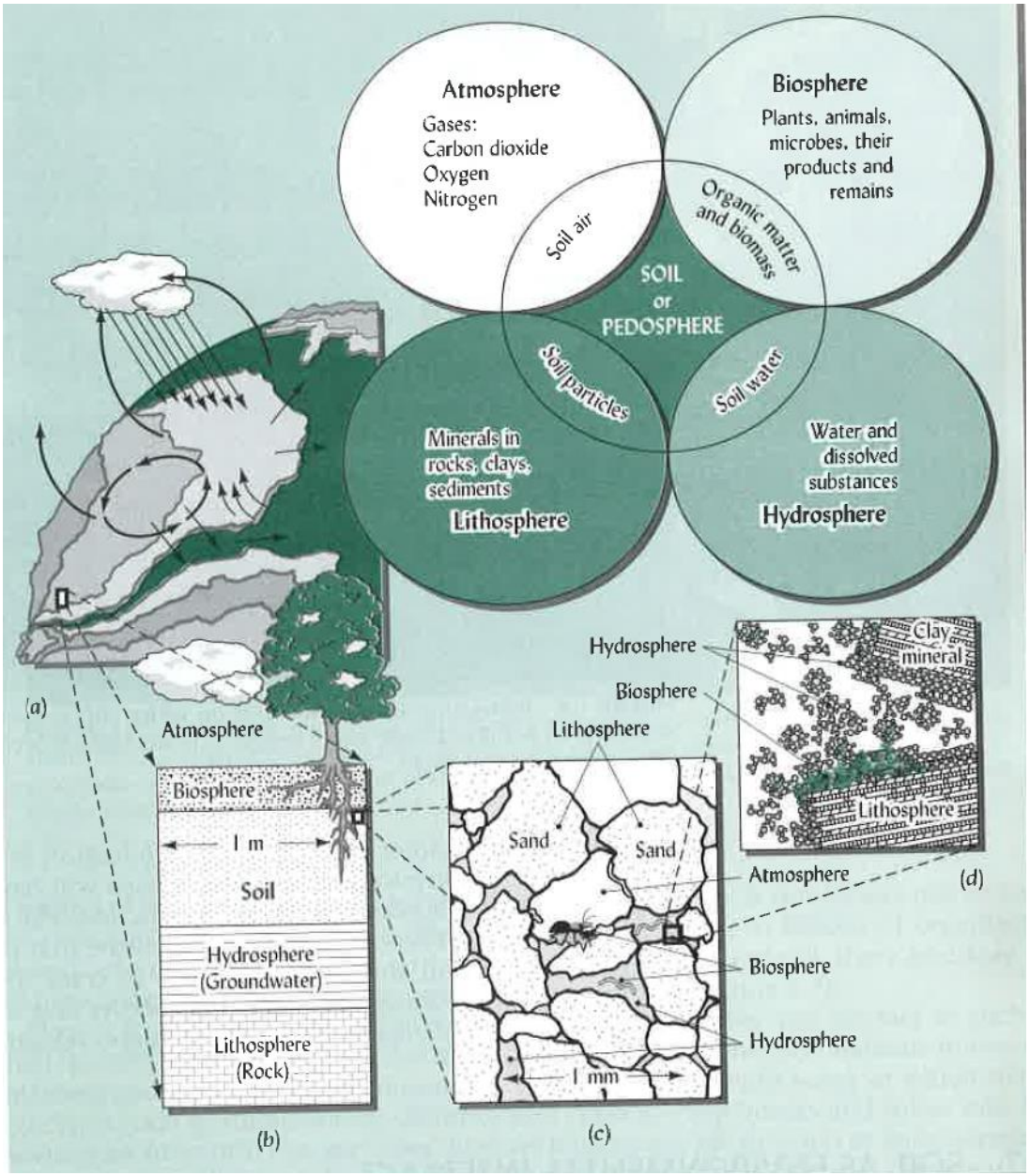
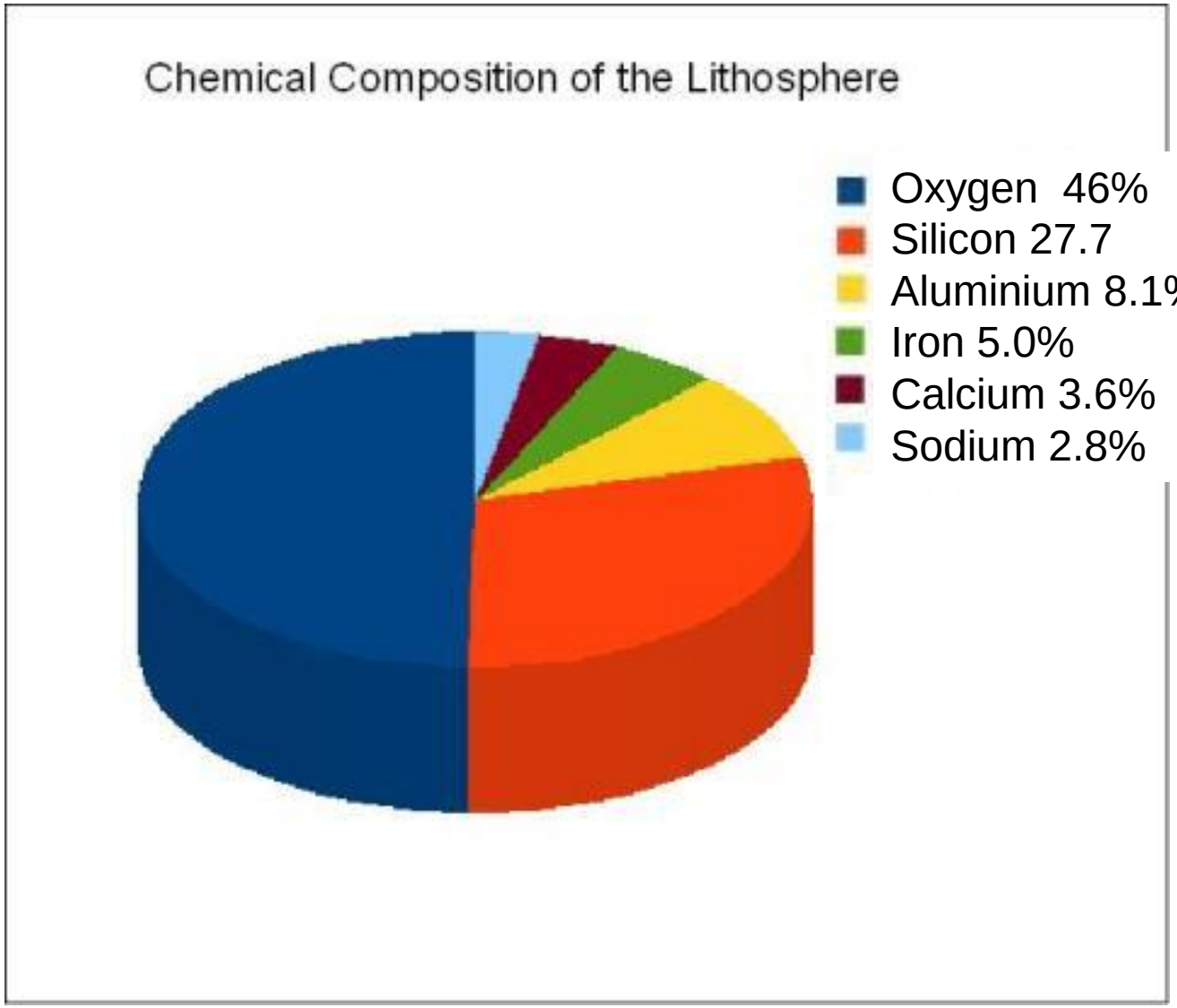
Introduction to soil chemistry

Minerals and rocks

Repetition: What are soils?



Chemical composition of the lithosphere



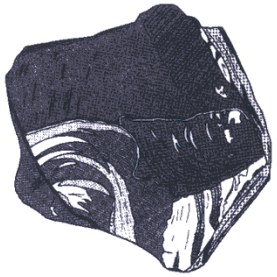
O + Si + Al > 80% of all mass of the lithosphere

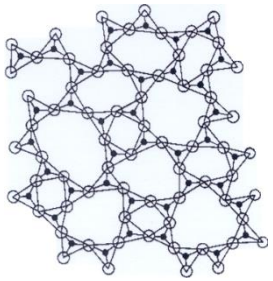
Minerals - Definition

Minerals are physically and chemically homogeneous, hard, inorganic entities usually of crystalline form and abiogenic in origin in the earth crust. They form rocks and the inorganic solid phase of soils.

Amorphous and crystalline minerals

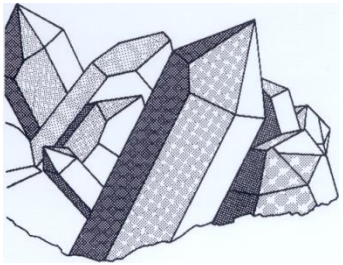
Obsidian (SiO_2):

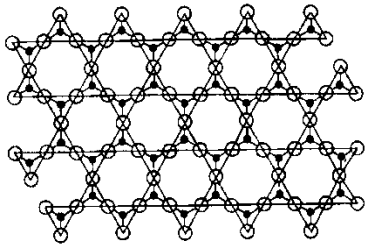




Amorphous structure

Quartz (SiO_2):





Crystalline structure

Minerals – Differentiation according to physical properties

A) Crystal form

- **7 crystal systems**

B) Color

C) Luminescence

- **UV-Fluorescence**

D) Transparence

- **transparent, translucent, opaque**

E) Fissionability

F) Density

- **Density of mineral in soils: 2.65 g cm^{-3}**
- **Heavey minerale > 2.9 g cm^{-3}**

G) Hardness

- **Scratch**

Hardness

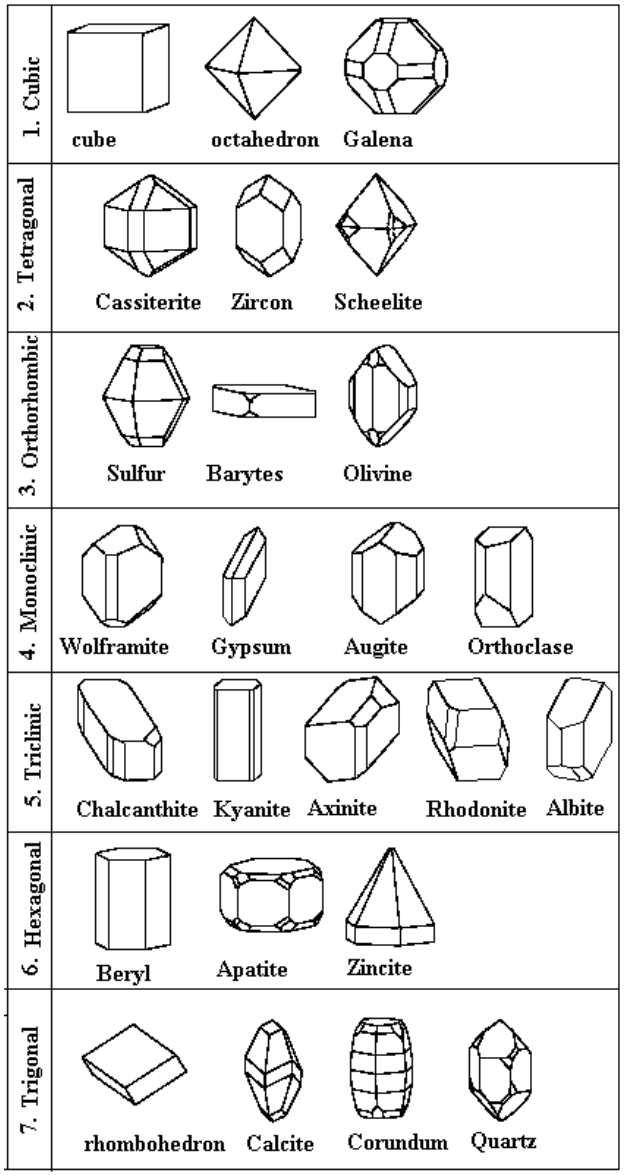
according to Mohs

Minerals – Differentiation according to physical properties

A) Crystal form

- **7 crystal systems**

Crystal form of the seven crystal systems



Minerals – Differentiation according to physical properties

A) Crystal form

- **7 crystal systems**

B) Color

C) Luminescence

- **UV-Fluorescence**

D) Transparence

- **transparent, translucent, opaque**

E) Fissionability

F) Density

- **Density of minerals in soils: 2.65 g cm^{-3}**
- **Heavey mineral > 2.9 g cm^{-3}**

G) Hardness

- **Scratch Hardness** according to Mohs

Minerals – Differentiation according to physical properties

A) Crystal form

- 7 crystal systems

B) Color

C) Luminescence

- UV-Fluorescence

D) Transparence

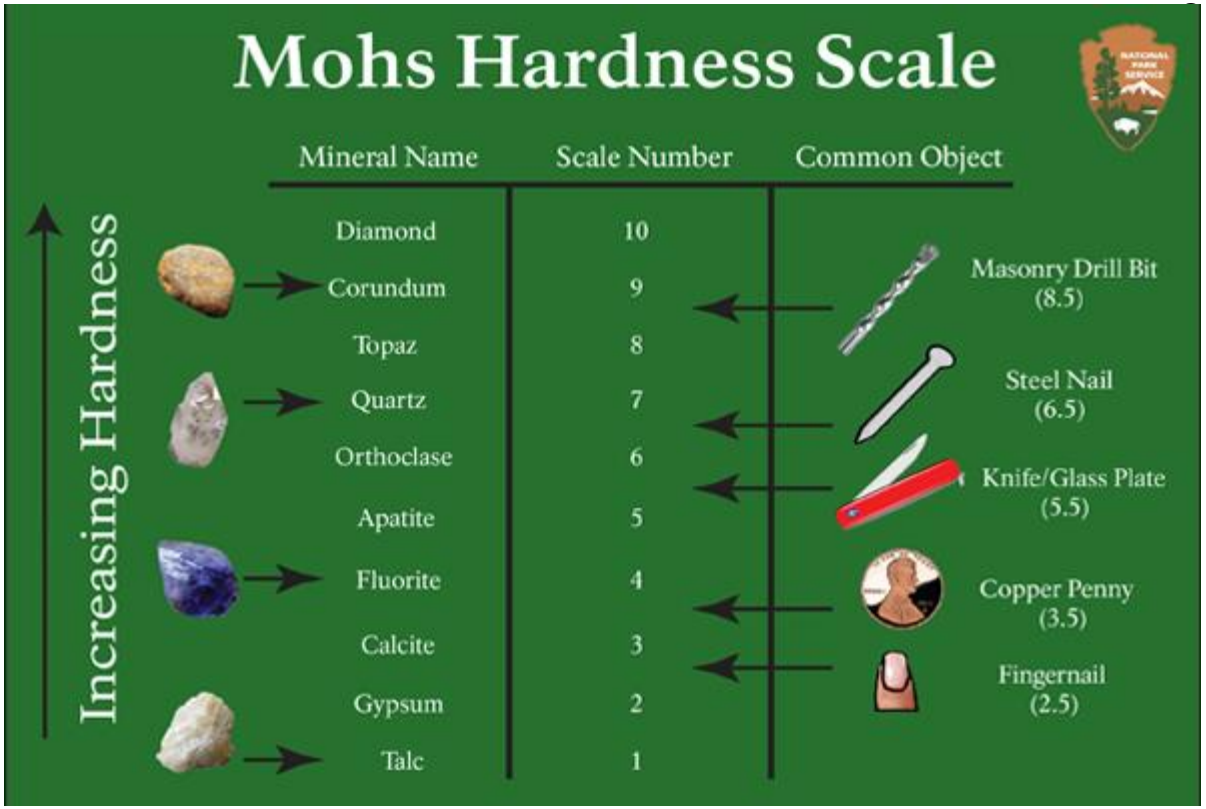
- transparent, translucent, opaque

E) Fissionability

F) Density

G) Hardness

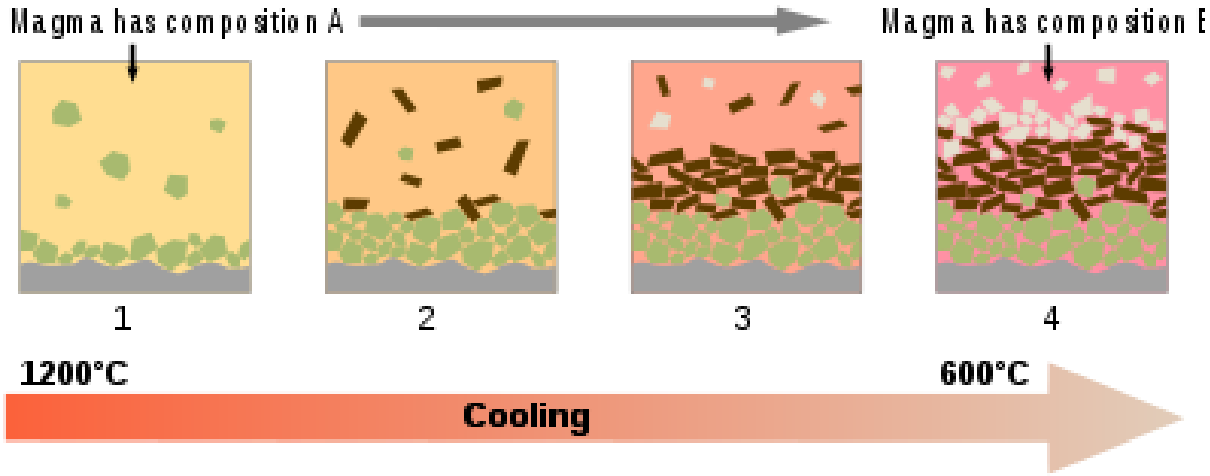
- **Scratch Hardness** according to Mohs



Primary minerals

A) Primary Minerals

- **Definition: Minerals that have crystalized from magma**
- **Fractional crystallisation in a magma**
- **Minerals have different melting points (1200°C ⇒ 600°C)**



1: olivine crystallizes; **2**: olivine and pyroxene crystallize; **3**: pyroxene and plagioclase crystallize; **4**: plagioclase crystallizes. At the bottom of the magma reservoir, a cumulate rock forms.

Secundary minerals

B) Secundary minerals

- **Definition: Minerals that form during weathering and soil formation at the earth surface**
- **They comprise weathering products as well as minerals that newly from during weathering**
- **Examples: Al-, Fe- und Mn-Oxides/Hydroxides, clay minerals**

Minerals - Differentiation according to chemical properties

I) Element
- Example: Diamant, gold, copper

II) Sulfide
- Example: Pyrite (under anaerobic conditions)

III) Halogenide
- Compounds containing F, Cl, Br, J

IV) Oxide und Hydroxide
- Example: Silicon, iron- and aluminiumoxide

V) Carbonate, Nitrate, Borate
- Example: Calcite, dolomite

VI) Sulfate, Chromate, Molybdate
- Example: Gypsum

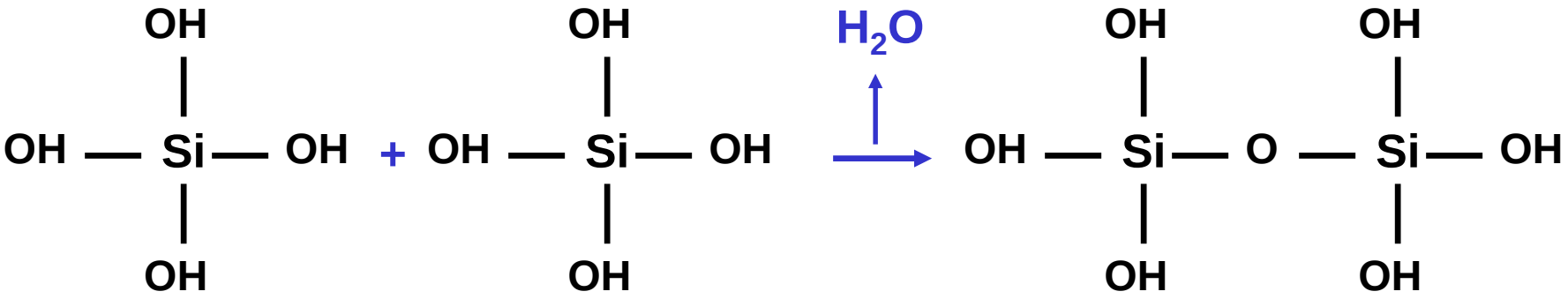
VII) Phosphate, Arsenate, Vanadate
- Example: Apatite

VIII) Silicate
- Bsp.: Primary and secundary silicates

Silicon oxide

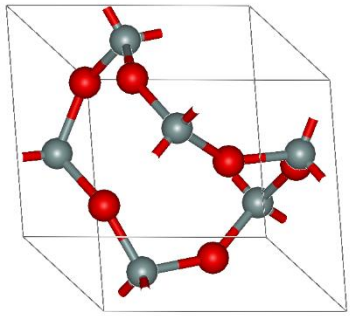
A) Quartz (SiO_2):

- **Mostly of magmatic origin (primary mineral) Scratch hardness according to Mohs = 7, weathering resistant**
- **Quartz is the second most abundant mineral in Earth's continental crust, after feldspar.**
- **SiO_2 is completely polymerized Silicic acid (H_4SiO_4):**



B) Opal (SiO_2 ($+H_2O$)):

Amorphous Si-Oxide, precursor of quartz



Quartz

Minerals - Differentiation according to chemical properties

I) Element
- Example: Diamant, gold, copper

II) Sulfide
- Example: Pyrite (under anaerobic conditions)

III) Halogenide
- Compounds containing F, Cl, Br, J

IV) Oxide und Hydroxide
- Example: Silicon, iron- and aluminiumoxide

V) Carbonate, Nitrate, Borate
- Example: Calcite, dolomite

VI) Sulfate, Chromate, Molybdate
- Example: Gypsum

VII) Phosphate, Arsenate, Vanadate
- Example: Apatite

VIII) Silicate
- Bsp.: Primary and secundary silicates

Aluminium oxide:

A) Gibbsite ($Al(OH)_3$):

- Secundary mineral, formed from weathering products of silicates (Release of $Al^{3+}$and hydrolysis of the released Al^{3+})
- Solubility increaed with decreasing pH

Iron oxide:

- Secundary minerals, Oxidation of Fe^{2+} released from primary minerals
- The ratio of oxidized iron to total iron characterizes the degree of weathering of a soil
- Solubility depends on redox potential and pH

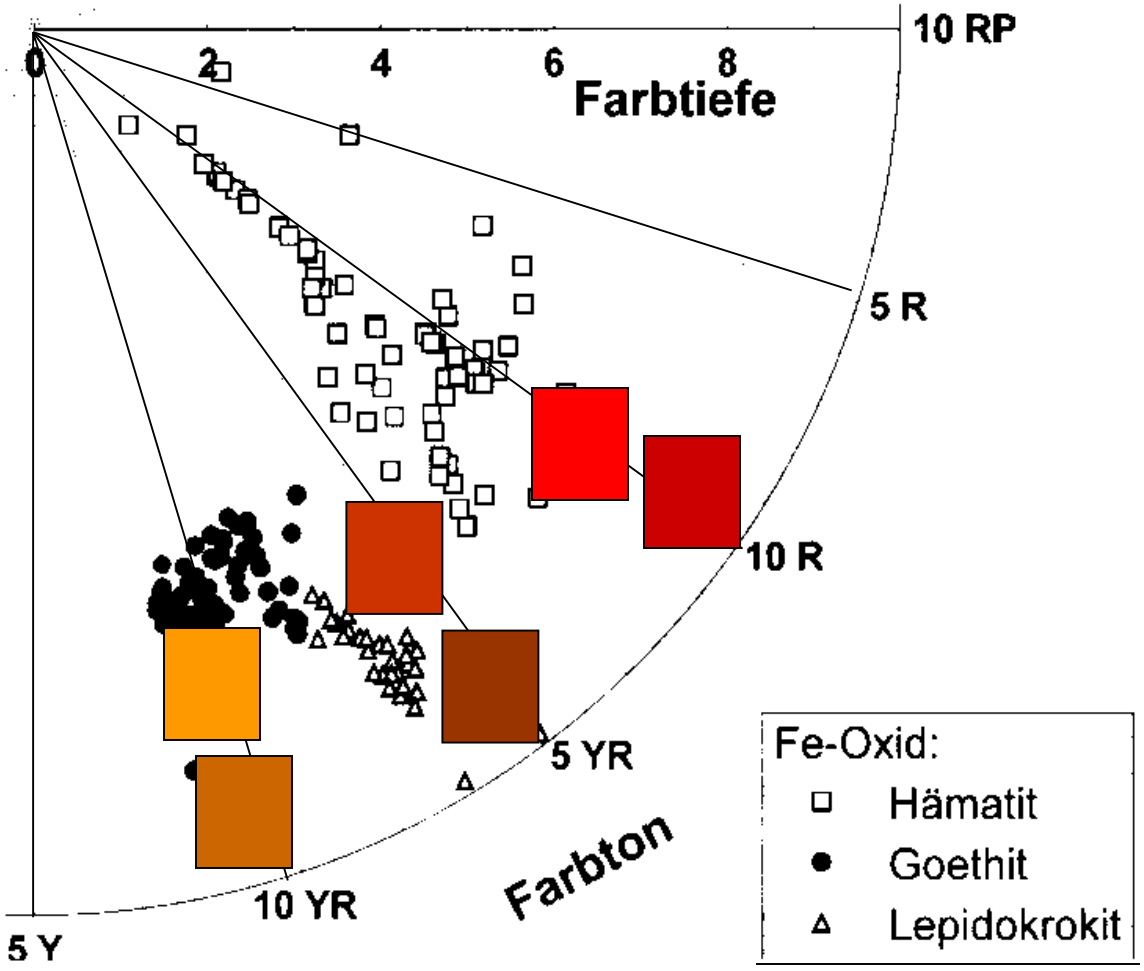
Hematite (α-Fe_2O_3)

Goethite (α-FeOOH)

Ferrihydrite ($5\ Fe_2O_3 \cdot 9H_2O$)

Iron oxides strongly affect the color of soils

Color of iron oxides



Carbonate, Sulfate:

A) Carbonate:

- ♦ Calcite ($CaCO_3$)
- ♦ Dolomite ($CaMg(CO_3)_2$)
- ♦ Magnesite ($MgCO_3$)

- Salts of carbonic acid (H_2CO_3), secundary minerals
- Main component of limestone
- Also important for limining in forests and croplands

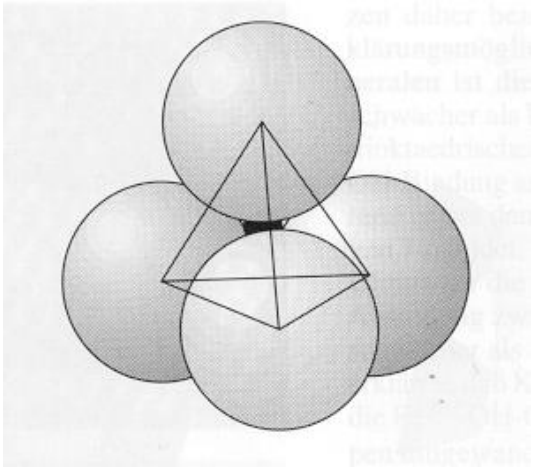
B) Sulfate:

- ♦ Gypsum ($CaSO_4 \cdot 2\ H_2O$):

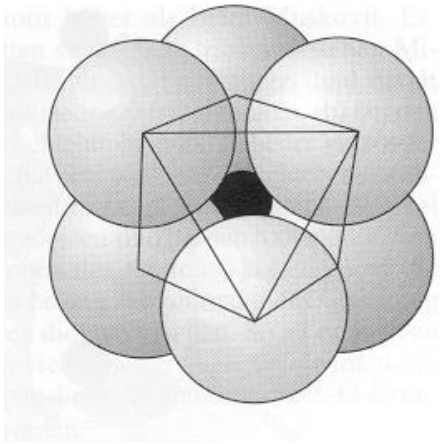
- Evaporite, high solubility

Primary silicates

Building blocks of silicates



SiO_4-tetrahedron



AlO_6-octahedron

$(Al,Si)O_4$

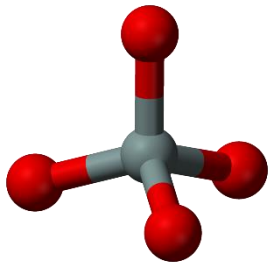
$(Al,Mg,Fe)O_6$

Isomorphic replacement: One of the central atoms is replaced by a an atom with a simiar size but a different charge → Leads to negative charge

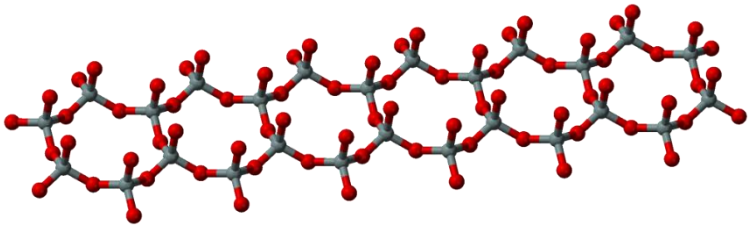
Primary silicates

Primary silicates are differentiated according to the structure formed by the tetrahedons and octahedrons

- **Nesosilicate (German: *Inselsilikate*)**
- **Inosilicate (*Ketten-, Bandsilikate*)**
- **Phyllosilicate (*Schichtsilikate*)**
- **Tectosilicate (*Gerüstsilikate*)**



Nesosilicate



Inosilicate

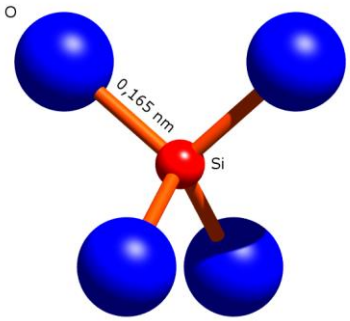
Primary silicates

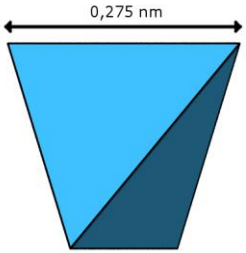
A) Nesosilicate (*Inselsilikate*)

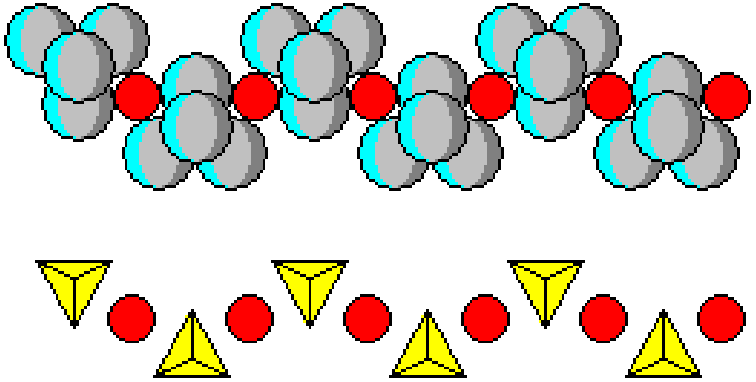
- **Greek, *nesos*, island**
- **SiO_4-tetrahedron are not connected through joint O-atoms but through Fe and Mg ions**

⇒ **Olivine: $(Mg, Fe)_2SiO_4$**

- **Olivine is and important Mg source in igneous rock (basalt)**



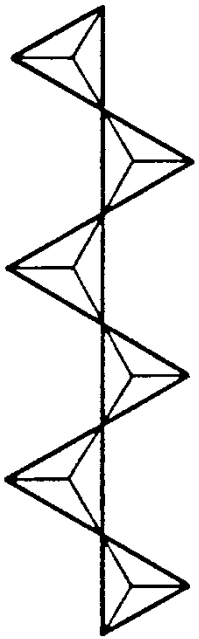




Primary silicates

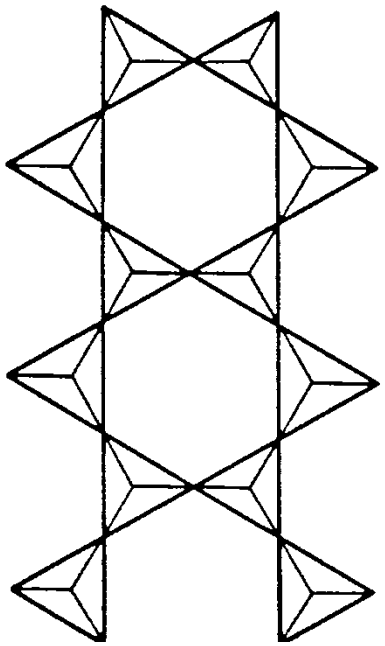
B) Inosilicate (Pyroxene, Amphibole) (*Ketten-, Bandsilikate*)

- **Si^{4+} in the tetrahedron is replaced by Al^{3+} (= isomorphic substitution)**
- **Balance of negative charge by incorporation of cations such as Ca^{2+}, Mg^{2+} , Fe^{2+} into the mineral**



Augite

$(Ca, Mg, Fe, Al)_2(Si, Al)_2O_6$

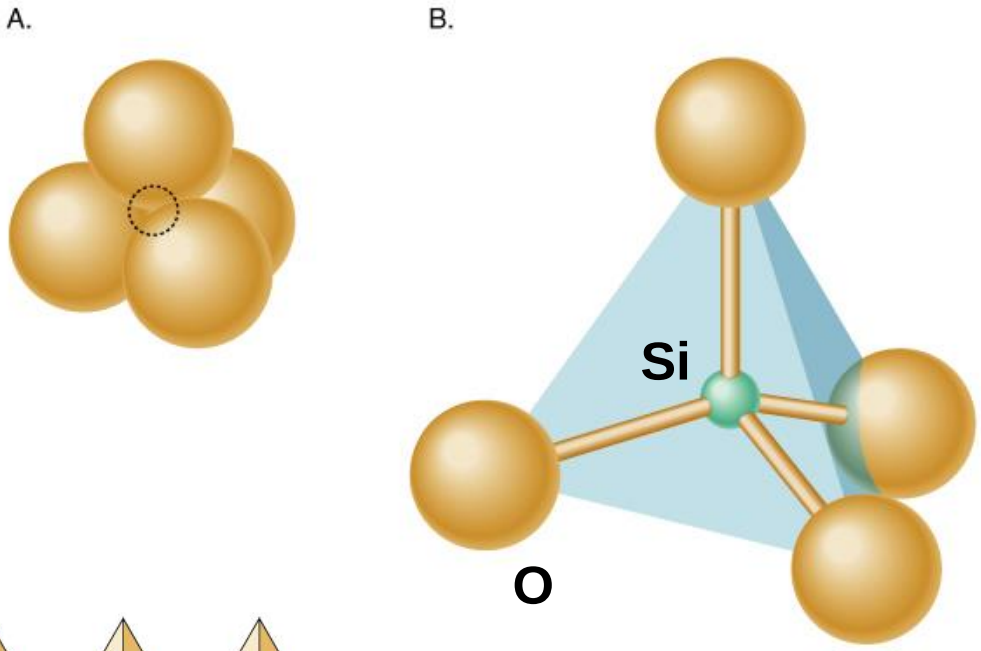


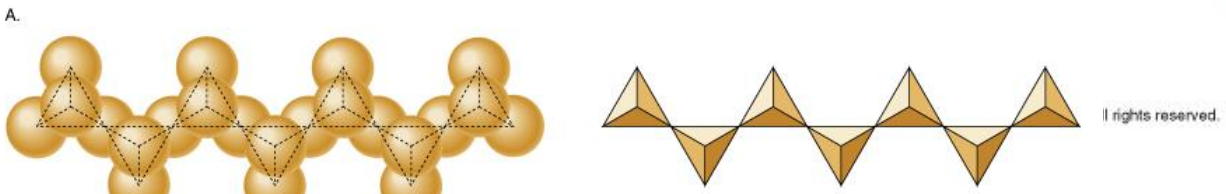
Hornblende

$(Mg, Fe, Al)_5(Si, Al)_8O_{22}(OH)_2$

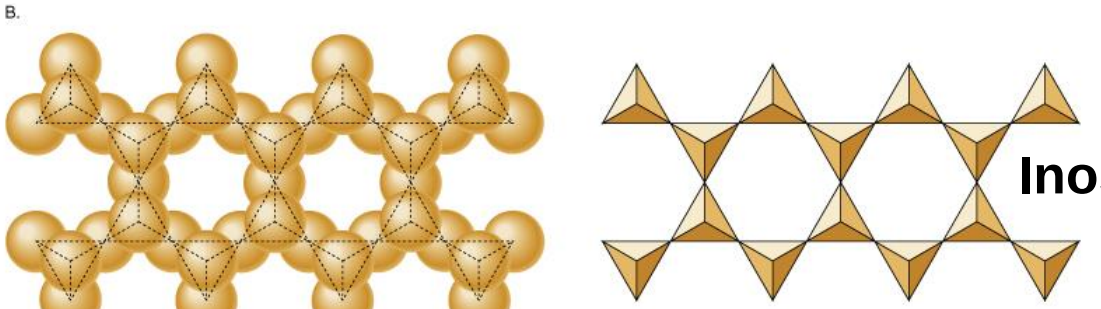
Primary silicates

⇒ **Polymerization of the SiO_4-tetrahedron**





Inosilicate (Chain, *Kettensilikat*)



Inosilicate (Band, *Bandsilikat*)

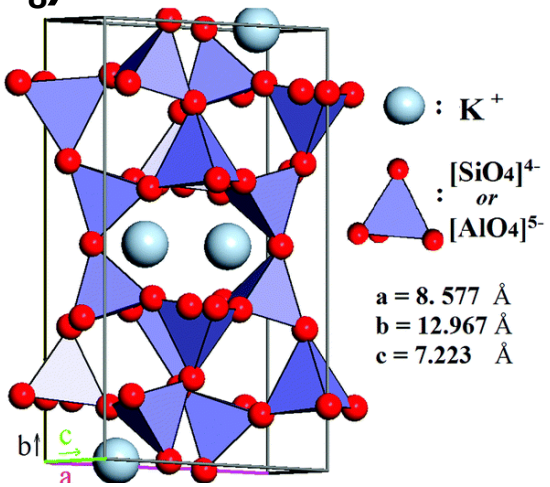
Primary silicates

C) Tectosilicates (Feldspar, Plagioclase) (*Gerüstsilikate*)

- **20-50% of all Si^{4+} in the tetrahedron are replaced by Al^{3+} (= isomorphic substitution).**
- **Balance of negative charge by incorporation of cations such as K^+, Na^+, Ca^{2+}, Mg^{2+} into the mineral**

⇒ **Kalifeldspar (Orthoclase):** $K(AlSi_3O_8)$
⇒ **Natronfeldspar (Albite):** $Na(AlSi_3O_8)$
⇒ **Calciumfeldspar (Anorthite):** $Ca(Al_2Si_2O_8)$

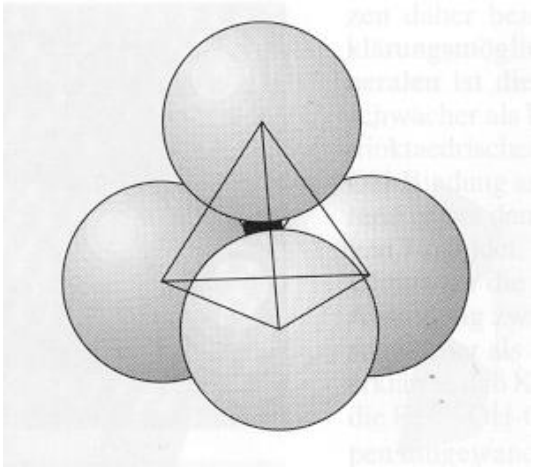
- **Feldspars are important sources of nutrients**



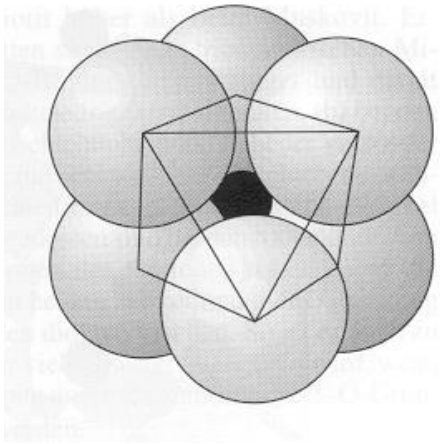
$K(AlSi_3O_8)$

Primary silicates

Building block of silicates



SiO_4-tetrahedron



AlO_6-octahedron

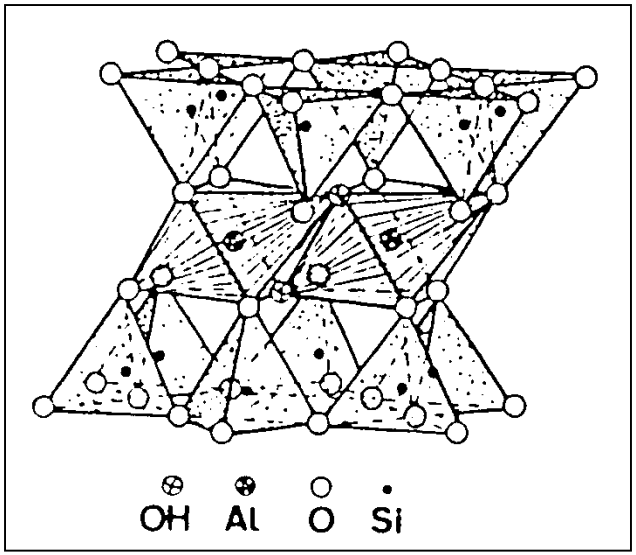
$(Al,Si)O_4$

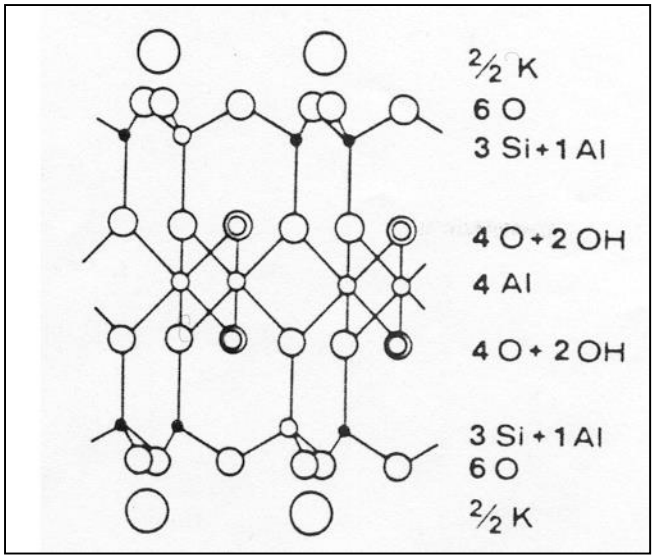
$(Al,Mg,Fe)O_6$

Primary silicates

D) Phyllosilicate (Mica) (*Schichtsilikate*)

- **Built of (Si, Al)O_4-tetrahedron and (Al, Mg, Fe)(O, OH)$_6$-octahedron**
- **Connection of tetrahedrons and octahedrons via joint O and OH.**





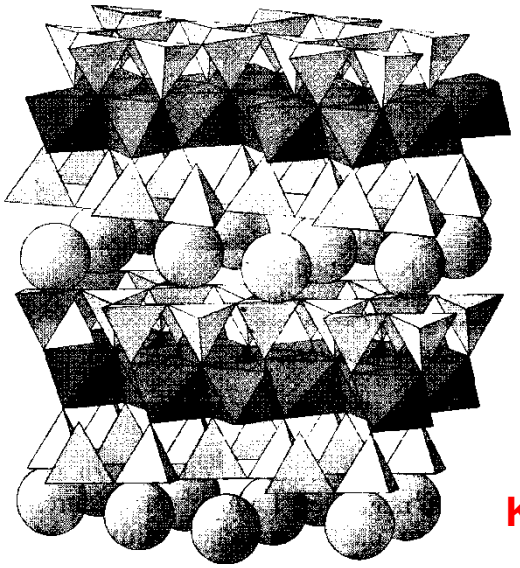
- **Isomorphic substitution occurs in the octahedron layer and in the tetrahedron layer and charge is balanced by incorporation of cations**

Primary silicates

D) Phyllosilicate (Mica) (*Schichtsilikate*)

⇒ **Muscovite $KAl_2(Si_3Al)O_{10}(OH)_2$:**
Isomorphic replacement occurs in the tetrahedron layer by Al^{3+}
Charge-balancing by incorporation of K^+

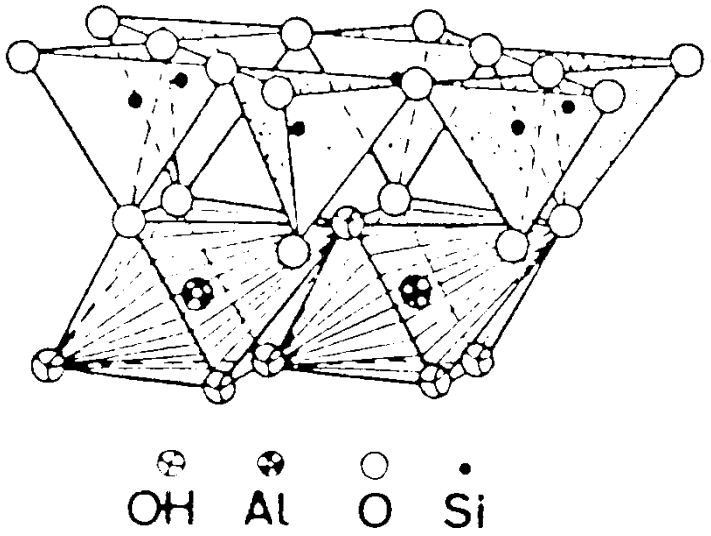
⇒ **Biotite $K(Mg, Fe, Mn)_3(Si_3Al)O_{10}(OH)_2$:**
Structured similar to muscovite, but Al^{3+} in the center of the octahedron is replaced by bivalent cation (low weathering resistance)



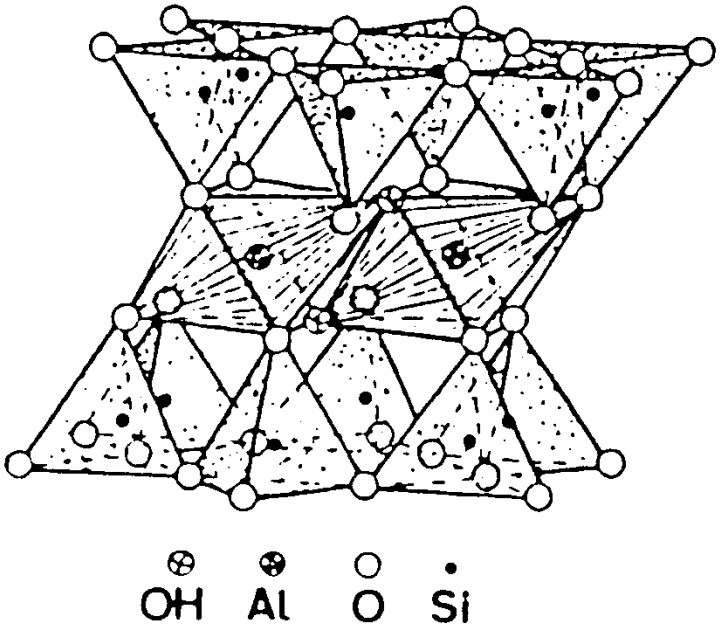
Tetrahedron
Octahedron
Tetrahedron
K^+-Ions in the interlayer
Tetrahedron
Octahedron
Tetrahedron
K^+-Ions in the interlayer

Secundary minerals (clay minerals)

- Clay minerals belong to the phyllosilicates (similar structure)
- They form during weathering
- Clay minerals are divided into 2-layer and 3-layer clay minerals

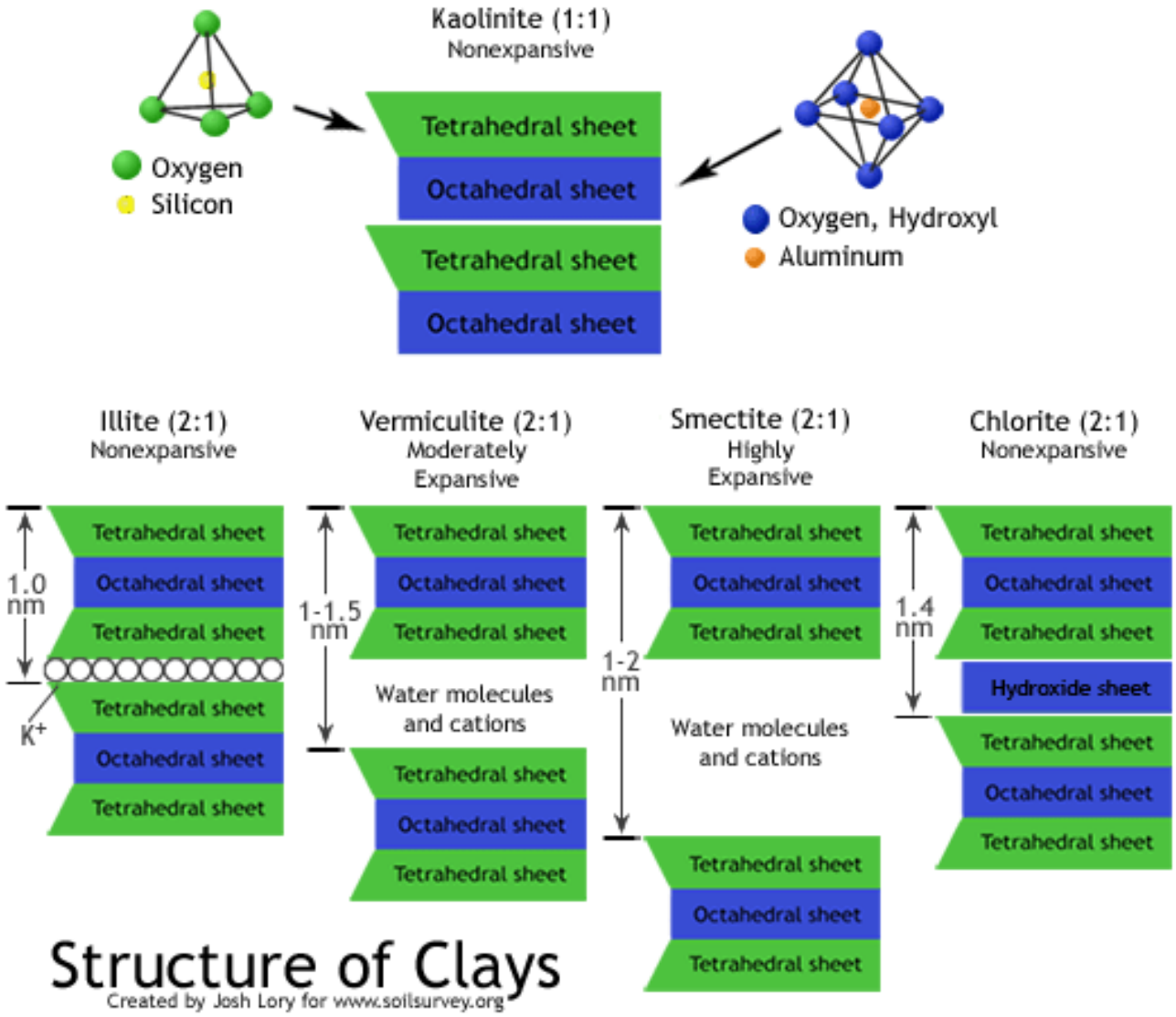


2-layer mineral



3-layer mineral

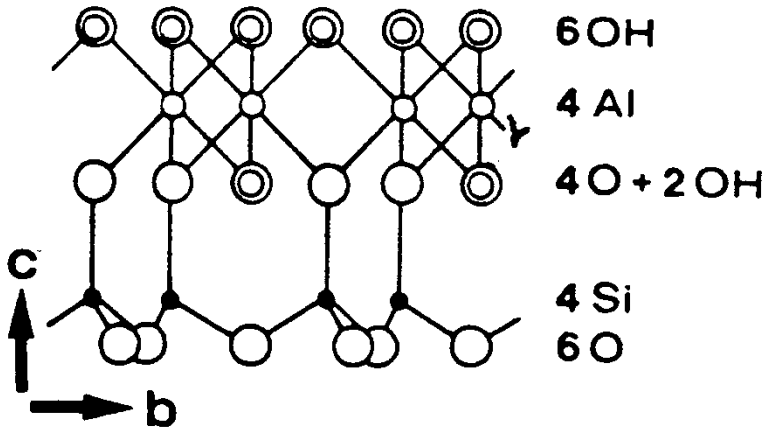
Secundary minerals (clay minerals)



Secundary minerals (clay minerals)

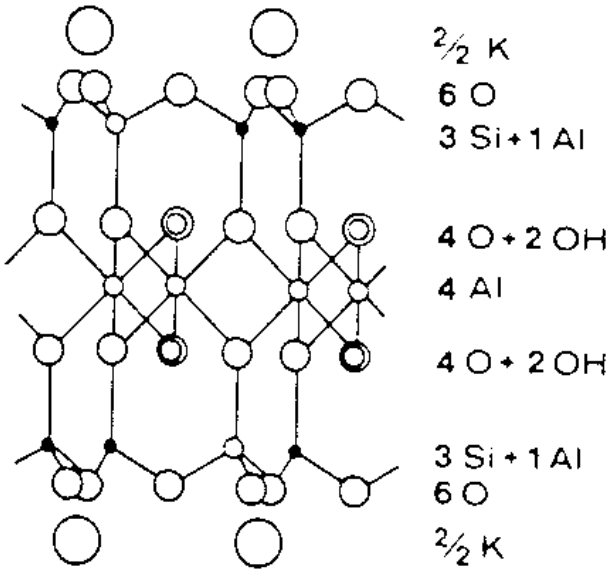
A) Kaolinite

- 2-layer clay mineral
- No isomorphic substitution
- Connection of layers by H-bridges
- In strongly weathered soils



B) Illite

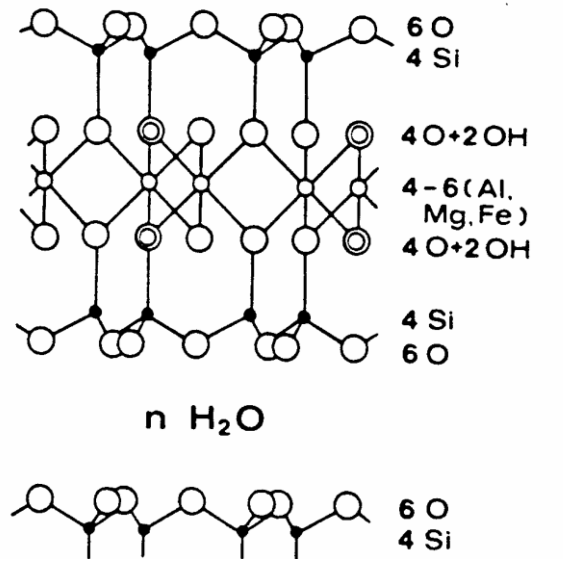
- 3-layer clay mineral
- Stuctured as mica
- K^+ between layers

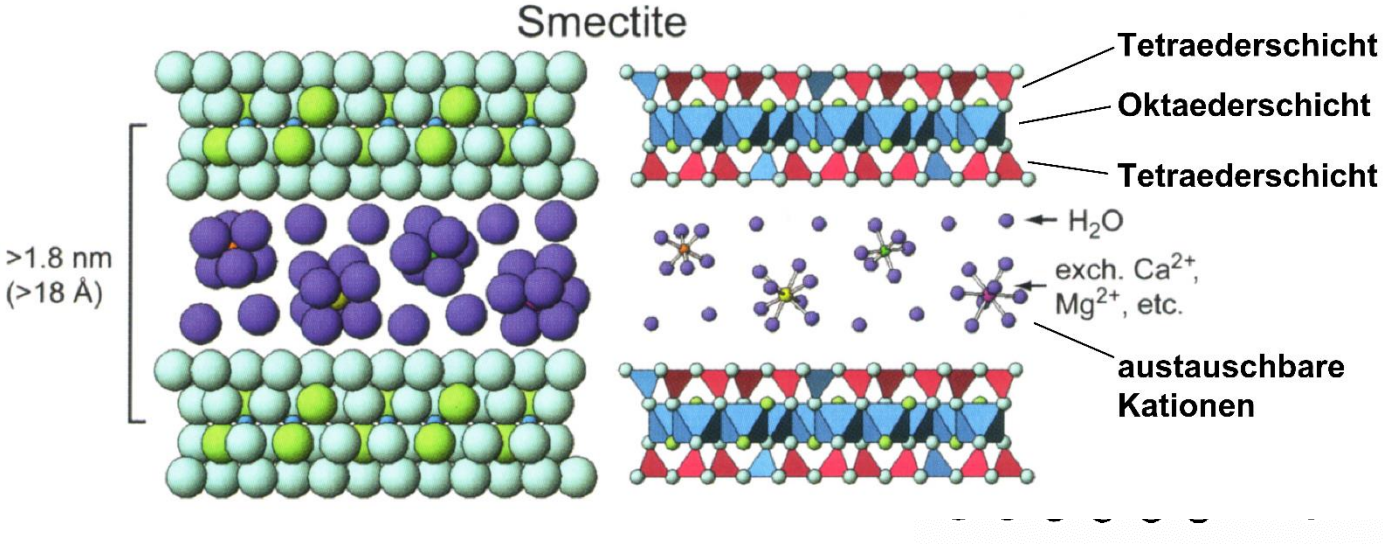


Secundary minerals (clay minerals)

C) Vermiculite, Smectite

- 3-layer clay mineral
- Structured as Illite but with cations in the interlayer
- Swellable

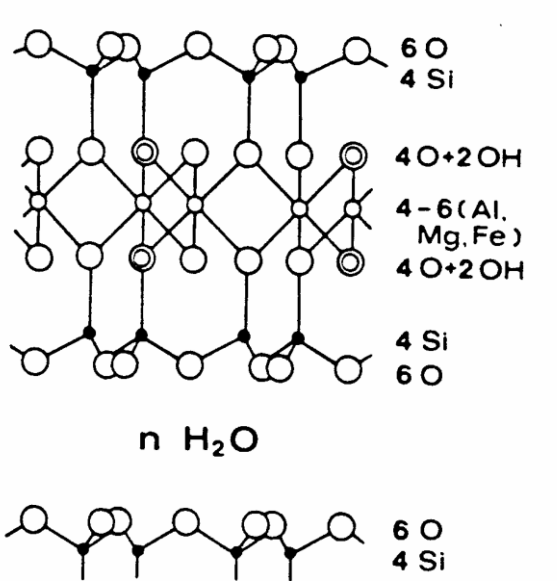




Secundary minerals (clay minerals)

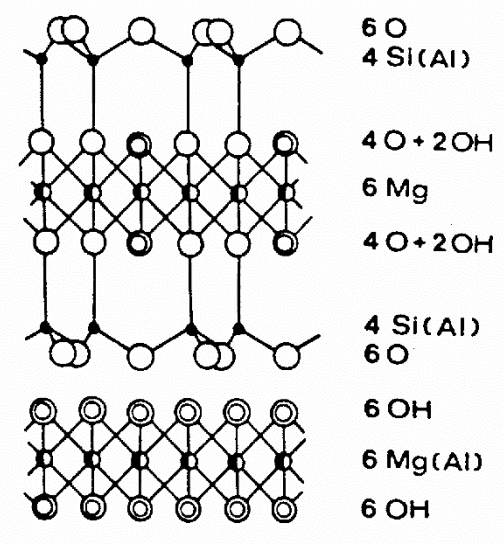
C) Vermiculite, Smectite

- 3-layer clay mineral
- Structured as Illite but with cations in the interlayer
- Swellable



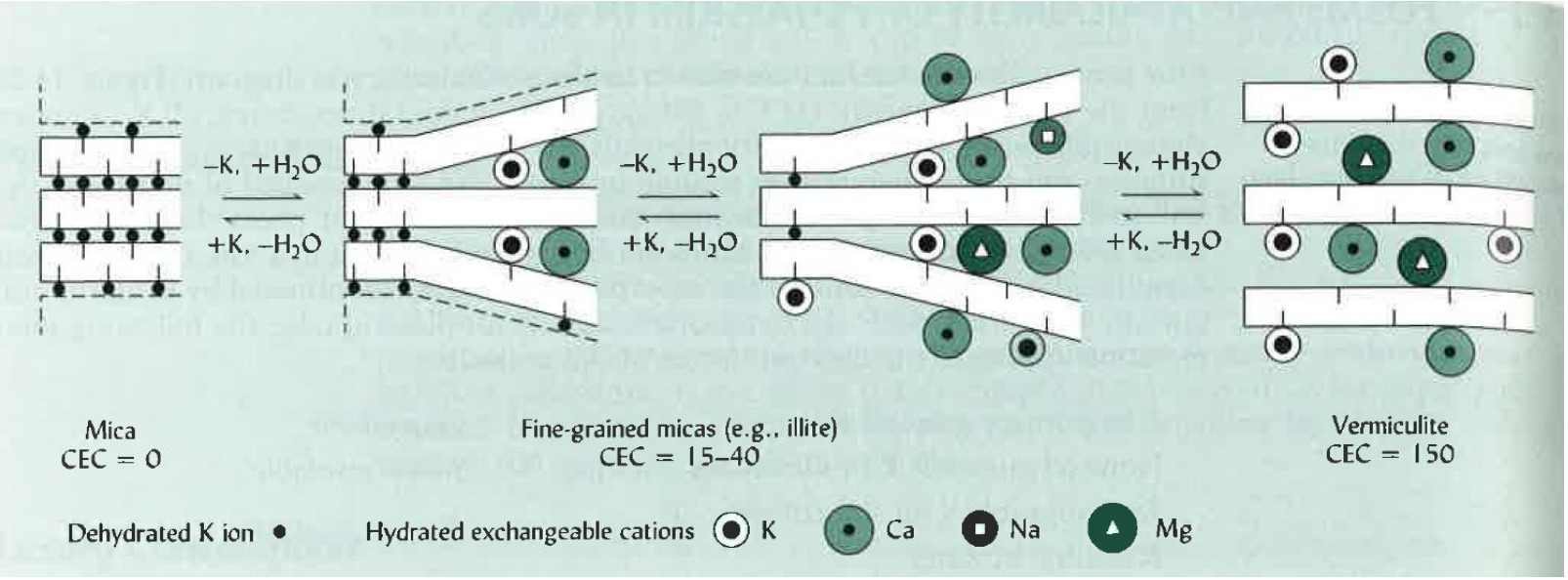
B) Secundary Chlorite

- 3-layer clay mineral
- Al-hydroxy interlay
- Not swellable



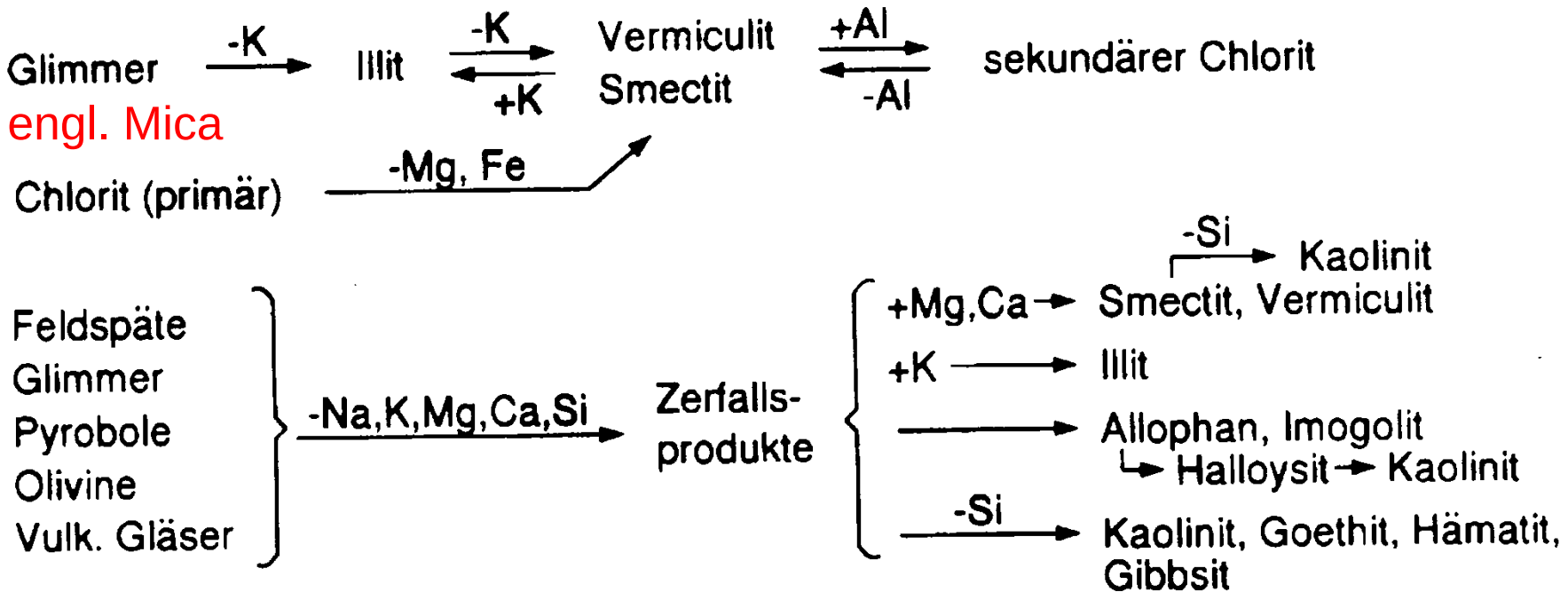
Formation of secondary minerals (clay minerals)

Formation and reformation of clay minerals



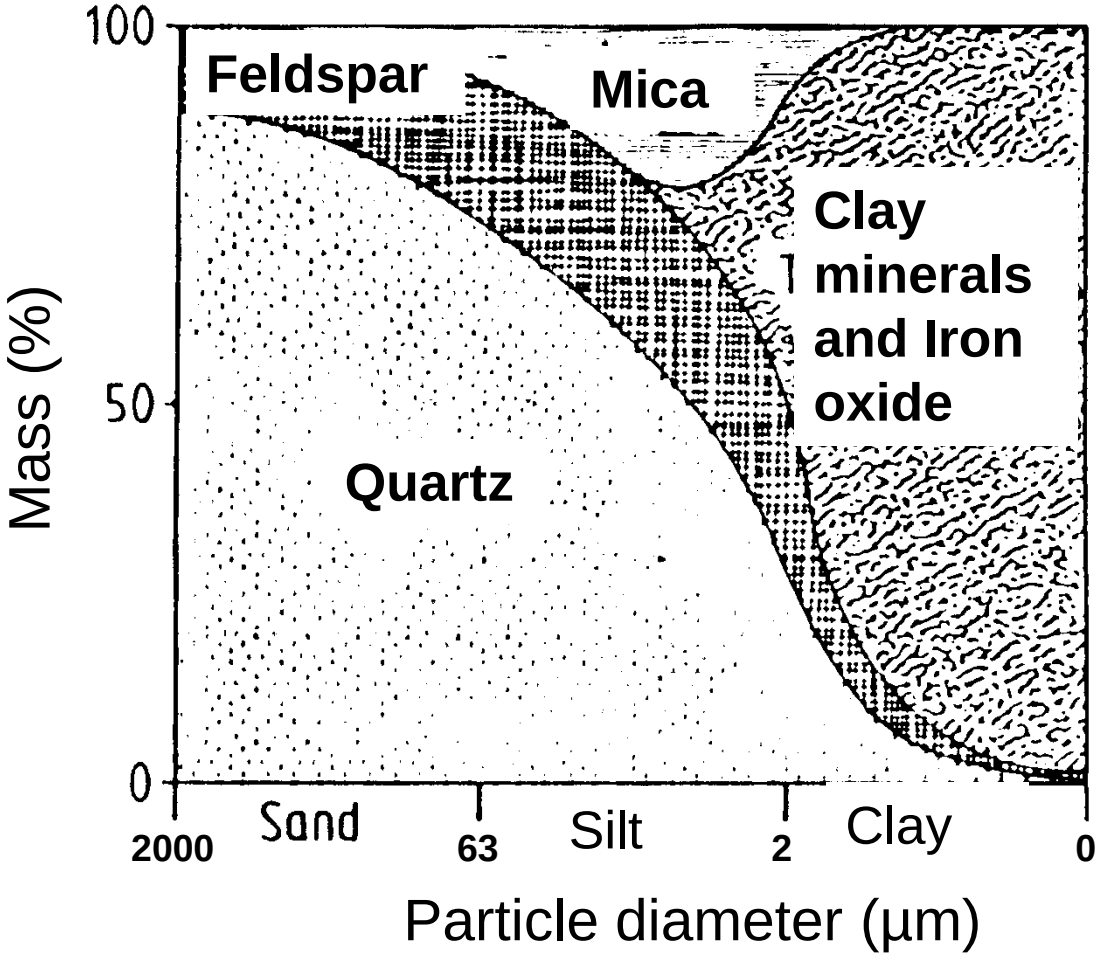
Formation of secondary minerals (clay minerals)

Formation and reformation of clay minerals

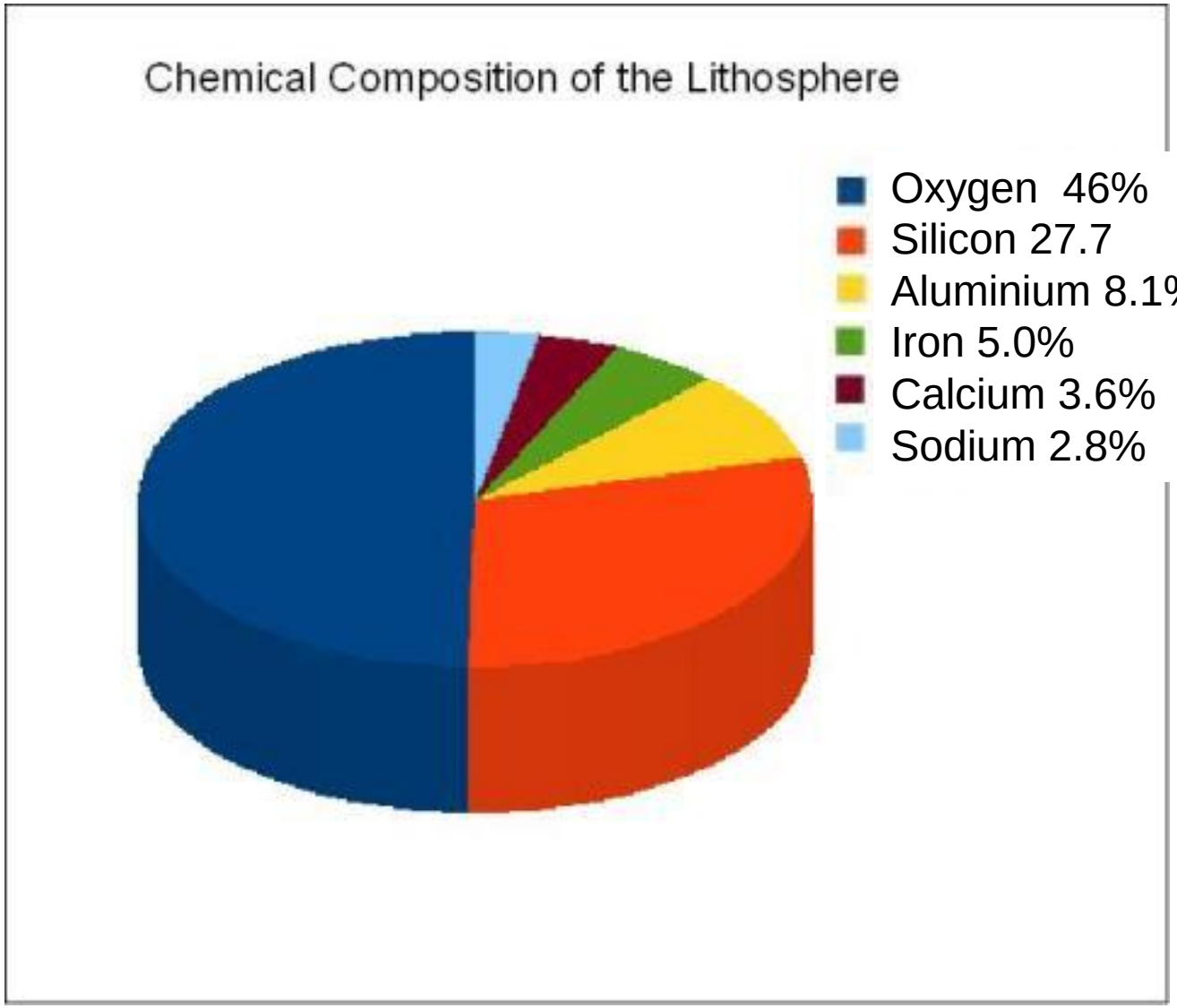


Minerals in the particle size classes:

Minerals in particle size fractions in soils of the temperate zone

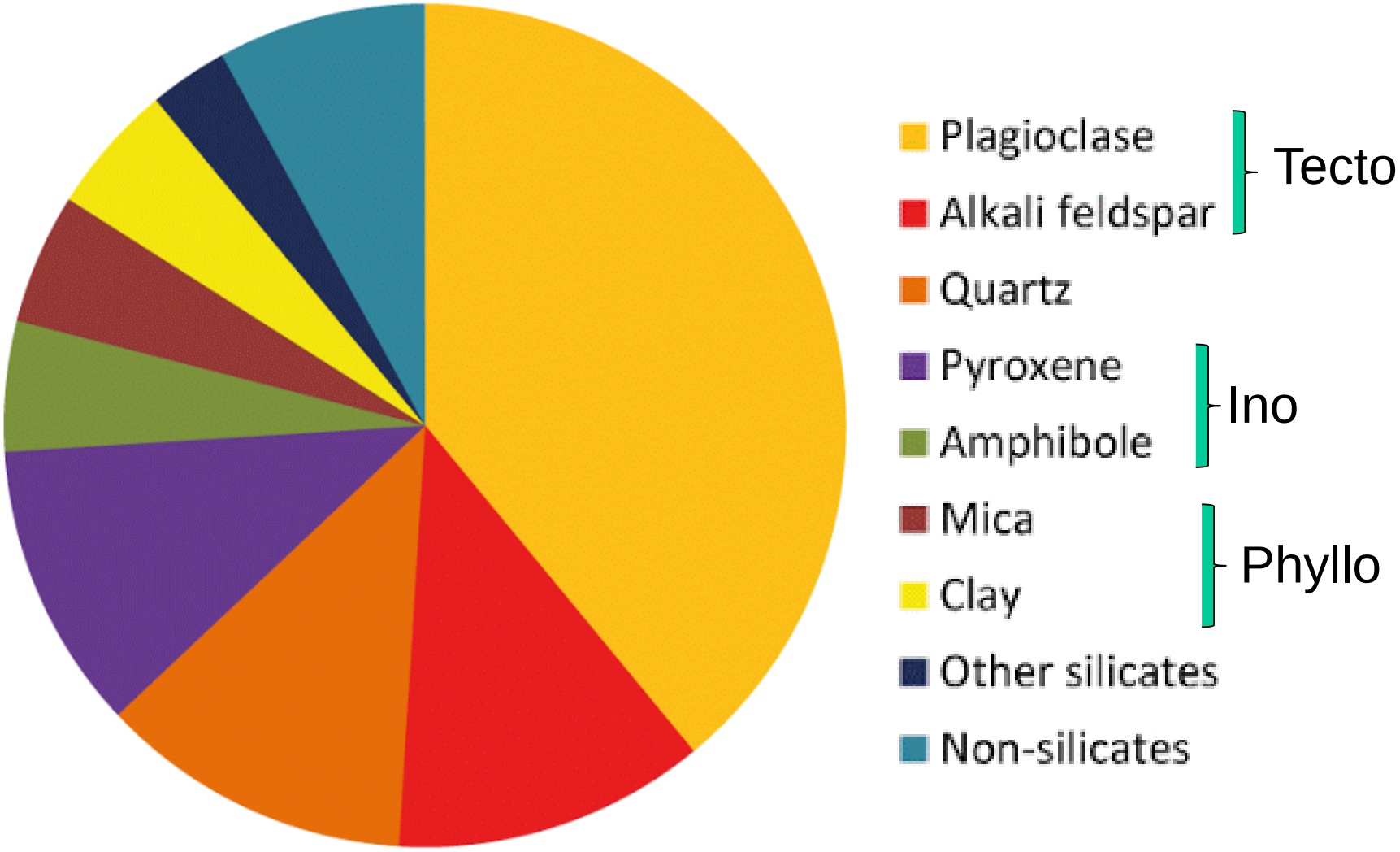


Chemical composition of the lithosphere



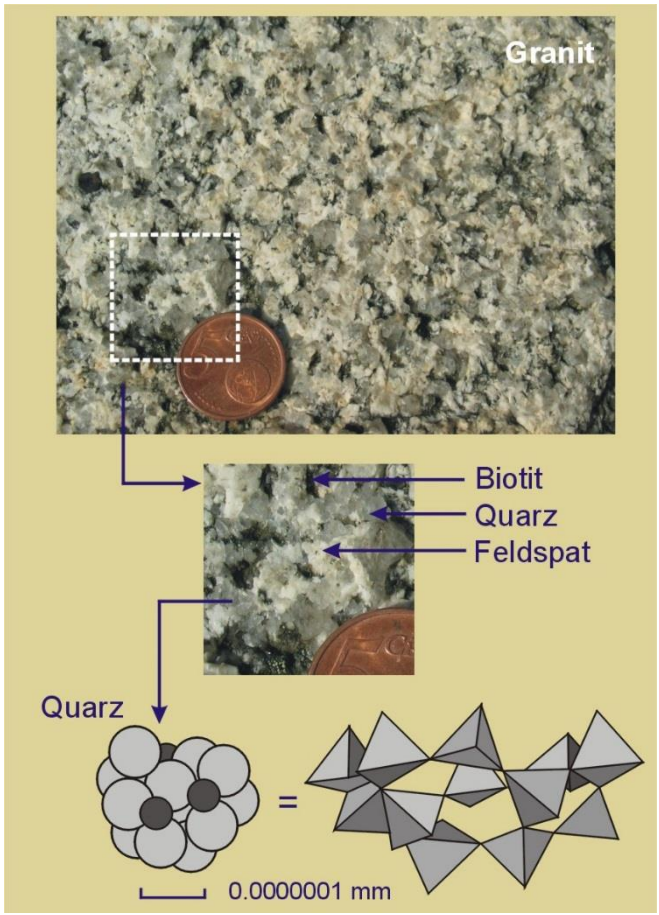
O + Si + Al > 80% of all mass of the lithosphere

Mineral composition of the lithosphere



Rock - Definition

Rocks are monomineralic of polymineralic aggregates of minerals in the Eath`s crust



Rock - Definition

Rocks are monomineralic of polymineralic aggregates of minerals in the Eath`s crust

Classes

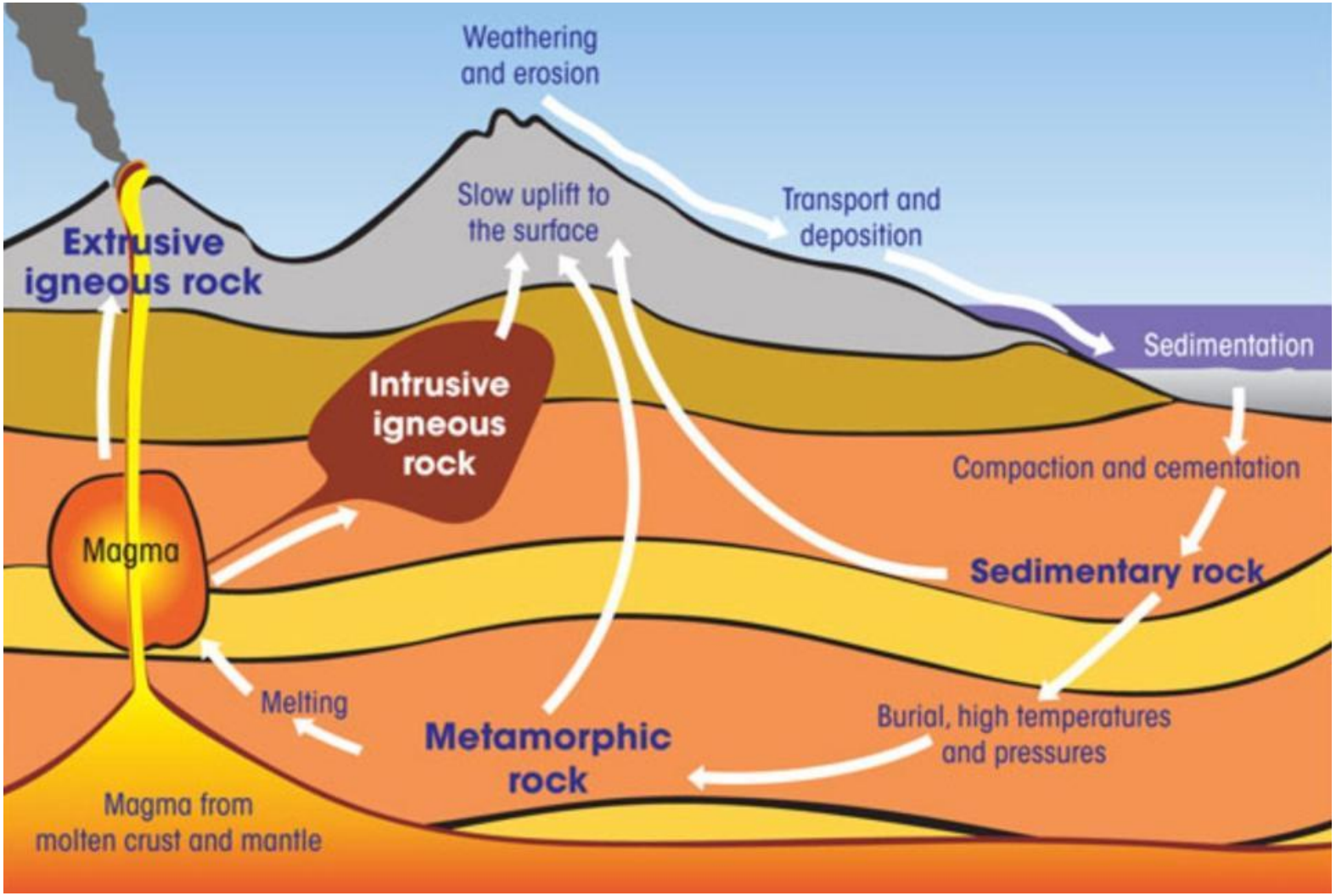
Differentiation according to stucture and genesis

A) Igneous

B) Methamorphic

C) Sedimentary

The rock cycle



Igneous rock

- **Changes in structure caused by hyigh temperature and presure**

	Type of rock	
Dominant mineral	*Sedimentary*	*Metamorphic*
Calcite ($CaCO_3$)	Limestone	Marble
Dolomite ($CaCO_3 \cdot MgCO_3$)	Dolomite	Marble
Quartz (SiO_2)	Sandstone	Quartzite
Clays	Shale	Slate
Variable	Conglomerate[a]	Gneiss[b]
Variable		Schist[b]

- **Example: Granite → Gneiss**

Sediments

Formation through weathering, transport and sedimentation on the Earth surface

A) Clastic Sediments:

- **Mechanical transport (Wind, water, glaciar)**
- **Fractionation according to paticle size fractions**
- **Examples: claystone, sandstone, siltstone, loess**

B) Chemical and biogenic sediments:

- **Exampe: Limestone**

Magmatic rock

Color of magmatic rock

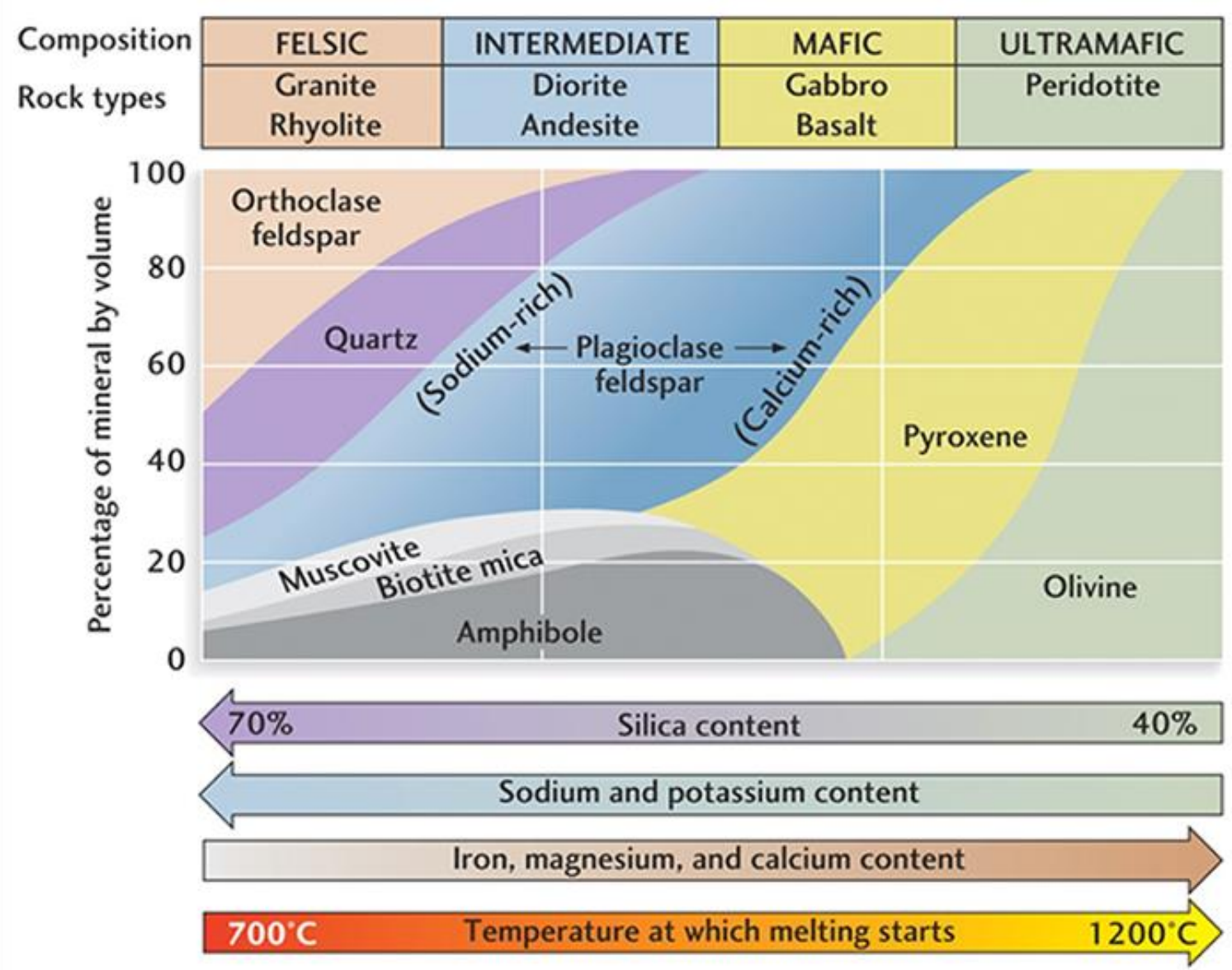
Granite **Diorite** **Gabbro**

Fe-Content →

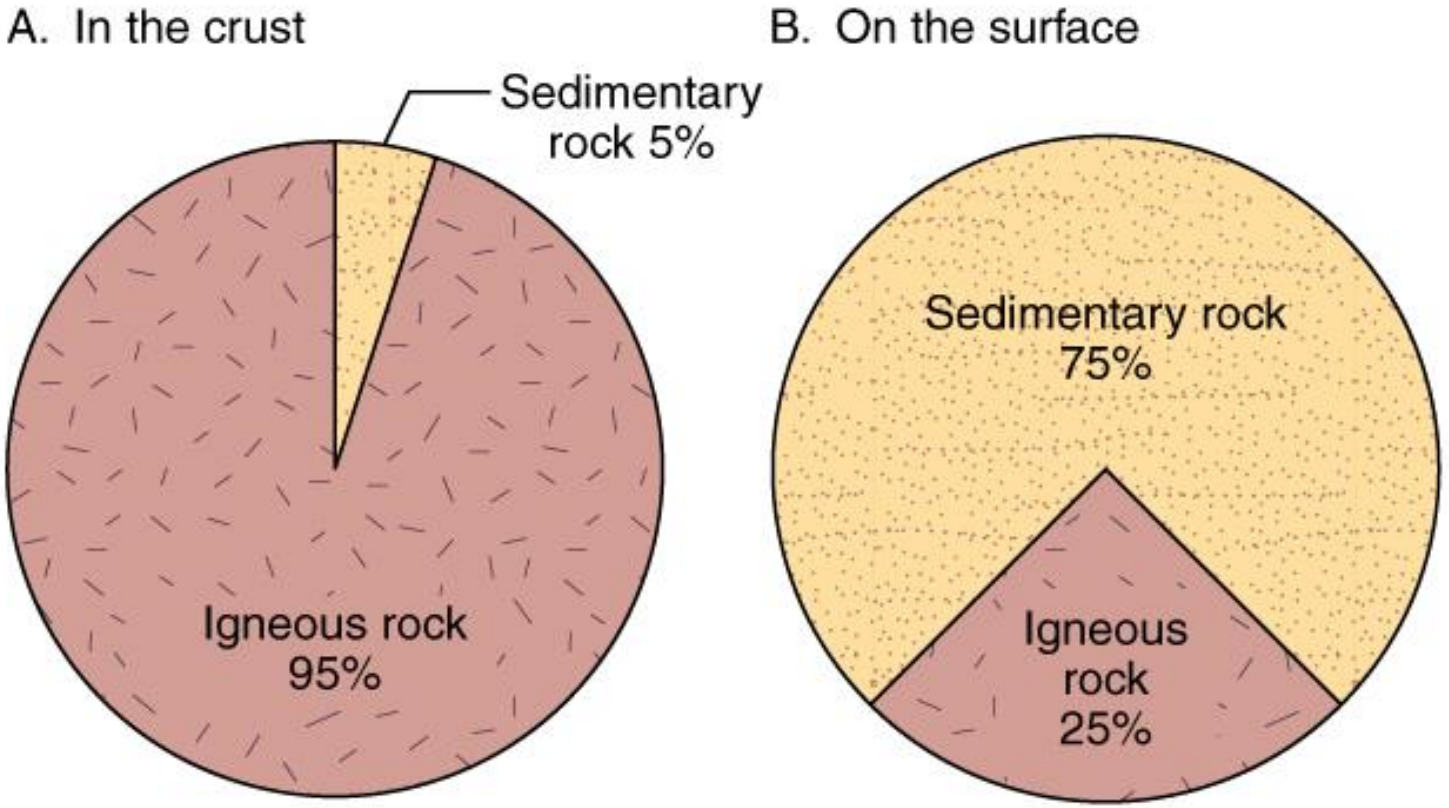
Ca-, Mg-Content →

← **Si-Content**

Mineral composition of igneous rock

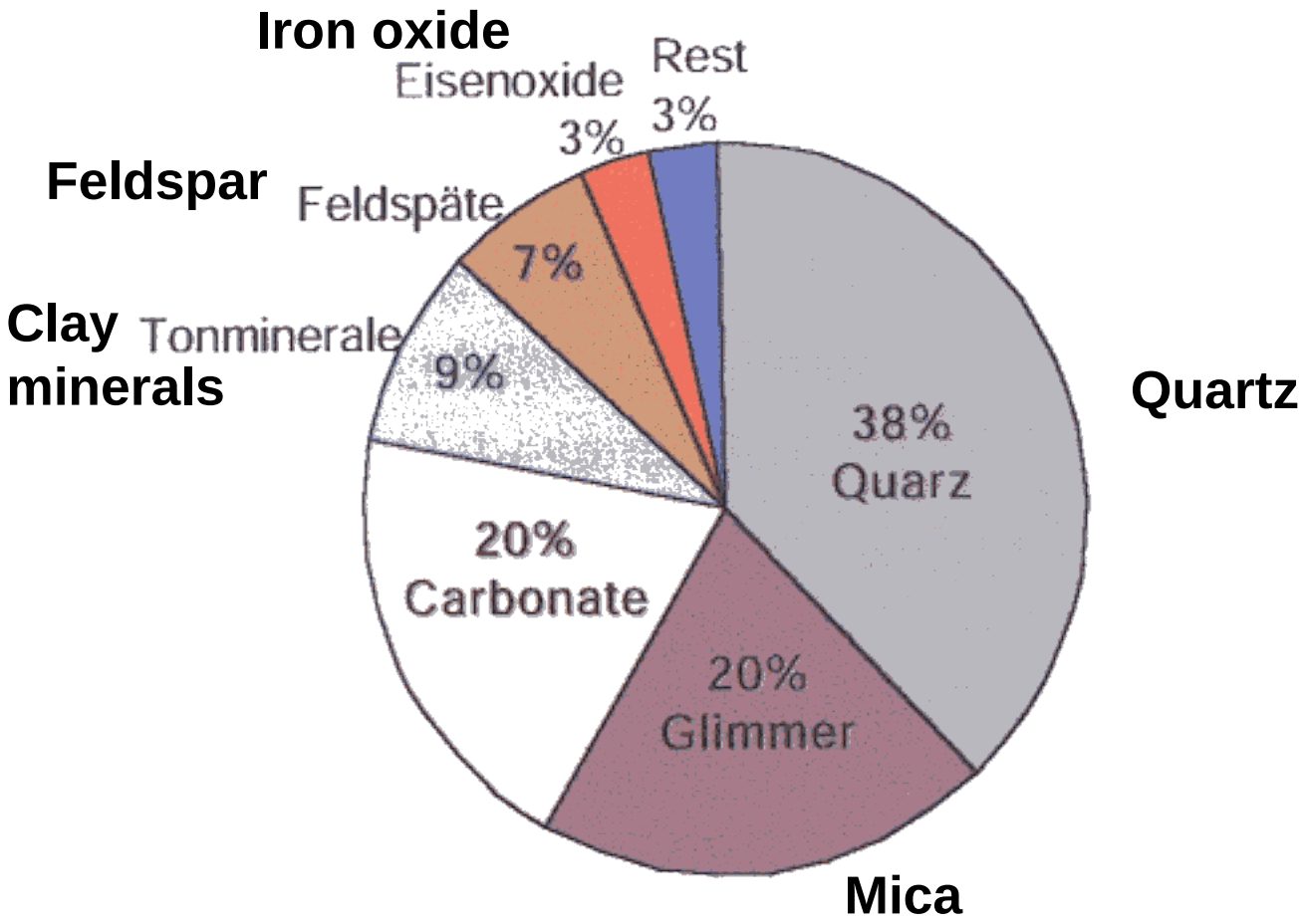


Sedimente



Mineral composition of sedimentary rock

Sediments only form about 8% of the Earth crust but they cover about 75% of the Earth surface



Take home message

Minerals:

- Primary minerals
- Secondary minerals

Primary silicates :

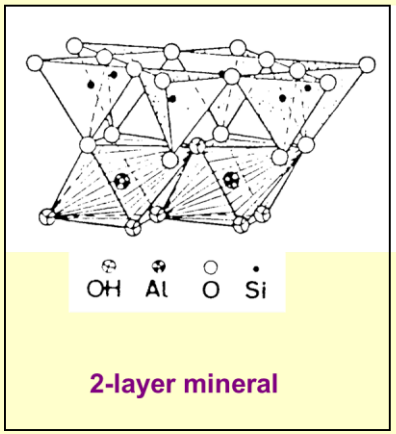
- Nesosilicate
- Inosilicate
- Phyllosilicate
- Tectosilicate

Rock:

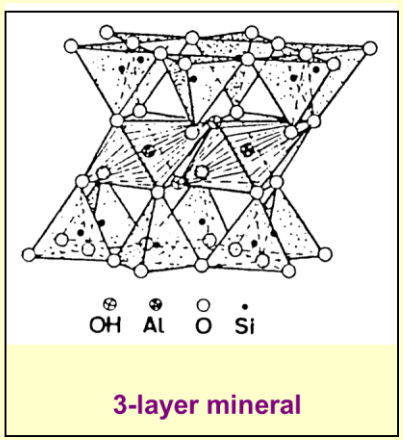
- Sedimentary
- Igneous
- Metamorphic

Seconday silicates (clay minerals):

- Two layer minerals (1:1)
- Three layer minerals (2:1)



2-layer mineral



3-layer mineral