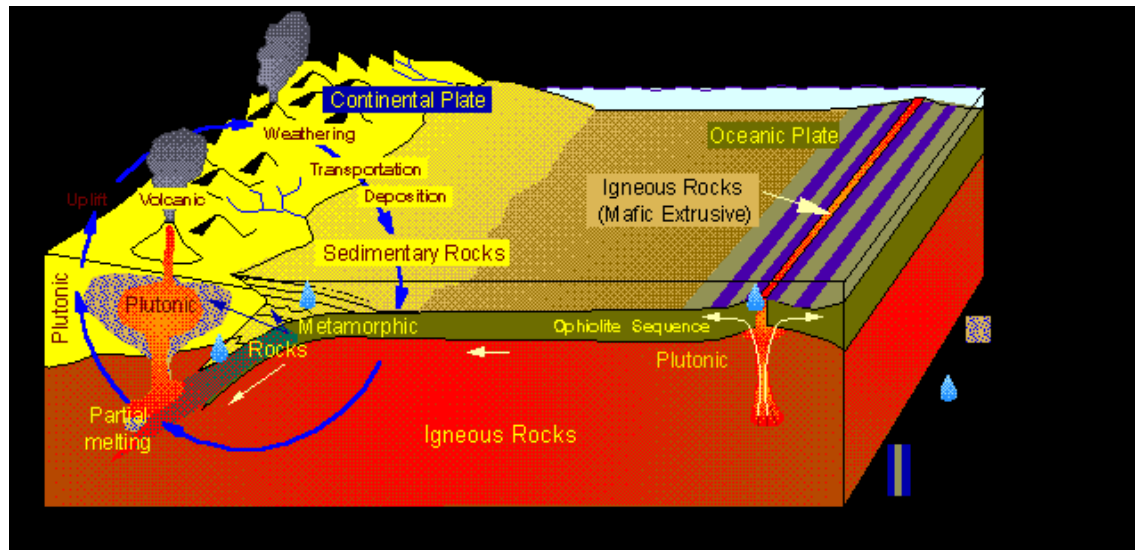
OCEAN CRUST – SIMA Silicon and Magnesium based (dark coloured Mafic) minerals



### LOCAL



### GLOBAL





1. Minerals are the building blocks of rocks.
2. Minerals record the formation and history of a rock and determine its physical and chemical characteristics.



Each mineral is characterised by:

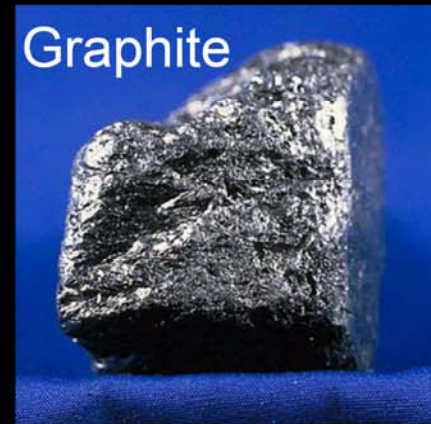
1. composition
2. Crystal structure
3. Stability range (pressure and temperature)



Diamond

Courtesy of the U. S. Geological Survey.  
Photograph in the public domain.

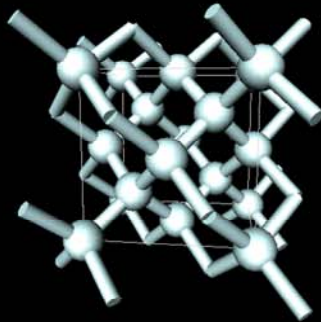
Diamond is pure carbon C,  
as is graphite



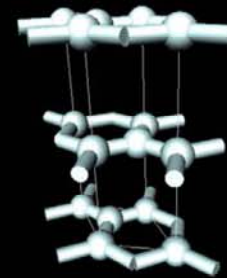
Graphite

Courtesy of the U. S. Geological Survey and the Mineral  
Information Institute. Photograph in the public domain.

Diamond has a dense, cubic structure



Graphite has a hexagonal structure





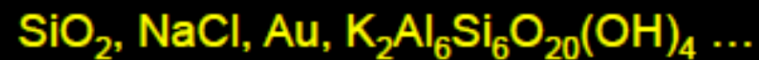
## There are thousands of minerals....

They are separated into groups based on their:

1. Crystal structure



2. Chemistry

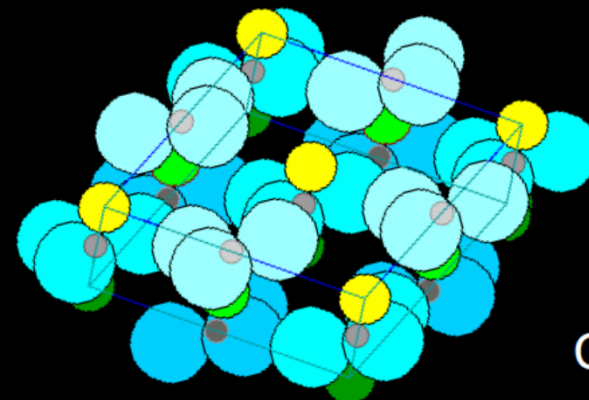




# 1. Crystal-structure



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Calcite

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The geometry of the crystal lattice constrains the form of the crystal



## Covalent bonds



Courtesy of the [U. S. Geological Survey](#).  
Photograph in the public domain.

Some minerals are made up of covalent bonds characterized by shared electrons between different atoms. Diamond is a good example.



Most minerals, however, are composed of ionic bonds, in which cations and anions attract each other. A simple example is Halite.

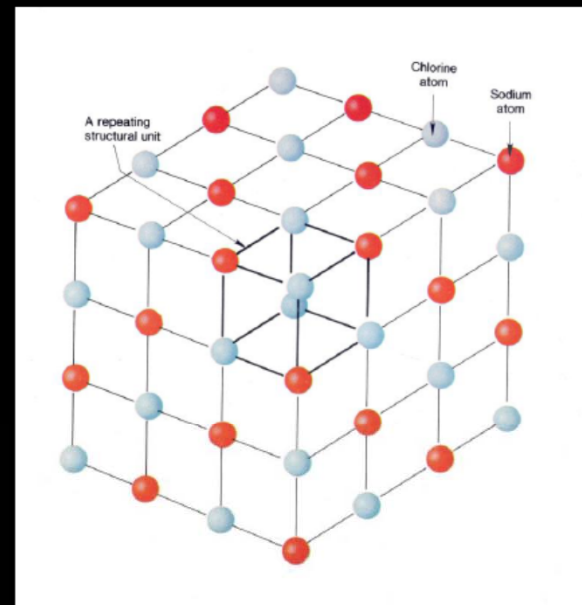


Courtesy of Chris Ralph. Photograph in the public domain.

## Halite

NaCl is “Tablesalt” composed of  $\text{Na}^+$  and  $\text{Cl}^-$  ions.

## Ionic bonding



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## 2. Composition



Diamond

C

Courtesy of the [U. S. Geological Survey](#).  
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Halite

Sodium Chloride, NaCl

Courtesy of [Chris Ralph](#). Photograph  
in the public domain.

Both have the same Structure,  
But a different composition (and bonding...)

... and a different value



## Systematic Mineralogy:

### Separation of Minerals in Groups

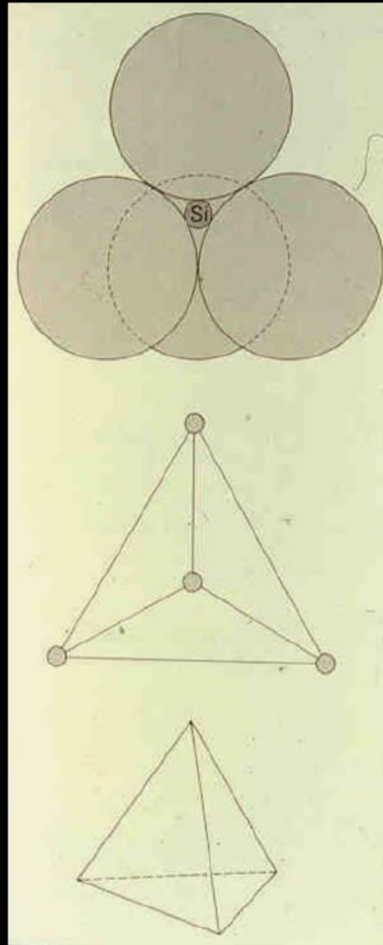


# Silicates

Silicates are the most common & important rock forming minerals on Earth

Silicates are composed of a combination of  $\text{SiO}_4$  Tetrahedrons and Cations:

$\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{2+}$  or  $\text{Al}^{3+}$



## The principal building block of rock forming minerals

### The $\text{SiO}_4$ Tetrahedrons

Silicates are the most important rock forming minerals. They are composed of a very stable molecule made up of Silicon and Oxygen atoms. Those form through covalent bonds a  $\text{SiO}_4$  tetrahedron.

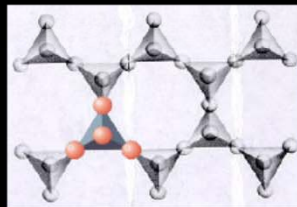
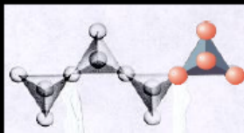
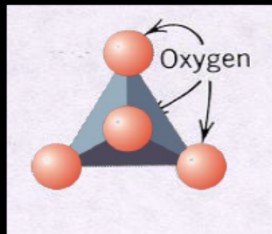
These tetrahedra can be combined in multiple ways. For example, they can be arranged by sharing an oxygen atom or through adding different cations.

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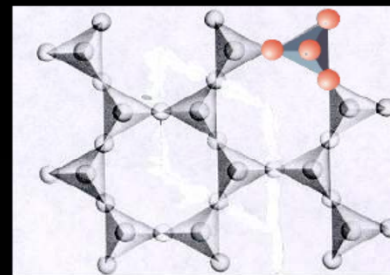
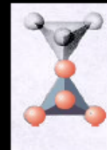
## Structure of silicate minerals

Neso-silicate  $[\text{SiO}_4]^{4-}$



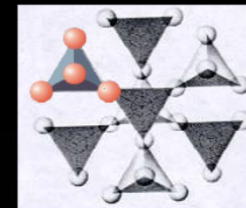
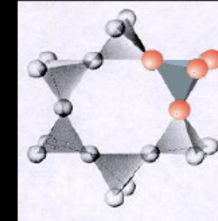
Inosilicates  
Single Chain-silicate  
Double chain-silicates

Soro-silicate  
 $[\text{Si}_2\text{O}_7]^{6-}$



Phyllo-silicate

cyclo-silicate



Tecto-silicate  
 $[\text{Al}_x\text{Si}_y\text{O}_{2(x+y)}]^{x-}$

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## Tecto-silicate



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# Quartz



Quartz is one of the most common minerals. Despite that, it is considered semi-precious based on its color and shapes.



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Quartz frequently forms hexagonal prisms and pyramids.

It is the hardest of the most common minerals.



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## Tecto-silicate

# Forms of Silica

Silica ( $\text{SiO}_2$ ) most commonly occurs as quartz.

It can however occur in microcrystalline varieties Flint, Chert and Agate forms, which form from low T fluids.



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Tecto-silicate

## Feldspars



Alkali-feldspar (or Orthoclase)  
(K<sup>+</sup> and Na<sup>+</sup> bearing)



Amazonite is semi-precious



Plagioclase  
(Na<sup>+</sup> und Ca<sup>2+</sup> bearing)

Feldspars are  
Tectosilicates in which  
the SiO<sub>4</sub> tetrahedron is  
combined with K<sup>+</sup>, Na<sup>+</sup>,  
Ca<sup>2+</sup> and Al<sup>3+</sup>.



## Tecto-silicate

# Feldspar group

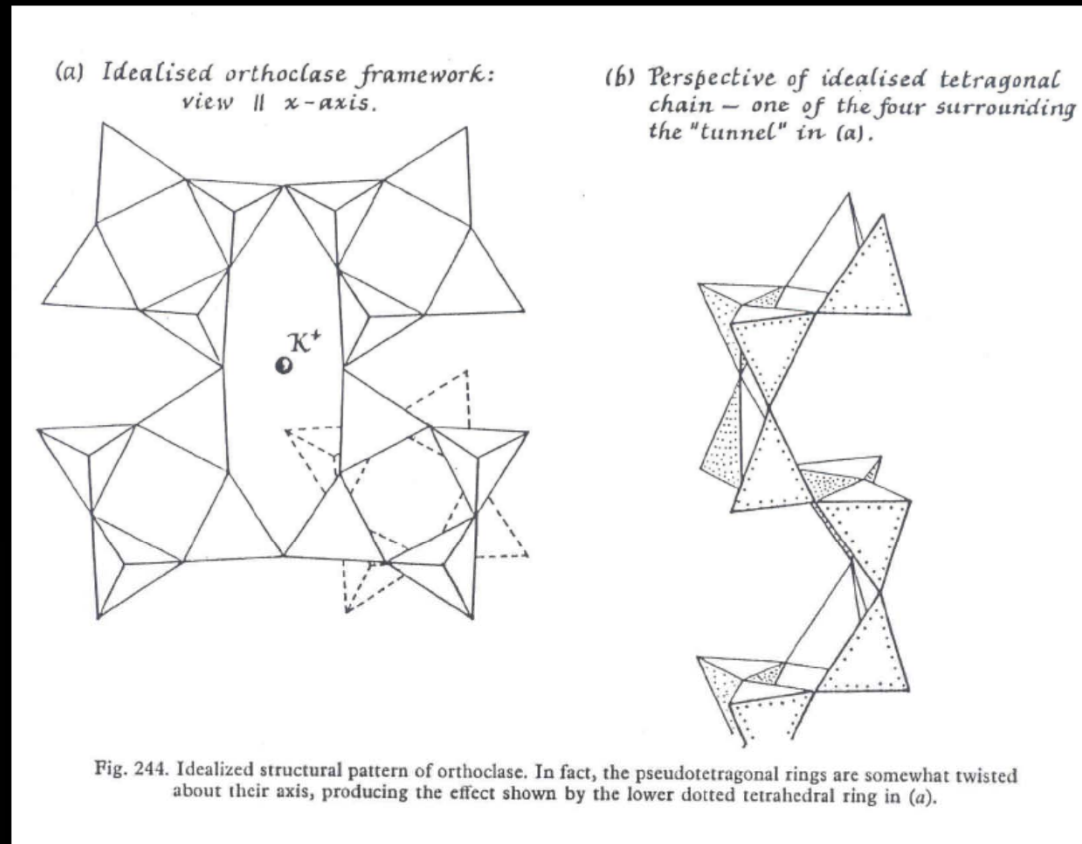


Fig. 244. Idealized structural pattern of orthoclase. In fact, the pseudotetragonal rings are somewhat twisted about their axis, producing the effect shown by the lower dotted tetrahedral ring in (a).

Feldspars are Tectosilicates in which the  $\text{SiO}_4$  tetrahedron is combined with  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Al}^{3+}$ .



## Phyllo-silicates



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**Muscovite**  
(K<sup>+</sup> and Al<sup>3+</sup> bearing)

“cleavage”

Mica, as clay minerals, are sheet silicates in which SiO<sub>4</sub> tetrahedron layers are combined with K<sup>+</sup>, Mg<sup>2+</sup>, Fe<sup>2+</sup>, Al<sup>3+</sup> and OH<sup>-</sup>.



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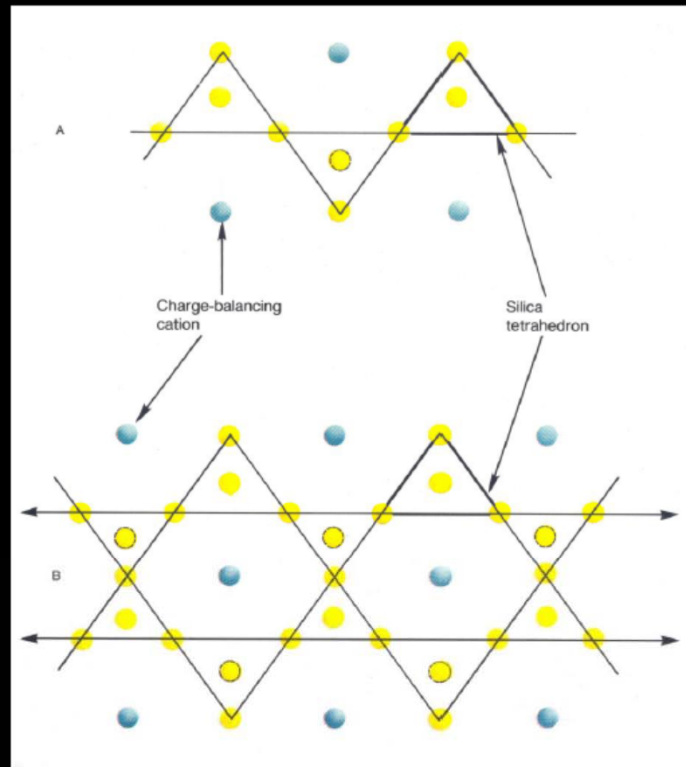
**Biotite**  
(K<sup>+</sup>, Fe<sup>2+</sup> and Mg<sup>2+</sup> bearing)<sub>19</sub>



# Ino-silicate

single-chain silicate

double-chain silicate



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## Ino-silicate

Pyroxenes are single-chain-silicates in which  $[\text{SiO}_4]^{4-}$  tetrahedrons are combined with  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{Fe}^{2+}$  cations.



Augite is the most common Pyroxene  
( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{Fe}^{2+}$  bearing)

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## Ino-silicate

Amphiboles are Double-chain Silicates in which  $\text{SiO}_4$  tetrahedra are combined with  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Fe}^{2+}$ ,  $\text{Al}^{3+}$  and  $\text{OH}^-$ .



Hornblende is the most common mineral of the Amphibole group (Ca-, Mg-, Na-, Al- and Fe-bearing)



Asbestos is a fibrous Amphibole (Ca-, Mg-, Na-, Al- and Fe-bearing)

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## Neso-silicate

Olivine has isolated  $\text{SiO}_4$  tetrahedra, combined by  $\text{Mg}^{2+}$  and  $\text{Fe}^{2+}$



Courtesy of [Bryant Olsen](#) on flickr. License: CC BY NC.

Olivine has a semi-precious variety (Peridot) even though it is the most common mineral in the upper mantle (-> Peridotite).



## Neso-silicate

Garnet also has isolated  $\text{SiO}_4$  tetrahedra which are combined with  $\text{Ca}^{2+}$ ,  $\text{Al}^{3+}$ ,  $\text{Mg}^{2+}$  and  $\text{Fe}^{2+}$



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Garnet is common in metamorphic rocks formed under high pressure.



## Non-silicate minerals

Luckily there aren't that many which are of importance. But those few are either

Very common

And play an important role in earth processes.

Or

Are an important for economic reasons.

The most important ones are:

Carbonates

Sulfates

Oxides

Fluorides

Sulfides

Phosphates

Native minerals (elements)



Courtesy of [Alkivar](#). Photograph in the public domain.

## Calcite

Calcite ( $\text{CaCO}_3$ ) is the main mineral in carbonates and shells of organisms

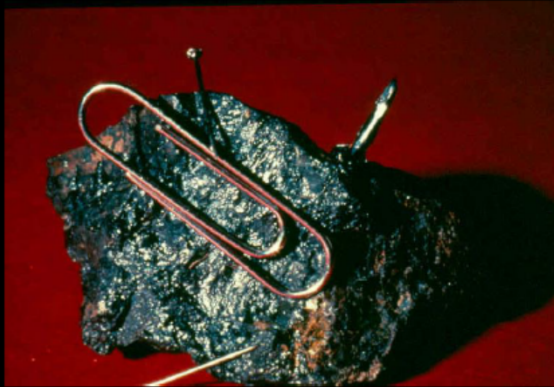
# Carbonate

## Dolomite

Magnesium and Calcium carbonate ( $\text{Mg,CaCO}_3$ ) common in many old carbonates (as for example in the Dolomites)



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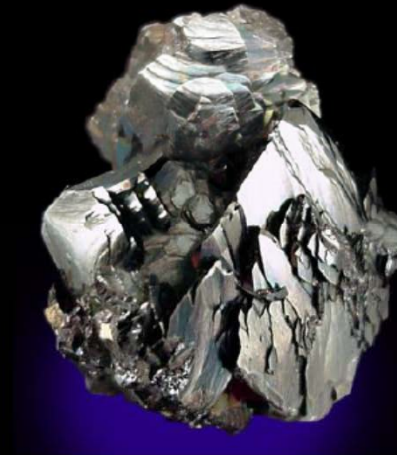
## Magnetite

Iron oxide ( $\text{Fe}_3\text{O}_4$ ) is the most common Metal-oxide in most plutonic rocks. Strongly magnetic.

## Oxide

## Hematite

Iron oxide ( $\text{Fe}_2\text{O}_3$ ), common ore mineral responsible for the red color in many Sandstones. Has been used as pigment for centuries.





# Sulfide



Galena

Lead-sulfide PbS

Pyrite

Iron-sulfide  $\text{FeS}_2$  is very common, known as fool's-gold....

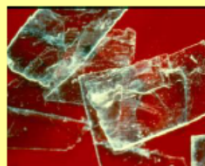


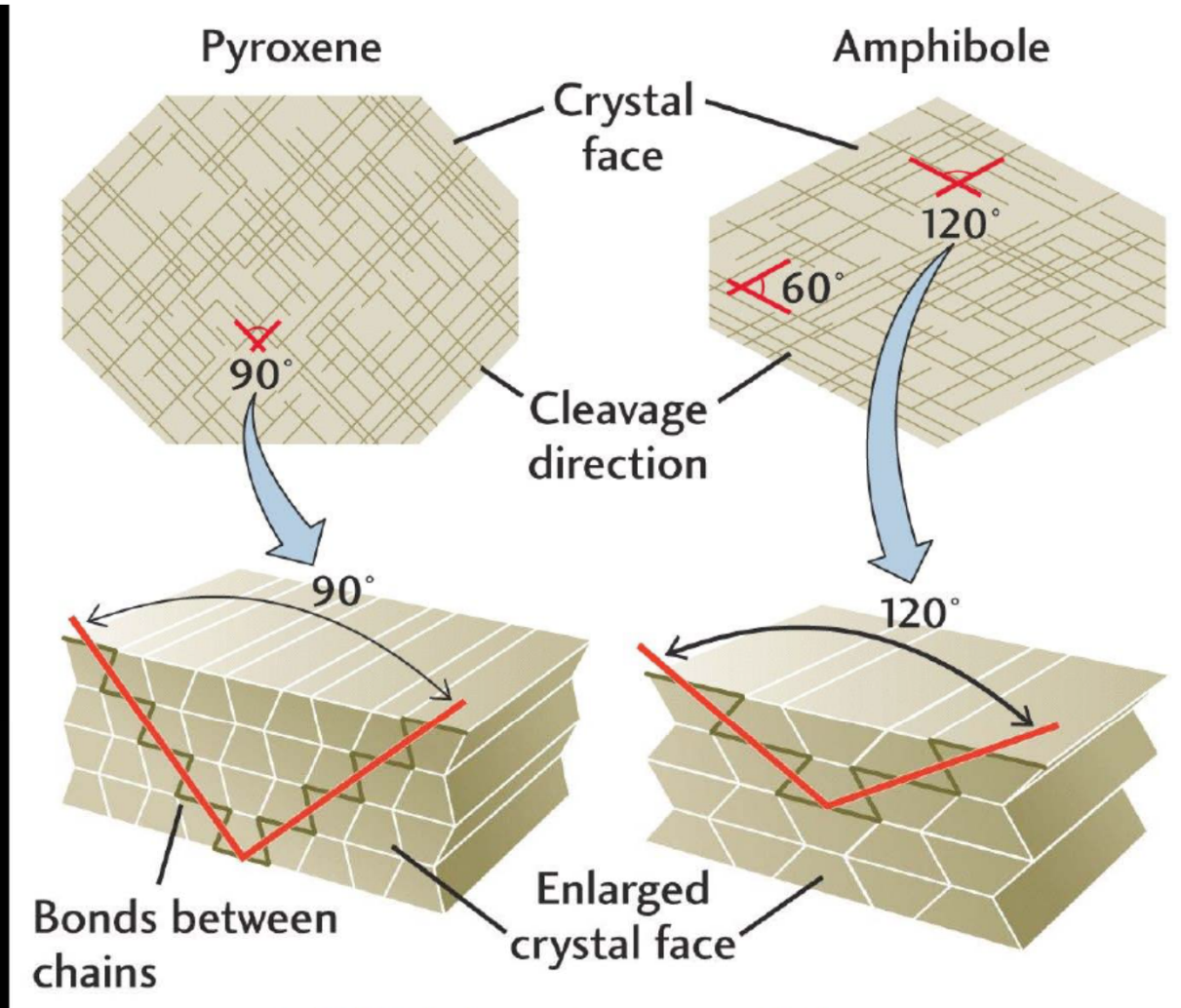
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## Criteria to identify minerals:

- hardness
- density
- habit
- cleavage
- color/streak
- association
- taste
- odor





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HORIZON SOIL SURVEY

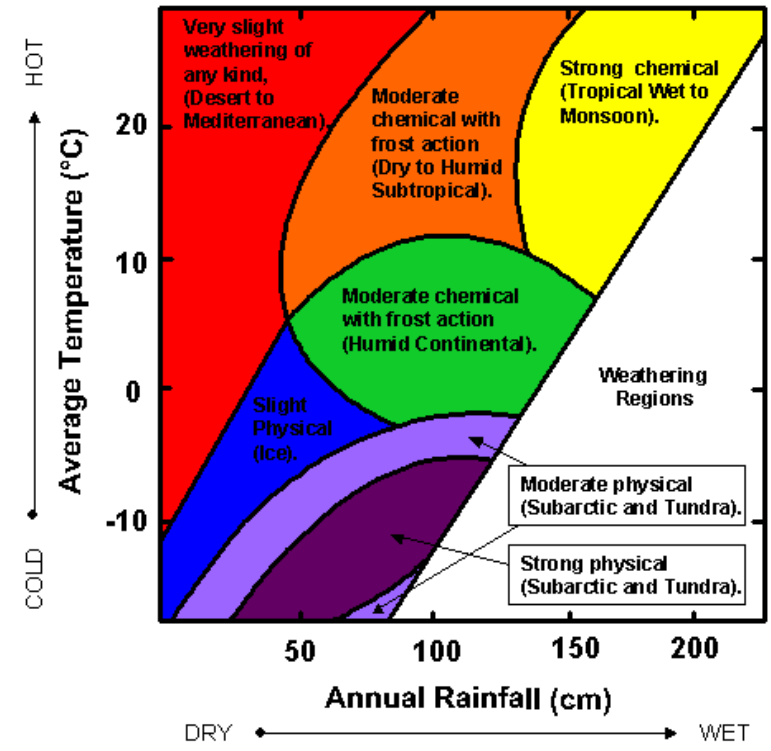
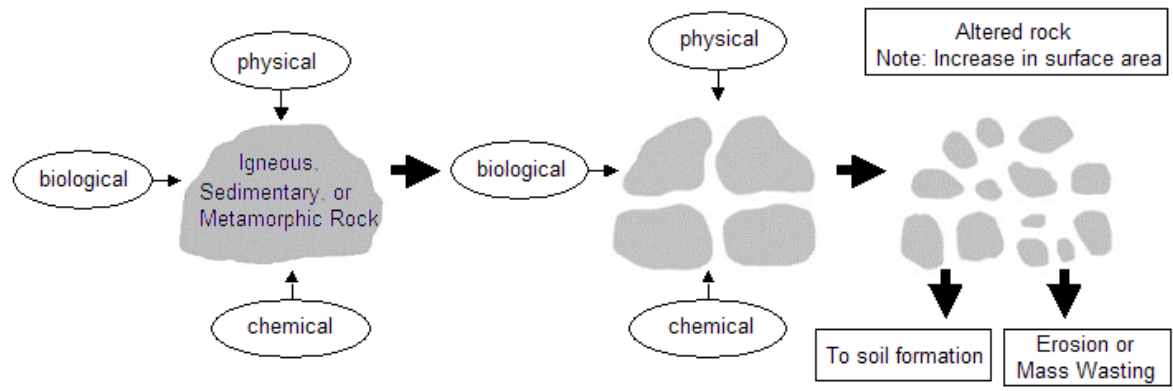
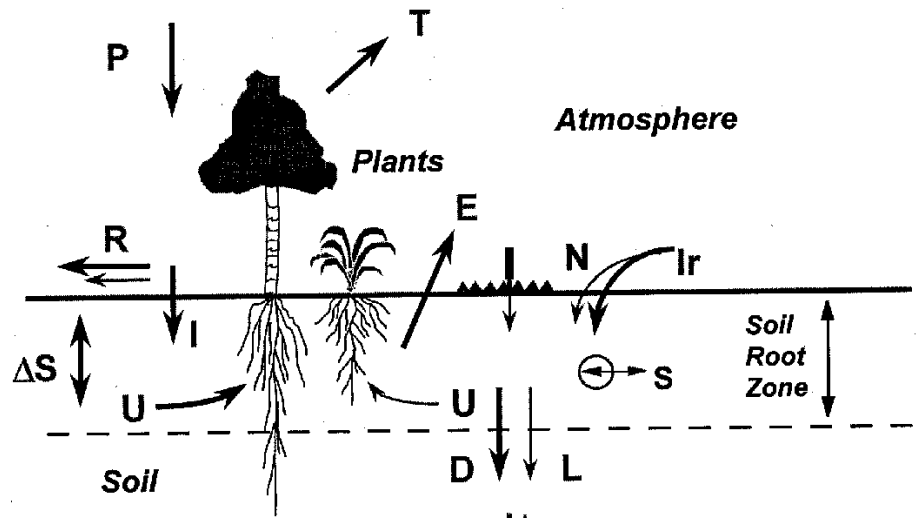
# Minerals – Fracture



Courtesy of [Callan Bentley](#). Used with permission.



# Minerals - weathering





## Stability of Common Minerals under Weathering Conditions Compared with Bowen's Reactions Series

### STABILITY OF MINERALS

### BOWEN'S REACTION SERIES

#### Most Stable

Iron oxides (hematite)

Aluminum hydroxides (gibbsite)

Quartz

Clay minerals

Muscovite mica

Potassium feldspar (orthoclase)

Biotite mica

Sodium-rich feldspar (albite)

Amphibole

Pyroxene

Calcium-rich feldspar (anorthite)

Olivine

Calcite

Halite

#### Least stable

#### Last to crystallize

Quartz

Muscovite

Orthoclase

Biotite

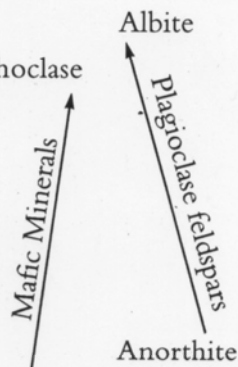
Amphibole

Pyroxene

Anorthite

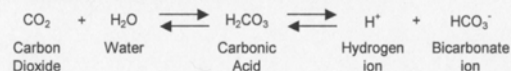
Olivine

#### First to crystallize

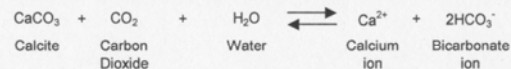


### CHEMICAL EQUATIONS IMPORTANT TO WEATHERING

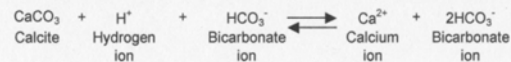
#### A. Solution of Carbon Dioxide in Water to form Carbonic Acid.



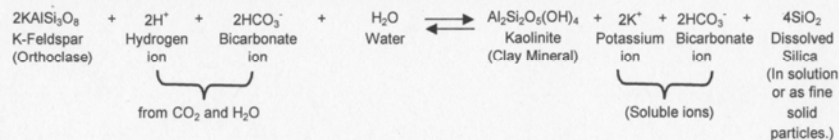
#### B. Solution of Calcite (dissolving of calcite in the presence of carbon dioxide and water.)



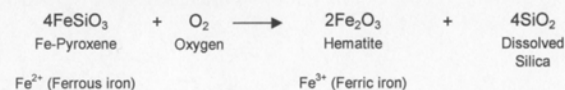
#### C. Solution of Calcite (dissolving of calcite in the presence of hydrogen and bicarbonate ions.)

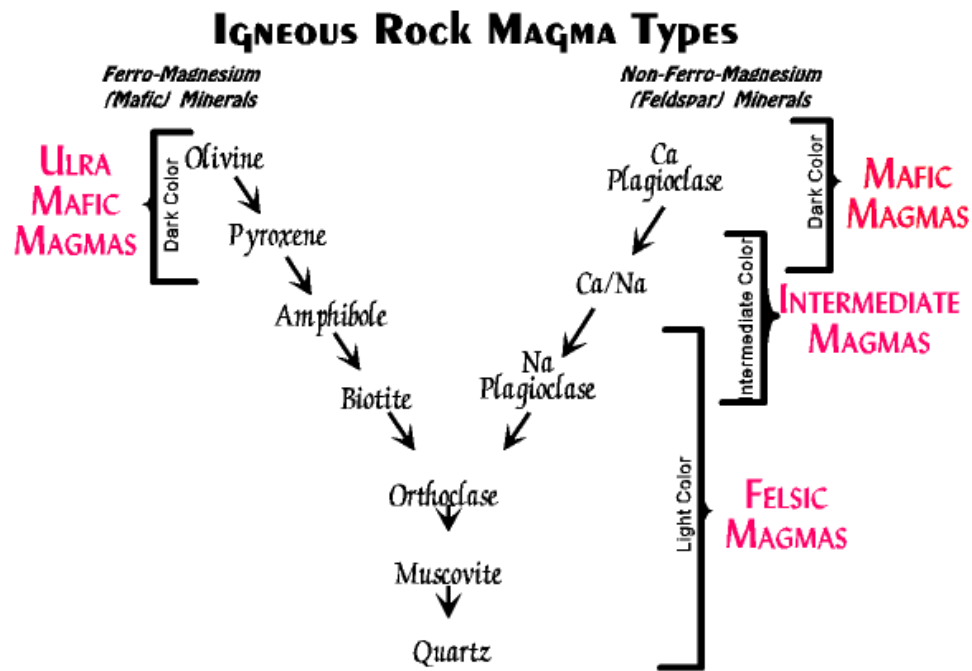


#### D. Chemical Weathering of K-Feldspar to form a Clay Mineral (Kaolinite.)



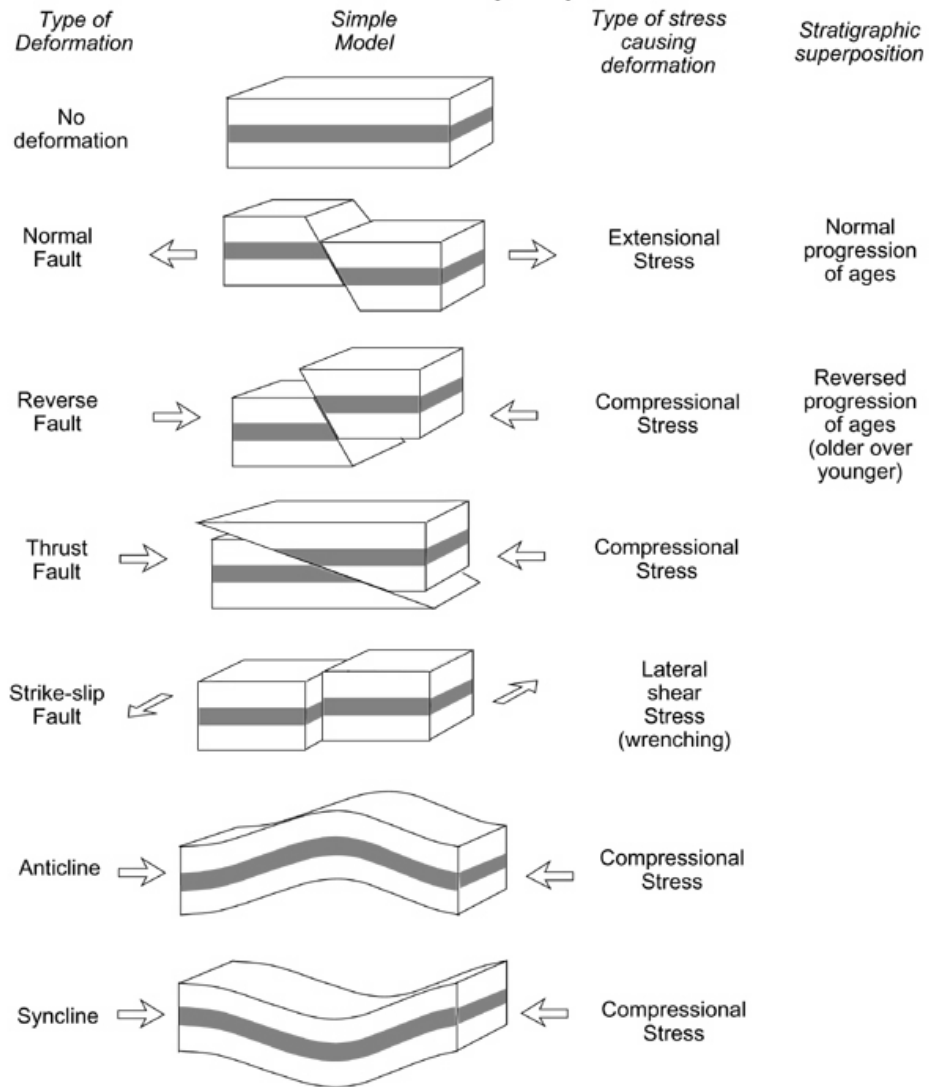
#### E. Oxidation of Iron-bearing Silicates.







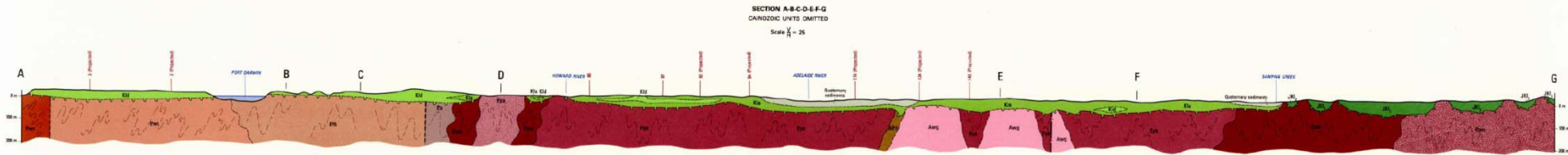
### Faults and folds, and why they form





HORIZON SOIL SURVEY

# Geological structure – Section



## GEOLOGIC SYMBOLS

-----	Geologic boundary, position approximate	
-----	Geologic boundary, intertidal, position approximate	
.....	Basal Cretaceous unconformity, position inferred	
.....	Cretaceous boundary, inferred, concealed	
-----	Bedrock boundary, concealed; queried, position inferred	
-----	Anticline } showing trend and plunge of axis; solid line observed; broken line, approximate; dotted line concealed	} airphoto interpretation
-----	Syncline } showing trend and plunge of axis; solid line observed; broken line, approximate; dotted line concealed	
-----	Minor anticline showing trend of plunge	
-----	Minor anticline showing trend and plunge	
-----	Minor syncline showing trend of plunge	
-----	Minor syncline showing trend and plunge	
-----	Fault; solid line, observed; broken line, approximate; queried inferred	
-----	Fault; showing relative horizontal displacement (u, d indicate relative vertical displacement; up, down)	
-----	Fault zone with crushing	
-----	Strike and dip of strata	
-----	Strike and prevailing dip of strata	
-----	Vertical strata	
-----	Bedding trend, showing prevailing dip	
-----	Lineament	
-----	Strike and dip of cleavage	
-----	Strike and dip direction of cleavage	
-----	Vertical cleavage	
-----	Strike and dip of foliation	
-----	Strike and dip direction of foliation	
-----	Vertical foliation	
-----	Strike and foliation, dip indeterminate	
-----	Dyke, q--quartz, m--minette, t--felsite, *--no direction evident	
-----	Macrofossil location	
-----	Geologic section	
-----	Scout or stratigraphic drillhole number refers to tabulation in Table 7 in accompanying Explanatory Notes	

**Discontinuities** – any separation in rock mass having zero or low tensile strength

- Faults – geological breaks with shear displacement
- Joints – geological breaks with no displacement
- Bedding planes – divide rocks into strata
- Cleavage – fracture and flow cleavage – parallel stress fractures independent of mineral alignment

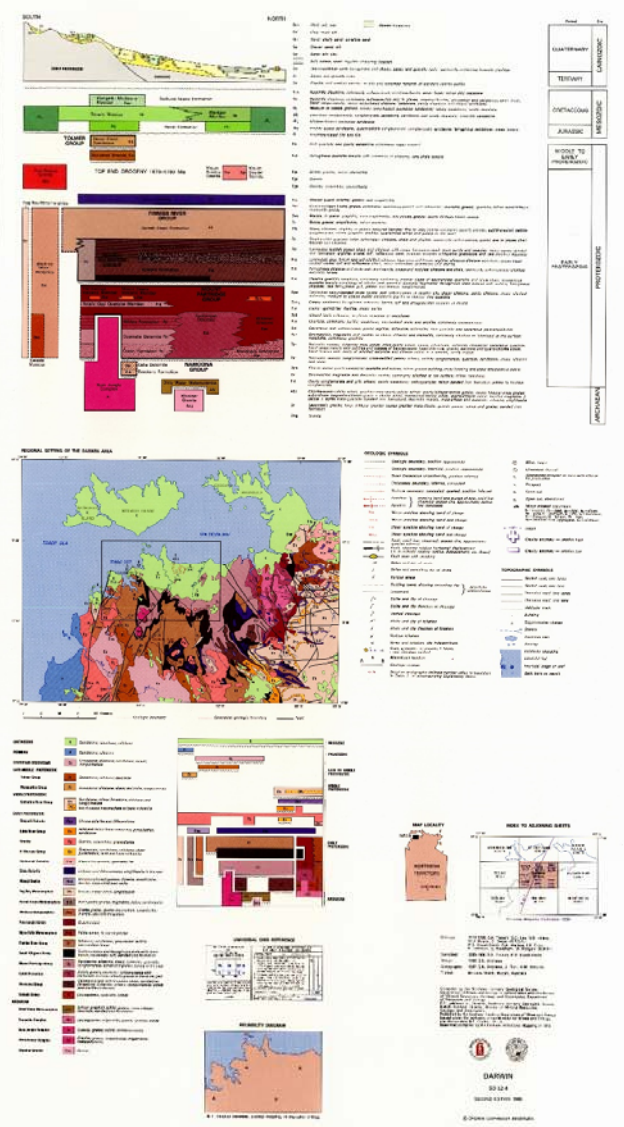
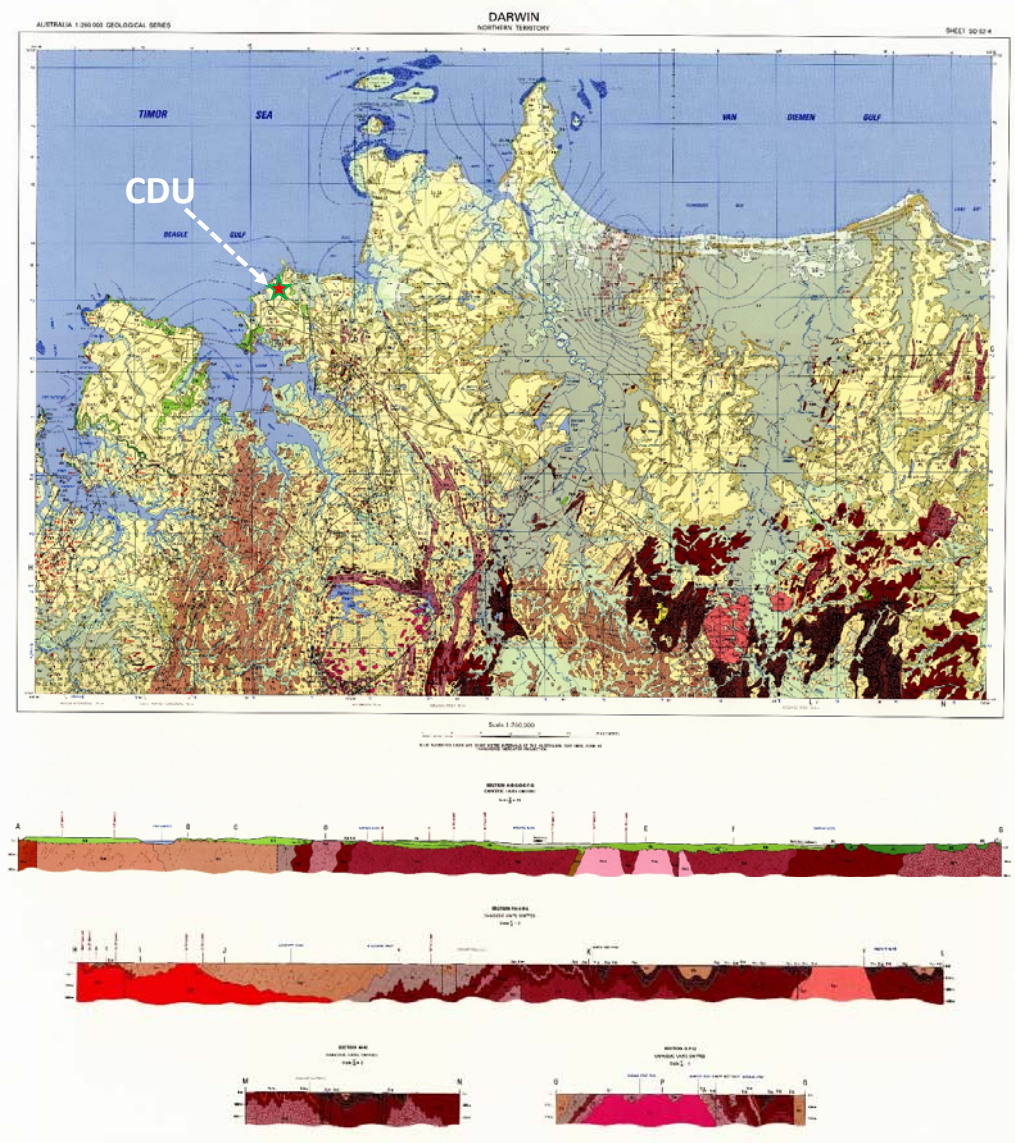
**Unconformities** – a buried erosional or non-depositional surface separating two rock masses or strata of different ages indicating that sediment deposition was interrupted and with an erosional phase

**Disconformity** - is an unconformity between parallel layers of sedimentary rocks which represents a period of erosion or non-deposition.

**Nonconformity** - A nonconformity exists between sedimentary rocks and metamorphic or igneous rocks when the sedimentary rock lies above and was deposited on the pre-existing and eroded metamorphic or igneous rock.



# Geological maps – Darwin





**Development of Joints** - as a result of expansion due to cooling or relief of pressure as overlying rocks are removed by erosion. Joints form free space in rock by which other agents of chemical or physical weathering can enter.

**Crystal Growth** - As water percolates through fractures and pore spaces it may contain ions that precipitate to form crystals. As these crystals grow they may exert an outward force that can expand or weaken rocks.

**Heat** - Although daily heating and cooling of rocks do not seem to have an effect, sudden exposure to high temperature, such as in a forest or grass fire may cause expansion and eventual breakage of rock. Campfire example.

**Plant and Animal Activities** -

Plant roots can extend into fractures and grow, causing expansion of the fracture. Growth of plants can break rock - look at the sidewalks of New Orleans for an example.

Animals burrowing or moving through cracks can break rock.

**Frost Wedging** - Upon freezing, there is an increase in the volume of the water (that's why we use antifreeze in auto engines or why the pipes break in New Orleans during the rare freeze). As the water freezes it expands and exerts a force on its surroundings. Frost wedging is more prevalent at high altitudes where there may be many freeze-thaw cycles.



Since many rocks and minerals are formed under conditions present deep within the Earth, when they arrive near the surface as a result of uplift and erosion, they encounter conditions very different from those under which they originally formed. Among the conditions present near the Earth's surface that are different from those deep within the Earth are:

Lower Temperature (Near the surface  $T = 0-50^{\circ}\text{C}$ )

Lower Pressure (Near the surface  $P = 1$  - several hundred atmospheres)

Higher free water (there is lots of liquid water near the surface, compared with deep in the Earth)

Higher free oxygen (although O is the most abundant element in the crust, most of it is tied up bonded into silicate and oxide minerals, at the surface there is much more free oxygen, particularly in the atmosphere).



Water is the main agent responsible for chemical weathering reactions and weak acids formed in water. An acid is solution that has abundant free H<sup>+</sup> ions.

The most common weak acid that occurs in surface waters is carbonic acid.

Carbonic acid is produced in rainwater by reaction of the water with carbon dioxide (CO<sub>2</sub>) gas in the atmosphere.





Hydrolysis - H<sup>+</sup> or OH<sup>-</sup> replaces an ion in the mineral.

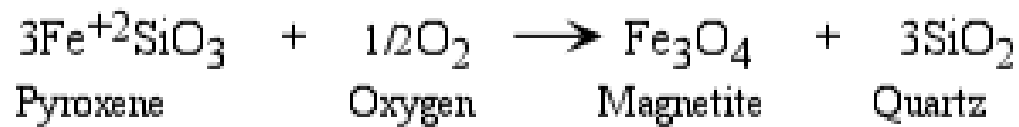


Leaching - ions are removed by dissolution into water. In the example above the K<sup>+</sup> ion was leached



Oxidation - Since free oxygen (O<sub>2</sub>) is more common near the Earth's surface, it may react with minerals to change the oxidation state of an ion.

This is more common in Fe (iron) bearing minerals, since Fe can have several oxidation states, Fe, Fe<sup>+2</sup>, Fe<sup>+3</sup>. Deep in the Earth the most common oxidation state of Fe is Fe<sup>+2</sup>





Complete Dissolution - the mineral is completely dissolved by the water.





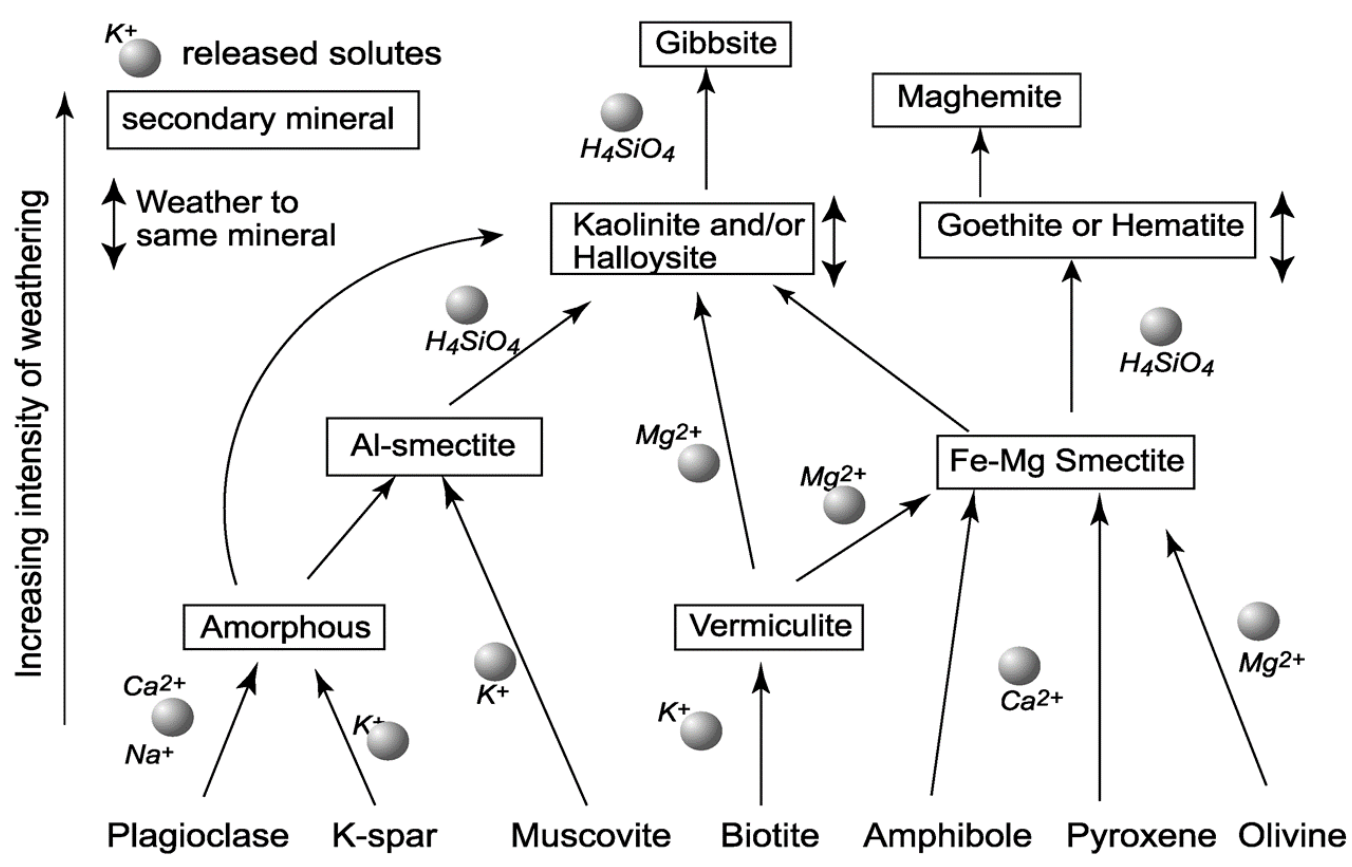
Soils are an important natural resource – representing primary ecosystem productivity.

Soils represent the interface between the lithosphere and the biosphere - as soils provide nutrients for plants.

Soils consist of weathered rock plus organic material that comes from decaying plants and animals. The same factors that control weathering control soil formation with the exception, that soils also requires the input of organic material as some form of Carbon.



# Chemical Weathering – Soils





Thankyou

