Física do Solo
CCR/UFSM

Introdução: FS x planta
Relação massa/volume
Granulometria
Área superficial específica

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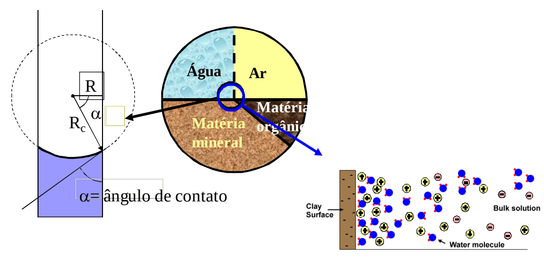
CONCEITO FÍSICO de SOLO

Meio poroso, não rígido, trifásico, formado de partículas que possuem complexidade de forma, tamanho e estrutura mineralógica e com algumas partículas finitamente divididas de maneira a apresentar uma grande área superficial.

Propriedades Físicas do Solo

- Solo é um sistema trifásico



SOLO FISICAMENTE IDEAL

É aquele que apresenta:

- Boa aeração e retenção de água;
- Bom armazenamento de calor;
- Pouca resistência mecânica ao crescimento radicular.

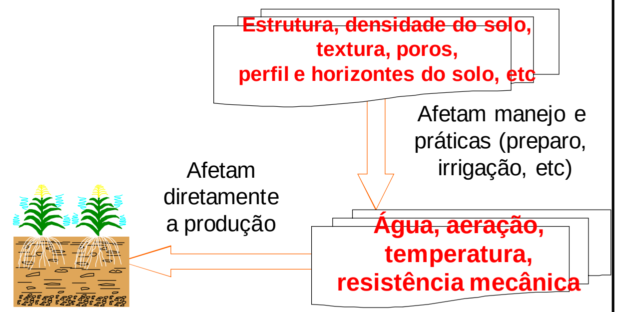
Por que medir propriedades físicas?

- Limites físicos às plantas
- Comportamento de ecossistemas
- Questões ambientais
- Zoneamentos
- ...

Propriedades do solo normalmente medidas

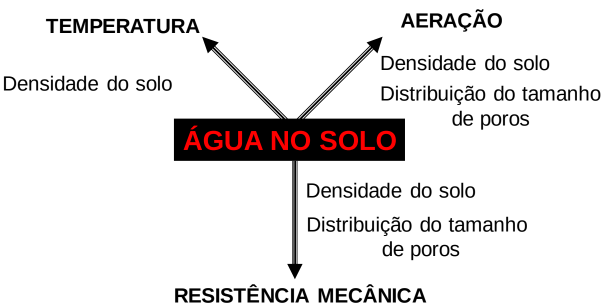
- **Densidade do solo**
- **Porosidade**
- **Umidade do solo**
- **Granulometria**
- **Estrutura (agregação + ...)**
- **...**

Propriedades do solo, fatores de crescimento & produção de plantas

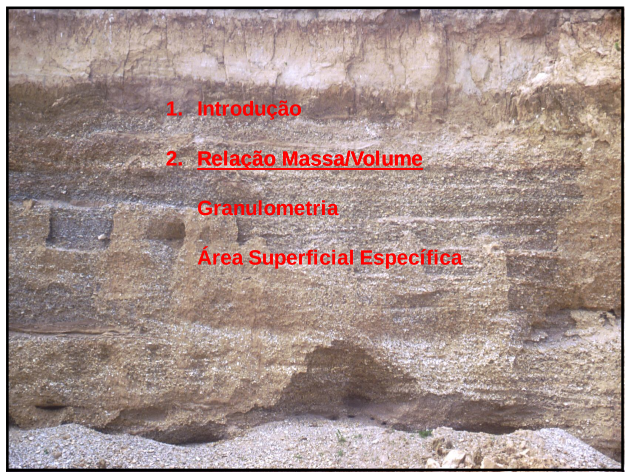


(Letey, 1985)

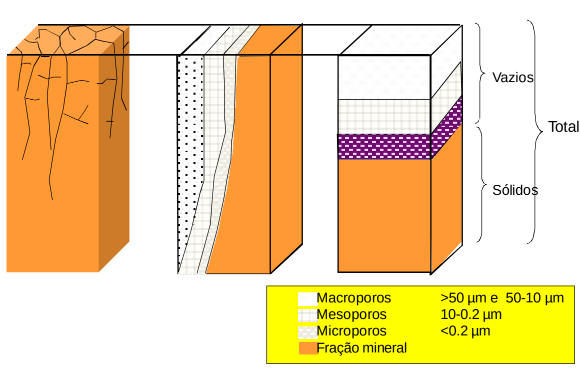
Interrelação fatores físicos



(Letey, 1985)

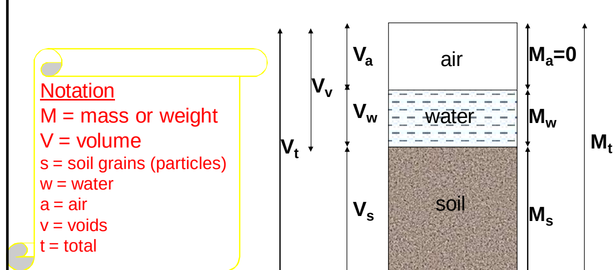


Representação da Relação Massa/Volume



Objectives

To compute the masses (or weights) and volumes of the three different phases.



Phase Diagram

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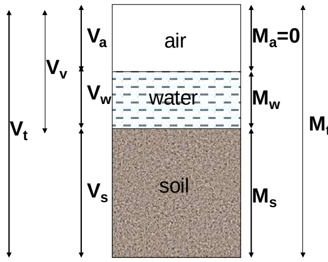
Definitions

Bulk (Dry)density (ρ_b) is the density of the soil in dry state.

$$Ds = \rho_b = \frac{M_S}{V_T}$$

Units: Mg/m^3, g/cm^3, kg/m^3



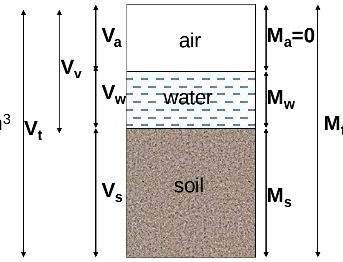
Phase Diagram

Definitions

Bulk density (ρ_m) is the density of the soil in the current state.

$$\rho_m = \frac{M_T}{V_T}$$

Units: Mg/m^3, g/cm^3, kg/m^3



Phase Diagram

Definitions

Saturated density (ρ_{sat}) is the density of the soil when the voids are filled with water.

Submerged density (ρ') is the effective density of the soil when it is submerged.

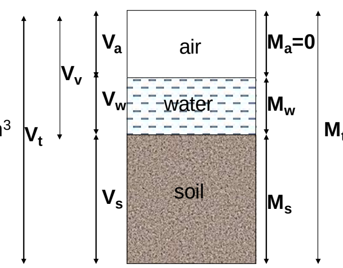
$$\rho' = \rho_{sat} - \rho_w$$

Definitions

Particle density (ρ_p) is the density of the solid particles in drystate.

$$\rho_p = \frac{M_s}{V_s}$$

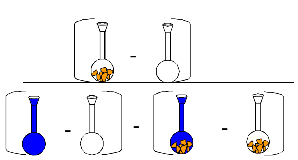
Units: Mg/m^3, g/cm^3, kg/m^3



Phase Diagram

Determinação da Densidade de Partículas

$$dp = \frac{M}{V} = \frac{(P_B - P)}{[(P_W - P) - (P_{BW} - P_B)]/d_W}$$



Definitions

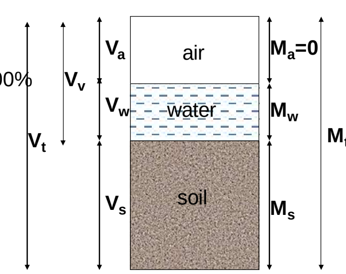
Gravimetric Water content (w) is a measure of the water present in the soil (mass base).

$$Ug = w = \frac{M_W}{M_S} \text{ X } 100\%$$

Expressed as percentage or kg/kg.

Range = 0 – 100+%

or 0 – 1+ kg/kg.



Phase Diagram

Definitions

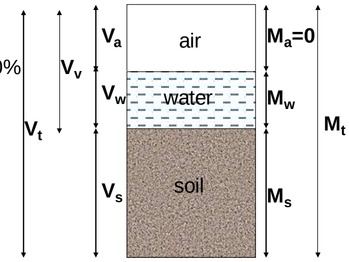
Volumetric Water content (θ) is a measure of the water present in the soil (volume base).

$$Uv = \theta = \frac{V_W}{Vt} \text{ X } 100\%$$

Expressed as percentage or m³/m³.

Range = 2 – 60%

or 0.02 – 0.6 m³/m³



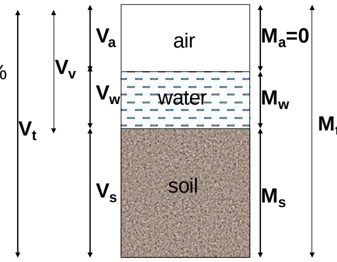
Phase Diagram

Definitions

Porosity (n) is also a measure of the void volume, expressed as a percentage.

$$Pt = n = \frac{V_V}{V_T} \text{ X } 100\%$$

Theoretical range: 0 – 100%

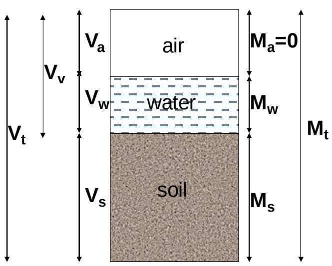


Phase Diagram

Definitions

Void ratio (e) is a measure of the void volume.

$$e = \frac{V_V}{V_S}$$



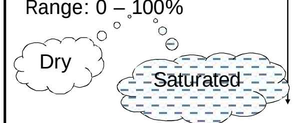
Phase Diagram

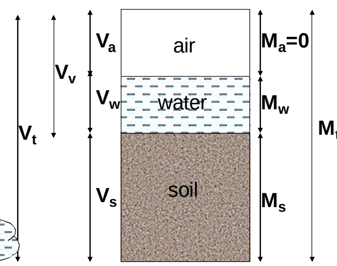
Definitions

Degree of saturation (S) is the percentage of the void volume filled by water.

$$S = \frac{V_W}{V_V} \text{ X } 100\%$$

Range: 0 – 100%





Phase Diagram

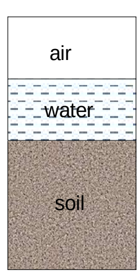
A Simple Example

In this illustration,

e = 1

n = 50%

S = 50%



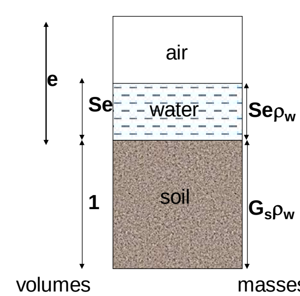
Phase Relations

Consider a fraction of the soil where V_s **= 1.**

The other volumes can be obtained from the previous definitions.

The masses can be obtained from:

Mass = Density x Volume



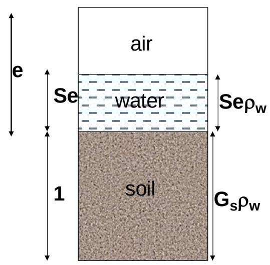
Phase Diagram

Phase Relations

From the previous definitions,

$$w = \frac{M_W}{M_S} = \frac{Se}{G_S}$$

$$n = \frac{V_V}{V_T} = \frac{e}{1+e}$$



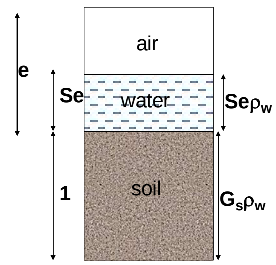
Phase Diagram

Phase Relations

$$\rho_m = \frac{M_T}{V_T} = \frac{G_S + Se}{1+e}\rho_W$$

$$\rho_{sat} = \frac{M_T}{V_T} = \frac{G_S + e}{1+e}\rho_W$$

$$\rho_d = \frac{M_S}{V_T} = \frac{G_S}{1+e}\rho_W$$



Phase Diagram

Inorganic Component

Primary Particles ↓

Discrete units;
cannot be further subdivided;
also known as soil separates
sand, silt, clay

Secondary Particles ↓

Consist of primary particles;
can be further subdivided into its separates

Particle size distribution ↓

Quantitative
measure of particle
size constituting
the solid fraction

Texture ↓

Qualitative
based on feel method
-coarse, gritty, fine,
smooth

↓

Particle size is important soil physical properties:

Total porosity, pore size, surface area, …

Distribuição de tamanho de partícula e Textura

Textura é relacionada com as propriedades plasticidade, pegajosidade e resistência.

Textura é o resultado da distribuição relativa das frações granulométricas.

Systems of Classification

1. United States Department of Agriculture (USDA)
2. International Society of Soil Science (ISSS)
3. American Society of testing materials (ASTM)
4. Massachusetts Institute of Technology (MIT)
5. US Public Road Administration (USPRA)
6. British Standard Institute (BSI)
7. German Standard (DIN)

Sociedade Internacional de Ciência do Solo	Argila	Silte	Areia: Fina	Areia: Grossa	Cascalho
Limites (mm)	0,002	0,02	0,2	2,0	

Departamento de Agricultura dos Estados Unidos	Argila	Silte	Areia: Muito fina	Areia: Fina	Areia: Média	Areia: Grossa	Areia: Muito grossa	Cascalho
Limites (mm)	0,002	0,05	0,10	0,25	0,5	1,0	2,0	

Administração Pública de Estradas dos Estados Unidos	Argila	Silte	Areia: Fina	Areia: Grossa	Cascalho
Limites (mm)	0,005	0,05	0,25	2,0	

Diâmetro de partícula (mm, escala logarítimica)

Classes de tamanho de partículas do solo SBCS

FRAÇÃO GRANULOMÉTRICA	DIÂMETRO (mm)
Matacão	> 200
Calhau	200 –20
Cascalho	20 - 2
Areia grossa	2 – 0,2
Areia fina	0,2 – 0,05
Silte	0,05 – 0,002
Argila	< 0,002

Fractionation is the process of physically separating the particles into different size fractions

Methods of fractionation	Approximate size range (mm)
Sieving	100.0 - 0.05
Sedimentation	2.0 - < 0.002
Optical Microscope	1.0 - 0.001
Gravity sedimentation	0.1 - 0.0005
Permeability	0.1 - 0.0001
Gas absorption	0.1 - 0.0001
Electron microscope	0.005 - 0.00001
Elutriation	0.05 - 0.005
Centrifugal sedimentation	0.01 - 0.00005
Turbidimetry	0.005 - 0.00005

Sieving or Direct sieving:

Dispersed soil suspension is passed through a nest of sieves of different seizes:

2 mm, 1mm, 0.5 mm, 0.25 mm, 0.10 mm

Primarily suited for coarse fraction

Sedimentation analysis:

Based on rate of fall of particles through liquid and depends on particle size and properties of liquid

G.G. Stokes (1851) law –

“Resistance offered by a liquid to a falling rigid spherical particle varies with the radius of the particle and not with its surface”

Process of determination of particle size fractions is known mechanical analysis

Dispersion **Fractionation**

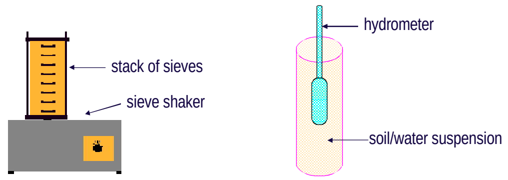
Dispersion is removal of cementing materials to break secondary particles into primary

Cementing material	Dispersing agent
Organic matter	Hydrogen peroxide (H_2O_2)
Oxides of Fe and Al	Oxalic acid, sodium sulfide
Electrolytes	Leaching with dilute acids
Cohesion/adhesion	Rehydration by boiling in H_2O, shaking, titration, ultrasound vibration

Grain Size Distribution

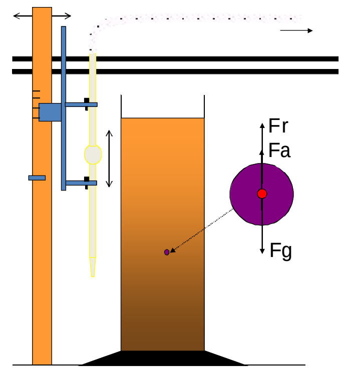
Determination of GSD:

- In coarse grain soils ...... By sieve analysis
- In fine grain soils ...... By hydrometer analysis



Sieve Analysis — Hydrometer or Pipette Analysis

Sedimentação – Lei de Stoke



Força cisalhante

$$F_r = 6\pi R \eta v$$

Força gravitacional

$$F_g = m_s g = d_F \left(\frac{4\pi R^3}{3} \right) g$$

Empuxo

$$F_a = m_l g = d_l \left(\frac{4\pi R^3}{3} \right) g$$

Velocidade constante de Sedimentação

$$\Sigma F_i = 0 = F_g - F_a - F_r$$

Resultante

$$=> v = (d_F - d_L) \frac{2\pi R^2 g}{9\eta}$$

Lei de Stokes

$$V = \frac{h}{t} = \frac{d^2 g (D_p - D_f)}{18\eta}$$

d = diâmetro de partículas efetivo;

h = distância;

t = tempo;

g = aceleração da gravidade = 9,81 Newton por quilograma (9,81 N/kg);

η = viscosidade da água a 20 °C = 1/1000 Newton–segundo por m^2 (10^{-3} N.s/m^2);

D*p* = densidade das partículas sólidas, para muitos solos = 2,65 x 10^3 kg/m^3;

D*f* = densidade do fluido (água) = 1,0 x 10^3 kg/m^3.

Lei de Stoke - Assunções

$$v = \frac{2 \cdot r^2 \cdot g \cdot (d_F - d_W)}{9\eta}$$

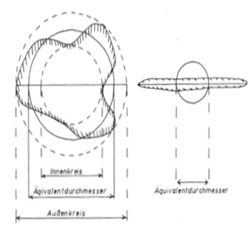


Abb. 1.1 Kornformen und Äquivalentdurchmesser. Letztere sind Ersatzwerte für nicht bestimmbare, repräsentative, geometrisch definierte Durchmesser. Sie sind schematisch als Kreise eingezeichnet.

Assumptions of Stokes Law:

1. Particles are spheres
2. Particles are of uniform density
3. Particles settle independently
4. Laminar fluid flow
5. No thermal flow

Fallzeiten bei verschiedener Eintauchtiefe in Abhängigkeit von der Temperatur der Suspension

(für 500ml-Steilwandflaschen)

Fallhöhe / Fraktion / Temperatur	5 cm < 60 µ	4 cm < 20 µ	4 cm < 6 µ	2 cm < 2 µ
17 °C	17"	2' 00"	22' 17"	1h 40' 17"
18 °C	16"	1' 57"	21' 44"	1h 37' 47"
19 °C	16"	1' 54"	21' 11"	1h 35' 21"
20 °C	16"	1' 52"	20' 40"	1h 33' 02"
21 °C	15"	1' 49"	20' 11"	1h 30' 48"
22 °C	15"	1' 46"	19' 42"	1h 28' 40"
23 °C	14"	1' 44"	19' 15"	1h 26' 37"
24 °C	14"	1' 41"	18' 47"	1h 24' 34"

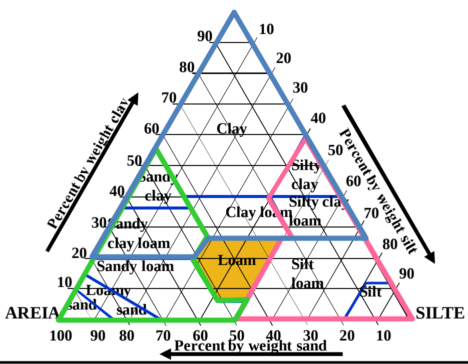
Por quê medir DTP?

Predição do comportamento do solo com base numa única medida

(funções de pedotransferência)

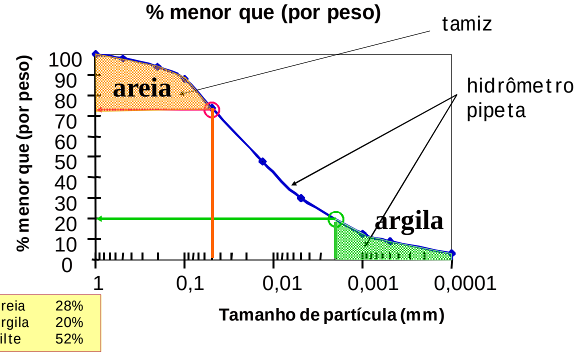
Como apresentar os dados:

1. Classes texturais



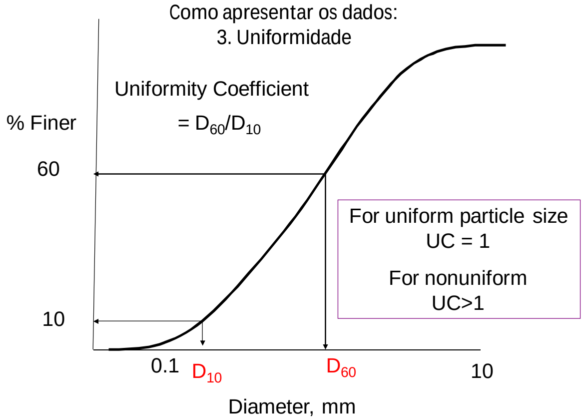
Como apresentar os dados:

2. Gráfico DTP



Como apresentar os dados:

3. Uniformidade



Como apresentar os dados:

3. Uniformidade

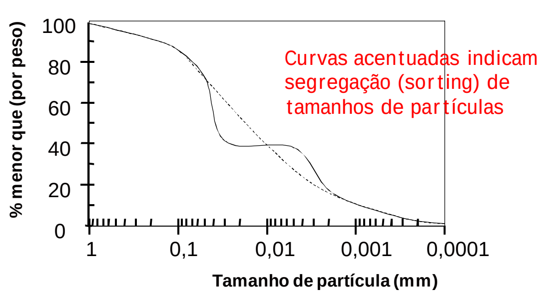
- Índice de uniformidade (engenharia)

$$I_U = d_{60}/d_{10}$$

- Distribuição (grading) perfeita I → 1000
- Segregação (sorting) perfeita I = 1

Como apresentar os dados:

3. Uniformidade



Indices for Particle Shape:

1. Roundness : measure of the sharpness of corners
2. Sphericity: how close to a sphere

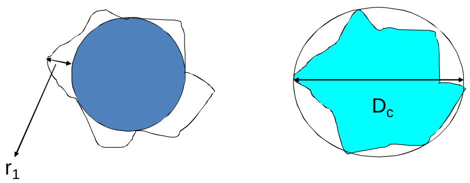
$$Roundness = \frac{\sum_{i=1}^{n} r_i/R}{n} \qquad Sphericity = \frac{D_d}{D_c}$$

r_i – radius of corner

R- radius of maximum circle

D_d – diameter of a circle with an area equal to that of the particle projection as it rests on flat surface

D_c- diameter of smallest circumscribing circle



Soil Shapes:

Well rounded	rounded	subrounded
subangular	angular	very angular

Particle Shape

(micrograph)

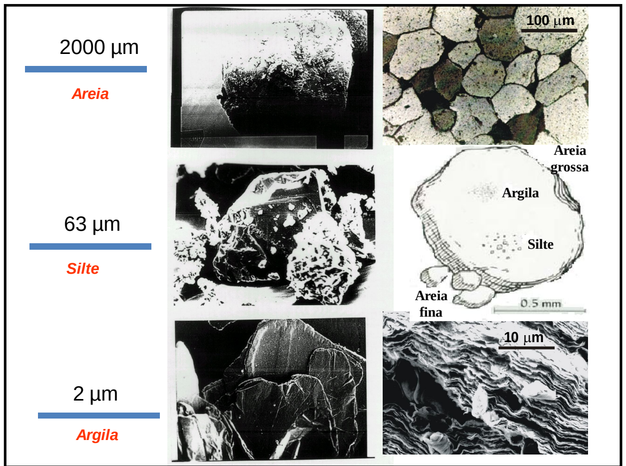
Depends on :

- Size of particle (coarser more irregular)
- Parent material
- Degree of weathering

Coarse fractions such as sand and silt are often angular or zigzag in shape

Clay particles: plate or tubular shape

Angularity (a shape having one or more sharp angles) reflects degree of weathering
- Inverse relationship
- Highly angular particles are less weathered
- Become rounded with progressive weathering by water and wind



Sand – mostly quartz, feldspar and mica (fragments)

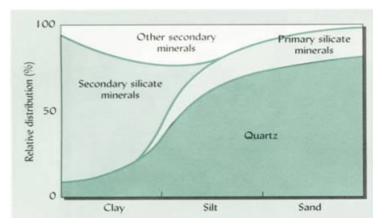
traces of heavy metal, low surface area

Silt – mineralogical composition is similar to sand,

intermediate surface area

Clay – reactive fraction of soil, colloidal, large surface

area, high charge density

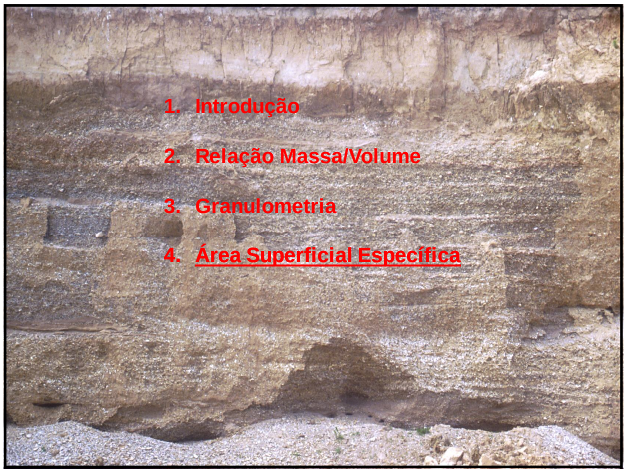


Important properties of clay fraction

1. Easy hydration because of high affinity to water
2. High swell/shrink capacity because of expanding nature of clay lattice
3. High plasticity as it can retain shape when moist
4. Develops cracks when shrinks
5. Forms a cake when swells (cohesive forces)
6. High density of negative charge, which leads to the formation of electrostatic double layer when fully hydrated

Soil Separates

Property	Sand	Silt	Clay
Size	2-0.02 mm	0.02-0.002 mm	<0.002 mm
Shape	jagged	slightly irregular	platy/tube like
Feel	gritty	smooth, floury	sticky
Plasticity	not plastic	slightly plastic	plastic
Cohesion	not cohesive	slightly cohesive	cohesive, gelatinous
Surface area	very low	moderate	very high
Mineralogy	primary	primary minerals	secondary minerals
Heat of wetting	none	minimal	high
Secondary particles	no	few	forms aggregates
Water holding capacity	none/slight	moderate	high, hygroscopic
Hardness	5.5-7 (mhos scale)	5.5-7.0	--
Ion exchange capacity	none	very low	high to very high



Por que medir Área Superficial Específica - ASE?

Predição do comportamento do solo com base numa única medida
(funções de pedotransferência)

- Interações químicas e físicas ocorrem somente na superfície de uma partícula
- A razão Superfície/Volume é uma propriedade importante do solo.
- Definição:
  - **m²/g**
  - **m²/cm³**

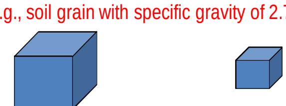
$$a_m = \frac{A_s}{M_s}$$

$$a_v = \frac{A_s}{V_s}$$

Specific Surface

- surface area per unit mass (m^2/g)
- smaller the grain, higher the specific surface

e.g., soil grain with specific gravity of 2.7



10 mm cube	1 mm cube
spec. surface = 222.2 mm^2/g	spec. surface = 2222.2 mm^2/g

Definition

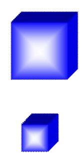
Specific surface = surface / volume

Specific surface = surface / mass → Preferred

$$\frac{\text{Surface related force}}{\text{Gravational force}}$$

Surface related forces: van der Waals forces, capillary forces, etc.

Example:



$1\times1\times1\,\text{cm cube},\ \rho = 2.65\text{g/cm}^3$

$$S_s = \frac{6\cdot 1\text{cm}^2}{1\text{cm}^3\cdot 2.65\text{g/cm}^3} = 2.3\cdot10^{-4}\cdot\text{m}^2/\text{g}$$

$1\times1\times1\,\mu\text{m cube},\ \rho = 2.65\text{g/cm}^3$

$$S_s = \frac{6\cdot 1\mu\text{m}^2}{1\mu\text{m}^3\cdot 2.65\text{g/cm}^3} = 2.3\cdot\text{m}^2/\text{g}$$

S_s is inversely proportional to the particle size

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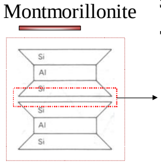
Typical Values

Montmorillonite



50-120 m^2/gm (external surface)

700-840 m^2/gm (including the interlayer surface)

Illite

65-100 m^2/gm

Kaolinite

10-20 m^2/gm

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Estimativa da ASE

- Procedimento
  1. Solo seco
  2. Satura o solo com substância inerte
  3. Evacua solo (evaporação da substância)
  4. Mede diferença de massa
  5. Assume uma única monocamada da substância inerte cobridno as partículas de solo

Glicerol (G)
etileno glycol (EG)
etileno glicol-monoetil éter (EGME)

$$a_s = \frac{w_a}{w_d\, w_g}$$

w_a = massa de líquido adsovido (g)
w_d = massa de solo seco (g)
w_g = fator = massa necessária por m^2

Estimativa da ASE

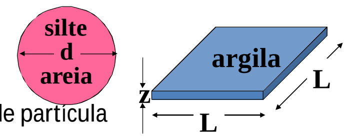
- Adsorção (Boer, 1953)

$$\sigma_a = k_i \, P \exp\left(\frac{Q_a}{RT}\right)$$

σ_a: quantidade de gás adsorvida por unidade de superfície
K_i: constante;
R: constante universal dos gases
P: pressão
T: temperatura
Q: calor de adsorção

Estimativa da ASE

- Analiticamente
  – Assuma uma forma de partícula



$$a_m = \frac{A_s}{M_s} = \frac{4\pi R^2}{\rho_s V} = \frac{4\pi R^2}{\rho_s (4/3)\pi R^3} = \frac{3}{\rho_s R} = \frac{6}{\rho_s d} \quad \text{m}^2/\text{g}$$

$$a_v = \frac{A_s}{V_s} = \frac{4\pi R^2}{(4/3)\pi R^3} = \frac{3}{R} = \frac{6}{d} \quad \text{m}^2/\text{cm}^3$$

ÁREA SUPERFICIAL ESPECÍFICA

Influenciada por

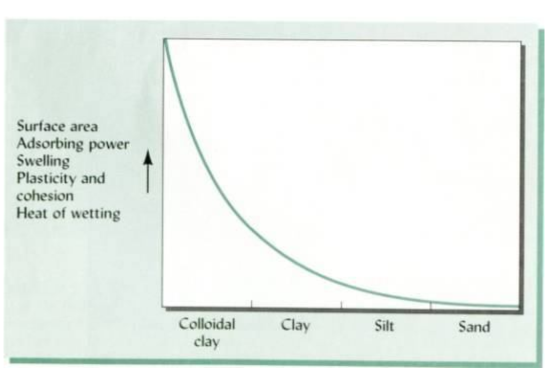
➔ Tamanho da partícula afeta:
atrito, adsorção, tensão superficial.
➔ Forma da partícula
➔ Natureza da partícula:
↑MO, ↑decomposição, ↑ASE
➔ Composição da partícula:
atividade, superfície interna

ÁREA SUPERFICIAL ESPECÍFICA

Relacionada com

➔ CTC, retenção de água e nutrientes;
➔ retenção e liberação de poluentes;
➔ expansão / contração;
➔ propriedades mecânicas:
coesão, resistência, plasticidade.

Área superficial específica



Próximo assunto:

Argilas e eletroquímica