SOIL FORMATION AND TYPES

Georgia Institute of Technology

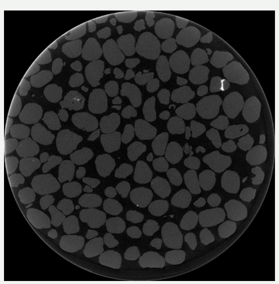
CREATING THE NEXT®

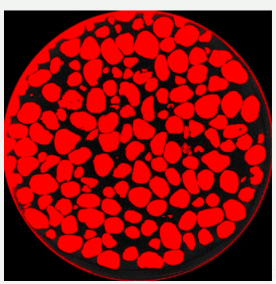
Lecture Topics

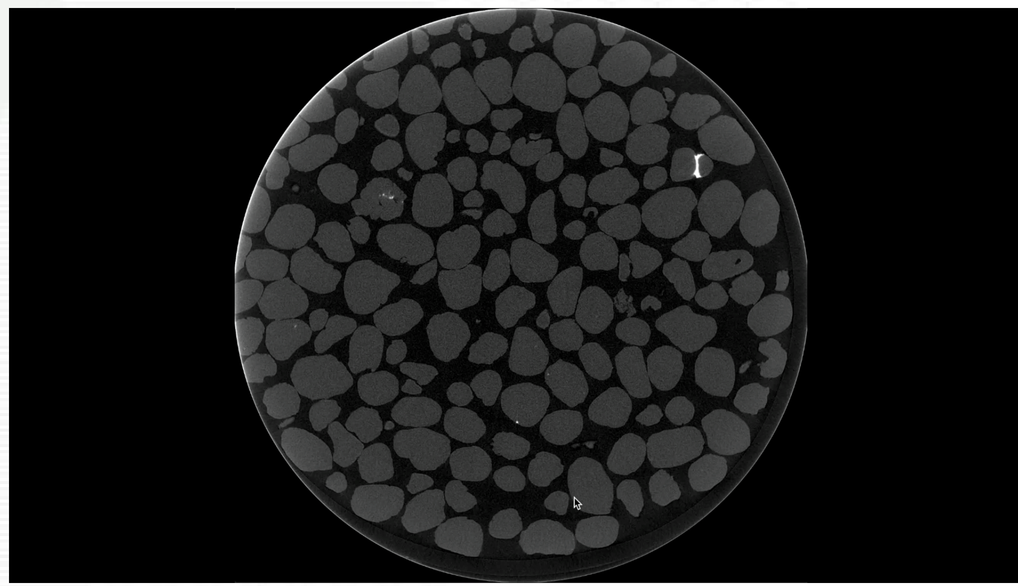
- Introduction
- Formation of soils
- Types of soils
- Soil classification
  - Coarse grain
  - Fine grain
- Clay minerals
  - Mineralogy
  - Water
- Soil fabric

Soils as a building material

- Why do we study soil separately from other materials?
  - Particulate material, with no cohesion
  - Water changes the stress state of our material
  - Variability, uncertainty (must make educated assumptions about the behavior of complex material)







How are soils formed

- Geology → Science behind geotechnical engineering

- Parent rock in a geological region governs development of soil type

- Soils result from weathering of rocks
  - Physical weathering
    - erosion
    - freeze thaw
  - Chemical weathering
    - hydration forces
    - precipitation
    - oxidation

QUARTZ

http://upload.wikimedia.org/wikipedia/commons/1/14/Quartz,_Tibe

SCHIST

http://webmineral.com/

http://upload.wikimedia.org/wikipedia/commons/6/6f/Schist_detail.jpg

Georgia's Geologic Provinces

https://www.researchgate.net/figure/Map-showing-the-extent-of-generally-undeformed-Devonian-shale-units-in-the-Appalachian_fig1_292103028

Types of Soil: Residual

- Rock weathered in place to form soil
- Not transported
- Parent rock structure remains
- Stress history is formed in place

Weathering in Borrow Pit

Weathering in Highway Cut

Parent Rock in Piedmont Region (Atlanta, GA)

- Main rocks in Piedmont

  - granite (quartz and feldspar, mica)

  - gneiss (quartz and feldspar, biotite)

  - schist (mica,chlorite,talc,hornblende)

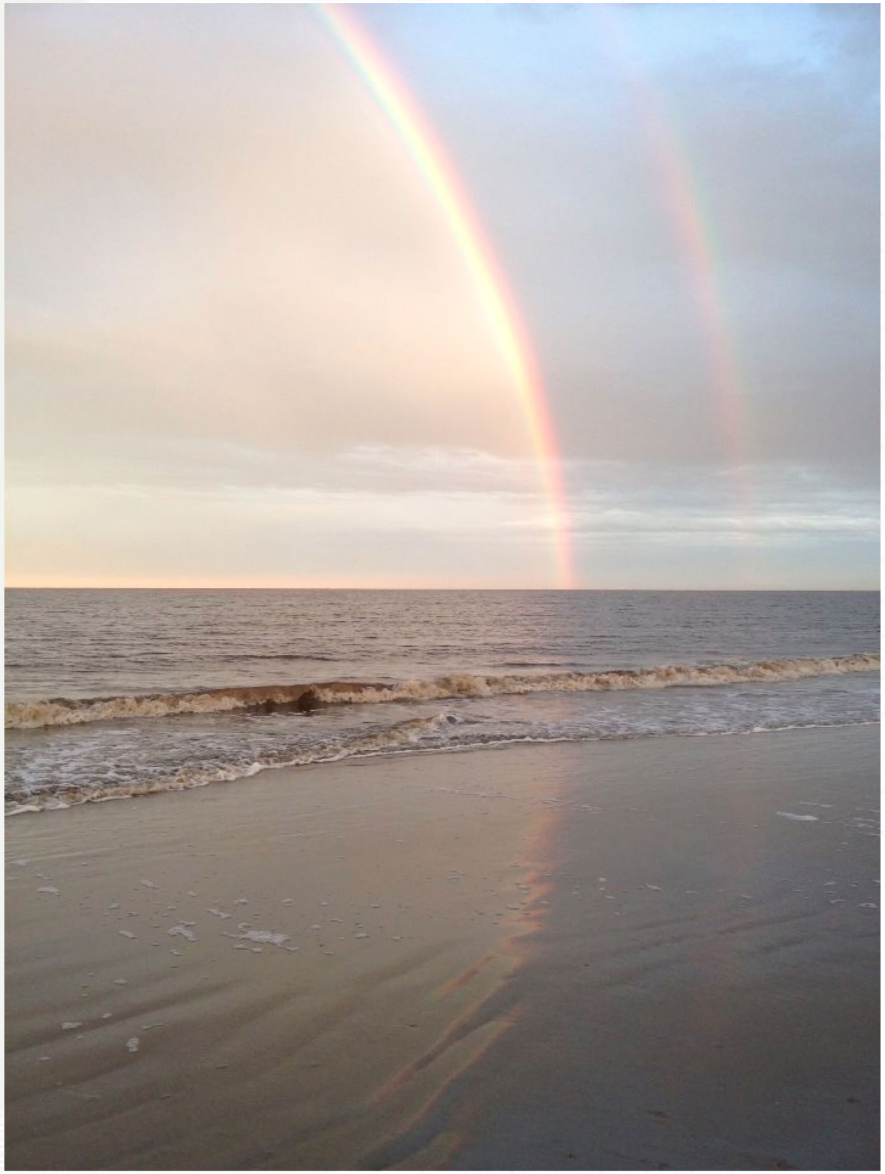
Photos: Wikipedia

Types of Soil: Alluvial

- Soils deposited by surface water

Lacustrine means soils deposited in a lake

Beach sand, Jerkyll Island, Georgia



Types of Soil: Glacial Till

- Parent rock ground by the weight of advancing / receding glaciers
- Wide range of particle sizes

Photo: Wikipedia

Types of Soil: Loess

- Typically silt sized particles
- Transported by wind
- Able to hold vertical cut
- Cemented by calcium carbonate

Loess Deposit, Northwestern Alabama, USA

Soil Classification

- Grain size
  - Coarse
  - Fine
- Mineral type
  - Geochemical analysis

Soil Classification: Coarse Grained

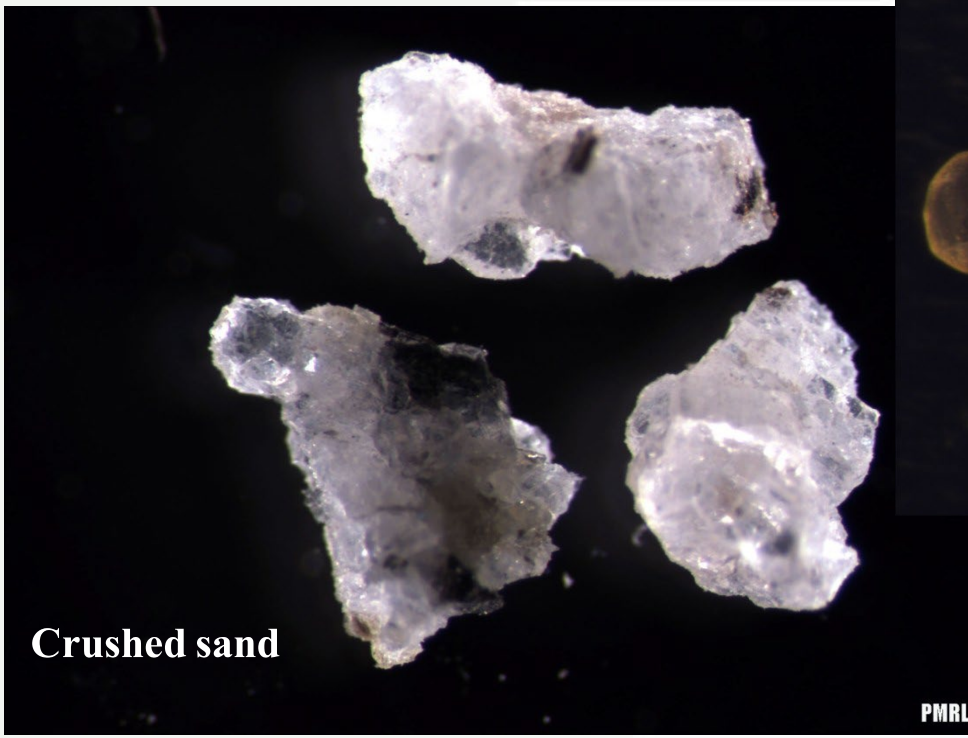
- Not sensitive to type of mineral content
- Behavior controlled by gravitational forces
- Can see grains with the naked eye

- Gravel
  - quartz (SiO_2), feldspar ($KAlSi_3O_8$ – $NaAlSi_3O_8$ – $CaAl_2Si_2O_8$)
  - Greater than 4.75 mm (0.187 in)
  - Apples to peas

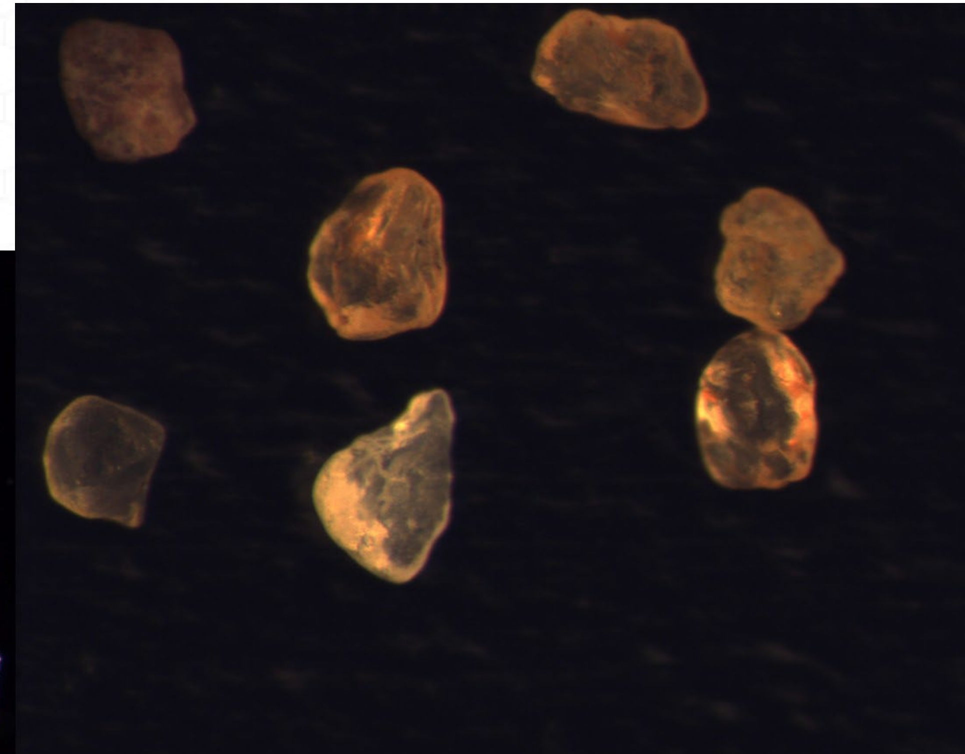
- Sands
  - mostly quartz and feldspar
  - 2.0 mm - 4.75 mm coarse
  - 0.425 mm – 2.0 mm medium
  - 0.075 mm – 0.425 mm fine (0.003 in)
  - Peas to baking flour

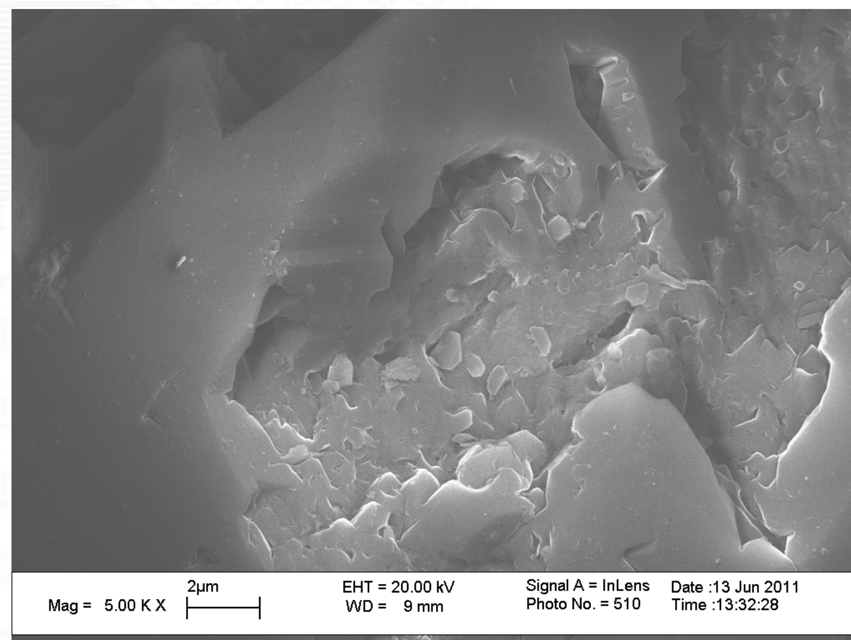
Photos: American Landscape Supply and NPR

Soils



Crushed sand

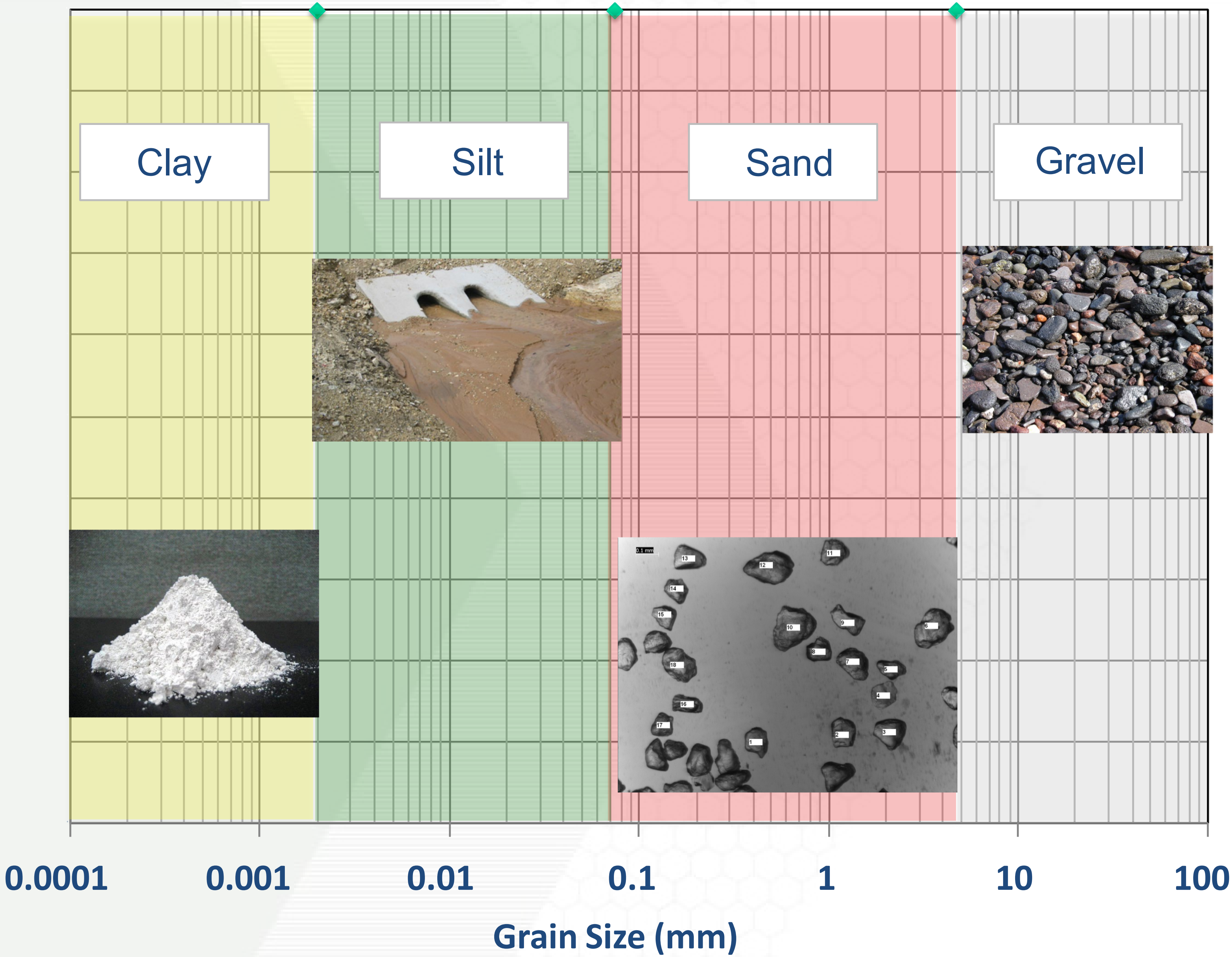




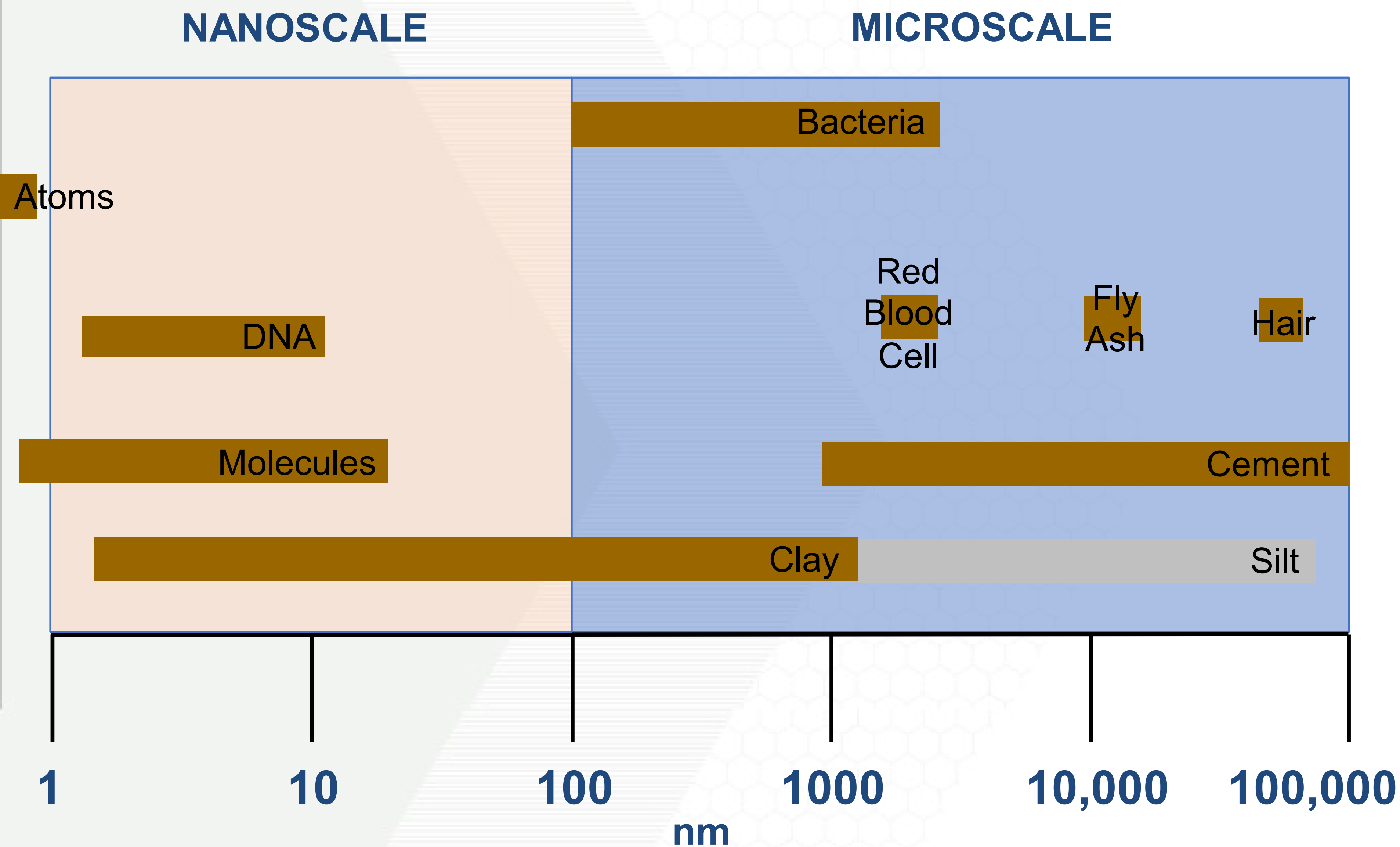
http://pmrl.ce.gate

Soil Classification: Fine Grained

- Smaller than <0.075 mm (no. 200 sieve)
- Sensitive to mineral type and content
- Electrical forces are important in behavior
- Cannot distinguish individual grain by eye
  - Silts
    - *- Sized between 0.002 mm and 0.075 mm*
    - *- Fine quartz grains and mica flakes*
  - Clay – Two ways to define
    - *- Can define as clay-sized particles – includes mineral particles smaller than 0.002 mm, quartz, feldspar, mica, clay minerals*
    - *- Can define as clay minerals –kaolinite, montmorillonite, illite, vermiculite, chlorite to name a few*



Photos from Wikipedia, Austin TX. gov, Mineralexporters.com



1 nm = 0.000000001 m = 1×10^{-9} m = 1 billionth of a meter

1 Angstrom = 1×10^{-10} m

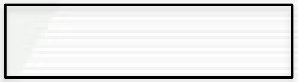
Clay Minerals

- Unique properties and behavior
  - Presence of water is an especially important factor in the behavior of clays
  - Water will affect the strength of clays (unlike sands)
- Clay Minerals are known as aluminosilicates
- Basic structure is composed of aluminum and silicon, with other atoms added in
- Usually have a “plate-like” shape – very thin but wide
- Two basic units construct the clay minerals.
  - Silica tetrahedron – four oxygen atoms surrounding a silicon atom, combine into silica sheets
  - Aluminum octahedron – six hydroxyls (OH-) surrounding and aluminum atom, combine into octahedral sheets

Clay Minerals

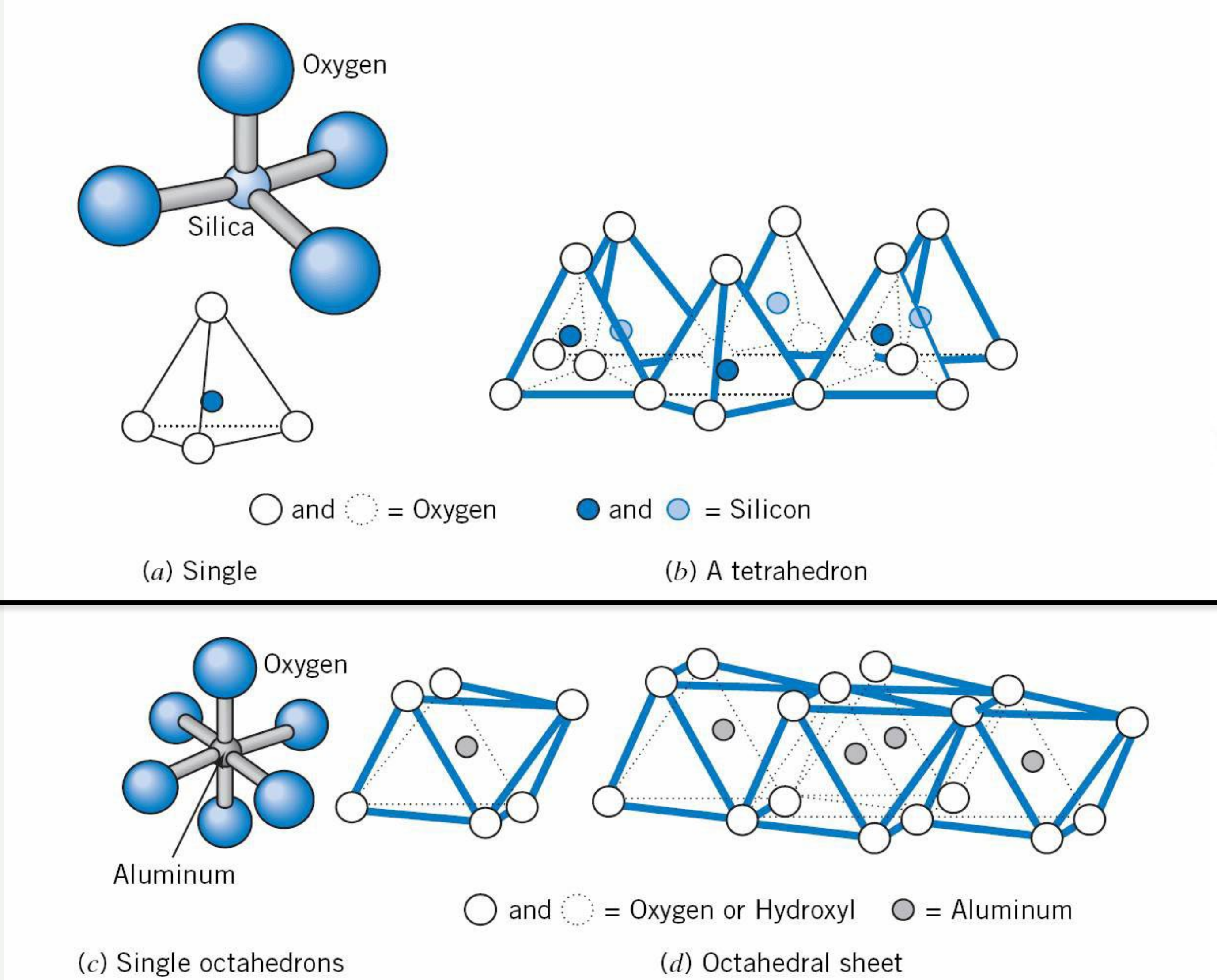
- Two basic units construct the clay minerals:
  - Silica tetrahedron – four oxygen atoms surrounding a silicon atom, combine into silica sheets

  - Aluminum octahedron – six hydroxyls (OH-) surrounding an aluminum atom, combine into octahedral sheets



  - Sheets can grow very long when compared to their width
  - Different clay minerals are formed by stacking the silica and octahedral sheets in different arrangements, and with different cations between the layers
  - Remember that a cation is a positively charged atom or group of atoms that has lost and electron: Na^{+} Ca^{++} K^{+} Mg^{++}

Clay Minerals: Aluminosilicates



(*a*) Single

(*b*) A tetrahedron

(*c*) Single octahedrons

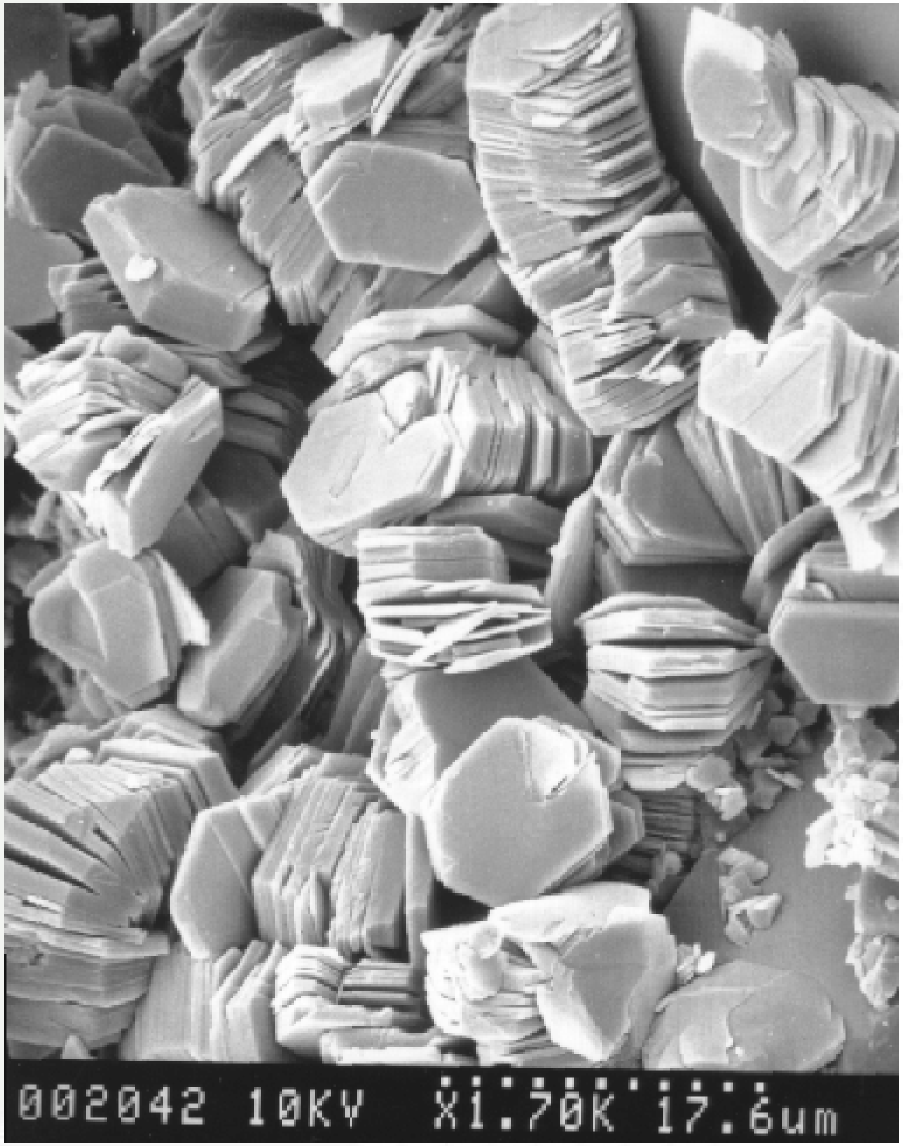
(*d*) Octahedral sheet

Clay Minerals: Kaolinite

- Kaolinite – clay mineral with one silica and one alumina sheet
  - Used in ceramics
  - Paper coating – gives the shine to magazine covers
- 1:1 stacking of the sheets
- Particle of kaolinite is typically composed of more than one hundred stacks of these layers
- Layers are 72 Ang thick, and are held together by hydrogen bonding
- Kaolinite grows in the form of platelets 1000 to 20,000 Ang in the lateral dimension, and 100-1000 Ang thick – called “books”

1 Angstrom = 1×10^{-10} m

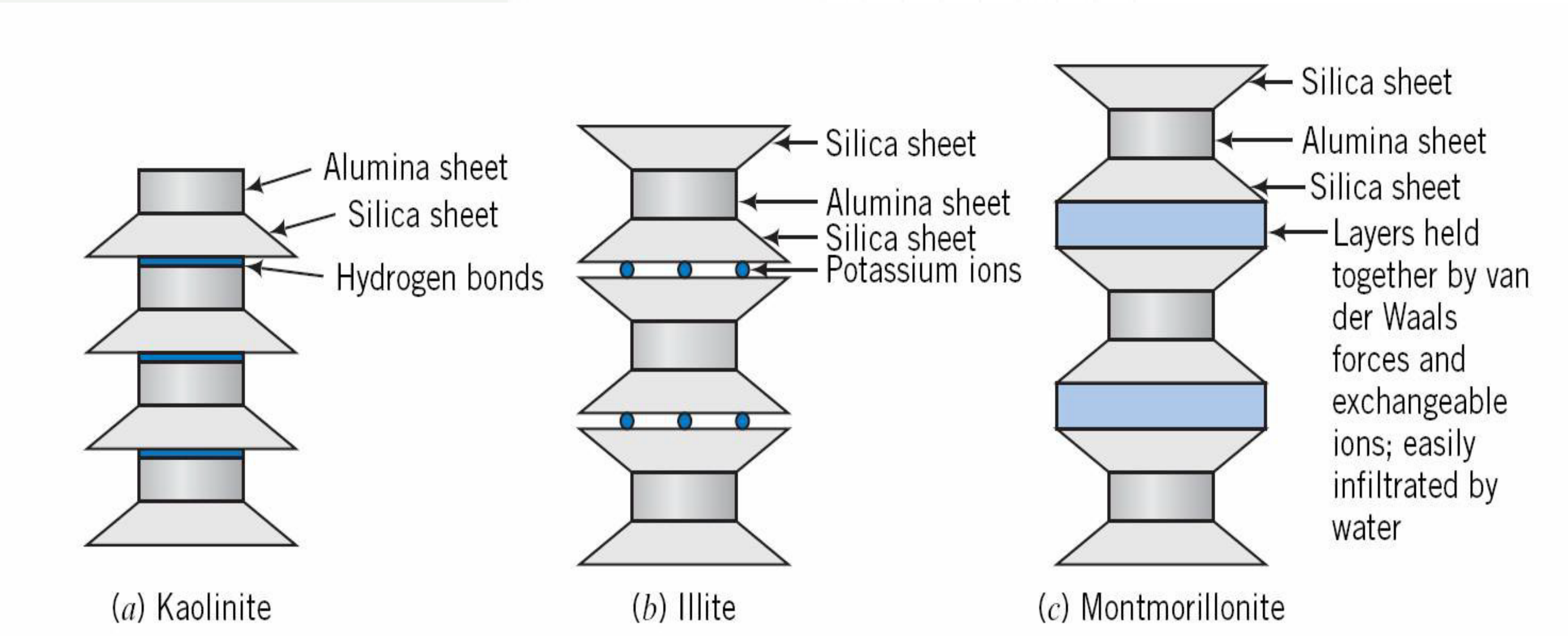
Kaolinite: http://www.arenisca.com



Georgia Kaolinite Deposits

https://www.georgiamining.org/

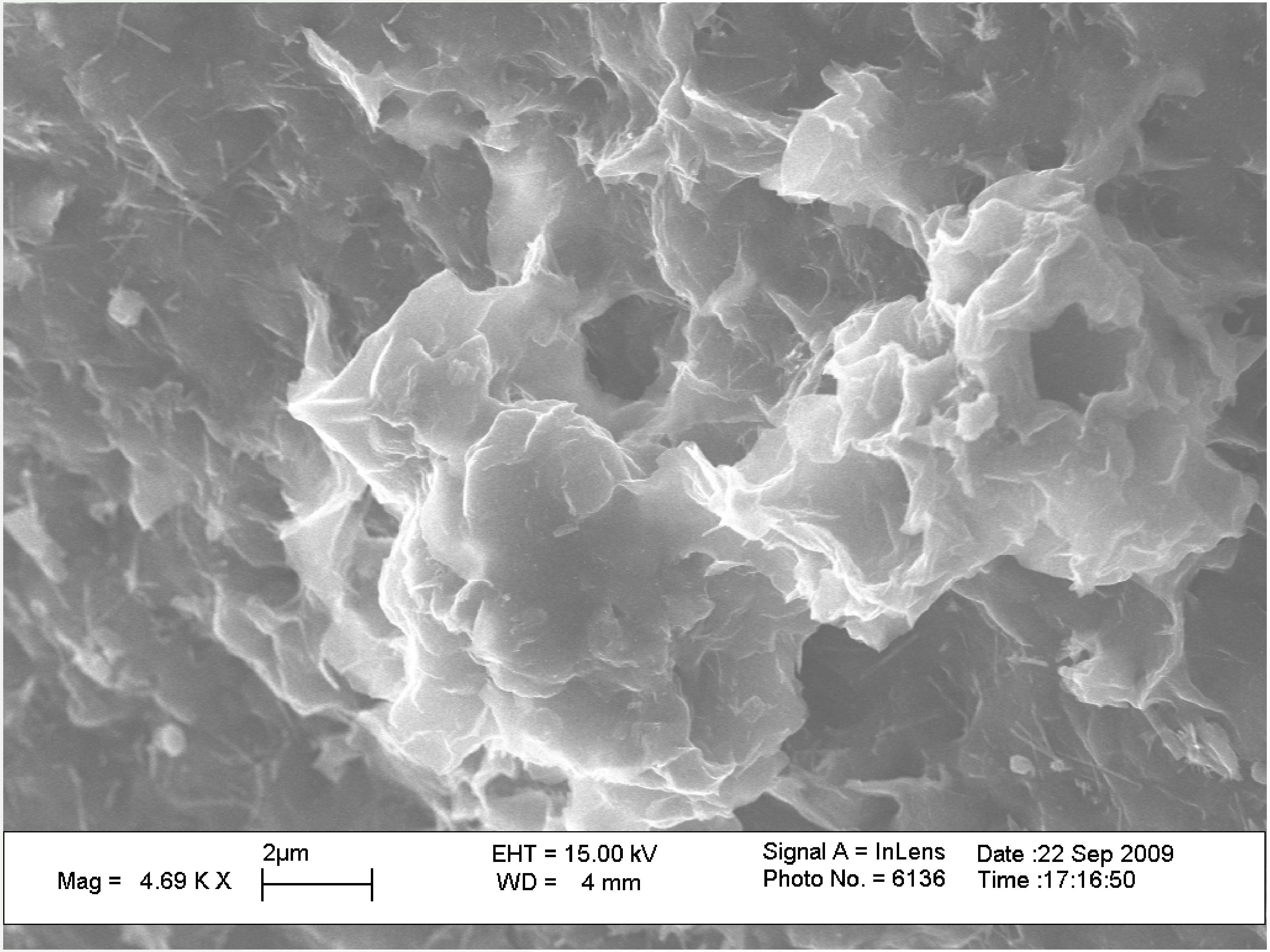
Clay Minerals: Stacking Structures



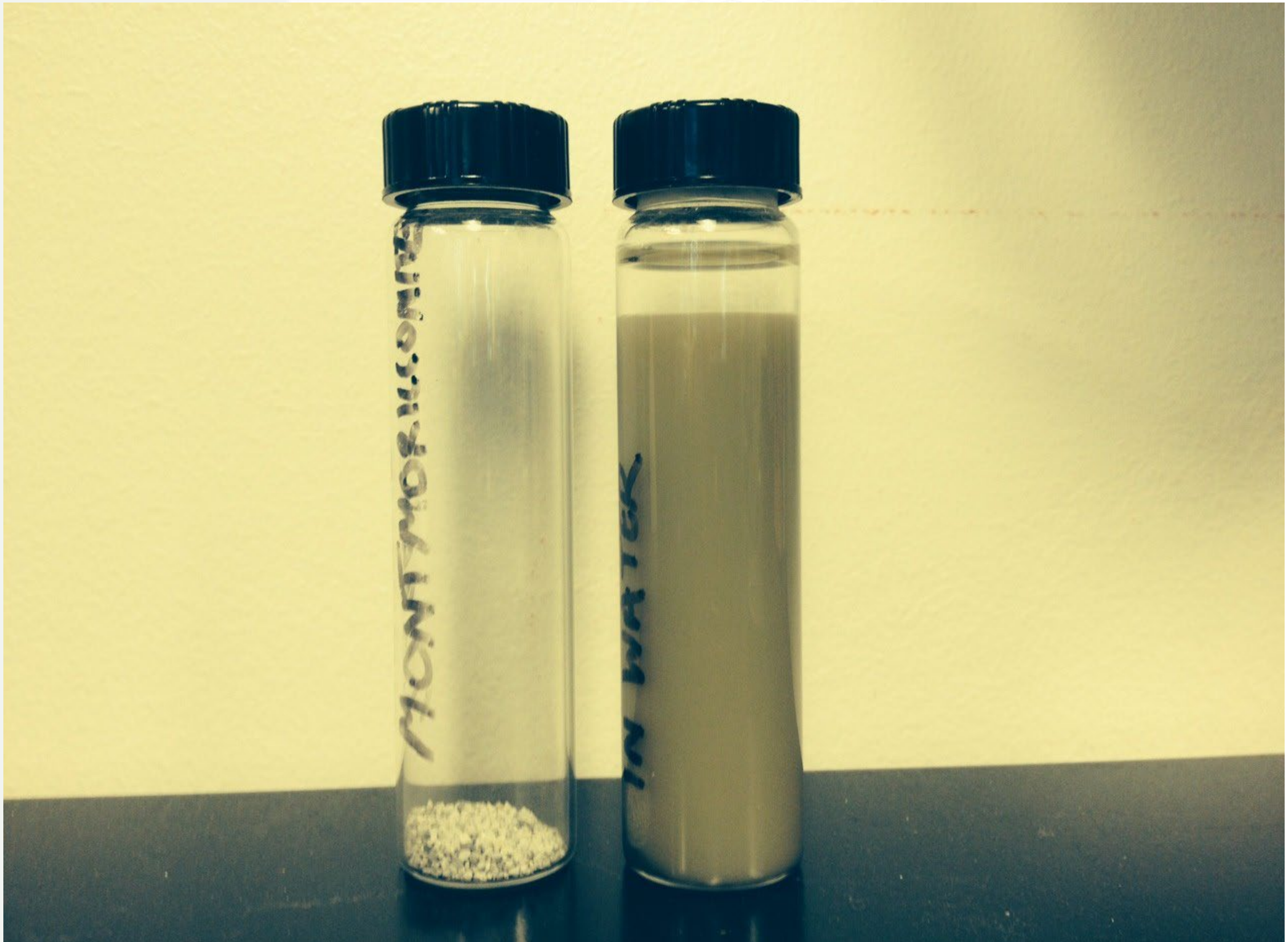
Clay Minerals: Montmorillonite

- Montmorillonite 2:1 stacking of sheets
- Substitution of iron (Fe^{2+}) and magnesium (Mg^{2+}) for aluminum (Al^{3+}) in the octahedral sheets
  - Lateral dimensions 1000-5000 Ang, Thicknesses 10-50 Ang
  - Specific surface 800 m2/g
  - Football field = 100 yds x 160 ft = 300 ft x 160 ft = 48,000 ft2
  - About 5-6 grams of montmorillonite (also called bentonite) can cover a football field if the particles are laid end to end
  - Because montmorillonite has such a large surface area, it can adsorb large amounts of water –
  - Water can easily force apart the layers of the clay - causes the shrink-swell behavior of what we call expansive clays
  - Used as kitty litter; used to clarify wine and beer

Montmorillonite: Image taken by Jim Larrahondo



2G Montmorillonite: Dry and Hydrated



Impact on Light Weight Structures

Brick Façade Cracking

http://www.foundationrepairstructo.com/foundation_info.html

Specific Surface Area

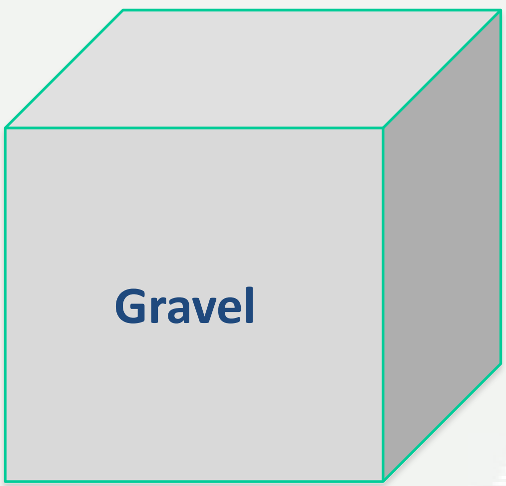
Gravel cube, dimensions 1cm x 1cm x 1cm

Sand cube, dimensions 1mm x 1mm x 1mm

Clay cube, dimensions 1µm x 1µm x 1µm

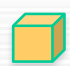
Calculate surface area to volume ratio:

$$Specific\ Surface\ Area = \frac{Surface\ area}{Volume} * \frac{1}{\rho} = \frac{L^2}{L^3} \cdot \frac{L^3}{M} = \frac{L^2}{M}$$



$$\frac{6 \cdot (1cm^2)}{1cm^3} = \frac{6}{cm} = \frac{0.6}{mm}$$

Sand



$$\frac{6 \cdot (1mm^2)}{1mm^3} = \frac{6}{mm}$$

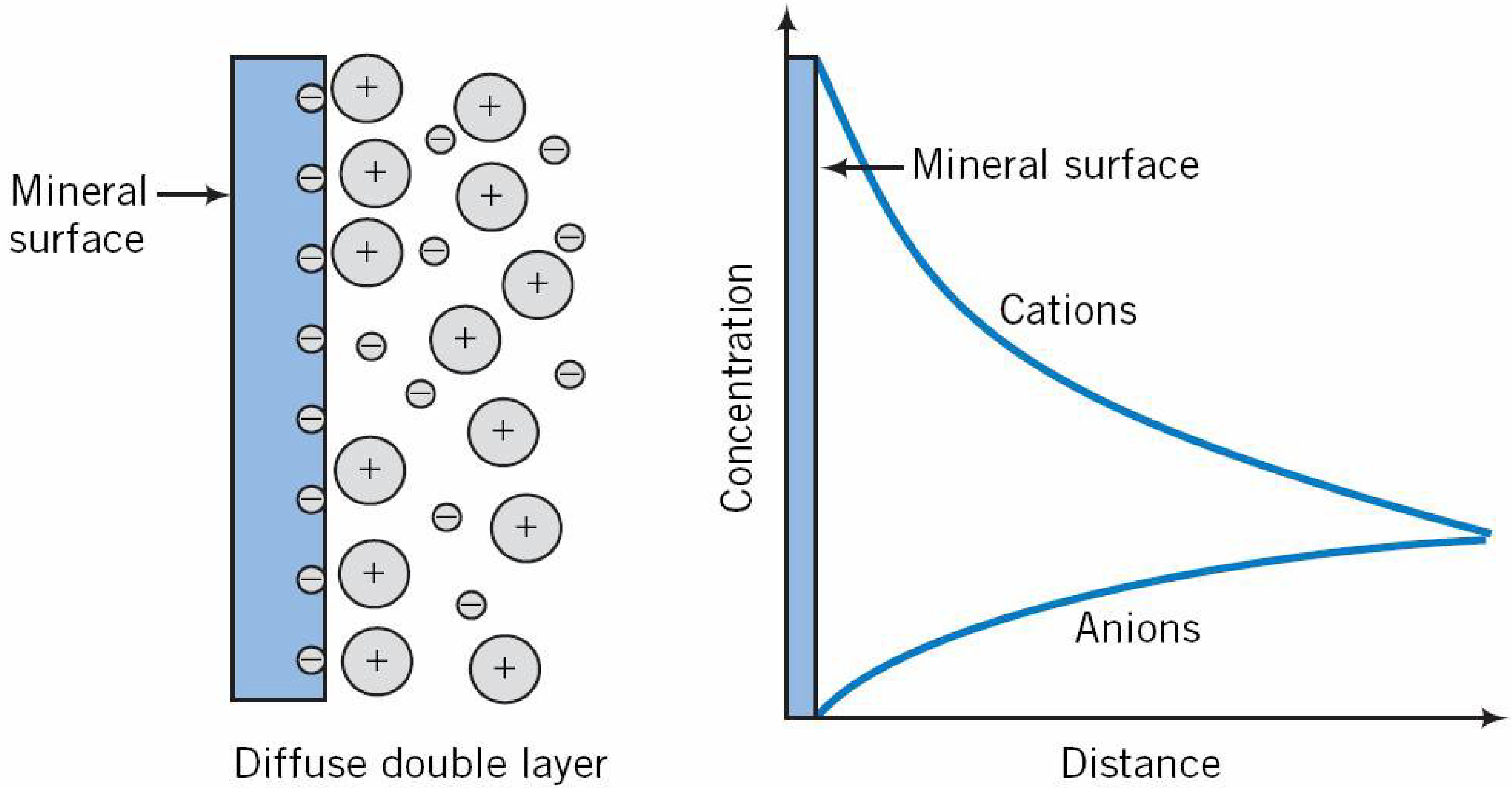
Clay

$$\frac{6 \cdot (1\mu m^2)}{1\mu m^3} = \frac{6}{\mu m} = \frac{6000}{mm}$$

Charge on Clay Particles

- When placed in water, clay minerals are typically negatively charged for three reasons
  - Isomorphous substitution: Replacement of lower valence cations in the clay structure, for example, replacing Al^{+3} with Mg^{+2}
  - Broken edges – at the edges of the clay particles, the bonds are unbalanced, and this leads to charge excesses
  - Hydroxyl (OH-) group can release a hydrogen to solution when the pH increases
    - Because the hydrogen is positively charged (H+) leaves O- on the edge (negatively charge)
- Place negatively charged clay particles in water
  - Water is strongly attracted to particle surface
  - Positive charges (cations) present in the fluid are attracted to neutralize charge
  - Cations also want to move away due to thermal energy (diffusion)
  - Cations form a layer of equal but opposite charge surrounding the particle surface – known as the diffuse double layer
- Diffuse double layer
  - High concentration of positive charge adjacent to the surface
- Eventually reach a distance where there is a return to "Normal Water" properties

Diffuse Double Layer



Double Layer Water

- Remember that water is a polar compound with concentrated areas of + and – charge: known as a dipole
- The excess positive charge of the water is attracted to the clay surface due to electrostatics
- Water is also attracted to the surface due to hydrogen bonding
- What results is a layer of tightly bound water that surrounds the clay particles
- Adsorbed water
  - Layer tightly bound to particle surface
- Double layer water
  - Water later adjacent to the absorbed water layer

Clays

- We spend time talking about the individual clay minerals because they exert a significant influence on the engineering behavior of soils as a whole
- As the clay mineral content increases, the engineering properties are significantly altered, and soil behavior becomes more sensitive to the presence of water

https://https://www.123rf.com/photo_13995786_crackedand-dry-claybackground.html

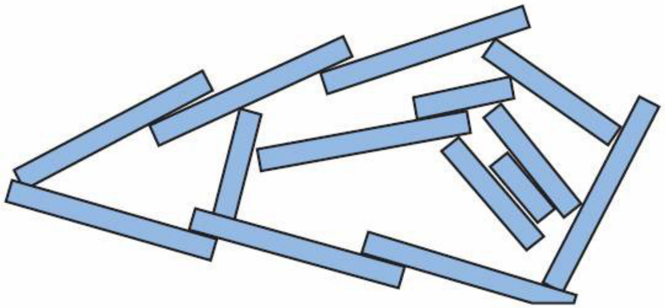
Soil Types

- In summary, soil has distinct categories:
  - Gravel
  - Sand
  - Silt
  - Clay
- We will talk about each of these as though the soils are pure
- In reality, natural soils are a mix of particle sizes and mineral types
- Coarse-grained soils
  - High mechanical strength when densely packed
  - Drain easily
  - Not significantly influenced by water
- Fine-grained soils
  - Relatively weak in comparison
  - Water strongly affects their strength and volume change properties
  - Low permeability to water

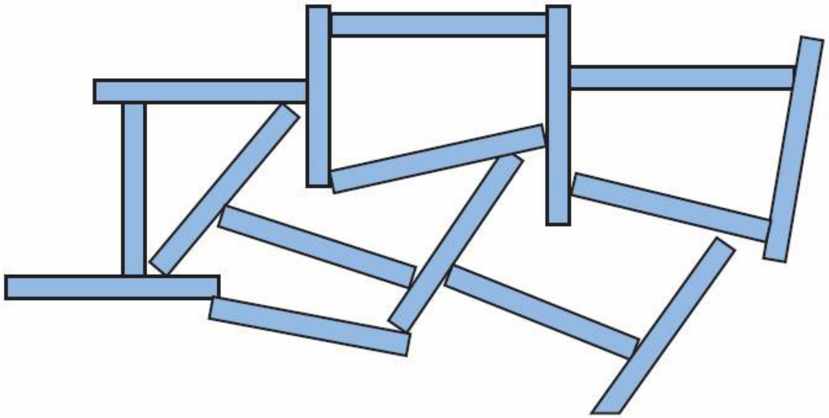
Soil Fabric

- One of the controlling factors in the behavior of soil is the way the soil particles are arranged in relation to each other – known as fabric
- Strongly influenced by the environment in which the soil is deposited – fine- grained soils are frequently in water (saltwater or fresh)
- Forms flocculated or dispersed structure

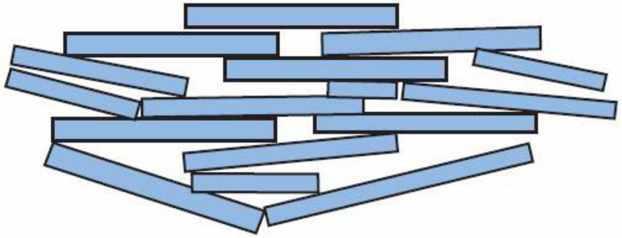
Fine-Grained (Clay) Soil Fabric



(*a*) Flocculated structure—saltwater environment



(*b*) Flocculated structure—freshwater environment



(*c*) Dispersed structure

Types of particle Associations: Fine Grain

- Flocculated
  - End to end or end to face
  - No association of individual particles or groupings of particles
- Aggregated
  - Associations of particles
- Dispersed
  - Particles are individuals
- Different fabrics will behave differently
  - Mechanical loading
  - Flow of water through their structure
- In addition to the particles
  - Composed of the void space between the particles
  - Can be filled with gas (typically air)
  - Or with liquid (typically water)

Coarse-Grained Soil Fabric: Particle Arrangement

- Figure a and b have the same particles or portions of the particles contained in the box
- Have the same void ratio
- Compressibility would be significantly higher in the second arrangement than in the first
- Particle arrangement is more significant in loose sands than in dense sands

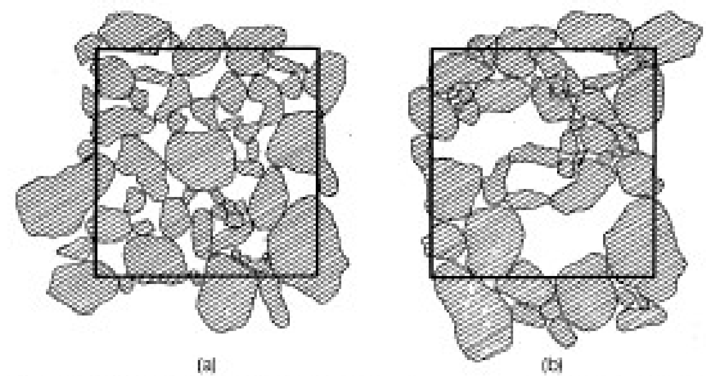


Fig. 1. Illustration of potential ranges in the arrangement of identical particles at the same relative density

Leonards et al. (1986) Geotechnique

Coarse-Grained Soil Fabric: Particle Orientation

- Same void ratio and relative density but a different particle orientation
- Figure a) is less compressible in the vertical direction than Figure b)
- More important in dense sands than in loose sands

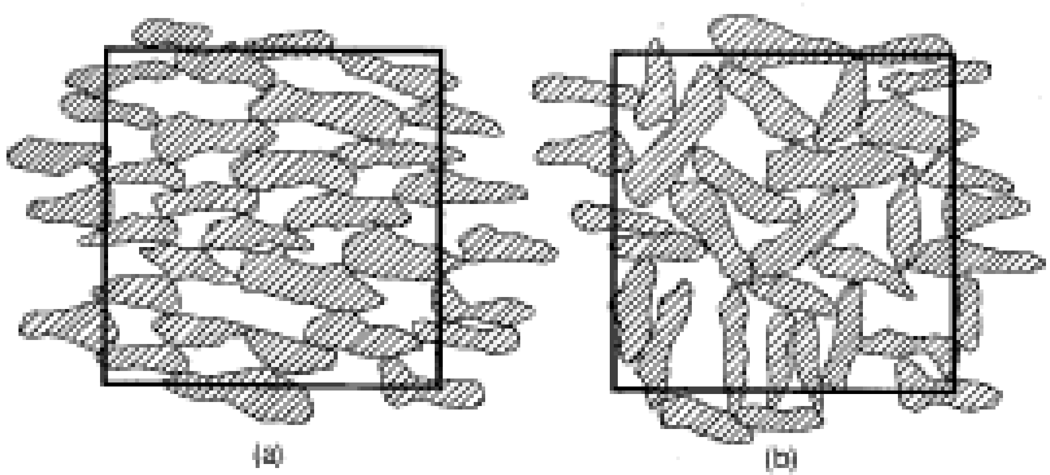


Fig. 2. Illustration of potential ranges in the orientation of identical particles at the same relative density