1/16/01

I SOIL COMPOSITION, ETC (4 pages + 3 sheets)

1. Background

1.1 Soil Types

1.2 Particle Size & Shape

2. Soil Composition

2.1 Silicate Frameworks

2.2 Silicate Sheets = Clay Minerals

2.3 Predominate Clay Minerals

3. Electrical Nature of Platy Clay Particles

3.1 Shape & Charges

3.2 Diffuse Double Layer

4 Three Common Clay Minerals

4.1 Na Kaolinite

4.2 Na Illite

4.3 Na Montmorillonite

Sheets A, B & C = Soil Composition & Clay Mineralogy

II CLAY-WATER FORCES (8 pages + 2 sheets)

1. Water Vapor Sorption

1.1 Water Content vs Relative Humidity (RH)

1.2 Capillary Pressure vs Relative Humidity

1.3 Mechanisms of Water Vapor Adsorption

1.4 Measurement of Water Content

1.5 Tensile Strength of Water

II Cont.

2. <u>Soil Suction</u>

2.1 Overview

2.2 Components of Soil Suction

2.3 Mechanisms Causing Matrix Suction

2.4 Direct Lab Measurements of Soil Suction

2.5 Soil Suction Measurement Techniques

3. <u>Nature of Adsorbed Water</u>

3.1 Total vs Pressure Head & Attraction Pressure

3.2 Physical Properties of Adsorbed Water

Sheets A & B - Soil suction measurement techniques

III INTERPARTICLE FORCES: Components & Interaction (4 pages & 3 sheets)

1. <u>Components of Effective Stress</u>

1.1 Physico-Chemical Effective Stress Eqn

1.2 Discussion

2. <u>Particle Interaction</u>

2.1 Energy Diagrams

2.2 Energy Diagram for Hypothetical Contact

2.3 Source of True Cohesion

Sheets A & B = Long range DL forces ; C = hypothetical energy diagram

IV STRENGTH GENERATION IN SOILS (2 pages + 1 sheet)

1. Frictional Resistance

1) Terzaghi-Bowden-Tabor Adhesion Theory

2) Granular Soils

3) Cohesive soils

2. Cohesive Resistance

Sheet A: Friction of Quartz

V MECHANISMS CONTROLLING COMPRESSIBILITY OF CLAYS (5 pages)

1. Background

1) Definition

2) Importance & definition of initial fabric (Particle orientation / " distribution)

3) Two models of clay compressibility (2 extremes)

- Mechanical = physical interaction with $\sigma' = \bar{F} \cdot a_c$ (all contacts)
- Physico-Chemical = " " " $\sigma' = (R-A)$ (all double layer)

2. Components of Volume Change (Table V)

1) Elastic deformation
2) Change in closest spacing
3) Particle reorientation
4) Crushing

3. Examples of Factors Affecting Initial Fabric

VI SOIL STRUCTURE: EFFECTS OF CLAY TYPE AND ENVIRONMENTAL FACTORS (6 pages + Summary & 8 sheets)

1. Smectite
   - 1.1 Na Montmorillonite } 1-D & CIUC data
   - 1.2 Ca " } 1-D & CIUC data
   - 1.3 CIDC(L) Data with $\sigma_3' = 0$
   - 1.4 Summary
2. Kaolinite
   - 2.1 Schematic
   - 2.2 1-D Compression
   - 2.3 Strength Data
   - 2.4 Summary
3. Illite
   - 3.1 Deposition: Fresh vs Sea Water for Natural Clay
   - 3.2 1-D Compression: Fractionated Illite
   - 3.3 Strength Data
4. Summary (Still being prepared)

Sheets: M1-4 for montmorillonite; K1-3 for kaolinite; I1-3 for illite

VII CLASSIFICATION TESTS & RADIOGRAPHY

1) Specific gravity
2) Grain size distribution
3) Atterberg limits
4) Summary plots
5) Plasticity chart
6) Correlations
7) Radiography

I SOIL COMPOSITION, ETC

1.361 References

1. BACKGROUND

II 1-1 & 4

1.1 Soil Types

- Inorganic -
  - Gravel (G), Sand (S): Granular
  - Silt (M), Clay (C): Cohesive
- Organic - Peat, Muck

How distinguish?
1) G vs S
2) gran. vs coh.
3) M vs C

1.2 Δ(Particle Size & Shape) → Δ Soil Types

II 1-1.2

- Decreasing particle size → decreasing k
  (increasing SSA) → increasing max u_c (capillary pressure)
  → " importance surface forces
- Spheres to platy shaped → larger differences in fabric
- Both result from Δ mineral composition

2. SOIL COMPOSITION

II 1-2

2.1 Silicate Frameworks (Sheet A)

1) Quartz Si_4O_8 2) K Feldspar $KAlSi_3O_8$
3) Plagioclase $NaAlSi_3O_8$, $CaAl_2Si_2O_8$ 4) Calcite. 5) Dolomite

} Relative abundance in sand & silt size

Why weather resistant?

2.2 Silicate Sheets = Clay Minerals (Sheets A, B & C)

1) Basic building blocks = $Si_4O_{10}^{-4}$ [S] ; [G or B] $Al_4(OH)_{12}$ - OHs, $Mg_6(OH)_{12}$ - OHs

2) 2 sheets/layer (7 Å) → Kaolinite, Halloysite =

3) 3 sheets/layer (10 Å) → Mica, Illite, Montmorillonite, etc =

*(A) = Composition of Soil (B) = Data on Common Clay Minerals (C) = "Clay Mineralogy"

1.361 References

2.3 Predominate Clay Minerals (Very general)

1) Cold climates → marine clays from glaciation with illite & chlorite (BBC, quick clays of Canada & Scandanavia)

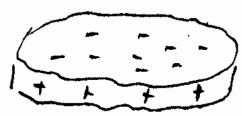
2) Moderate to arid climates → expansive clays with smectite (evap. > rainfall) (S. Africa, S. mid-west US)

3) Wet tropical → residual soils with kaolin, halloysite, Al/Fe oxides (red) (Caribbean islands)

3. ELECTRICAL NATURE OF PLATY CLAY PARTICLES — II 2-1 & 2

3.1 Shape & Charges — II 2-1.2

1) Why negative face charge?



Surface charge density $\sigma_0 \approx \frac{CEC}{SSA} \approx 0.2 \pm 0.1\ C/m^2$ (1-2 charges / 100 Å²)

Effect of environment on σ_0?

2) Edge charge & effect of pH: Incr. pH → ________
↑ Usually ___

3) Overall charge = ?   Electrophoresis =
Electroosmosis =

pH = $-\log_{10}$ (H^+ conc) : < 7 = acidic (High H^+); > 7 = basic (high OH^-)

3.2 Diffuse Double Layer (1 Å = 10^{-4} μm) — II 2-2.2

1) Definition

2) Debye thickness (t_D) = distance* between parallel plate condensers having the same σ_0 & electric potential (V) — II 2-2.2 (7a)

$$t_D(Å) = \frac{0.0199}{v}\sqrt{\frac{D \cdot T}{C_0}}$$

(for $v^+ = v^-$)

v = ion valence   T = temp. (°K)
D = dielectric constant = 80 H_2O, 20 alcohol
C_0 = conc. cations = conc. anions (for $v^+ = v^-$) in BULK pore water (M = moles/liter)

* Beyond Stern layer (≈ 5 Å); distance to $c = c_0$ approx. 2-3 × t_D

1.361 Refer.

(3.2 Cont.)

D	C_o (M)	t_D(Å) at 20°C (293°K) $\nu=1$	$\nu=2$
80 (H_2O)	5×10^{-5}	430	215
	10^{-4}	305	152
	10^{-3}	96	48
	10^{-2}	30	15
	10^{-1}	10	5
20 (alcohol)	10^{-4}	152	76
	10^{-2}	15	7.5

4. THREE COMMON CLAY MINERALS (Sheet C)

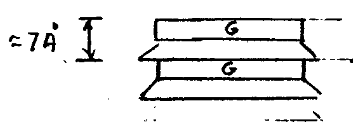
II 1 - 2.6, 2.7

II 2 - 3.2

4.1 Na Kaolinite $(Al)_4[Si]_4O_{10}(OH)_8$

1) Structure

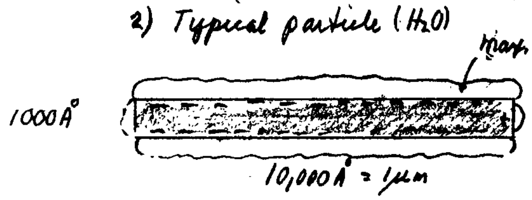
Halloysite =



σ_0 due to:

Bonding due to:

2) Typical particle (H_2O)

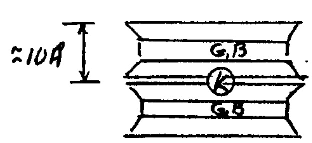


- 140 layers/particle
- SSA ≥ ≈ 10 m²/g
- $\sigma_0 \approx 0.3\ C/m^2$
- EDGE effects

4.2 Na Illite $K(Al,Mg,Fe)_{4or6}[Al,Si]_8O_{20}(OH)_4$

1) Structure

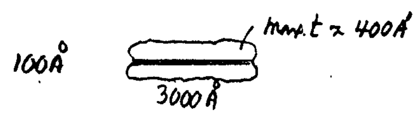
Mica =



σ_0 due to:

Bonding due to:

2) Typical particle (H_2O)

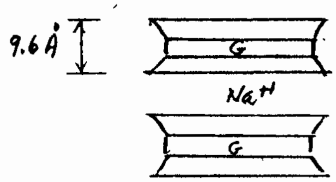


- 10 layers/particle
- SSA ≈ 80 m²/g
- $\sigma_0 \approx 0.3\ C/m^2$
- ∴ EDGE + DL effects

Dia H_2O = 3Å = 3×10^{-4} μm = 0.3 μm

4.3 <u>Na Montmorillonite</u> $(Al_{3.3}\,Mg_{0.7})\,[Si]_8\,O_{20}\,(OH)_4$

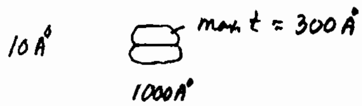
1) Structure



σ_0 due to:

Bonding due to:

2) Typical particle (H_2O)



- 1 layer / particle
- SSA ≈ 800 m^2/g
- σ_0 ≈ 0.1 C/m^2
- DL effects

NOTE: Part V will discuss how Δ pore fluid composition changes engr. properties of these 3 clay minerals (K, I & M)

1.322 Part AI

1.361-1.366 Part II-1

Data on Common Clay Minerals

1.322 Soil Technology — Dept. of Civil Engineering, M.I.T.

CCL & RTM 9/65
9/95

Mineral	Unit Cell Formula	Structural Symbol	Isomorphous Substitution	Charge Density[1] (meq/100g)	Interlayer Bonding	Typical Particle: Shape	Typical Particle: Size	CEC[2] (meq/100g)	SSA[3] (m^2/g)	σ[4] (charge/100 Å²)	Var. d(001)
Kaolinite	$(Al)_4[Si]_4O_{10}(OH)_8$	G, G	Al for Si, Mg for Al (~1 in 400)	~2	Secondary valence + H-bonding, Strong	Hexagonal sheets	$d = 3\text{-}10\mu$, $t = \frac{1}{3}\text{-}\frac{1}{10}d$	~3	10-15	1.2	No
Halloysite (Hydrated / Dehydrated)	$(Al)_4[Si]_4O_{10}(OH)_8 \cdot nH_2O$ (n=4 / n=0)	H_2O; G, G	As above	~8	As above except weak if larger spacing	Hollow tubes	OD = .07μ, ID = .04μ, ℓ ~ .5μ	~12	30-50	1.8	Yes / No
Muscovite (Mica)	$K_2(Al)_4[Al_2Si_6]O_{20}(OH)_4$	K; G, G	Al for Si (~1 in 4), maybe Mg, Fe for Al	250	K-bonding + sec. vol. Very strong	Platy	Very large	3-10	1-10	~2.2	No
Vermiculite	$(Mg,Al,Fe)_{6\ or\ 4}$ - $[Si,Al]_8O_{20}(OH)_4 \cdot nH_2O$	H_2O; Mg, Ca; G or B, G or B	Mainly Al for Si (~1 in 8), Also Mg, Fe for Al, Al, Fe for Mg	150±20	Weak primary val. (Ca, Mg) + sec. vol. Weak	Sheets	Variable	150 ±20	500-700 when expanded	2.2	Yes
Illite (Hydrous mica)	$K(Al,Mg,Fe)_{4\ or\ 6}$ - $[Si,Al]_8O_{20}(OH)_4$	K; G or B, G or B	Mainly Al for Si (1 in 6-8), Also Mg, Fe for Al, Al, Fe for Mg	~150	K-bonding + sec. vol. Fairly strong	Flakes	$d = .1\text{-}2\mu$, $t \le \frac{1}{10}d$	25 ±5	80-100	1.5	No
Sodium Montmorillonite	$(Al_{3.3}Mg_{0.7})[Si]_8O_{20}(OH)_4$	G, G	Mainly Mg for Al (~1 in 6)	100	Weak secondary valence	Sheets	$d = .1\text{-}1\mu$, $t \le \frac{1}{100}d$	95 ±10	700-800	0.75	Yes
Chlorite	$(Mg,Al,Fe)_{4\ or\ 6}[Si,Al]_8$ - $O_{20}(OH)_4 \cdot (Mg,Al,Fe)_6(OH)_{12}$	G or B, B+, G or B	Al for Si, Fe, Mg for Al, Fe, Al for Mg in B+	200-250	Primary valence via B+ sheet Very strong	Platy	Variable	2-40	5-30	—	No

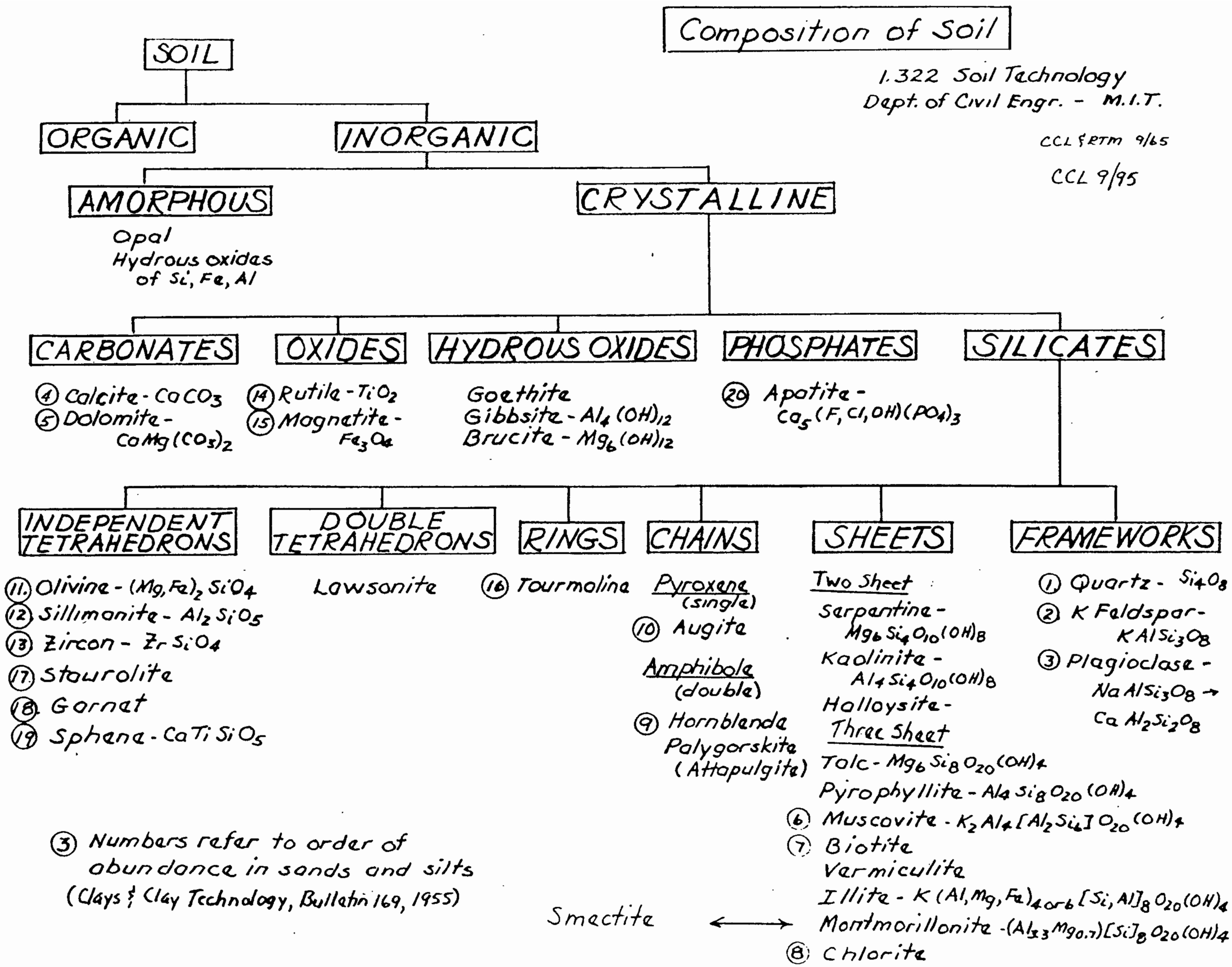
(1) Charge density = $\frac{\text{charge/formula} \times 10^5}{\text{formula weight}}$

Mineral	Formula Wgt.
Kaolinite	517
Talc	750
Pyrophyllite	710

(2) CEC = cation exchange capacity
(3) SSA: specific surface area
(4) σ = surface charge density

- Octahedral & Tetrahedral Sheets
- Unit Layer = 2 or 3 sheets
- Particle = Σ Layers

B

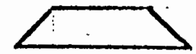
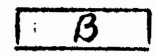

Composition of Soil
1.322 Soil Technology
Dept. of Civil Engr. - M.I.T.
CCL & RTM 9/65
CCL 9/95
SOIL
ORGANIC
INORGANIC
AMORPHOUS
Opal
Hydrous oxides of Si, Fe, Al
CRYSTALLINE
CARBONATES
④ Calcite - CaCO3
⑤ Dolomite - CaMg(CO3)2
OXIDES
⑭ Rutile - TiO2
⑮ Magnetite - Fe3O4
HYDROUS OXIDES
Goethite
Gibbsite - Al4 (OH)12
Brucite - Mg6 (OH)12
PHOSPHATES
⑳ Apatite - Ca5 (F, Cl, OH)(PO4)3
SILICATES
INDEPENDENT TETRAHEDRONS
⑪ Olivine - (Mg, Fe)2 SiO4
⑫ Sillimanite - Al2 SiO5
⑬ Zircon - Zr SiO4
⑰ Staurolite
⑱ Garnet
⑲ Sphene - CaTi SiO5
DOUBLE TETRAHEDRONS
Lawsonite
RINGS
⑯ Tourmaline
CHAINS
Pyroxene (single)
⑩ Augite
Amphibole (double)
⑨ Hornblende
Palygorskite (Attapulgite)
SHEETS
Two Sheet
Serpentine - Mg6 Si4 O10 (OH)8
Kaolinite - Al4 Si4 O10 (OH)8
Halloysite -
Three Sheet
Talc - Mg6 Si8 O20 (OH)4
Pyrophyllite - Al4 Si8 O20 (OH)4
⑥ Muscovite - K2 Al4 [Al2 Si6] O20 (OH)4
⑦ Biotite
Vermiculite
Illite - K (Al, Mg, Fe)4 or 6 [Si, Al]8 O20 (OH)4
Montmorillonite - (Al3.3 Mg0.7)[Si]8 O20 (OH)4
⑧ Chlorite
Smectite
FRAMEWORKS
① Quartz - Si4O8
② K Feldspar - KAlSi3O8
③ Plagioclase - NaAlSi3O8 → Ca Al2Si2O8
③ Numbers refer to order of abundance in sands and silts
(Clays & Clay Technology, Bulletin 169, 1955)

(A)

CCL 9/15/83 9/86
1.322 2/89 2/96

CLAY MINERALOGY

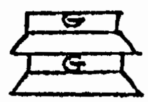
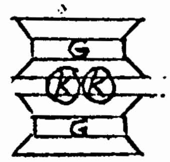
"BUILDING BLOCKS" = SHEETS COMPOSING THE LAYERS

	· Silica Tetrahedra	$Si_4O_{10}^{-4}$		sheets
Hydrous Oxides	· Gibbsite	$Al_4(OH)_{12}$ – OH's		sheets
	· Brucite	$Mg_6(OH)_{12}$ – OH's		sheets

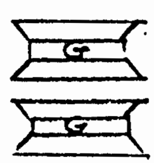
Which sheets combined in layer + nature of "glue" holding layers together to form particles → different clay minerals

CLAY MINERALS OF PRIME INTEREST

($1\ \mathring{A} = 10^{-8}\ cm = 10^{-10}\ m = 10^{-4}\ \mu m$)

Name	Symbol	Glue Between Layers	Remarks
(2S) Kaolinite		Hydrogen, van der Waals } strong	· Large hexagonal · $t \approx 1000\ \mathring{A}$ · SSA ≥ 10 m²/g
(2S) Halloysite	Above w/ H_2O between some layers.	Much weaker	· Hollow tubes → low γ_d · Drying → loss of bonded H_2O
(3S) Muscovite		Very strong K	· Very large particles · Reference for unit layer = 3 sheets

{ Isomorphous substitution: Cations of lower valance substituted during formation → net negative charge within layers. }

Name	Symbol	Glue Between Layers	Remarks
(3S) Illite	As above but: · G or B · Less I.S.	Weaker K	· Flaky particles · $t \approx 100\ \mathring{A}$ · SSA ≈ 80 m²/g · Marine clays
(3S) Smectite = Montmorillonite		If Na – then no bonding (Bentonite)	· Flaky particles · $t \to 10\ \mathring{A}$ (1 layer) · SSA → 800 m²/g · Axle grease

(Problem soil → expansive clays, very low residual ϕ', etc.)

C