Physical properties of soils

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Soil physics

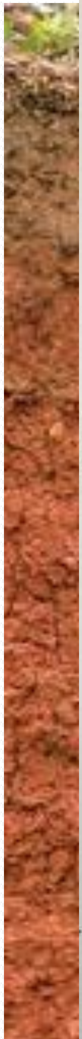
- Physical properties
- Physical processes

Physical properties of soils course outline

- Soil color
- Soil densities and porosity
- Soil texture
- Soil Structure
- Soil water
- Soil air/aeration
- Soil temperature

Soil color

- The color of the soil is usually the first thing we notice.

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in
-5-
-10-
-15-
-20-
-25-
-30-
-35-
-40-

Soil color

- Wetness: moist soils are darker than dry ones.
- Organic matter: Organic matter makes soils darker.
  Surface soils tend to be darker than subsoils.
- Drainage level: Red color indicates good drainage
  Gray color indicates poor drainage
- Presence of minerals: whitish gray – less minerals (such as Fe)

See the difference in color between wet and dry

Crushed granite: left side wet.

Monto Clay: Right side wet.

See the difference in color between high and low organic matter

SOIL COLOR

Dark color

– high percentage of organic matter

Red

– Good drainage

Yellow

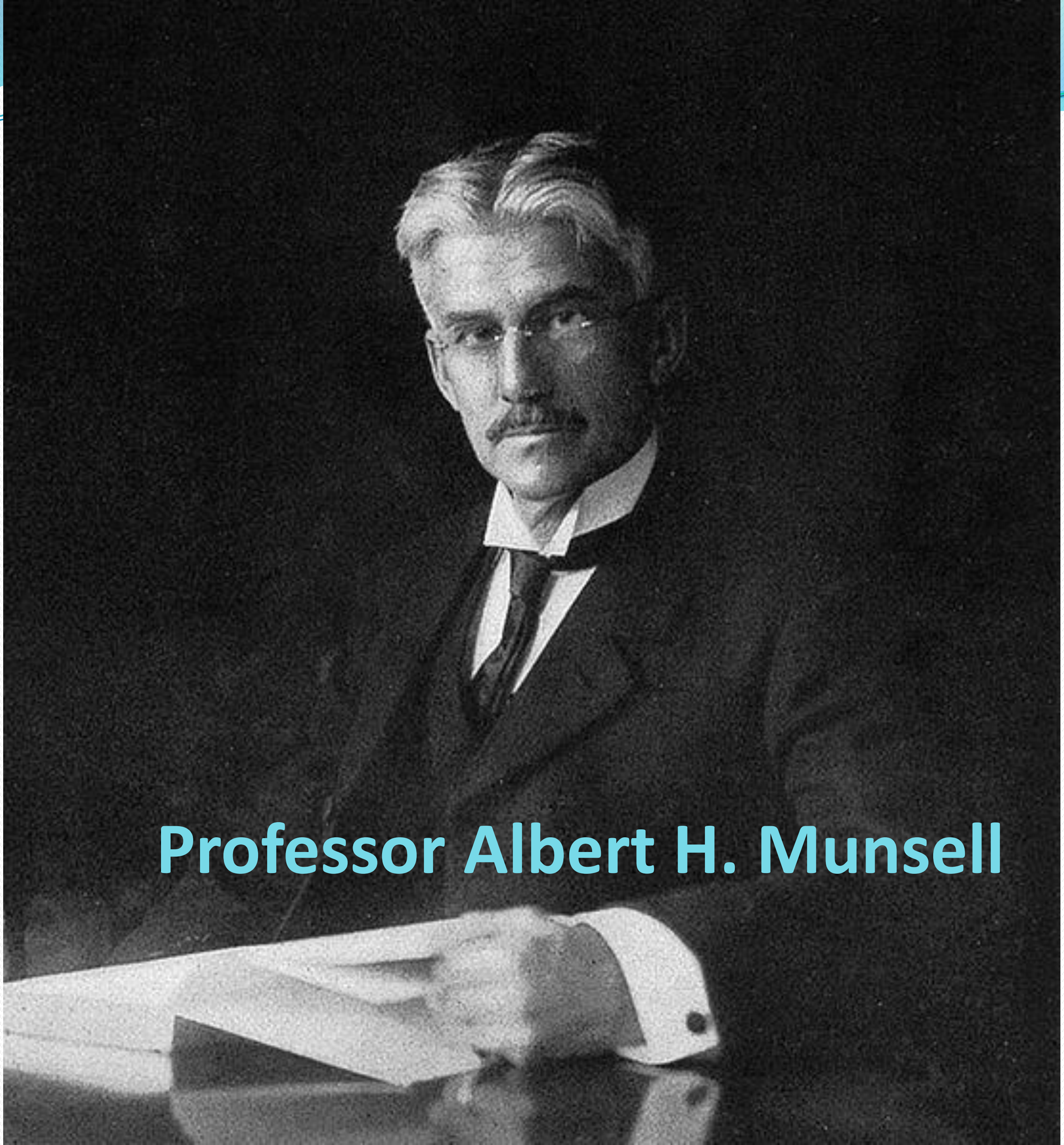
– well drained and low in iron

Whitish –gray

– low minerals.

Munsell color system

- Specifies colors based on three color dimensions: Hue, value (lightness), and chroma (color purity).
- Created by Prof. Albert H. Munsell.
- Adopted by the USDA.



Professor Albert H. Munsell


MUNSELL
BOOK OF
ATLAS
The
Munsell Color System
MUNSELL
BOOK OF
COLOR
MUNSELL
BOOK OF
COLOR

Hue

- The most obvious measurement.

  (how we define color in our every day language)
- Five principal hues:

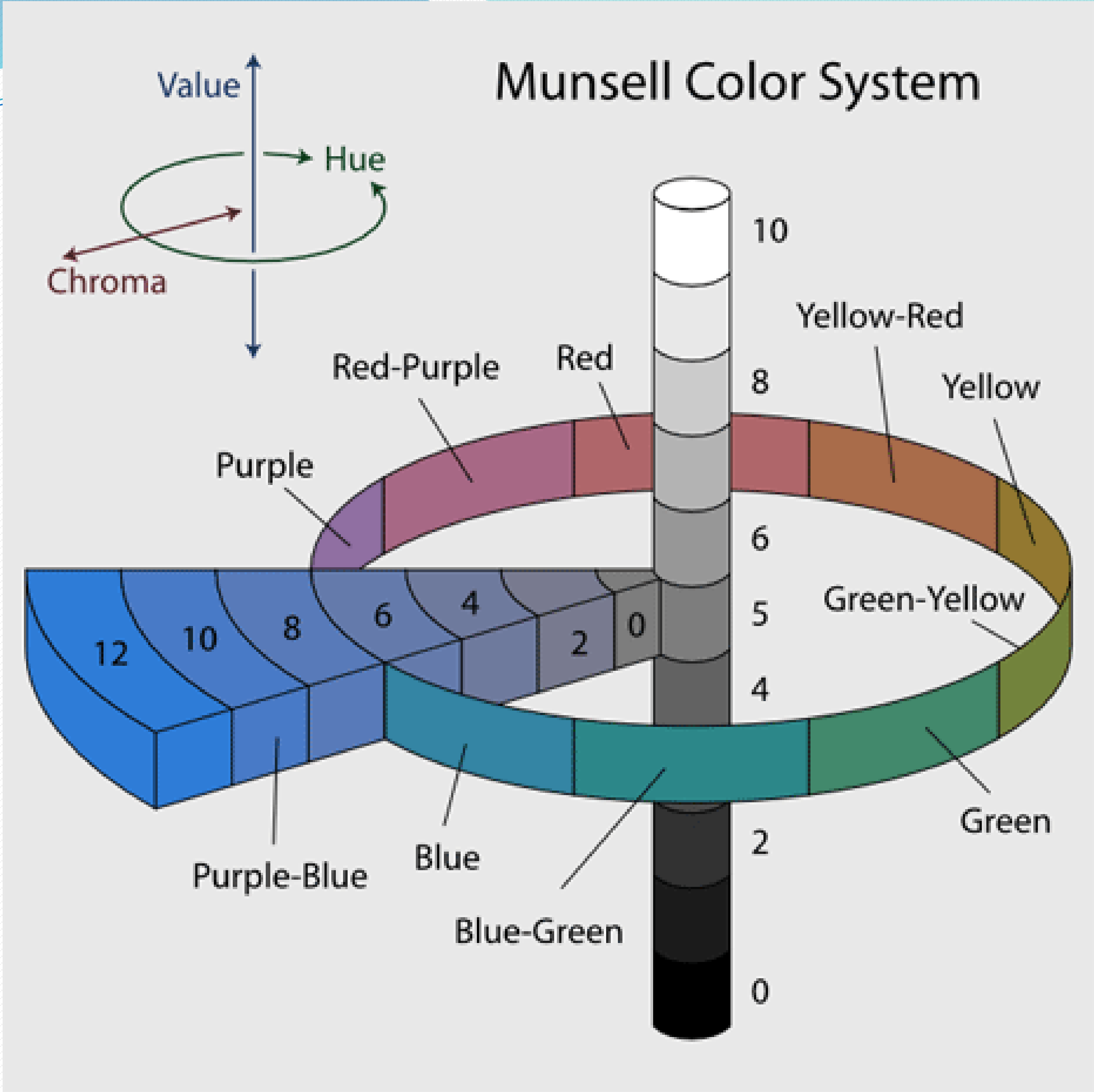
  Red, Yellow, Green, Blue, and Purple.
- Intermediate colors(Compound Hues): Yellow-Red, Green-Yellow, Blue-Green, Purple-Blue and Red-Purple.

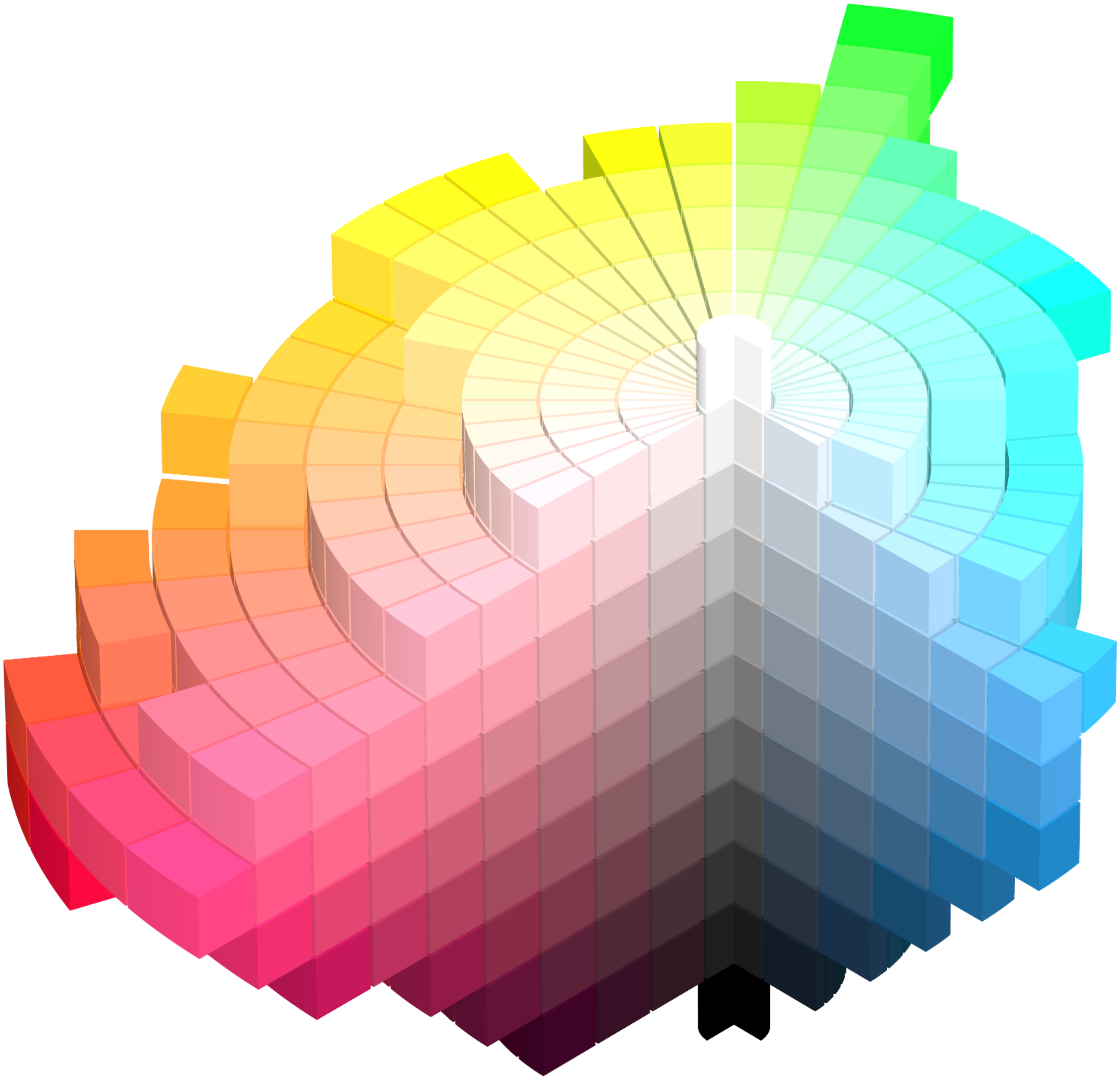
Value

- How light or dark a color is.
- Black is the lowest *Value* (*value* 0), white is the highest (*value* 10) .

Chroma

- How strong or weak a color is ("purity" of a color).
- Low Chroma means weak color (less pure, more washed out).


Munsell Color System
Value
Hue
Chroma
10
Yellow-Red
Red
Red-Purple
8
Yellow
Purple
6
Green-Yellow
5
4
2
0
12
10
8
6
4
2
0
Green
Purple-Blue
Blue
Blue-Green
0



Particle (true) density

- Mass of oven dry soil divided by soil solid volume

$$D_P = \frac{M_S}{V_S}$$

- Density of the particles.
- Well-defined quantity.
- Not dependent on the degree of compaction.
- For an average soil, D_P is about **2.65 g/cm³**.

Bulk density (D_B)

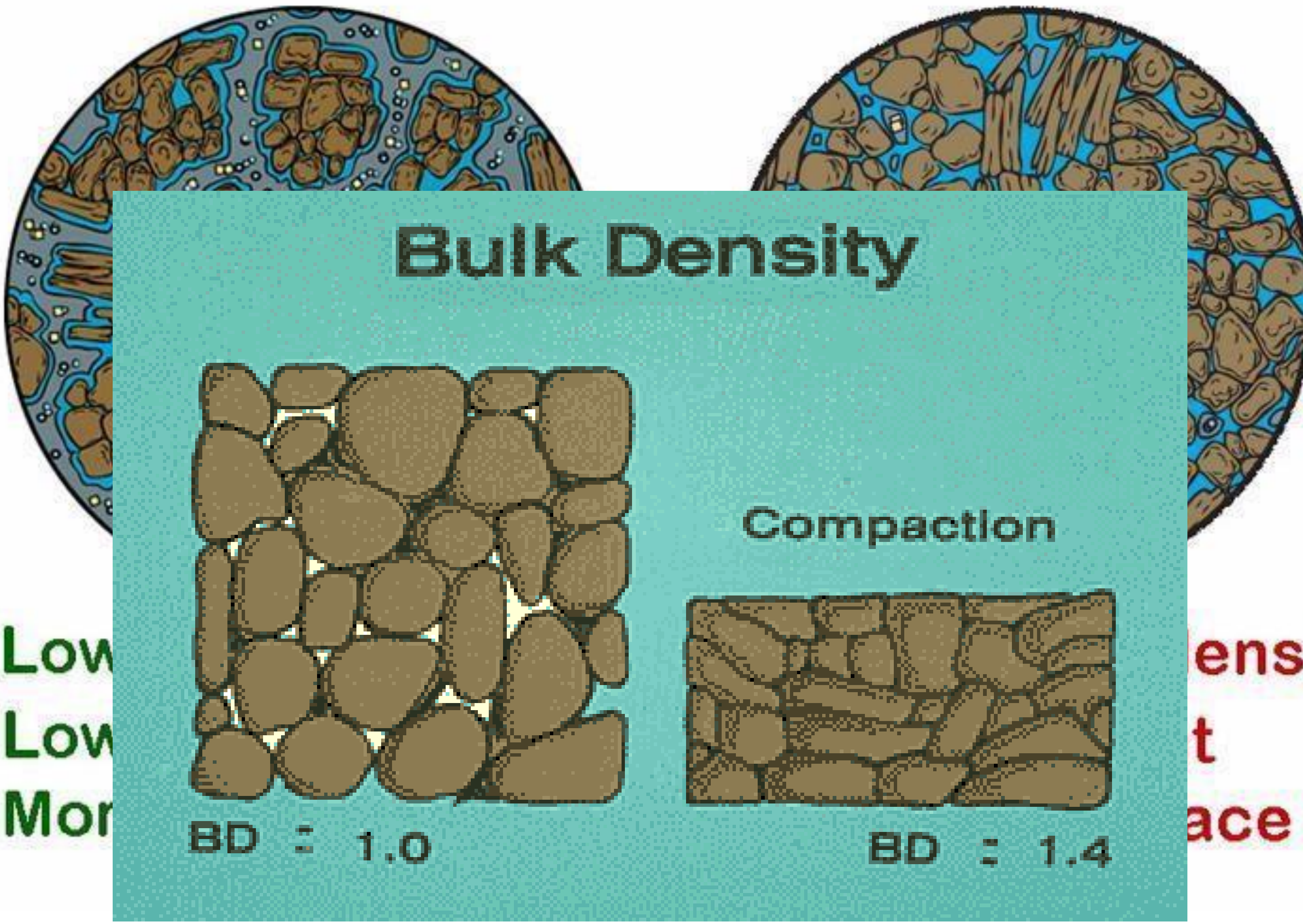
- Bulk density =Mass of solid divided by the **total volume**.

$$D_B = \frac{M_S}{V_T}$$

Total volume: particle volume, pore volume.

More pore space , lower bulk density.

- Not an intrinsic property. It will change depending on
  - how the material is handled
  - mineral make up of soil
  - degree of compaction.
- Undisturbed samples are needed.
- D_B of mineral soil is 1.0-1.6g/cm^3 (quartz ~2.65g/cm^3).



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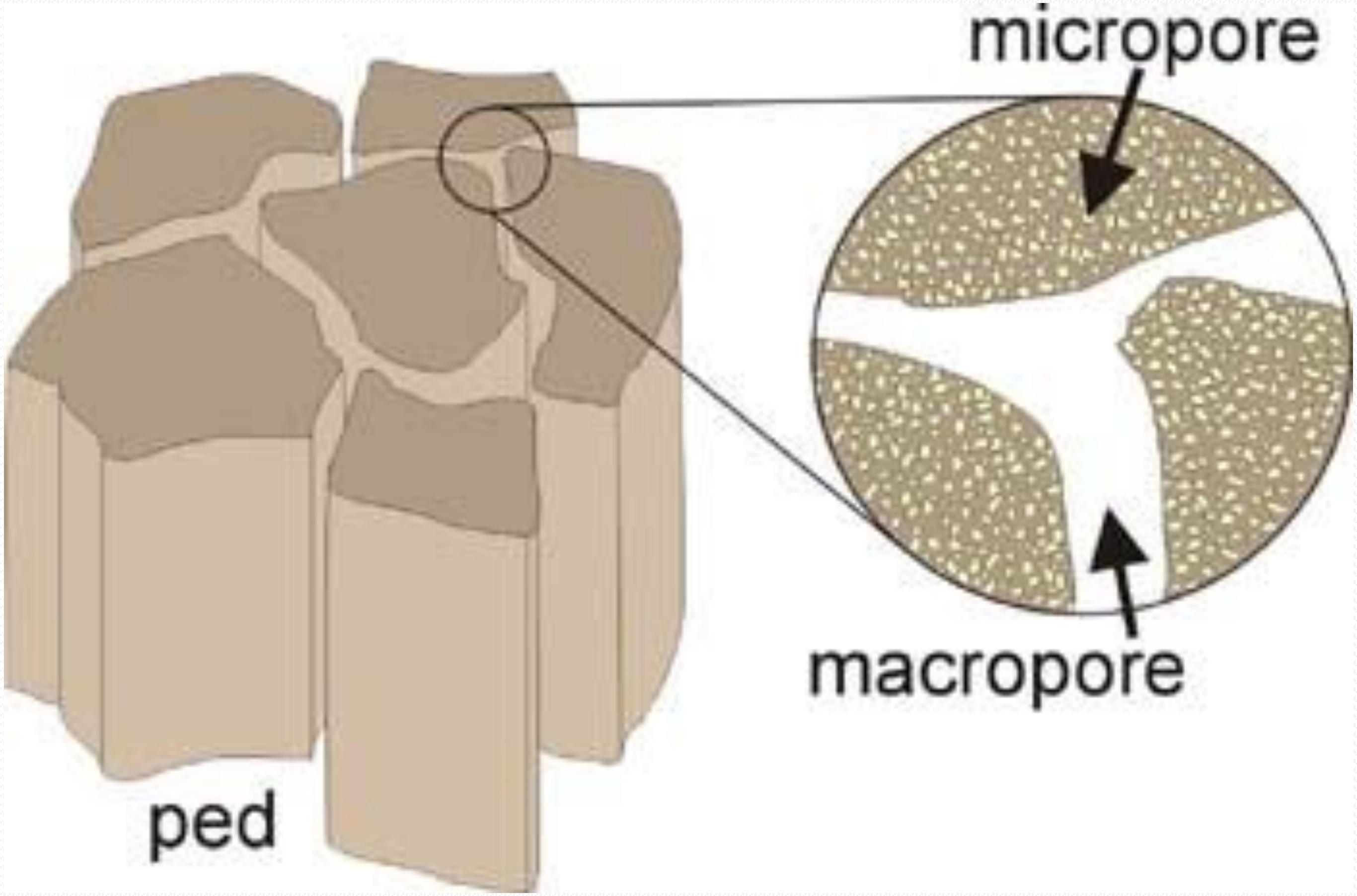
Pore Space

- The organization of the solid components in soil determines pore space.
- Determine how water and air are transmitted and retained

Types of soil pores

- **Macropores** (d>0.08mm) :
  - Allow ready movement of air and the drainage of water
  - Provide space for roots and organisms.
- **Micropores** (d<0.08mm) :
  - Usually filled with water , too small to allow much movement of air.
  - Water movement is extremely slow
  - Much of the water held is unavailable to plants.

Macro- vs. Micro-pores in the Soil



Porosity

- Measure of the void spaces in a material
- Fraction of the volume of voids over the total volume.
- Between 0–1, or as a percentage between 0–100%.

$$\phi = \frac{V_V}{V_T}$$

V_V - volume of void-space

V_T - total volume of material (void + solid)

$V_T = V_V + V_S$

V_S - volume of solid

Porosity of soil

- Porosity decreases as particle size increases.
- Typical bulk density of sandy soil - 1.5 and 1.7 g/cm^3.
  porosity between 0.43 and 0.36.
- Typical bulk density of clay soil - 1.1 and 1.3 g/cm^3.
  porosity between 0.58 and 0.51.

Calculation of soil porosity

$\phi = V_V / V_T$

$\phi = (V_T - V_S)/ V_T$

$\phi = 1 - (V_S / V_T)$

$D_B = M_S/V_T$, $V_T = M_S/D_B$

$D_P = M_S/V_S$, $V_S = M_S/D_P$

Calculation of soil porosity

$$\phi = V_V / V_T$$

$$\phi = (V_T - V_S)/ V_T$$

$$\phi = 1 - (V_S / V_T)$$

$$D_B = M_S/V_T \quad , \qquad V_T = M_S/D_B$$

$$D_P = M_S/V_S \quad , \qquad V_S = M_S/D_P$$

$$\phi = 1 - \left[\frac{M_S/D_P}{M_S/D_B} \right]$$

$$\phi = 1 - (D_B/ D_P)$$

$$\% \phi = [1 - (D_B/ D_P)] \times 100\%$$


Compare
2 minutes
2 hours
200 days
200 years
1 meter
Gravel
Sand
Silt
Clay

Soil Separates

- Soil particles, or soil separates, are divided into three general classes based on their diameter.
- The names of the particle size classes are:

sand, silt, and clay.

Barrel

Plate

Coin

	Sand	Silt	Clay
Feel	gritty	floury	sticky
USDA	2.00 - 0.05 mm	0.05 - 0.002 mm	< 0.002 mm
ISSS	2.00 - 0.02 mm,	0.02 - 0.002 mm	< 0.002 mm

Identification

Sand : - Can be detected by sight.

- No stickiness or plasticity when wet.

Silt: - Cannot be detected by sight

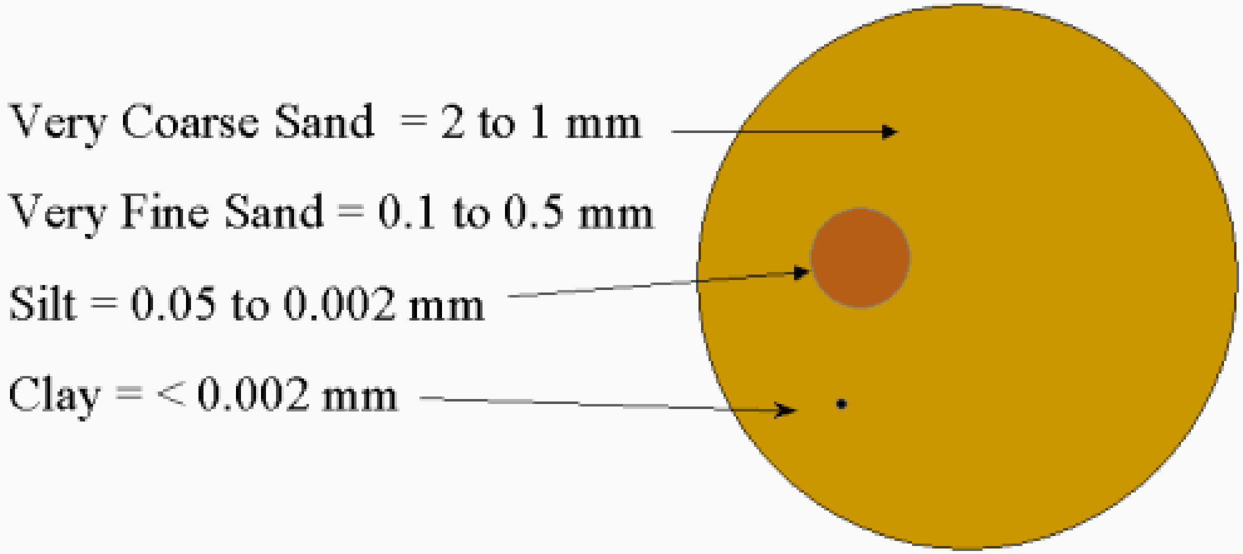
- Feel smooth and soapy, very slightly sticky.

Clay: - Obvious stickiness.

- High clay soil can be rolled easily, sticky and plastic when wet (or hard and cloddy when dry)

Soil Texture

Texture describes the proportionate distribution of the different sizes of mineral particles (amount of sand, silt, and clay) in a soil.



Mineralogical Characteristics

Sand and silt

- mainly primary minerals.
- mostly grains of quartz
- highly resistant to weathering.

Clays

- mainly composed of secondary minerals.

Physical Characteristics

Specific Surface Area (SSA)

The total surface area of per unit mass or per unit volume of soil

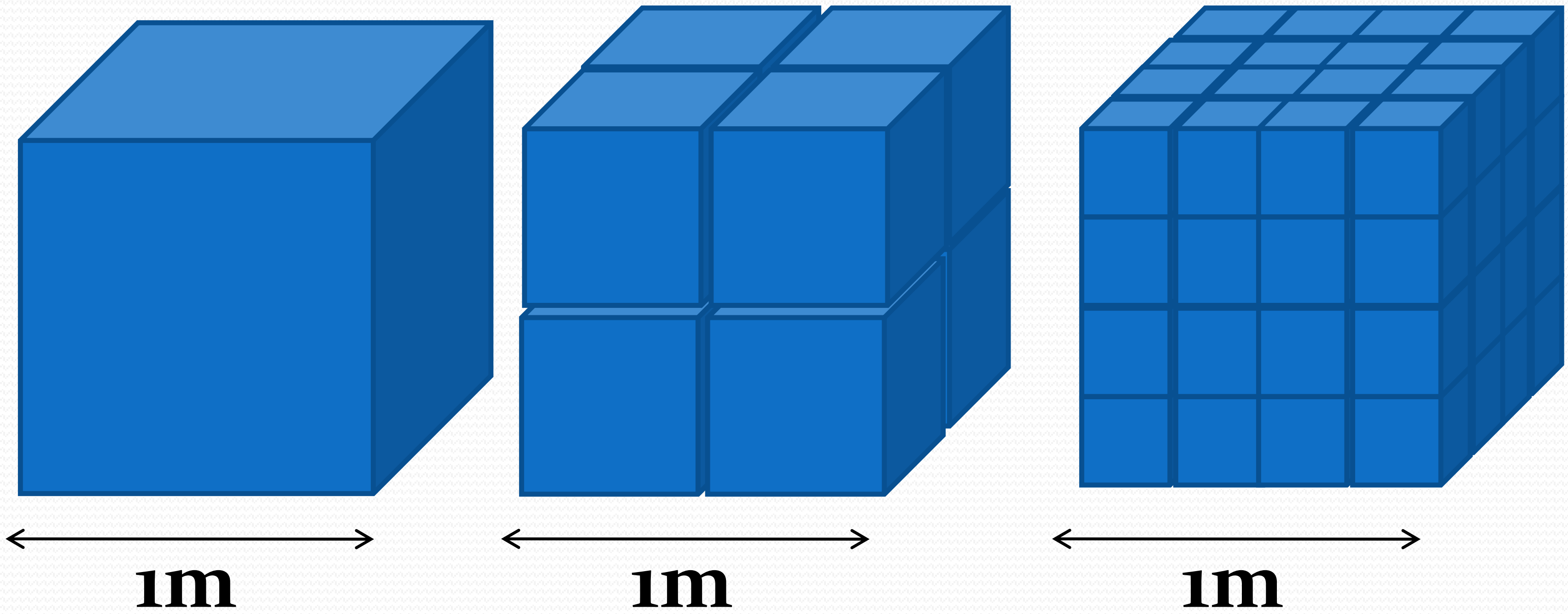
(mass base: m^2/kg or m^2/g) (volume base: m^2/m^3)

SSA is important because many important reactions in soil such as;

- Water retention
- Weathering
- Nutrient exchange

occur at the particle surfaces.

Specific surface area with particle sizes

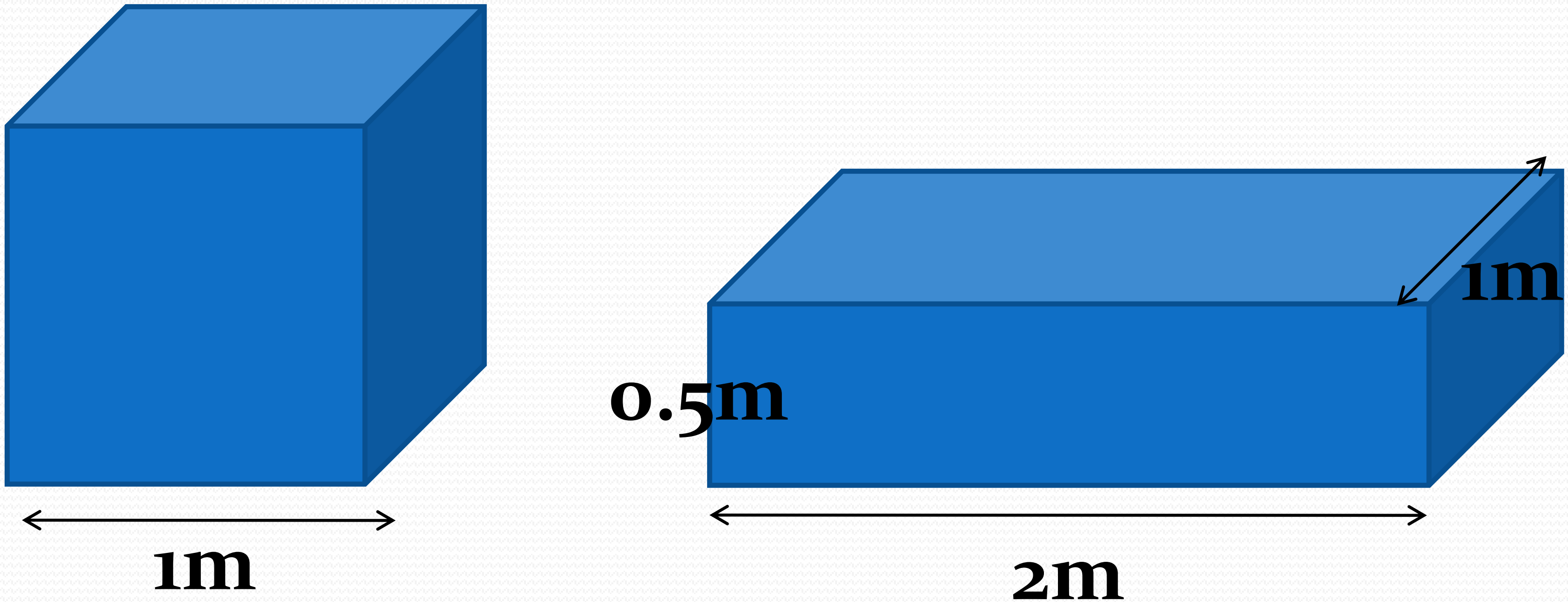


Area	Area	Area
$= 1 \times 1\ m^2 \times 6$	$= 0.5 \times 0.5 m^2 \times 6 \times 8$	$= 0.25 \times 0.25 m^2 \times 6 \times 64$
$= 6\ m^2$	$= 12\ m^2$	$= 24\ m^2$

Total surface area increases as you cut the cube into smaller pieces, but the total volume stays constant

Specific surface Area with particle shapes

same volume ($1m^3$)



Area

$= 1 \times 1\ m^2 \times 6$

$= 6\ m^2$

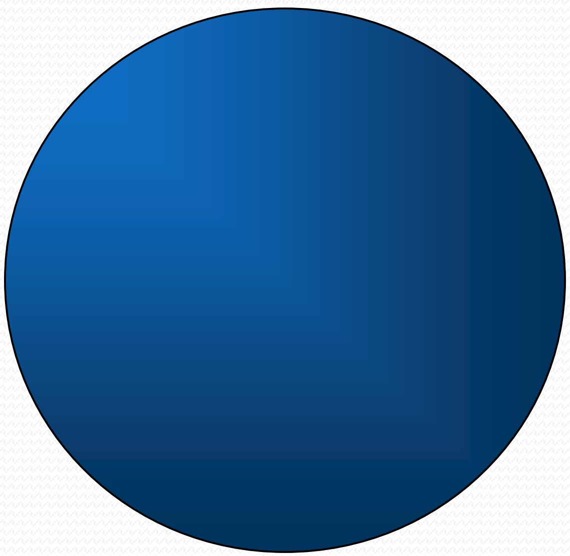
Area

$= [(1\times 2)2] + [(0.5\times 2)2] + [(0.5\times 1)2]m^2$

$= 7\ m^2$

Surface area of the sphere

Volume = 1m³



$4/3\ \pi\ r^3 = 1$

$r^3 = 3\ /4\pi$

$r^3 = 0.2386$

$r = 0.62$

$\text{Area} = 4\pi r^2$

$= 4.836\ m^2$

Particle shapes

- Sand & silt : rounded or blocky, depending on how weathered they are (Figure).
- Clay: flat, with multiple plate-like clay particles layered together (Figure).

How to measure soil particle size ???

- Mechanical sieving, if size > 0.05 mm
- Sedimentation - Stokes' law, if size < 0.05 mm
- Hydrometer method

How texture is determined?

Field method:

- Quick & cheep.
- *insitu* possible.
- High human error.
- Experience is a must.

How texture is determined?

Pipette method:

- uses Stokes' law
- High accuracy
- Expensive, time consuming

Hydrometer method

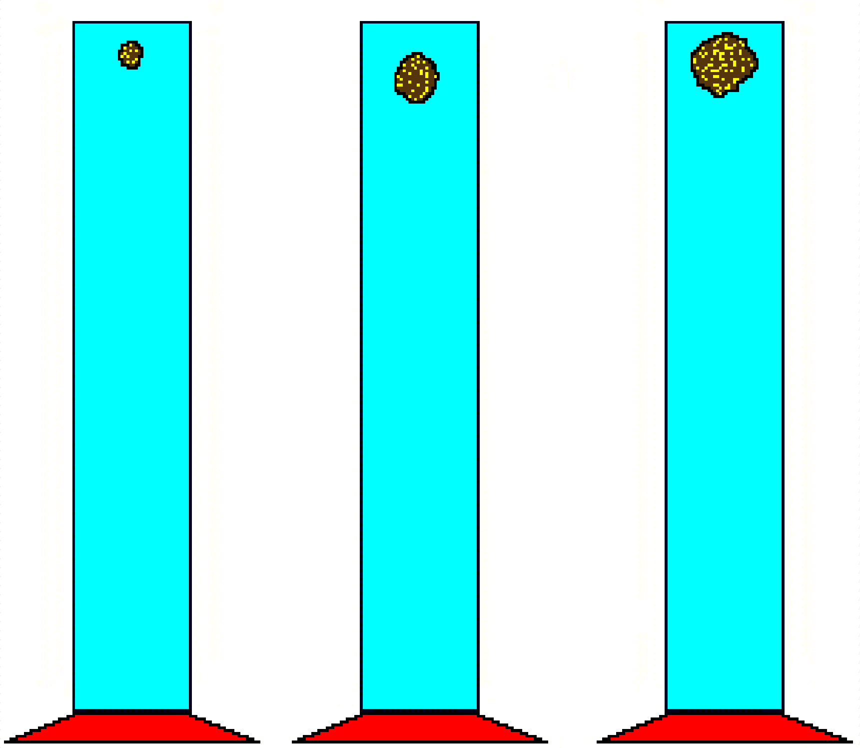
- Cheep and fast
- Not as accurate

Stokes' Law

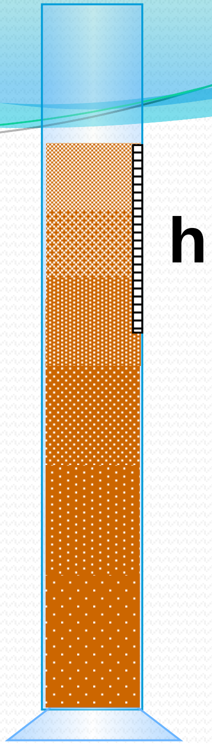
"When soil particles are suspended in water they tend to sink. Because the density of most soil particles is similar, their settling velocity (V) is proportional to the square of the diameter (d) particles".

$$V = kd^2$$

Settling of different-size particles



Stokes' Law



$$V = d^2 g\,(\rho_s - \rho_1)\,/18\eta$$

$$V = h/t$$

Where:

t = time (s)

h =height (m)

d = diameter of particles (m)

ρ_s = density of the solid particles, ~2.65 ×10^3 (kg/m^3)

ρ_1 = density of the liquid, 1 ×10^3 (kg/m^3)

g = acceleration due to gravity, 9.81 N kg^{-1}

η = viscosity of the liquid 1.0x10^{-3} (Ns m^{-2}) (at 20°C)

0.8x10^{-3} (Ns m^{-2}) (at 30°C)

Calculation of settling time for silt (<0.02 mm) at 30°C

$$V = \frac{(9.81\ \mathrm{N\ kg^{-1}})\ (2.65 \times 10^{3}\mathrm{kg\ m^{-3}} - 1.00 \times 10^{3}\mathrm{kg\ m^{-3}}) \times d^{2}}{18\ (0.8 \times 10^{-3}\ \mathrm{Ns\ m^{-2}})}$$

$V = 11.24 \times 10^{5}\ \mathrm{s^{-1}m^{-1}} \times d^{2}$ or $\mathbf{V = k\ d^{2}}$

$V = h/t$

$t = h/\ kd^{2}$

$$t = \frac{0.1\ \mathrm{m}}{11.24 \times 10^{5}\ \mathrm{s^{-1}m^{-1}} \times (\mathbf{0.02} \times 10^{-3}\ \mathrm{m})^{2}}$$

$t = 222.4\ \mathrm{s}$

$t =$ **3 min 42 sec**

Calculation of settling time for clay (<0.002 mm) at 30°C

$$V = \frac{(9.81\ N\ kg^{-1})\ (2.65 \times 10^{3} kg\ m^{-3} - 1.00 \times 10^{3} kg\ m^{-3}) \times d^{2}}{18\ (0.8 \times 10^{-3}\ Ns\ m^{-2})}$$

$V = 11.24 \times 10^{5}\ s^{-1} m^{-1} \times d^{2}$ or $V = kd^{2}$

$V = h/t$

$t = h/\ kd^{2}$

$$t = \frac{0.1\ m}{11.24 \times 10^{5}\ s^{-1} m^{-1} \times (\mathbf{0.002} \times 10^{-3}\ m)^{2}}$$

$t = 22240.76\ s$

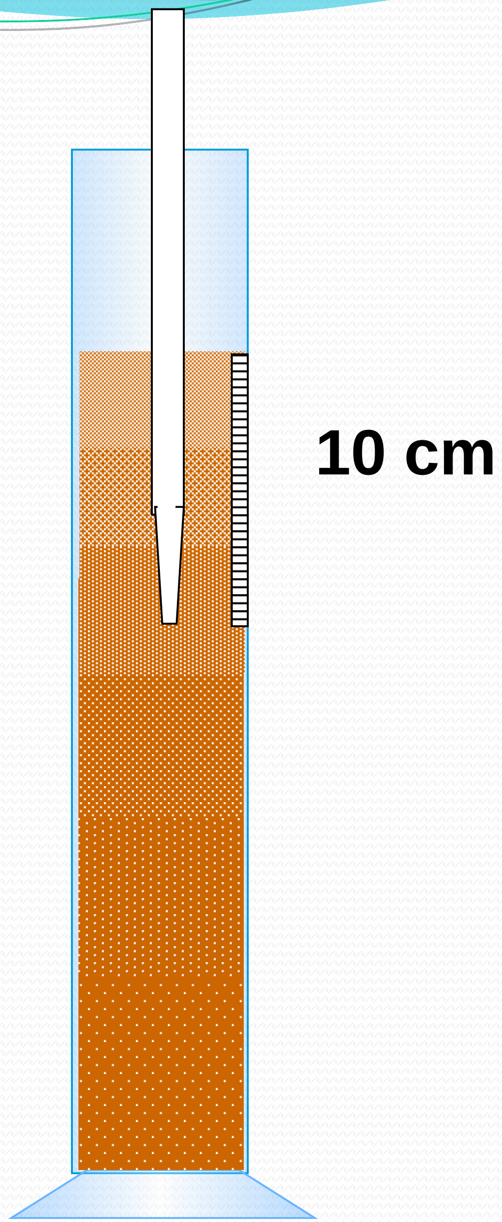
$t =$ **6 h 10 min 41 sec**

Prepare soil solution

- 1L measuring cylinder

Procedure

- For silt – after **3 min 42 sec**
  - Particle diameter < **0.02 mm**
- For clay – **6 h 10 min 41 sec**
  - Particle diameter < **0.002 mm**



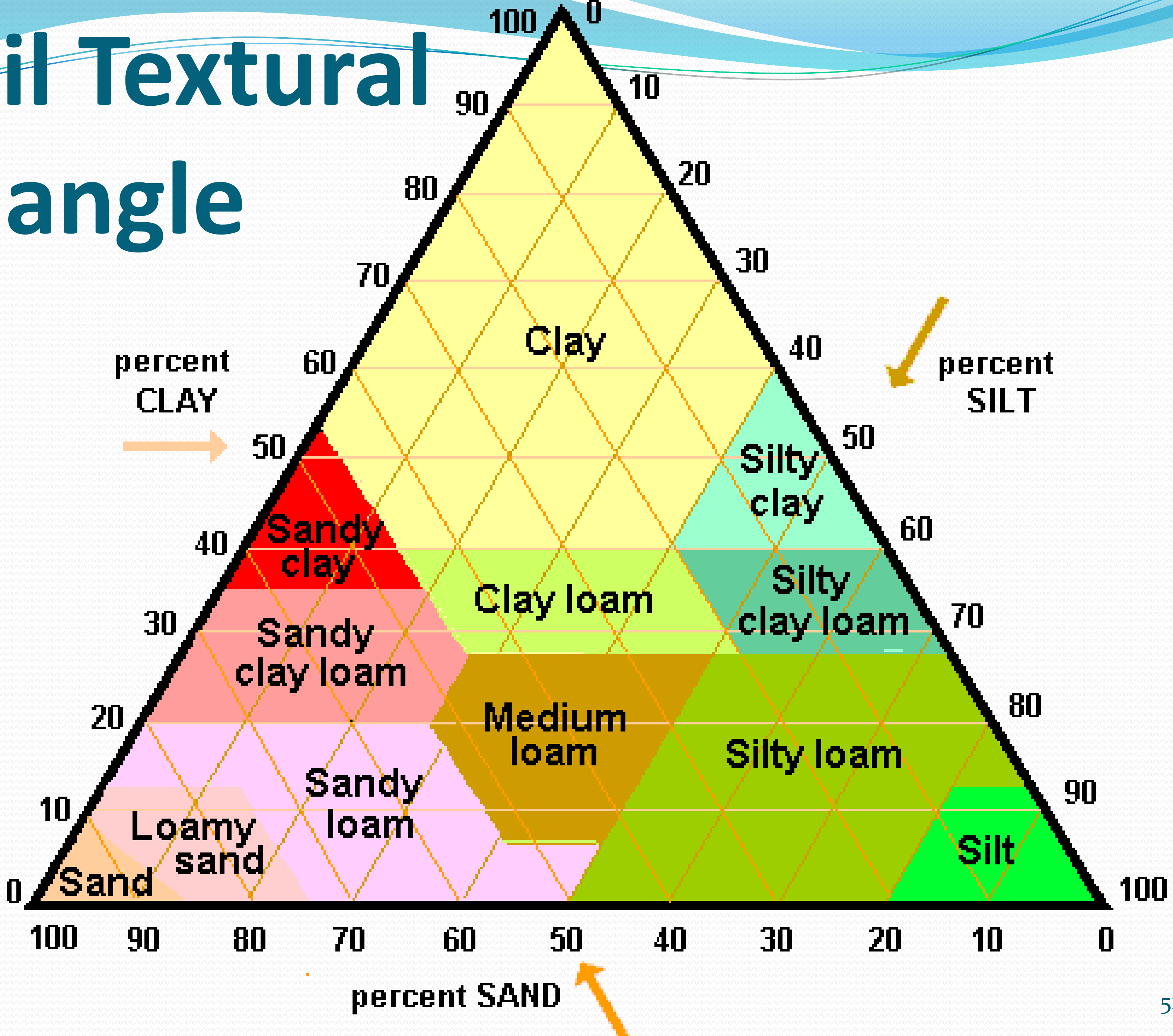
Assumptions and Limitations of Stokes' Law

Assumption	Limitation
Particles are rigid, spherical and smooth	particles are irregularly shaped
Falling - not affected by proximity of vessel/adjacent particles	fast falling particles drag finer particles with them
Density (particles and water), and viscosity (water) constant	Usually not so. Change with temperature
Suspension must be still. Movements will alter falling velocity	particles > 0.08 mm settle fast creating turbulence
Particles are large in comparison with the molecules of the liquid to avoid Brownian movement	particles < 0.0002 mm exhibit this movement
Temperature should be kept constant	Usually not so

The Textural Triangle

- Classify texture is based on the relative proportions of silt, sand and clay.
- For example, 30% sand, 30% clay and 40% silt:

Soil Textural Triangle



The Textural Triangle

- Classify texture is based on the relative proportions of silt, sand and clay.
- For example, 30% sand, 30% clay and 40% silt:

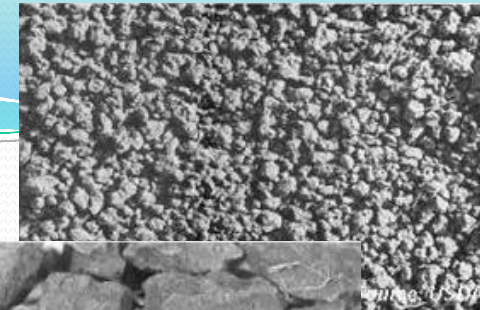
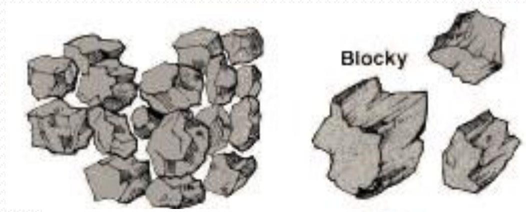
clay loam.

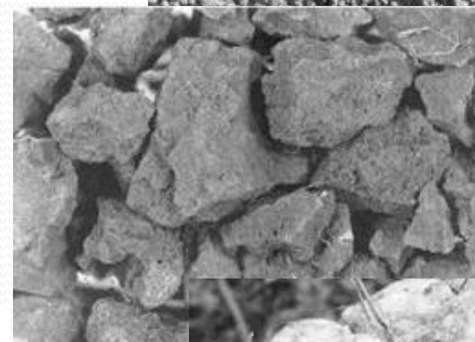
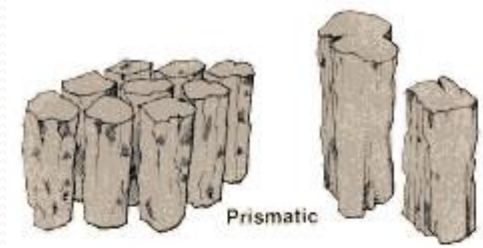
Soil structure

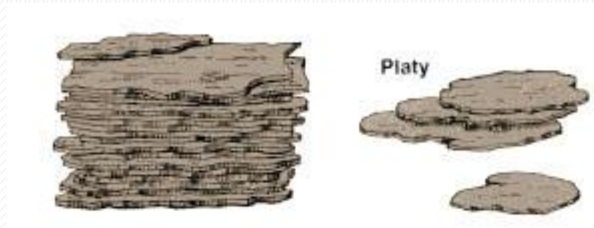
- Arrangement of soil particles into groupings (peds / aggregates

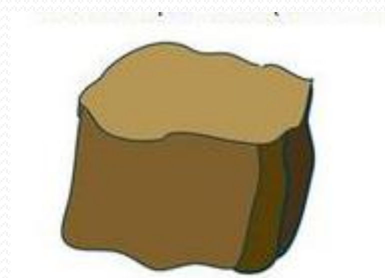
Soil Structure – types (shapes)

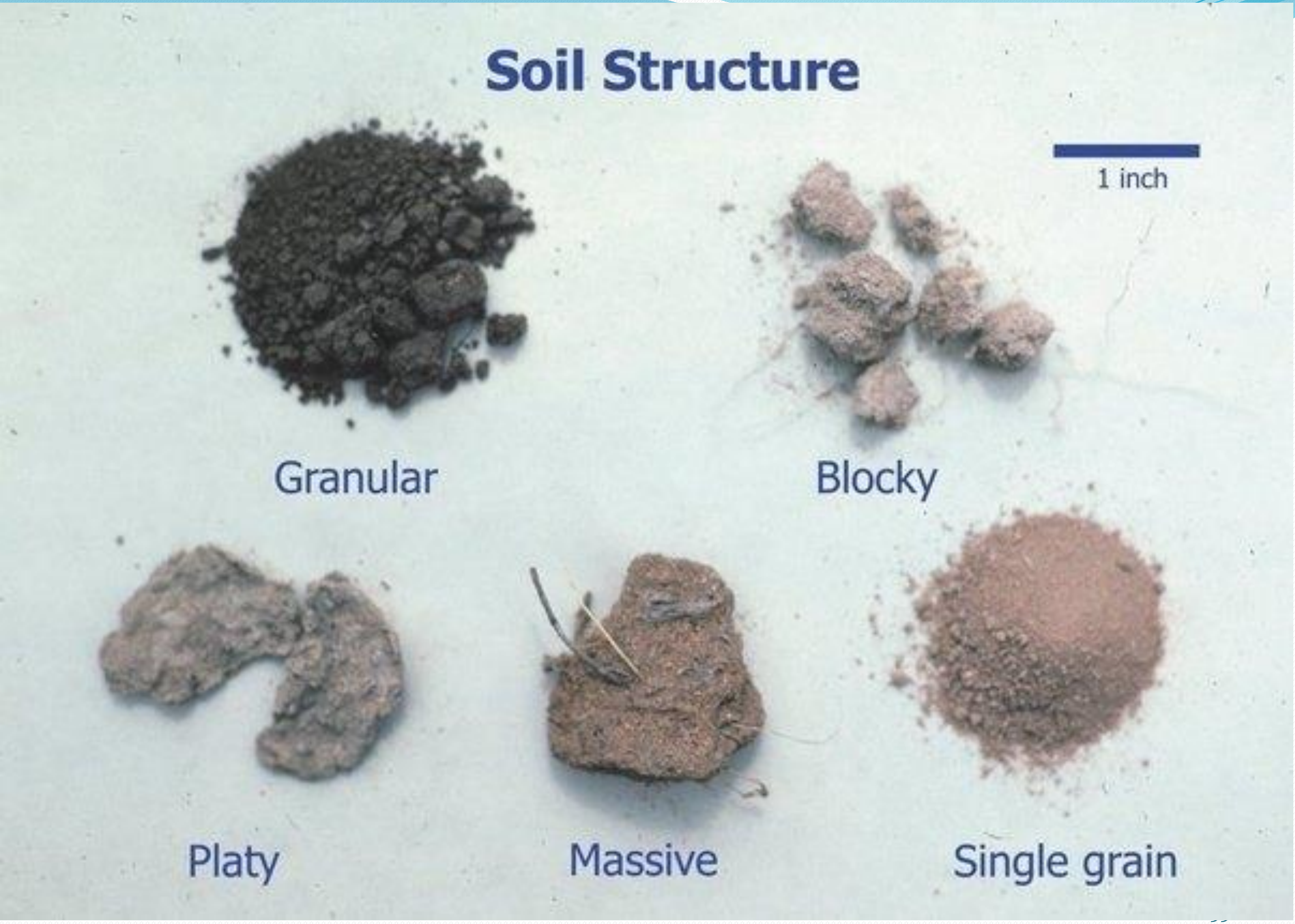
- Granular
- Blocky
- Prismatic
- Columnar
- Platy
- Massive
- Single grain

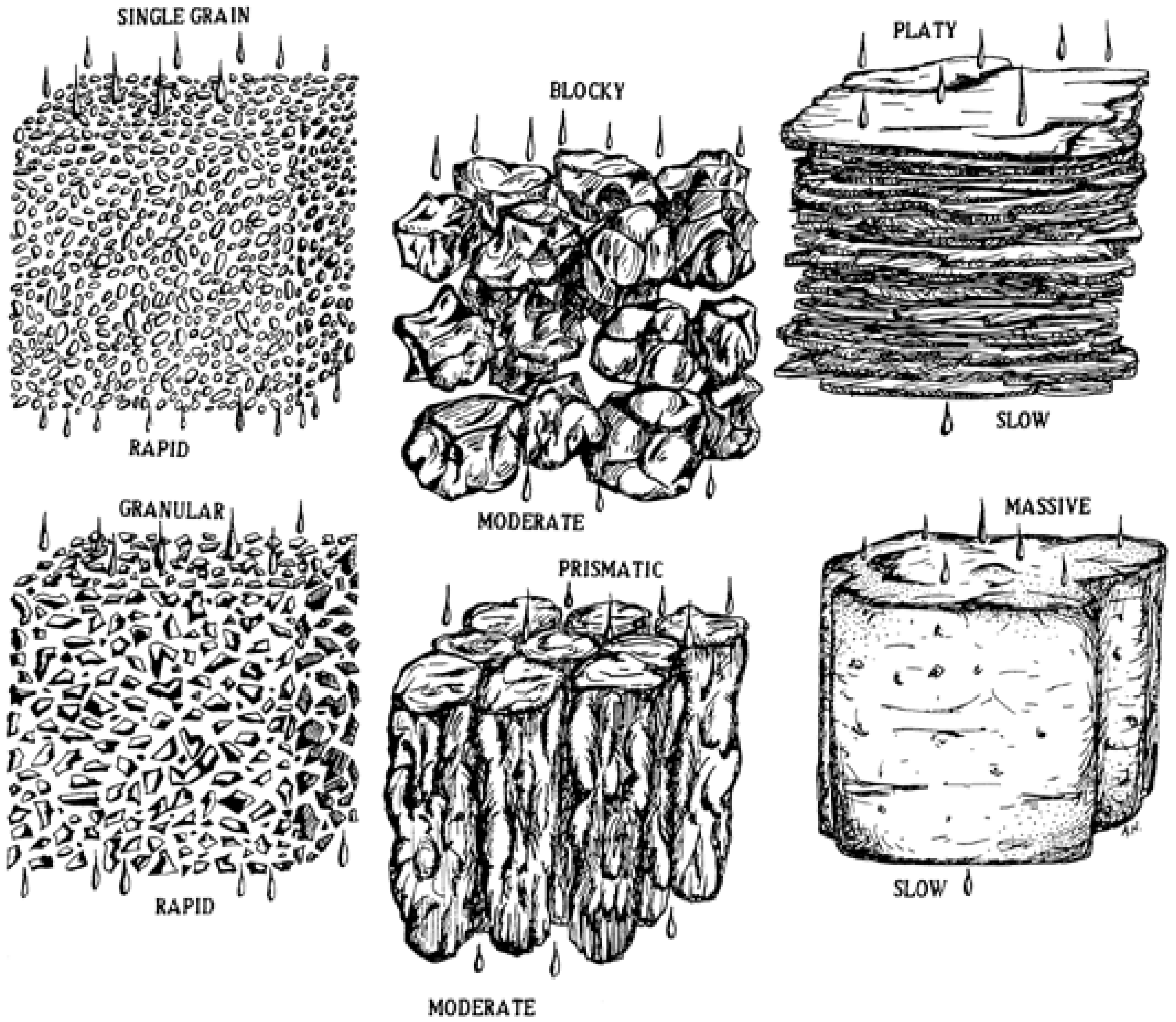





Soil Structure
1 inch
Granular
Blocky
Platy
Massive
Single grain

Water movement



SOIL WATER CONTENT

- Soil water content on a mass basis (θg) *(***Mass/ gravimetric water content***)*
  - the ratio of mass of water *(M*w*)* to total soil mass *(M*t*):*
  - $\theta g = M\text{w} / Mt$
- Soil water content on a volume basis (θv) (**volumetric water content**)
  - *the* ratio of water volume (*V*w*) to total soil volume (V*t*)*

MEASUREMENT OF SOIL WATER CONTENT

- Soil feel and appearance
- Gravimetric method
- Electrical resistance block method
- Neutron probe method
- Time domain reflectometry (TDR)

Gravimetric method

- The most widely used

Method

- Get a soil sample from the field
- Determine the mass of soil water relative to the mass of dry soil.

$$\theta = \left[\frac{\text{Wet sample wgt} - \text{Dry sample wgt}}{\text{Dry sample wgt}} \right] \times 100$$

- Measured Parameter:

  Mass water content
- Response Time: Approximately 24 hours

Advantages and disadvantages

Disadvantages:

- Destructive
- time consuming
- inapplicable to automatic control

Advantages:

- Accurate measurements
- not dependent on salinity and soil type
- easy to calculate

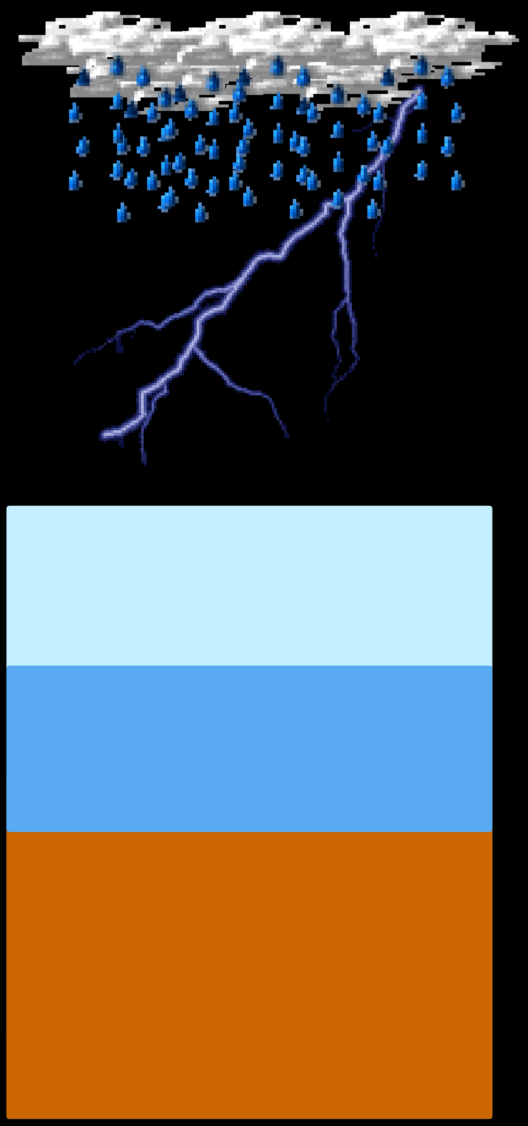

45%
Mineral
25%
Air
25%
Water
5%
Organic matter
eschooltoday.com

Soil Air

- Soil contains air

Aeration status of soil

- Refers to the extent of air gaps in soil.
- Plants need water and air to produce a good crop.
- Lack of water / too much water – decrease yield."
- Soil air is necessary for plant roots to utilize nutrients.
- Higher in CO_2 and water vapor, but less O_2 compared with atmospheric levels.



Red, yellow and gray hues of subsoils reflect the oxidation and hydration states or iron oxides

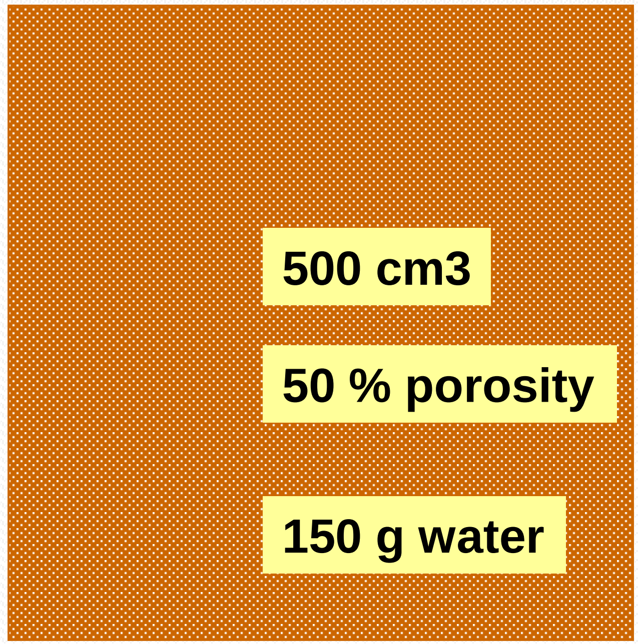
- Red and yellow hues:

  good drainage and aeration
- Mottled zones, splotches of one or more colors :

  transition between well drained, aerated zones and poorly drained, poorly aerated ones.
- Gray hues :

  poor aeration.

Air filled and water filled porosity



Air filled and water filled porosity

- Volume of soil = 200 cm^3
- Mass of water = 50 g
- Porosity of soil = 60%

water filled porosity

- Total volume of pores = (60/100) × 200 cm^3 = 120 cm^3
  Volume of water = 50 cm^3

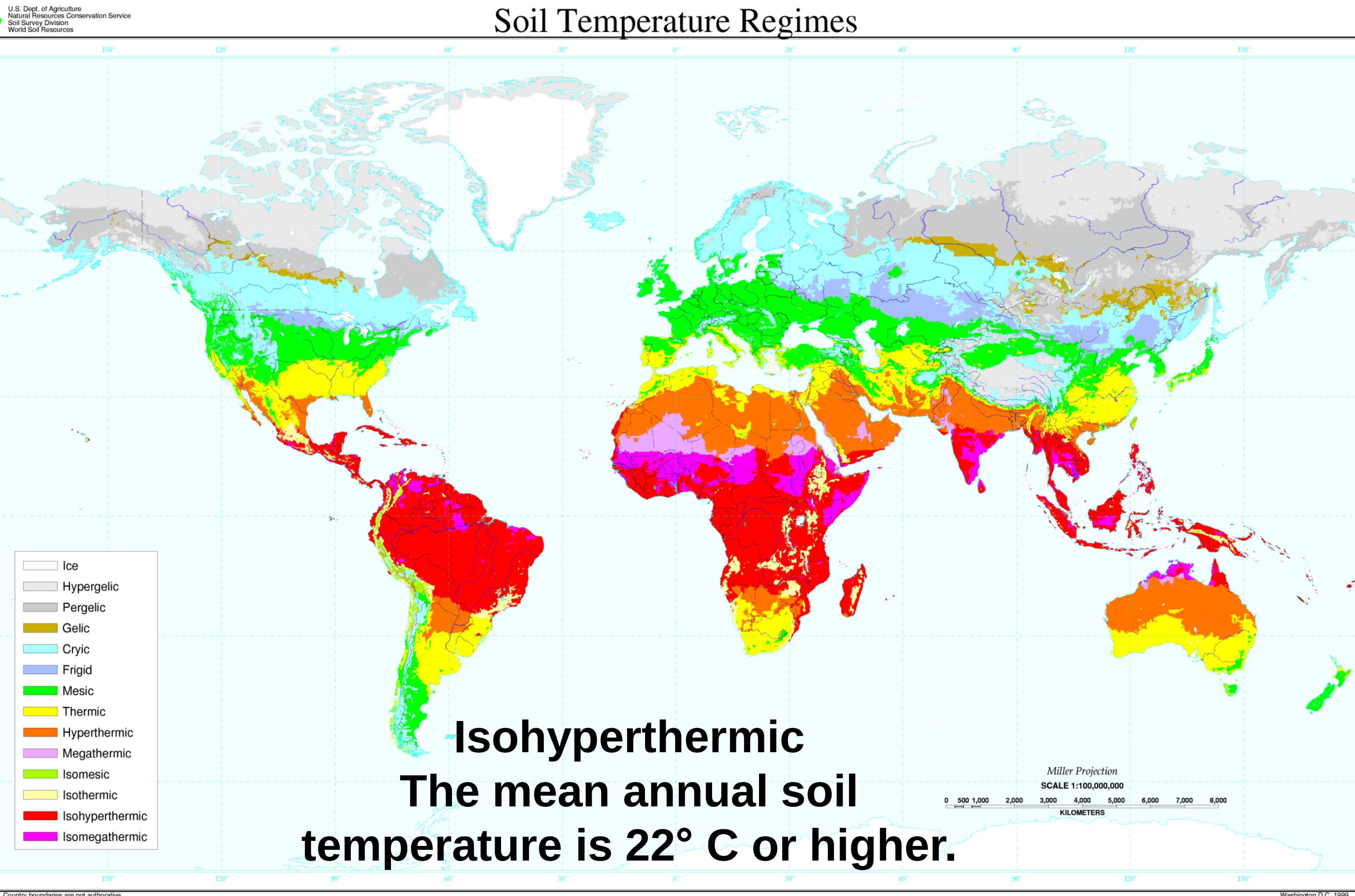
  water filled porosity = (50/120) × 100 % = 41.67%

Air filled porosity = 100 - water filled porosity

= 100 - 41.67 = 58.33%

Soil Temperature

- Soil temperature is important for many soil processes such as chemical reactions and biological interactions.

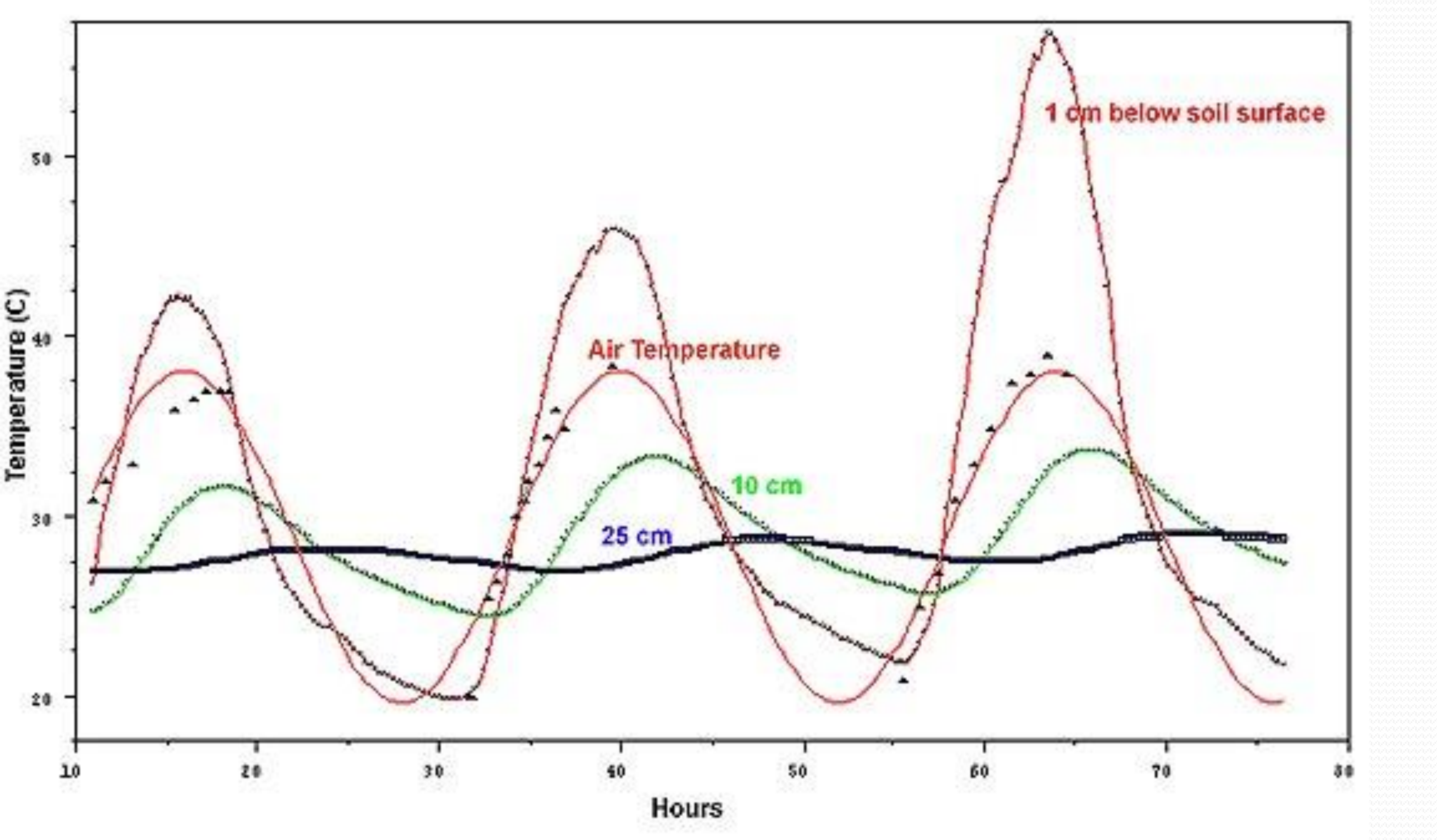


Isohyperthermic

The mean annual soil temperature is 22° C or higher.

Measuring soil temperature

Day time soil temperature variation at different soil depths (1, 10, 25 cm below).



Sand

back

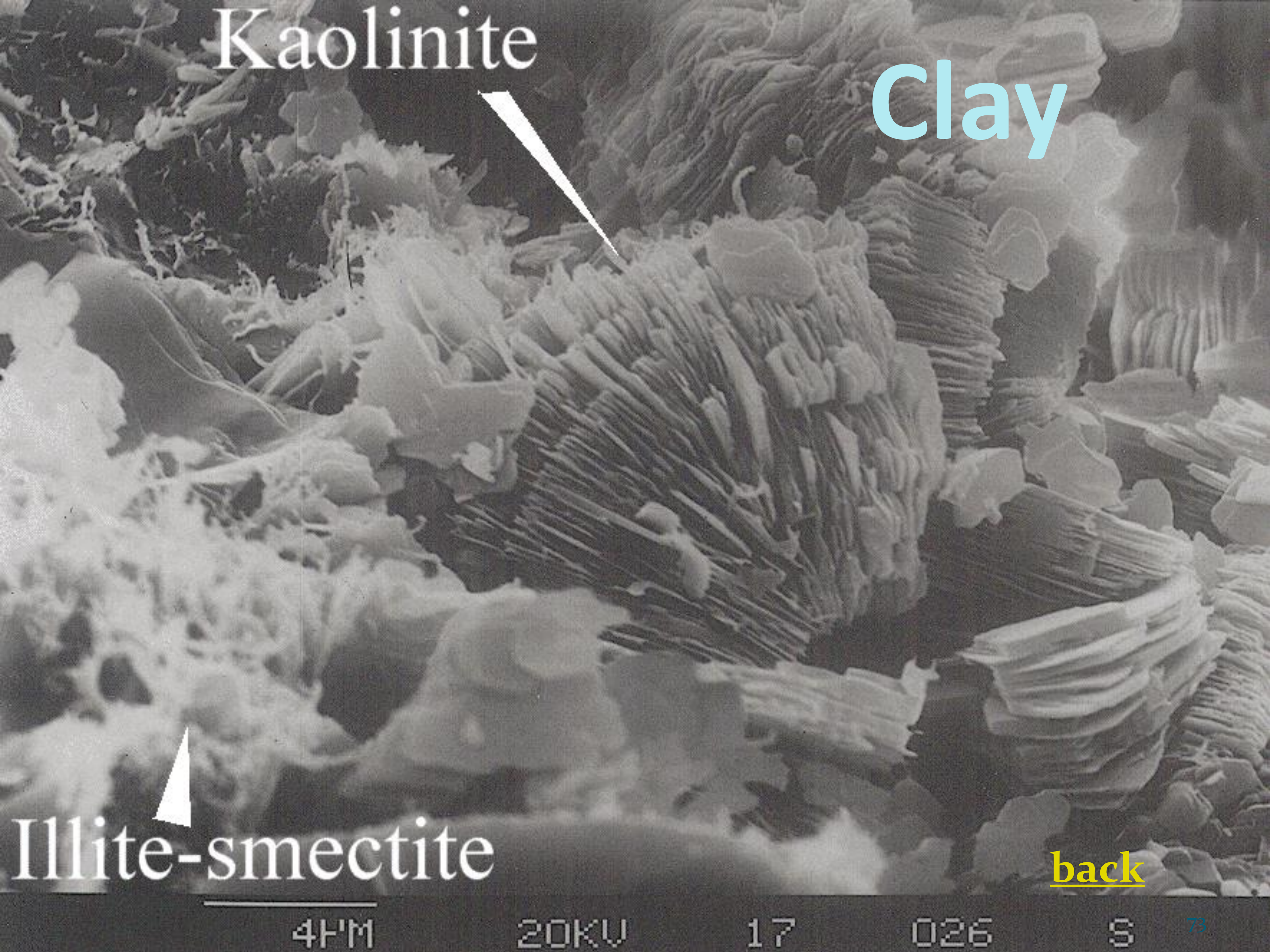

Kaolinite
Clay
Illite-smectite
back
4FM 20KV 17 026 S

Photo of kaolinite crystals

back