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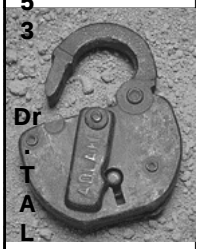

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Clay Minerals

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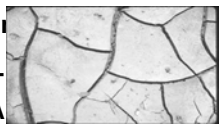
What is “clay” in civil engineering?

Grain size is effective diameter as measured from the fine-grained soil settling velocity in water.



“Clay” is clay-size particles.

“Clay” includes crystalline, non-crystalline, amorphous materials, and primary minerals such as quartz, mica, feldspar, etc.

‘Clay minerals’
This is secondary minerals.

They are not called ‘Clay minerals’.

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What is clay mineral?

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- Clay minerals are the result of chemical weathering of rocks.
- Therefore the difference between each clay mineral represents degree of weathering, and all of clay minerals are alumino-silicates.

Weathering process

Mica, Feldspar, Fe-Mg minerals → **illite** → **montmorillonite** → **kaolinite** → **aluminum or Iron oxide**

Volcanic ash → **allophane** → **halloisite** → **kaolinite** → **aluminum or Iron oxide**

Clay Minerals

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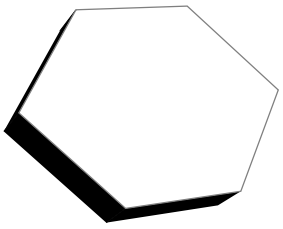
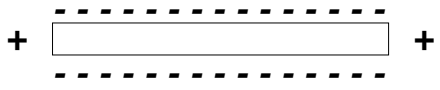


Idealized clay particle shape



- Are sheet silicates
- Have a crystalline structure that allows them to break easily along parallel sheets.
- Are primary constituents of soils and are also found in the sedimentary rock known as shale or mudstone.

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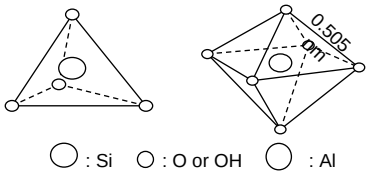
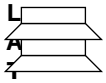
Crystal structure of clay minerals

Single crystal structure

Silica tetrahedron
Aluminum octahedron



Sheet structure

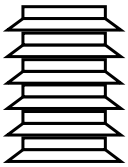


Silica and Aluminum sheets are shaped single unit structure respectively.

Stacking layer structure

Stacking layer structure consists of two or three sheet structures.

Repeating layer



Finally, clay particles are composed of repeating layer of stacking structure.

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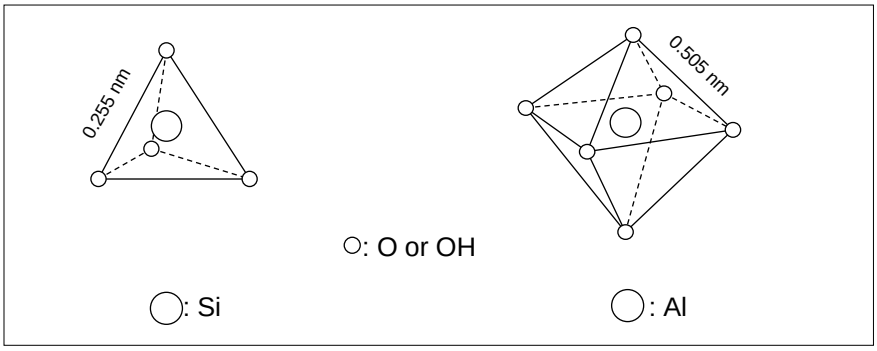
Schematic diagram of single unit



Single Silica tetrahedron

Silica unit consists of a silicon atom, Si, surrounded by four oxygen atoms, O, equidistant from the silicon.

Single Aluminum octahedron

The alumina unit contains an aluminum atom, Al, equidistant from the six oxygens or hydroxyls in octahedral co-ordination.

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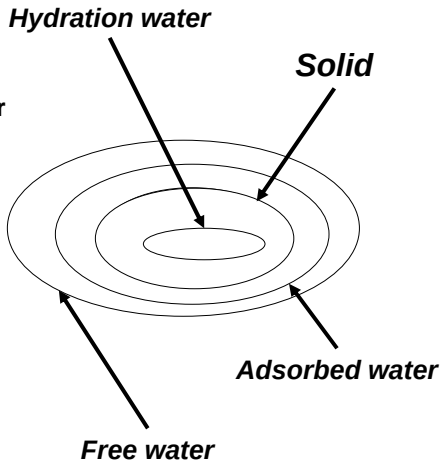
Water Zone in A Clay Particle



- **Hydration Water**
  - ✓ **Water present in the clay mineral crystal lattice**
- **Solid**
- **Adsorbed water**
  - ✓ **Interlayer water between the basic structural units of montmorillonite and halloysite**
- **Free water or Pore Water**

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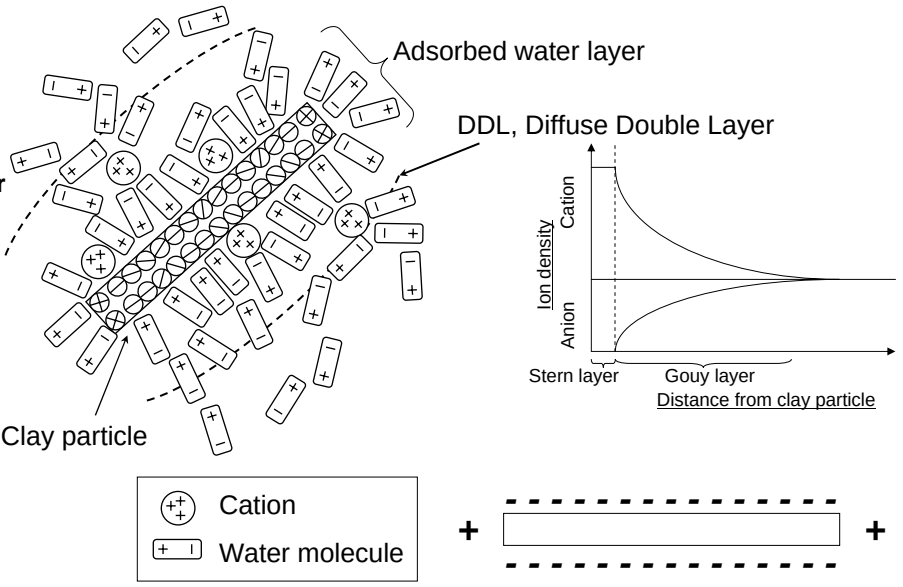
Hydration of clay minerals



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From where clay comes?

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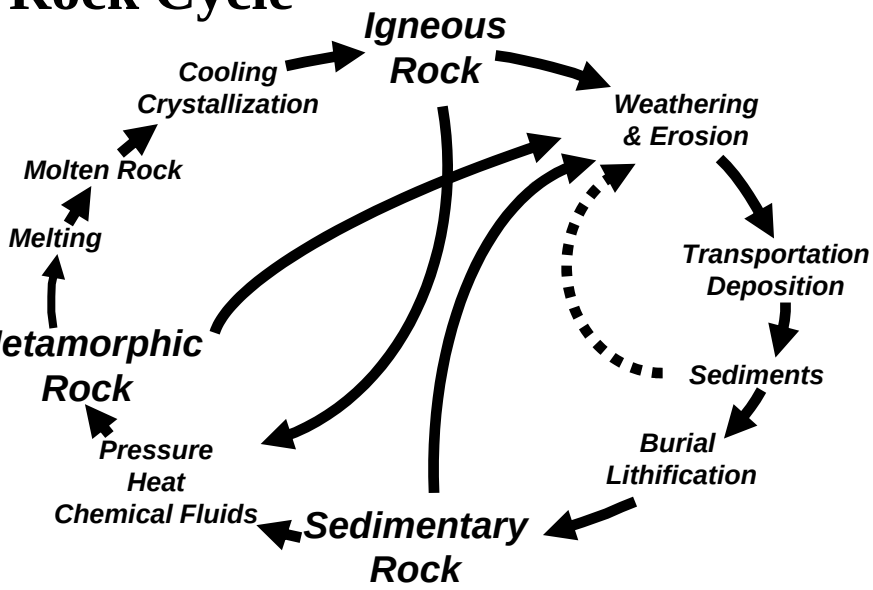
Rock Cycle



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Sedimentary Rocks

Rock Type	Group Name	Name	Formula
Sandstone		Quartz	SiO_2
Shale	Clay Minerals	Kaolinite	$Al_4\ Si_4\ O_{10}\ (OH)_8$
Limestone	Carbonates	Calcite	$CaCO_3$
		Dolomite	$(Ca,Mg)CO_3$

Calstic

- Precipitation of water soluble minerals
- Usually layered, bedding

Non Calstic

- Organic materials
- Karst topography

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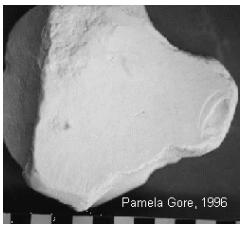
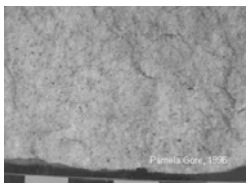
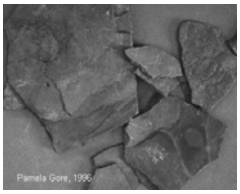
Sedimentary Rocks



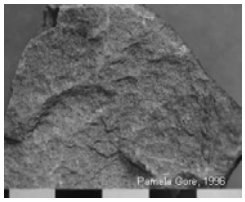
♦ Claystone – Kailonite



♦ Sandstone – Quartz



♦ Shale



♦ Siltstone

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Metamorphic Rocks

Rock Type	Group Name	Name	Formula
Slate	Clay Minerals	Illite	$K_{1\text{-}1.5}\ Al_{4\text{-}}\ (Si_{6.5\text{-}7}\ Al_{1\text{-}1.5}\ )O_{20}\ (OH)_4$

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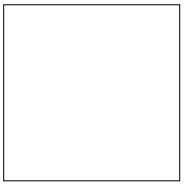
Igneous Rocks

Rock Type	Group Name	Name	Formula
Basalt / Gabbro	Feldspar	Albite	$NaAlSi_3O_8$

– **Example Granite, Basalt**

- ***Kaolinite***
  the weathering of a common mineral of the feldspar group, called albite (the milky-white mineral in granite) which through hydrolysis forms the clay mineral kaolinite



Granite

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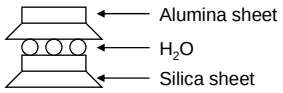
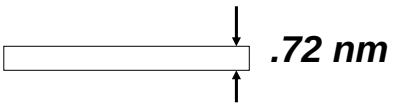
Clay Structure - Kaolinite $Al_2Si_2O_5(OH)_4$





1nm = 10 $^{-10}$mm

- Kaolinite can be dehydrated but it will change its engineering properties
- Be careful between testing it in the lab dry and using it in the field wet.

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Kaolinite Properties

- **The bond between successive layers is quite strong**
- **Does not exhibit significant swell behavior**
- **Kaolinite's relatively higher permeability**
- **Kaolinite have low liquid limit and low activity**
- **Kaolinite's a low tendency to crack upon drying.**

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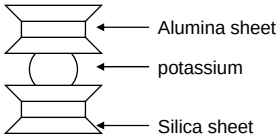
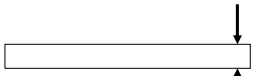
Clay Structure Illite

Silica (S)
Gibbisite (G)
Silica (S)
Potassium
Silica (S)
Gibbisite (G)
Silica (S)





1nm = 10 $^{-10}$mm

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Illite *Properties*

- **Is similar to montmorillonite in structure but has a layer of semi-permanent cations to satisfy unbalanced charges.**
- **Properties somewhere in between kaolinite and montmorillonite.**
- **Illite is often chosen for it's lower expansion and lower permeability**

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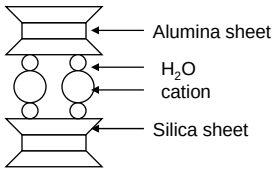
Clay Structure Montmorillonite

- $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$
- This is the main mineral in bentonite.
- Montmorillonite is formed when volcanic ash weathers in marine water.



*.79*10 $^{-9}$ mm*

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Montmorillonite *Properties*

- The most reactive and expansive abundant clay mineral.
- This is due to it's high net negative particle charge and covalent surface bonding.
- Montmorillonite has the ability to attract cations and polar molecules between successive layers to expand it's structure.
- Can expand to 100 times it's dry thickness and typically exhibits low permeability and high cracking potential.

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Comparison of Clay Minerals

	Particle Size	Specific Surface Area (m^2/g)	CEC (meq/ 100g)	Layer Distance at drying (nm)	Isomorphous substitution	Number of repeating layers
Kaolinite (1:1)	Big (>1μ)	10	10	0.7	None	100
Illite (2:1)	Middle (<1μ)	80	30	1.0	Tetrahedron Si out, Al in	30
Montmorillonite (2:1)	Small (<1μ)	800	100	1.0	Octahedron Al out, Mg in.	5

Generally, the order of CEC is as follows,
Humic acid > vermiculite > montmorillonite > illite > kaolinite

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Identifying the 3 types

- How can we identify the three types

❖ X- ray diffraction method

✓ X-ray at varying angles

✓ The reflection produced by the atoms in the structure create a characteristic pattern from which the atomic arrangement can be deduced

X-Ray Diffraction (XRD)

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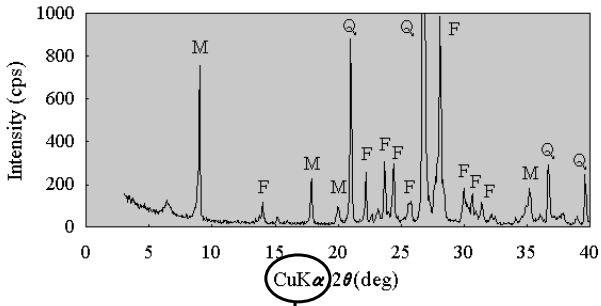
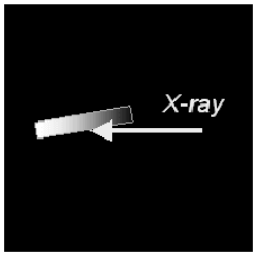
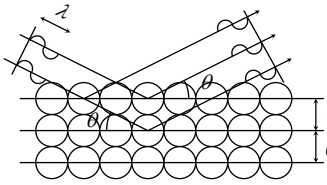




	Wave length of X-ray, λ (nm)			
	Kα1	Kα2	Kα	Kβ
Cr	0.228962	0.229352	0.22909	0.208479
Fe	0.193597	0.193991	0.19373	0.175654
Co	0.178890	0.173279	0.17902	0.162073
Cu	0.154050	0.154434	0.15418	0.139217
Mo	0.70926	0.071354	0.07107	0.063225

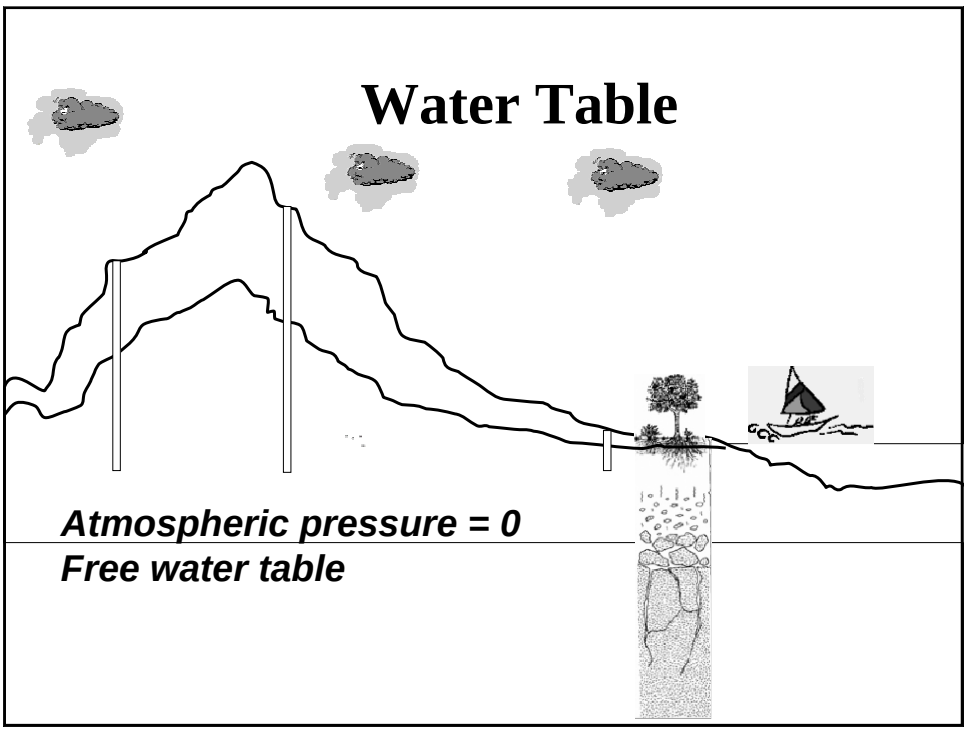
Bragg's law

$2d \sin\theta = n\lambda$



d: thickness of mineral

Water Table



Atmospheric pressure = 0

Free water table

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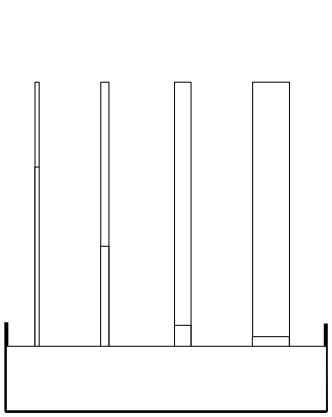
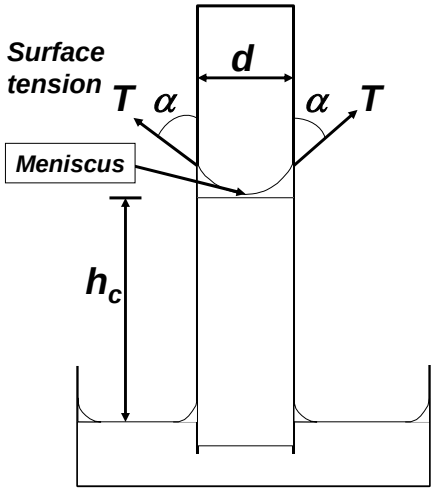
Capillary Rise





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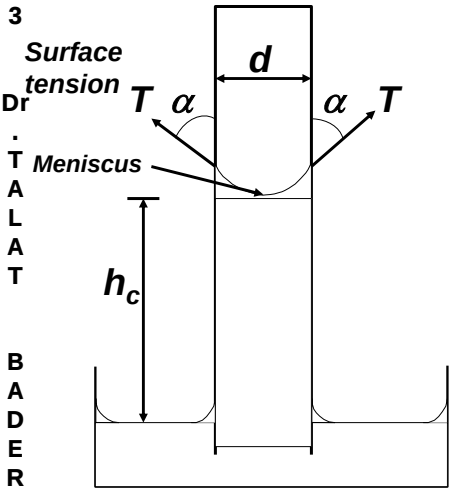
Capillary Rise



$$h_c = \frac{4T}{\gamma_w d}\cos\alpha$$

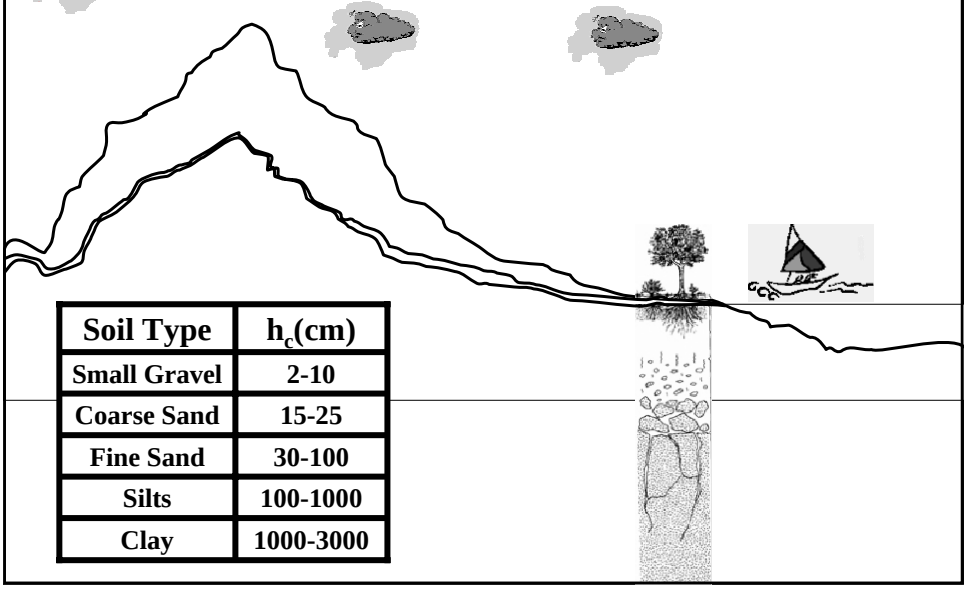
Factors Affecting Rise in Soil

- ***Shape***
- ***Size***
- ***Configuration of Voids***

- **α = 0**
- ***D = 10% Effective Particle Size***
- ***T = 75 dyn/cm***

$$h_c = 1.50/D_{10}$$

Water Table & Capillary Rise



Soil Type	h_c(cm)
Small Gravel	2-10
Coarse Sand	15-25
Fine Sand	30-100
Silts	100-1000
Clay	1000-3000

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B A D E R

- Athena Mineralogical Data Base
- http://un2sg4.unige.ch/athena/mineral/mineral.html