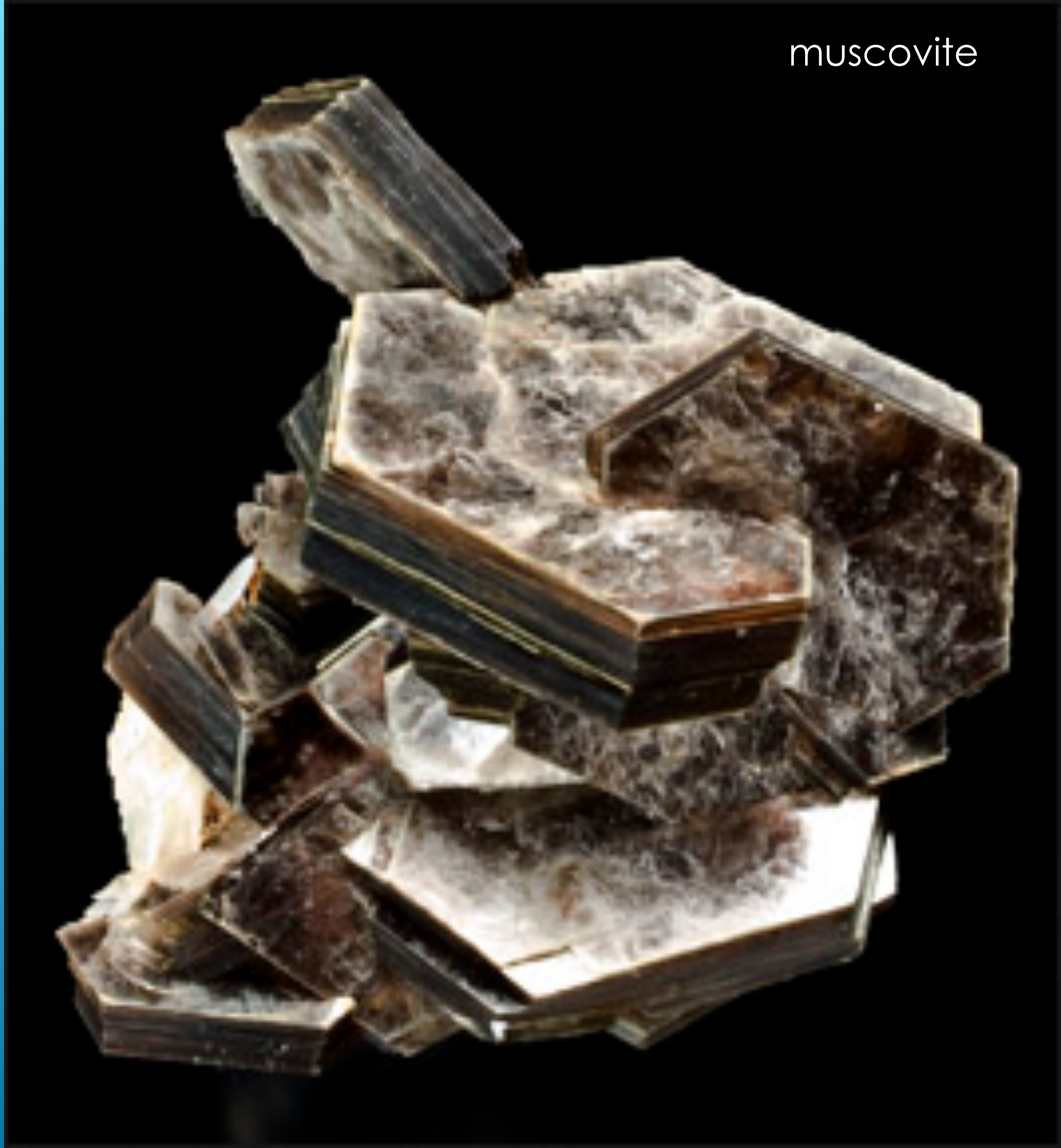
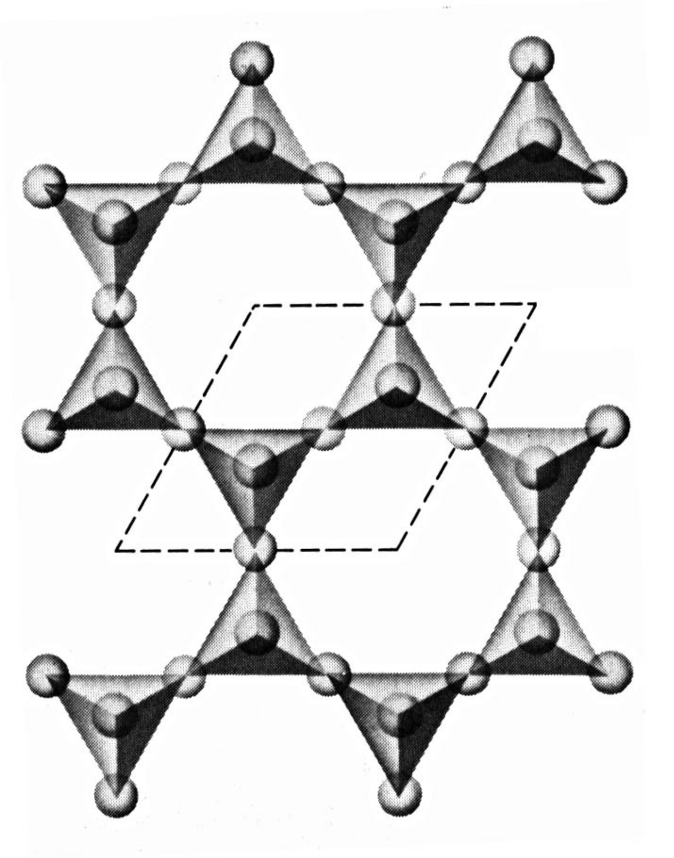
PART 4
SHEET SILICATES

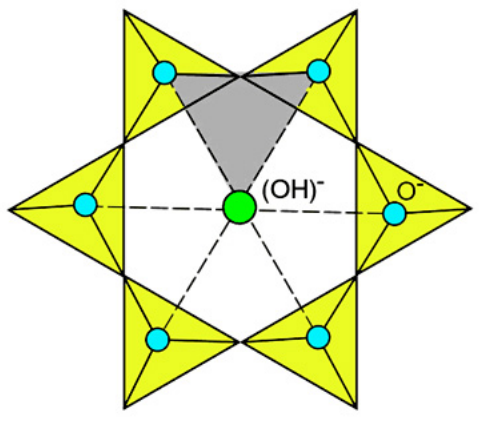


SHEET SILICATES = PHYLLOSILICATES

- **“Phyllon” = leaf**
- **Large group of mineral including many common minerals: muscovite, biotite, serpentine, chlorite, talc, clay minerals**
- **Structure:** interconnected rings (6-fold) of silica tetrahedra that extend outwards infinite sheet: 3 of the 4 oxygen in the silica tetrahedra are shared with other tetrahedra ⇒ **basic structural unit $Si_2O_5^{2-}$**



SHEET SILCATES

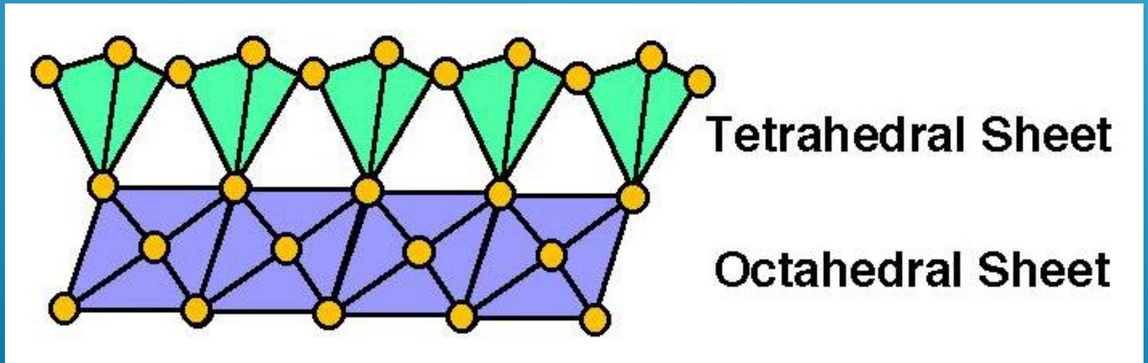


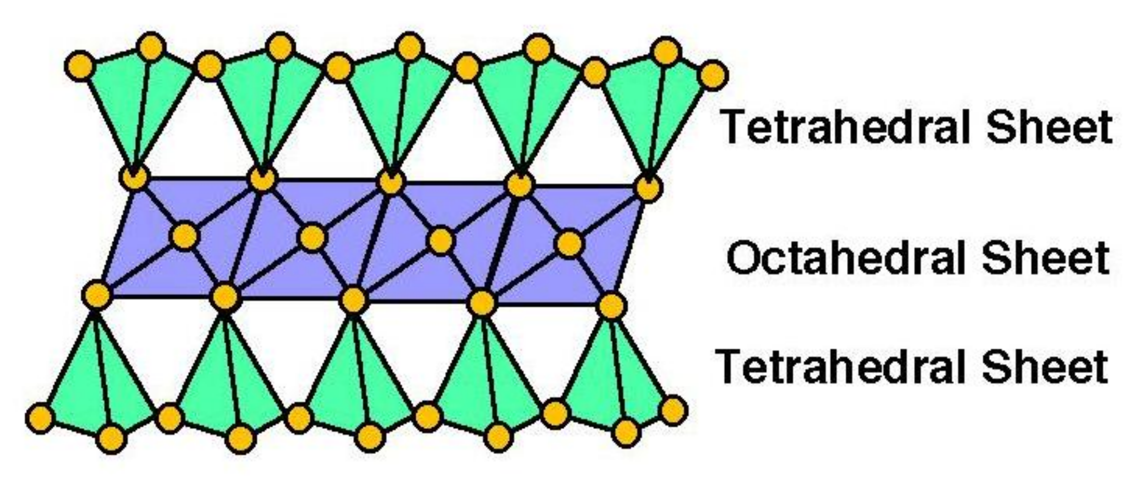
- **Most sheet silicates: hydrous**
- **Most phyllosilicates:** OH- located at the center of the rings ⇒ basic structural unit: $\mathbf{Si_2O_5(OH)^{3-}}$
- **Groups: based on structure**
- Two kind of "layers" within the "sheet":
  - **T layers:** tetrahedral sites: tetrahedral coordination of Si and Al
  - **O layers:** octahedral sites: mostly Al and Mg, occasionally Fe
- T and O layers bounded to form sheet – The space between sheets can be:
  - **Vacant**
  - **Filled with interlayer cations, water or other sheets**

SHEET SILCATES

- Different stacking arrangements of tetrahedral sheets and octahedral sheets, along with the type of cation that occupies the octahedral site, allow for the variety of phyllosicilicates that occur in nature.

- **Stacking of the sheets**



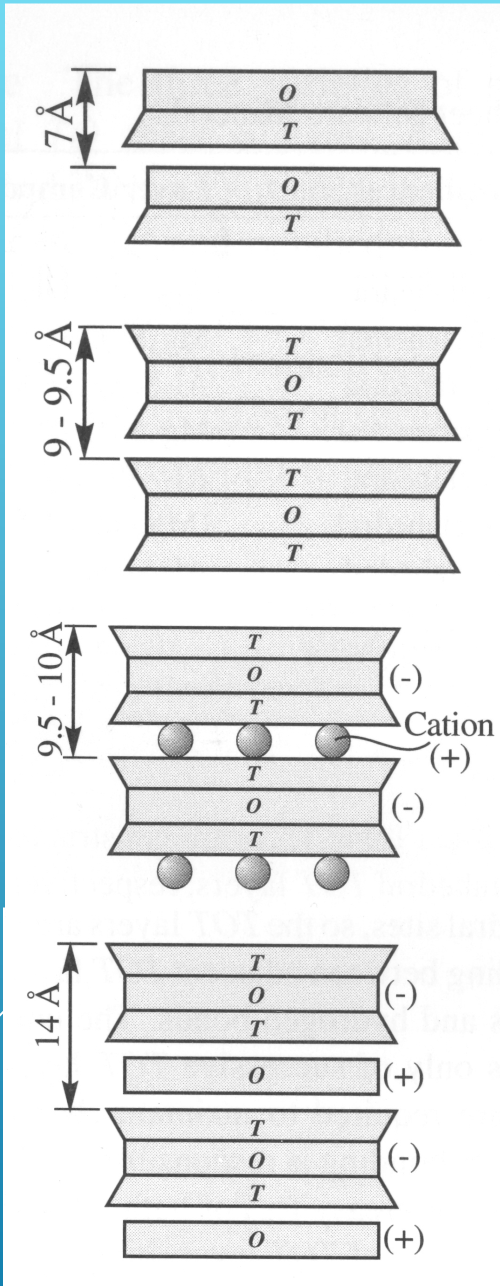


SHEET SILCATES

- Octahedral sheet variety:
- **Dioctahedral**:
  - cations are trivalent (Al^{3+} or Fe^{3+})
  - One every three sites is vacant
  - OH and O are bounded to 2 cations
- **Trioctahedral**
  - Cations are divalent (Mg^{2+} or Fe^{2+})
  - All cation sites are filled
  - OH and O are bounded to 3 cations

COMMON SHEET SILCATES

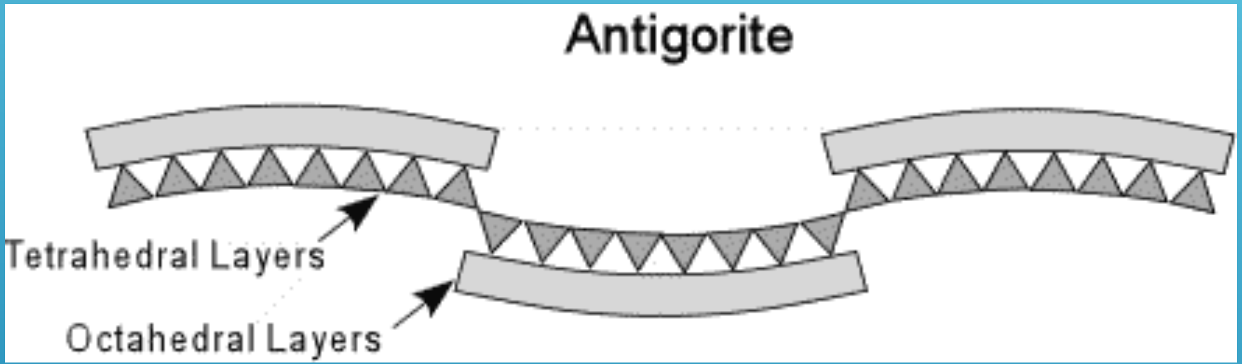
- **T-O Phyllosilicates Si2O5:**
  - Dioctahedral: kaolinite $Al_2Si_2O_5(OH)_4$
  - Trioctahedral:Serpentine $(Mg,Fe)_3Si_2O_5(OH)_4$
- **T-O-T phyllosilicates Si4O10**
  - Dioctahedral: pyrophyllite $Al_2Si_4O_{10}(OH)_2$
  - Trioctahedral: talc $(Mg,Fe)_3Si_4O_{10}(OH)_2$
- **T-O-T + interlayer cations: the micas**
  - Dioctahedral: muscovite $KAl_2Si_3Al_1O_{10}(OH)_2$
  - Trioctahedral: biotite $K(Mg,Fe)_3Si_3Al_1O_{10}(OH)_2$
- **T-O-T + interlayer octahedral sheet: chlorite**
  - Di-dioctahedral $[Al(OH)_3]Al_2(Si_4)O_{10}(OH)_2$
    Di-*Trioctahedral*: $[Al(OH)_3](Mg,Fe)_3(Si_4)O_{10}(OH)_2$
  - Tri-*Dioctahedral*: $[(Mg,Fe)(OH)_3]Al_2(Si_4)O_{10}(OH)_2$
    Tri-*Trioctahedral*: $[(Mg,Fe)(OH)_3](Mg,Fe)_3(Si_4)O_{10}(OH)_2$

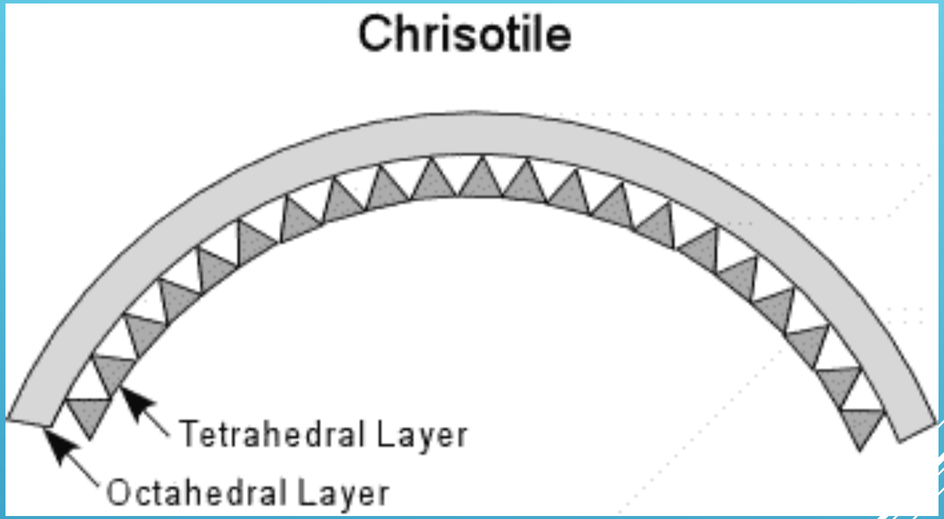


SERPENTINE GROUP (T-O STUCTURE)

- **Trioctahedral T-O Phyllosilicates:** $(Mg,Fe)_3Si_2O_5(OH)_4$
- 3 varieties: **Antigorite, Lizardite and Chrisotile**

Massive – fine grains (Antigorite, Lizardite) Fibrous (Chrisotile)





- **Where?** Serpentine = hydration product of Mg-rich silicates (pyroxene, olivine)

$$2Mg_2SiO_4 + 3H_2O <=> Mg_3Si_2O_5(OH)_4 + Mg(OH)_2$$

Olivine water Serpentine Brucite

- **Pseudomorph after olivine and pyroxene in alterated basic and ultrabasic igneous rocks (peridotite, dunite, basalt, gabbro) - often** associated with minerals magnesite ($MgCO_3$), chromite, and magnetite.
- Rock made up almost entirely of serpentine, it is called a ***serpentinite***.

TALC (T-O-T STUCTURE)

- **Trioctahedral T-O-T Phyllosilicates:** $(Mg,Fe)_3Si_4O_{10}(OH)_2$

- **Low hardness**

- **Where?** low grade metamorphic rocks that originated as ultrabasic to basic igneous rocks. Rock made up almost entirely of talc is called a ***soapstone*.**
  Ex.: Hydrothermal solutions concentrated during final stages of magma crystallization in batholiths or hot seawater solutions drawn down into subduction zones

- **Use: -** in paint, plastics, rubber, various roofing compounds: **as lubricant**
  - in cosmetic and body powder.
  - as "whiskistone"

MICA GROUP (T-O-T + C STUCTURE)

- White micas (dioctahedral) vs. black micas (trioctahedral)

Muscovite, Paragonite, and Margarite

Biotite and Clintonite

- **White micas:**
  - **Muscovite**, $KAl_3Si_3O_{10}(OH)_2$, and **Paragonite**, $NaAl_3Si_3O_{10}(OH)_2$: end members of the solid solution series involving K and Na but large immiscibility gap (solvus): Muscovite = 65 to 100% K vs paragonite = 80 to 100% Na
- **Where?**
  - Al-rich medium grade metamorphic rocks (Al-rich schist)
  - in siliceous, Al-rich plutonic igneous rocks (but not in volcanic rock) - association with alkali feldspar, quartz, and sometimes biotite, garnet, andalusite, sillimanite, or kyanite.
  - Substitution of Al by Li in the interlayer cation of muscovite: **Lepidolite** – pink mica found in pegmatite

MICA GROUP (T-O-T + C STUCTURE)

- **White micas (dioctahedral) vs. black micas (trioctahedral)**

Muscovite, Paragonite, and Margarite

Biotite and Clintonite

- **Black micas**
  - Biotite is a solid solution between the end members Phlogopite $KMg_3AlSi_3O_{10}(OH)_2$ and Annite $KFe_3AlSi_3O_{10}(OH)_2$, (but pure Annite does not occur in nature)
  - Substitutions: - minor Na, Rb, Cs, and Ba may substitute for K
    - minor F can substitute for OH: increase the stability at high temperature
  - **Where?**
  - Phlogopite: in hydrous ultrabasic volcanic rocks (kimberlite), in metamorphosed dolomite
  - Biotite: dacitic, rhyolitic, and trachytic volcanic rocks, granitic plutonic rocks, and a wide variety of metamorphic rocks.

CHLORITE (T-O-T + O LAYER)

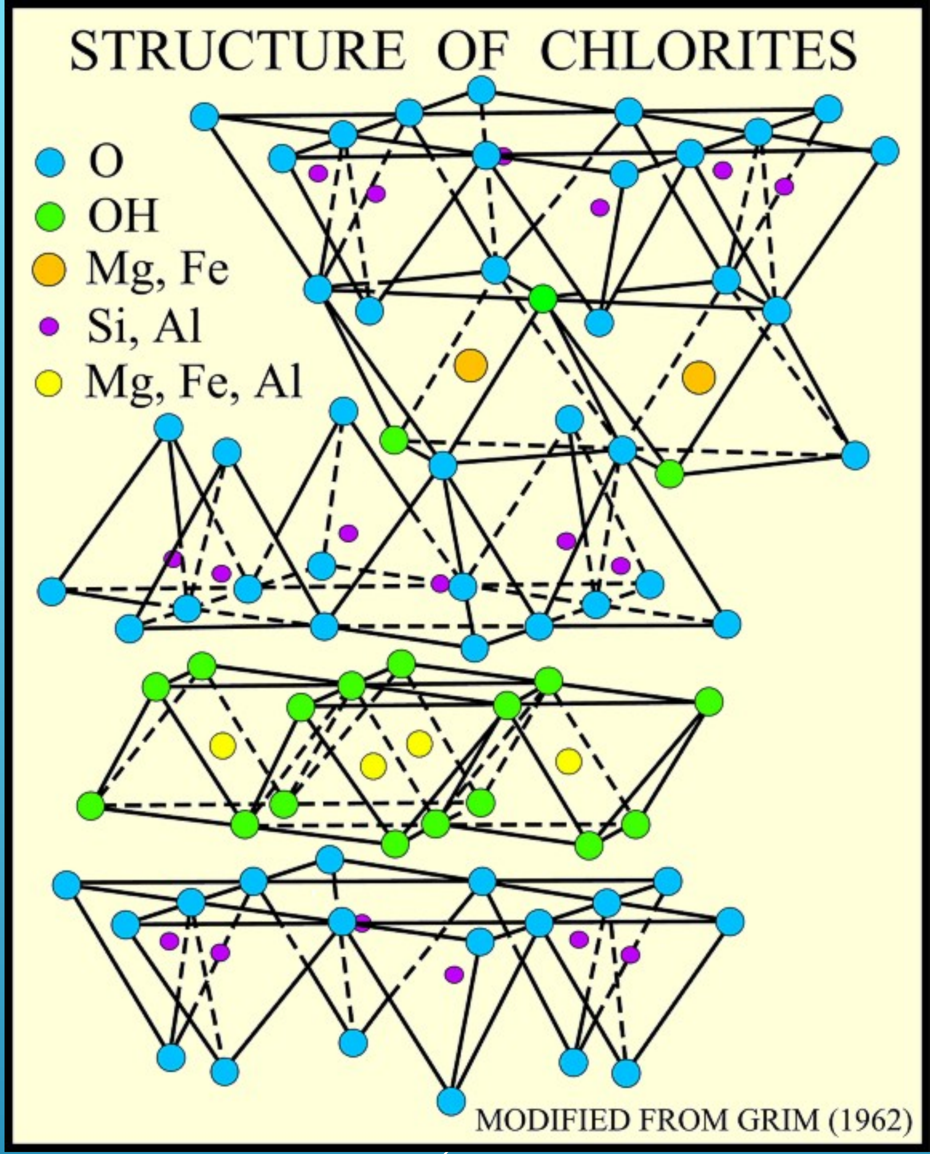
- structure that consists of phlogopite T-O-T layers sandwiching brucite-like octahedral layer.

- Substitutions: - Mg for Fe

  - Al for (Mg, Fe) in both the octahedral sites

  - Al for Si

Where? low grade metamorphic rocks – associated with actinolite, epidote, and biotite. It also forms as an alteration product of pyroxenes, amphiboles, biotite, and garnet in igneous as well a metamorphic rocks.



CLAY MINERALS

- **Products of chemical weathering – main constituent of mudrock (mudstone, claystone, shale)**
- **40% minerals in sedimentary rocks**
- **Understanding their behavior:** important economic use (ceramic), civil engineering (clay swelling)
- **Structural classification:**

Kandites (struc. ⇔ Kaolinite)	Smectites (struc. ⇔ Pyrophyllite)	Illites (struc. ⇔ muscovite)
T-O	T-O-T	T-O-T+c

CLAY MINERALS

- **Chemical Weathering:** Minerals form in depth are not stable at the surface of Earth:
  - **Lower T (-20 to 50°C)**
  - **Lower P (1 to few hundred atmospheres)**
  - **Higher free water**
  - **Higher free O**
- **Stability order at the near surface conditions:**

Iron oxide – Aluminium oxide, quartz, clay mineral, Muscovite, Alkali feldspar, biotite,

Amphibole, Pyroxenes, Ca-rich plagioclase, Olivine

CLAY MINERALS

- **Chemical Weathering – Main agent**: water and weak acids in water
  - **Acid in solution: abundant free H^+**
  - **Most common acid: Carbonic acid:** produced by reaction between rainwater and carbon dioxide in atmosphere:

H_2O	+	CO_2	→	H_2CO_3	→	H^+	+	HCO_3^-
Water		carbon dioxide		carbonic acid		hydrogen ion		bicarbonate ion

CLAY MINERALS

- **Type of chemical weathering reactions:**
  - **Hydrolysis**: H+ or OH- replaces an ion in the mineral

$4KAlSi_3O_8$ +	$4H^+$ +	$2H_2O \rightarrow$	$4K^+$ +	$Al_4Si_4O_{10}(OH)_8$ +	$8SiO_2$
Orthoclase	hydrogen ion	water	potassium ion	kaolinite	quartz

  - **Oxidation**: reaction of mineral with O_2: change of the oxidation state (Fe^{2+} to Fe^{3+})

$3Fe^{2+}SiO_3$ +	$1/2O_2$ $\rightarrow$	Fe_3O_4 +	$3SiO_2$
Pyroxene	oxygen	magnetite	quartz

  - **Dehydration** – Removal of H_2O or OH- ion from a mineral

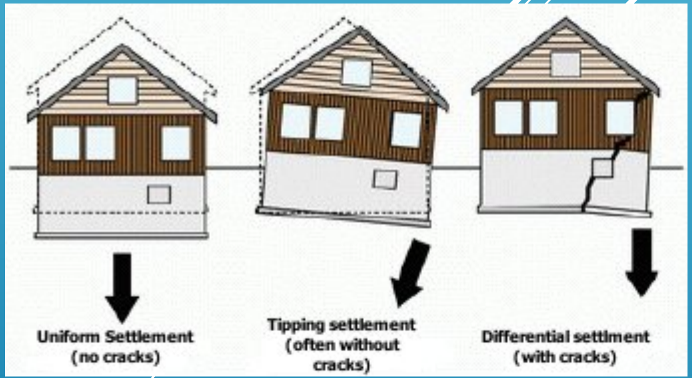
$2FeO{\cdot}OH$ $\rightarrow$	Fe_2O_3 +	H_2O
Goethite	hematite	water

  - **Complete dissolution** (in water)

CLAY MINERALS

- **Kandites (T-O structure)**
  - **Most common: kaolinite $Al_2Si_2O_5(OH)_4$**
  - **Other kandites:** Anauxite, Dickite, Nacrite
  - **Where?** Weathering of hydrothermal alteration of aluminosilicate minerals ⇒ feldspar-rich rocks (ex.: granitic rocks) weather to kaolinite

- **Smectites (T-O-T structure)**
  - **Structure similar to** pyrophyllite $Al_2Si_4O_{10}(OH)_2$
  - Possible substitution of Al with Mg or Fe ⇒ di- and trioctahedral
  - **Possibility to absorb water between the TOT sheets:** cause volume of the mineral to increase in contact with water : **expanding clays**
  - **Most common: Montmorillinite** **$(\frac{1}{2}Ca,Na)(Al,Mg,Fe)_4(Si,Al)_8O_{20}(OH)_4 \cdot nH_2O$** = main constituent of Bentonite, derived by weathering of volcanic ash.



CLAY MINERALS

- **Illites (T-O-T+c structure)**
  - $K_yAl_4(Si_{8-y},Al_y)O_{20}(OH)_4$ usually with $1 < y < 1.5$, but always with $y < 2$.
  - **Possible substitution of K by Ca or Mg (to preserve balance)**
  - **The most common in soils.**
  - **Not an expanding clay**
  - **Where?** formed from weathering of K and Al-rich rocks under high pH conditions ⇔ by alteration of minerals like muscovite and feldspar. Main constituent of ancient mudrocks and shales.

- **Mixed layer clays**
  - = change from one type to another through a stacking sequence
  - **Common, regular and ordered or irregular and unordered**

- **Identification?** To thin/small to be recognize in hand samples or petrographic microscope ⇒ use of the X-ray technique