# Basic Principles of Soil Mechanics

CI1-150 Geotechnics

# Classification/Description

**Why?**

- To predict engineering performance
- Engineering properties (Strength, stiffness and permeability) will depend on both the *nature* and *state* of soil

**Description**

Describe what you see and how soil responds to simple tests.

**Classification**

Process of separating soils into broad groups that have similar behaviour or characteristics.

Atkinson, J. H. (2007) *The Mechanics of Soils and Foundations.* 2nd Ed., London, Taylor & Francis. Section 5.1.

# Nature and State

## Nature;

The essential characteristics or basic qualities of the soil

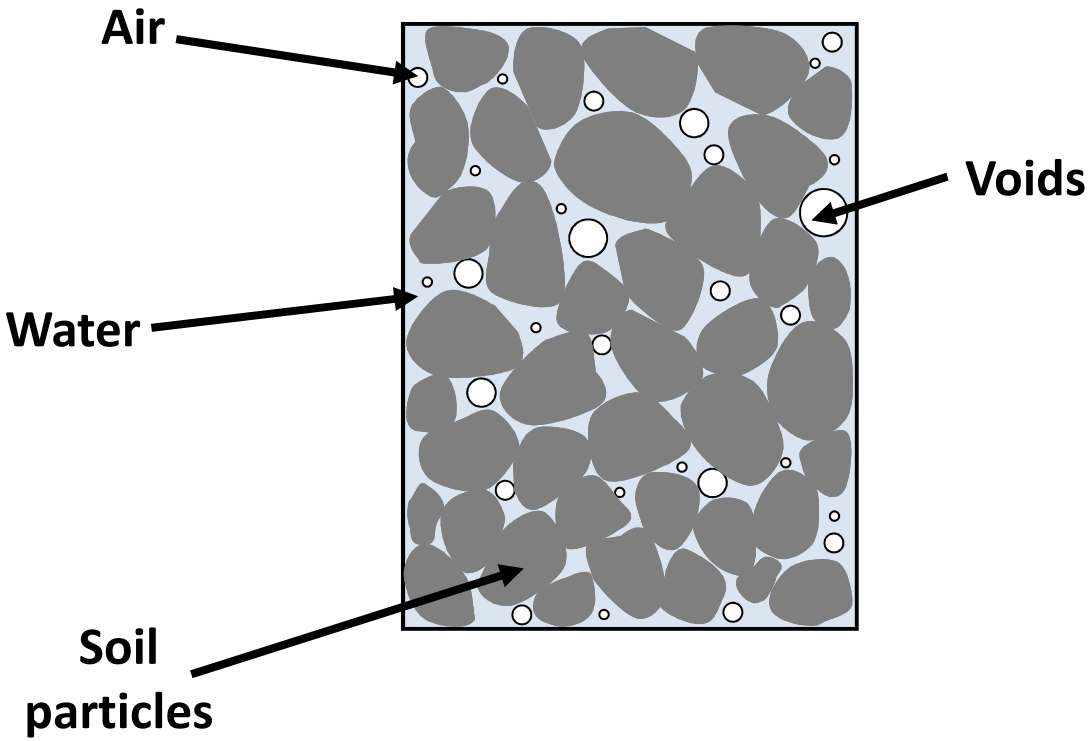
## State;

The physical condition in which the soil exists

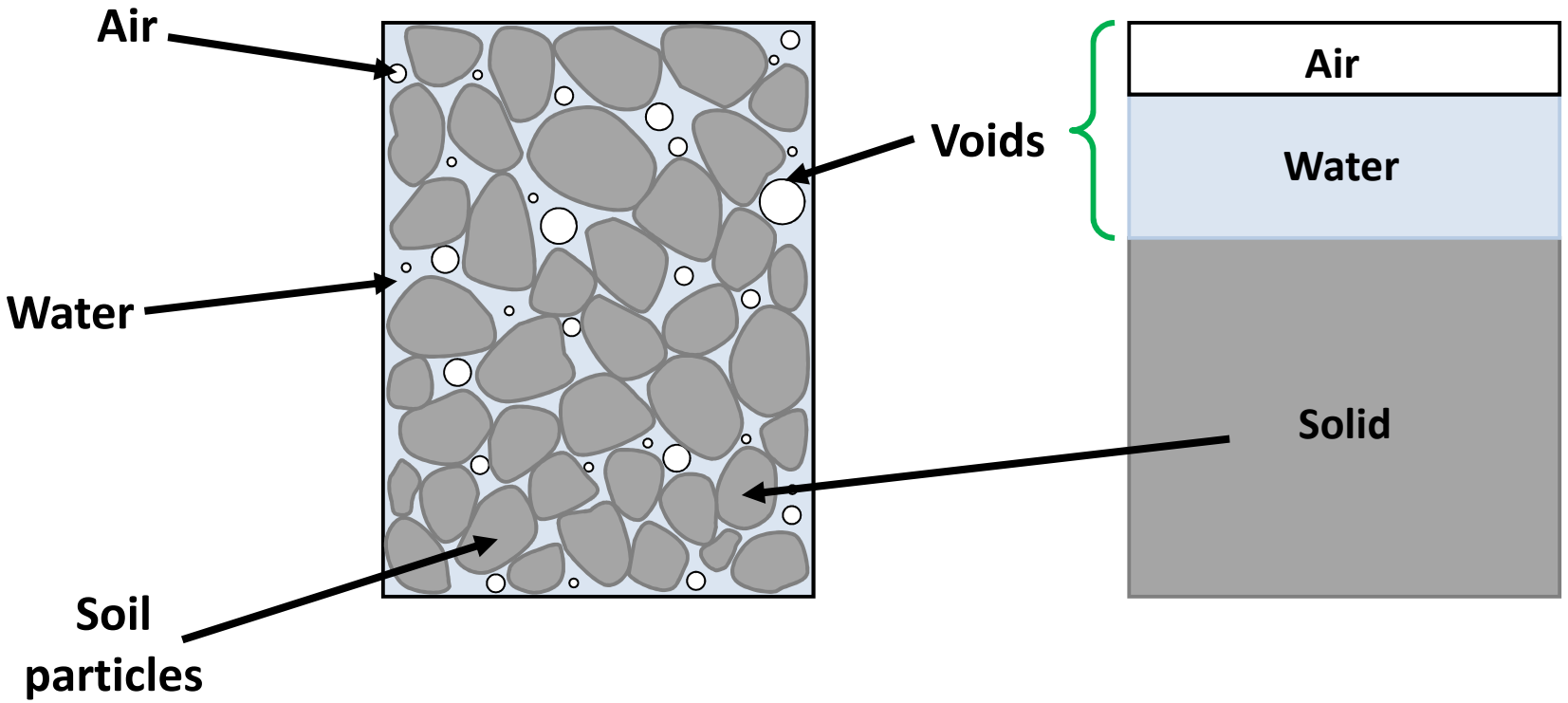
# Nature

The essential characteristics or basic qualities of the soil

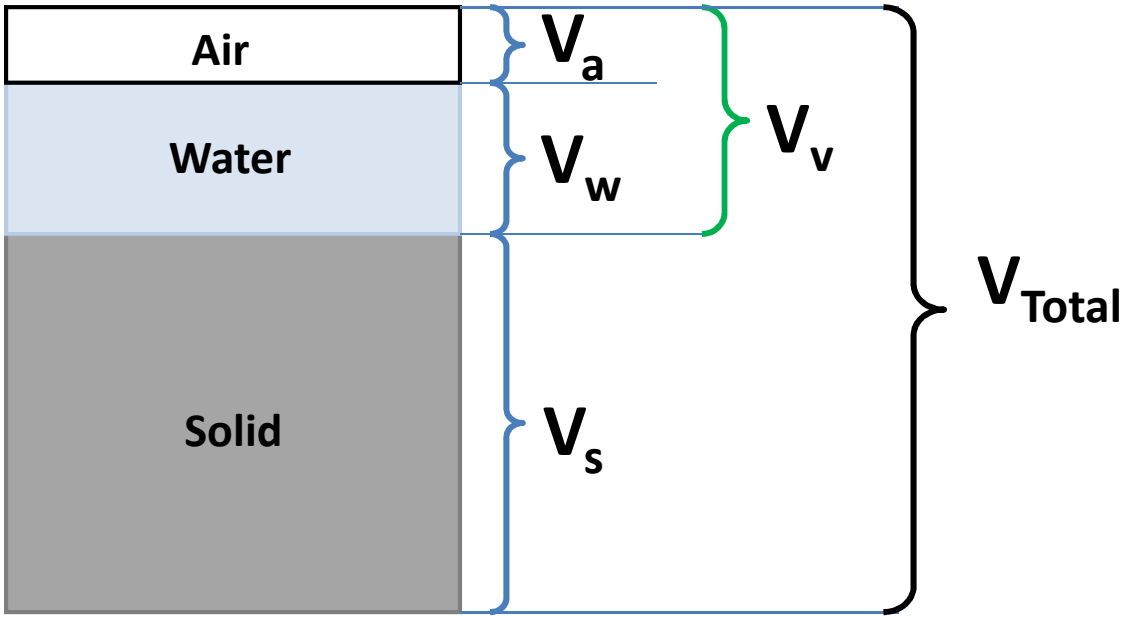
# What is soil composed of?



# Phase Diagram



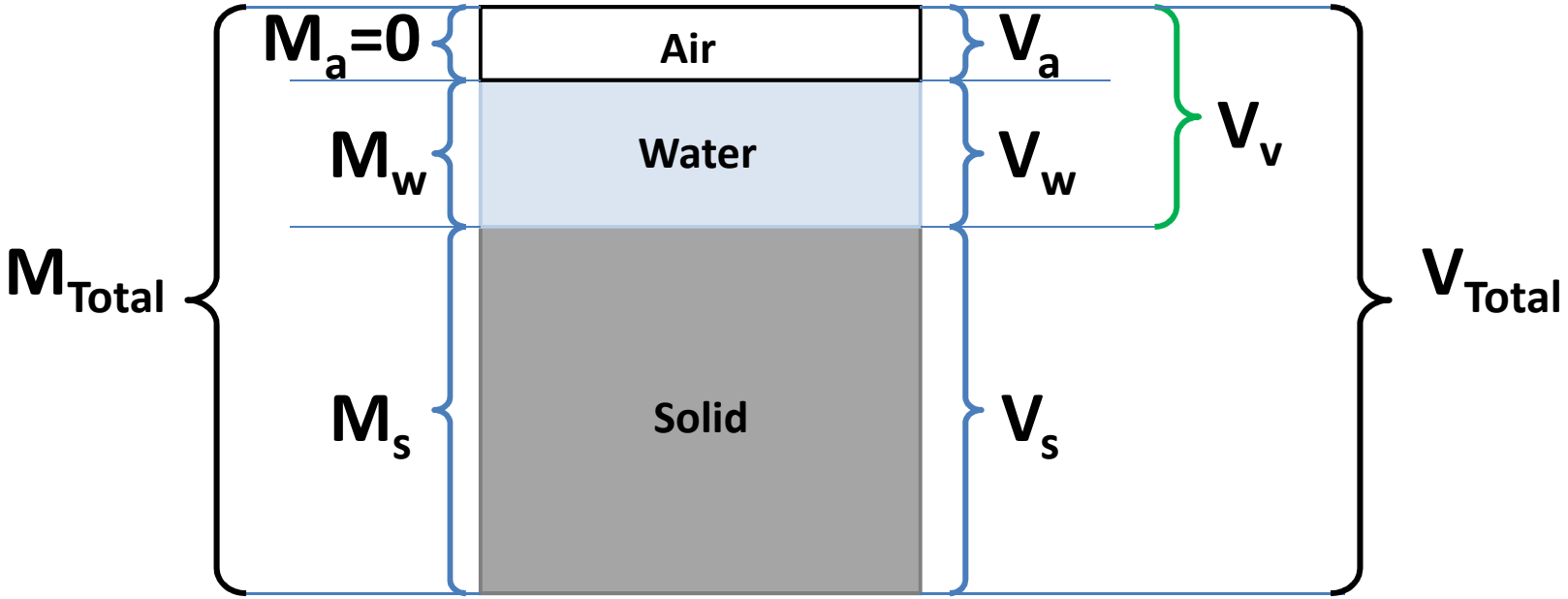
# Volume




$$V_{Total} = V_v + V_s$$

$$V_v = V_a + V_w$$

# Mass

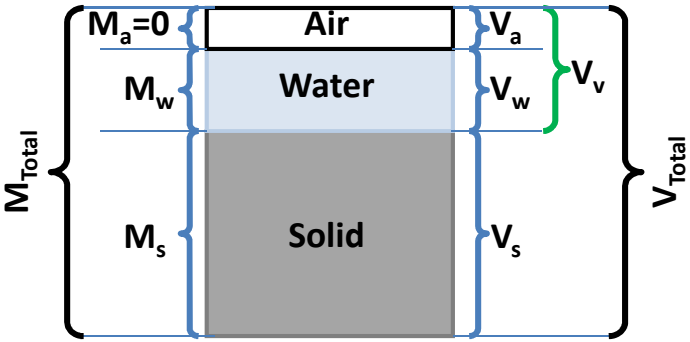



$$M_{Total} = M_w + M_s$$

# Definitions

| | | |
|---|---|---|
| **Density of water** | $\rho_w = 1000$ | kg/m$^3$ |
| **Water Content** | $w = \frac{M_w}{M_s}$ | [%] |
| **Degree of Saturation** | $S_r = \frac{V_w}{V_v}$ | [%] |
| **Bulk Unit Weight** | $\gamma_{bulk} = \frac{M_{Total} \cdot g}{V_{Total}}$ | kN/m$^3$ |

| | |
|---|---|
| **Specific Gravity** | $G_s = \frac{\rho_s}{\rho_w}$ |
| **Void Ratio** | $e = \frac{V_v}{V_s}$ |
| **Porosity** | $n = \frac{V_v}{V_{Total}}$ |




Barnes (2000) Soil Mechanics: Principles and Practice. 2nd Ed., Houndmills, Palgrave: p33-34.
Knappett & Craig (2012) Craig's Soil Mechanics. 8th Ed, Abingdon, Spon Press: p22-25.

# Proofs

**In addition to:**

$$v = e + 1$$

**You should be able to prove:**

$$e = \frac{n}{1-n} \qquad n = \frac{e}{1+e}$$

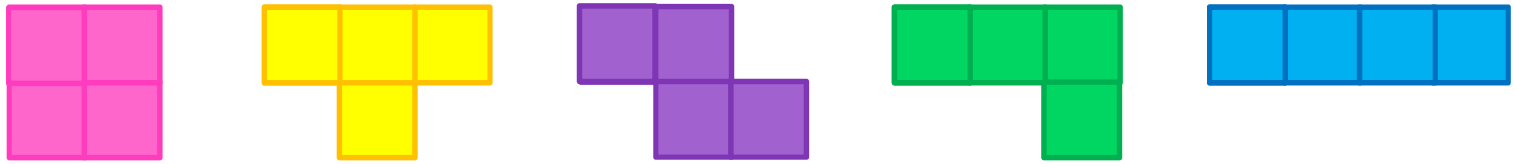
$$\rho = G_s \cdot \rho_w \cdot \left( \frac{1+w}{1+e} \right)$$

# Packing Density

**Solid**

$M_s = 4$

$V_s = 4$

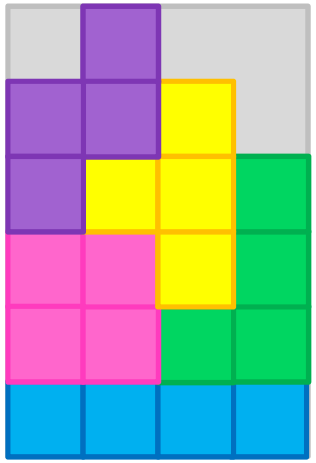


**Void**

$M_v = 0$

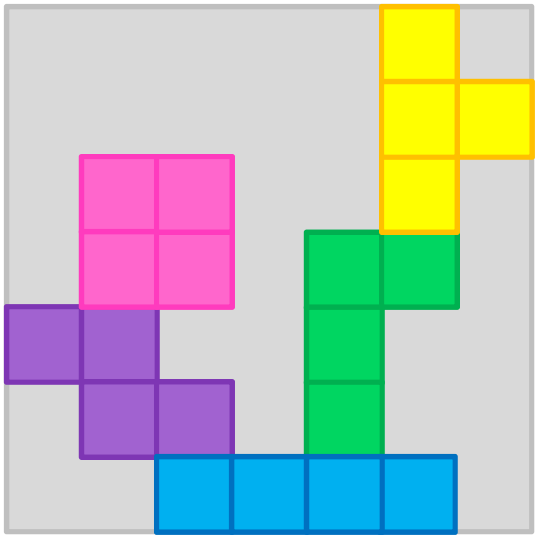
$V_v = 1$

$$e = \frac{V_v}{V_s} = \frac{29}{20} = 1.45$$



**Dense**

$e = 0.2$

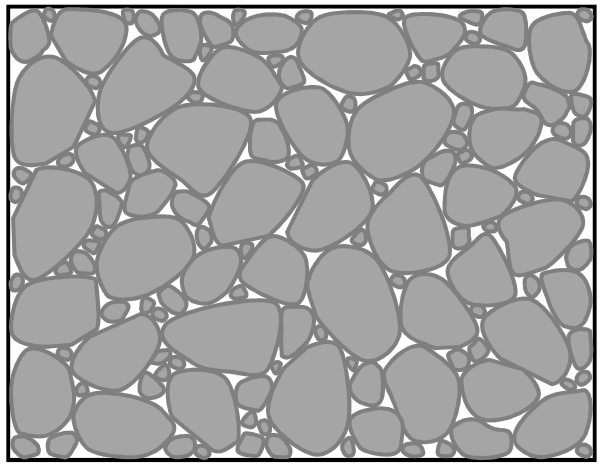


**Loose**

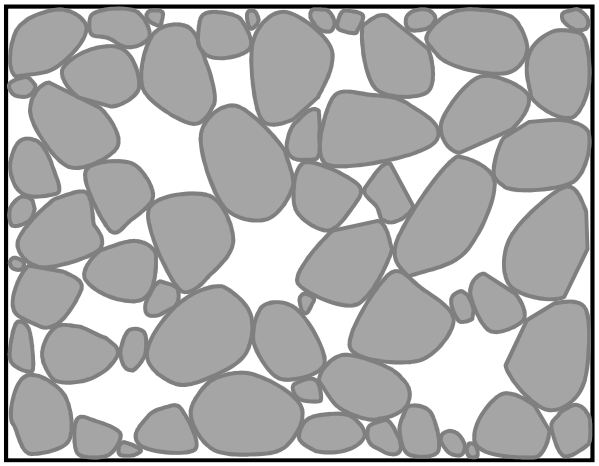
$e = 1.45$

# Packing Density

… a similar situation in soils:



**Dense**



**Loose**

**Min Void Ratio, $e_{min}$**

The densest pack possible for the soil

**Max Void Ratio, $e_{max}$**

The loosest pack possible for the soil

# Packing density

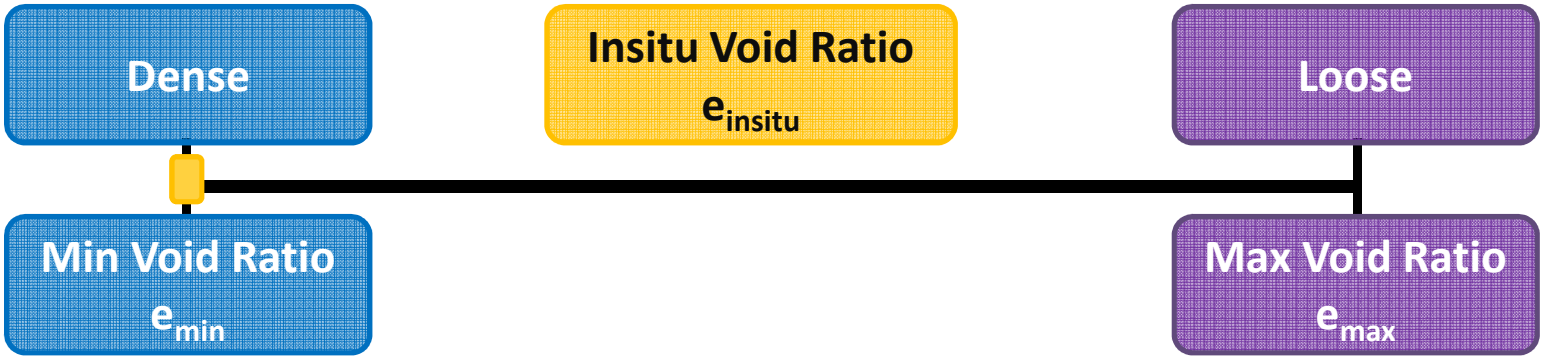
## Relative Density, $D_r$

$$D_r = \frac{e_{\max} - e_{insitu}}{e_{\max} - e_{\min}}$$

1.0

- ***Insitu Void Ratio, $e_{insitu}$***

  The void ratio of the soil on site, in its undisturbed/natural state.

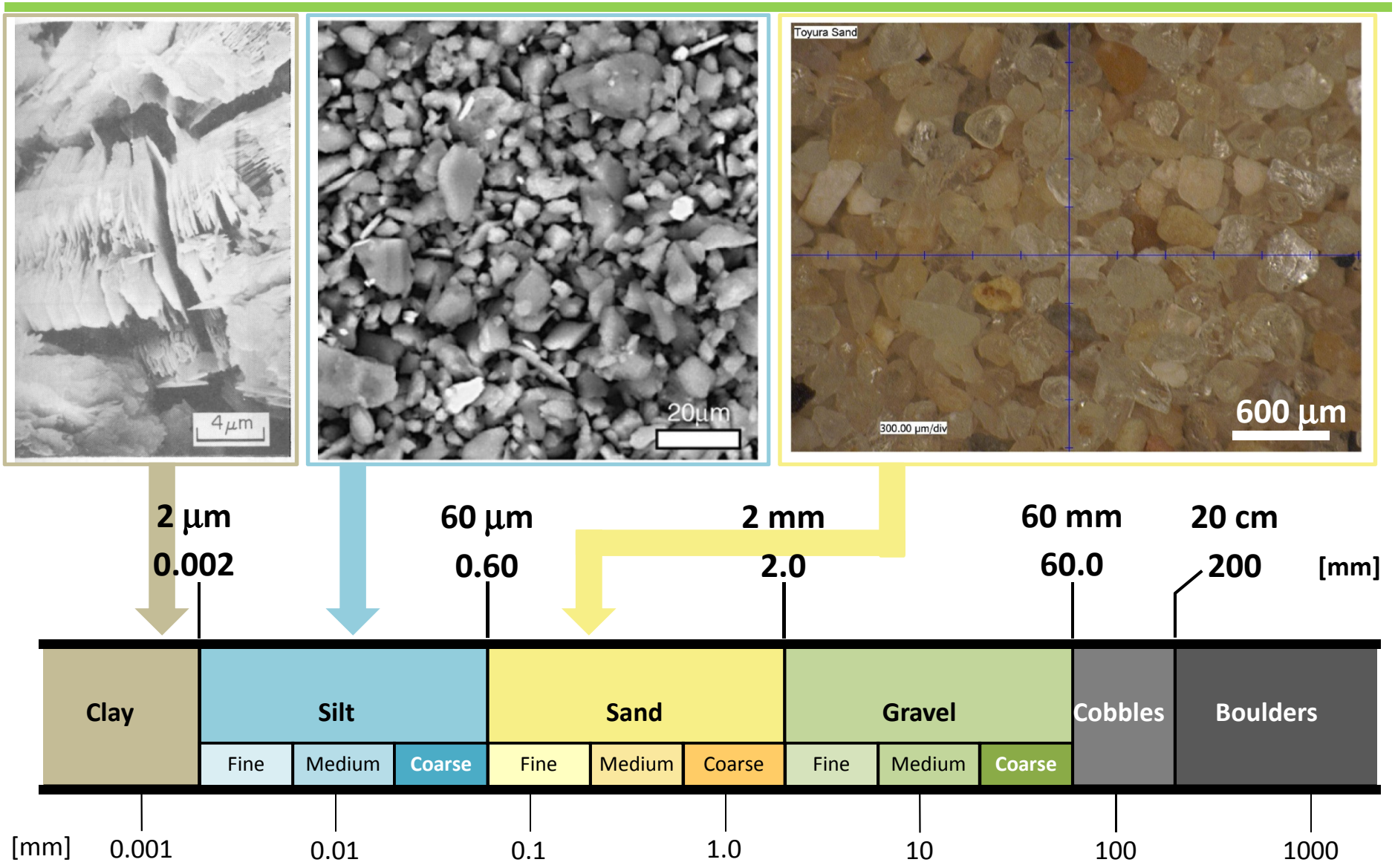


# Classification

# Particle Size - Terminology

| | | |
|---|---|---|
| Clay | Silt | Sand |
| Gravel | Cobbles | Boulders |
| Fine | Medium | Coarse |

# Particle Size - Definitions




BSI (1999) BS 5930:1999 + A2:2010 *Code of practice for site investigations.* London, British Standards Institution.

# Description

# Consistency

| **Term used for field description** | **Consistency description definition** [after BS EN ISO 14688-1:2002, **5.14**] |
|---|---|
| Very soft | Finger easily pushed in up to 25 mm. Exudes between fingers |
| Soft | Finger pushed in up to 10 mm. Moulds by light finger pressure |
| Firm | Thumb makes impression easily. Cannot be moulded by fingers, rolls in the hand to a 3 mm thick thread without breaking or crumbling |
| Stiff | Can be indented slightly by thumb. Crumbles in rolling a 3 mm thick thread, but can then be remoulded into a lump |
| Very stiff | Can be indented by thumb nail. Cannot be moulded but crumbles under pressure |
| Hard | Can be scratched by thumbnail |

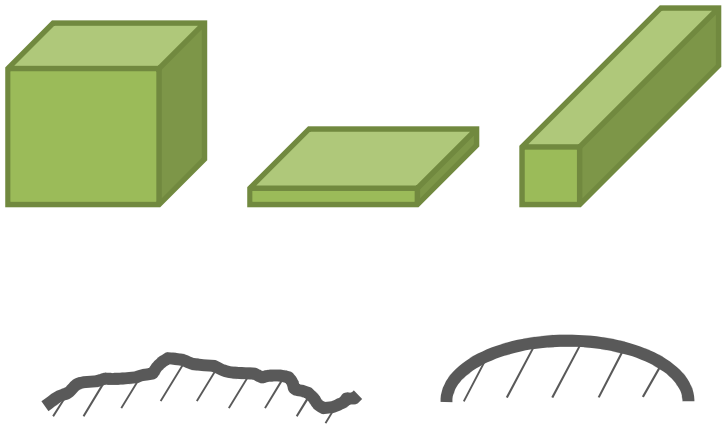
BSI (1999) BS 5930:1999 + A2:2010 *Code of practice for site investigations.* London, British Standards Institution.

# Sands

Granular (Discrete Grains) material

# Describing shape

| | |
|---|---|
| Angularity | very angular<br>angular<br>subangular<br>subrounded<br>rounded<br>well rounded |
| Form | cubic<br>flat (or tabular)<br>elongate |
| Surface texture | rough<br>smooth |



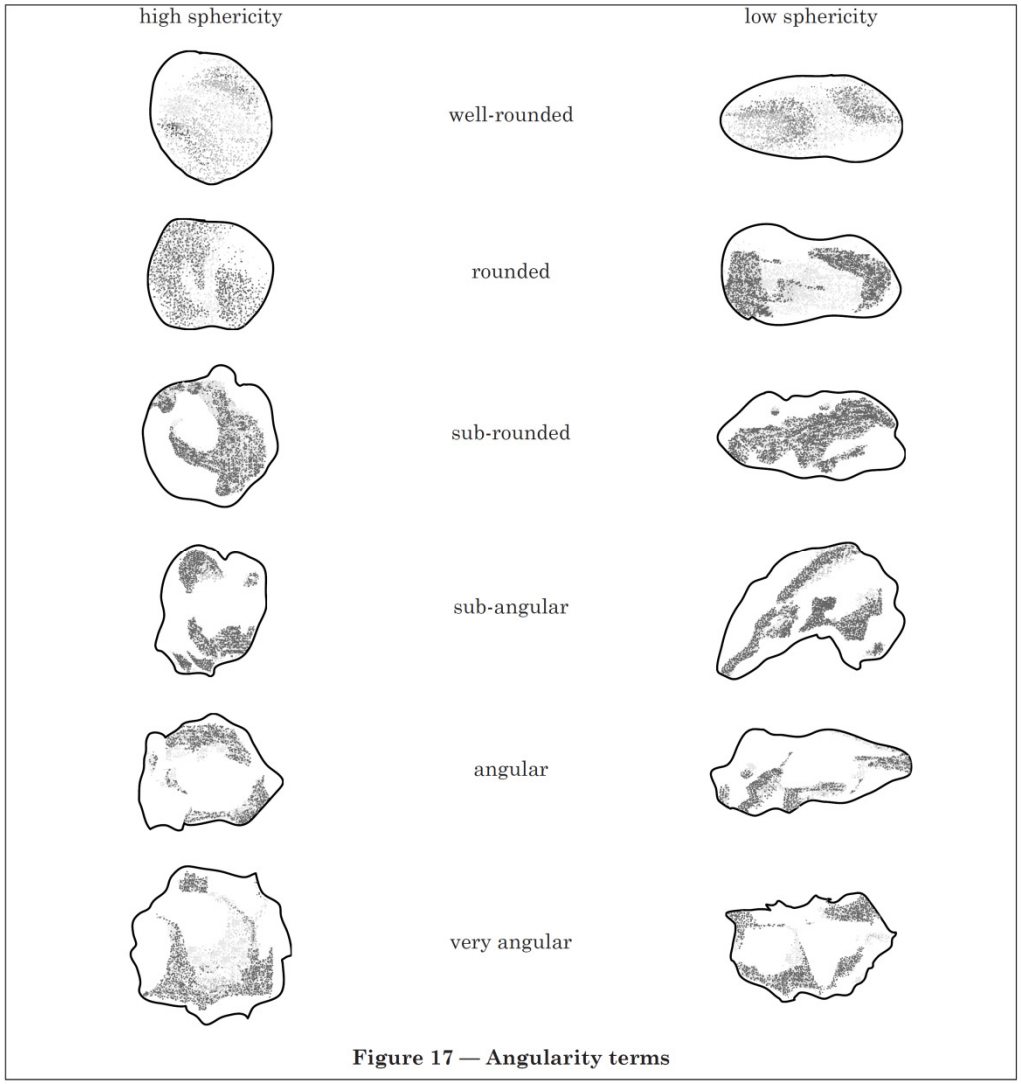
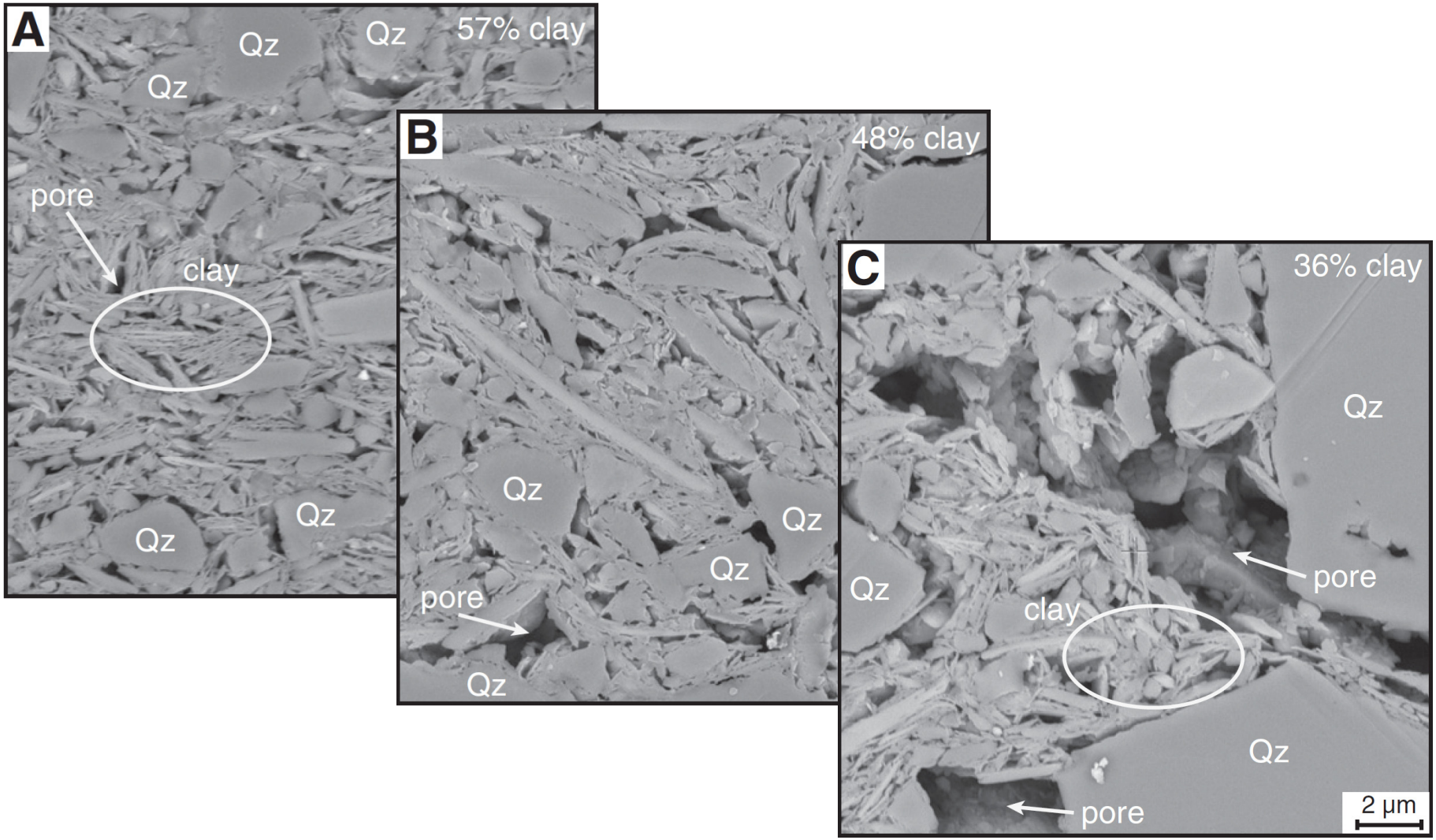



Figure 17 — Angularity terms

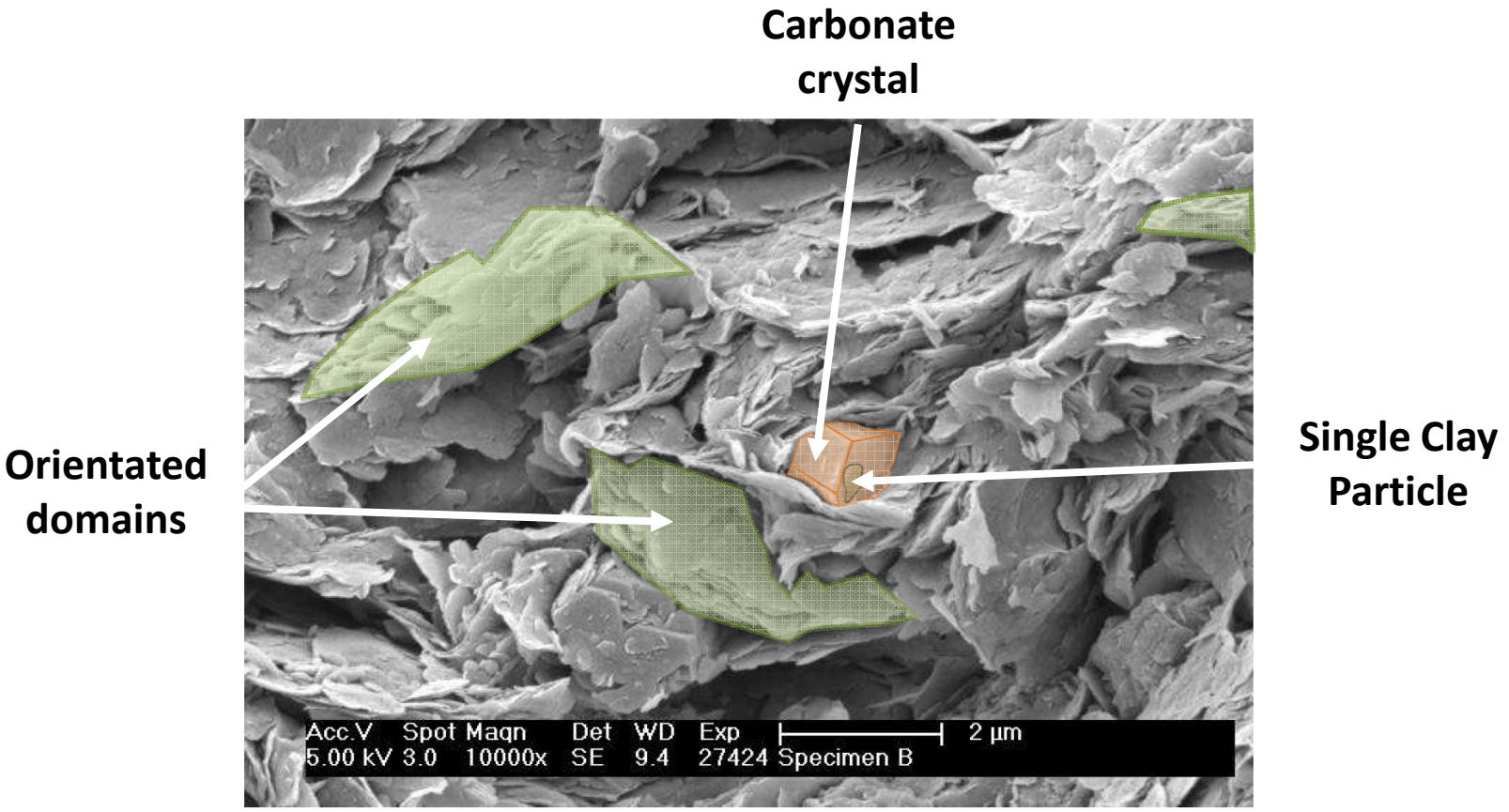
BSI (1999) BS 5930:1999 + A2:2010 *Code of practice for site investigations.* London, British Standards Institution.

# Clay Structure




Schneider et al. (2011) Insights into pore-scale controls on mudstone permeability through resedimentation experiments. *Geology* **39** (11): 1011-1014.

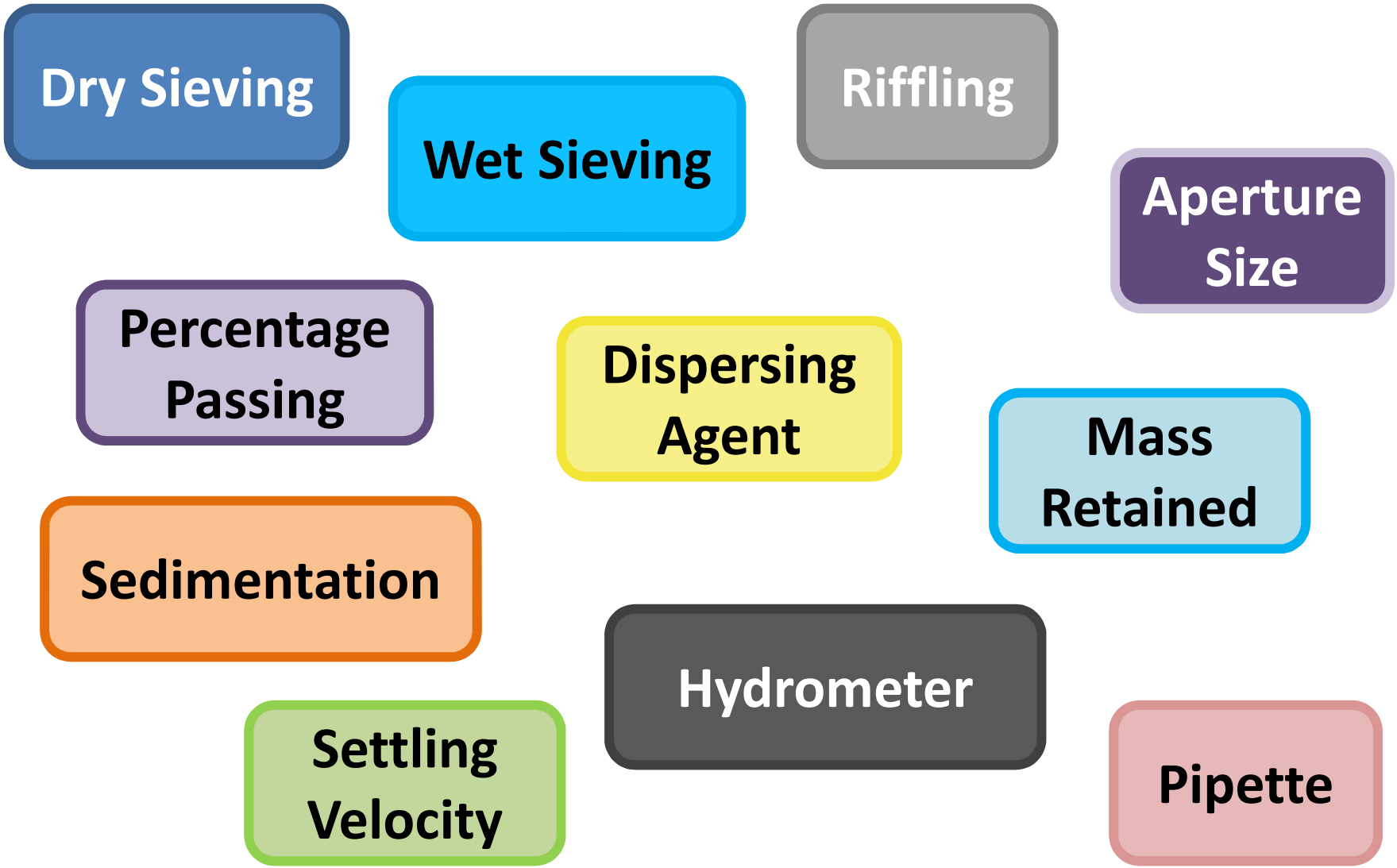
# Clay Structure




Gasparre, A (2005) *Advanced laboratory characterisation of London Clay*. PhD thesis, Imperial College London.

# Classification of particle size

# Particle Size Distribution [PSD]




BSI (1990) BS 1377-2 *Methods of test for soils for civil engineering purposes – Part 2: Classification tests.* London, British Standards Institution.

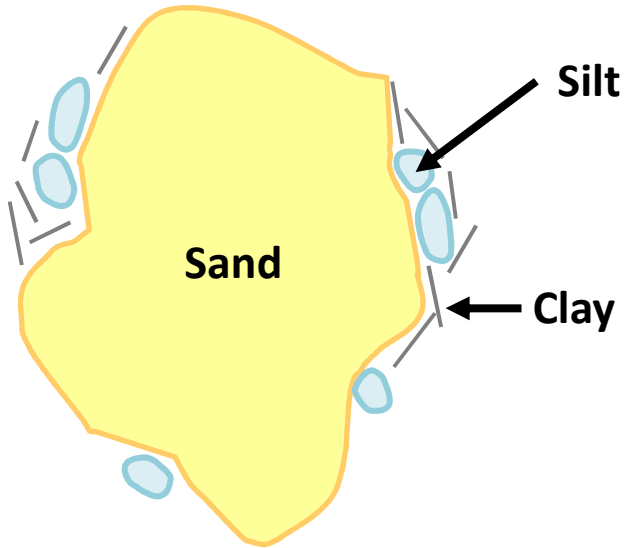
# Coarse fraction

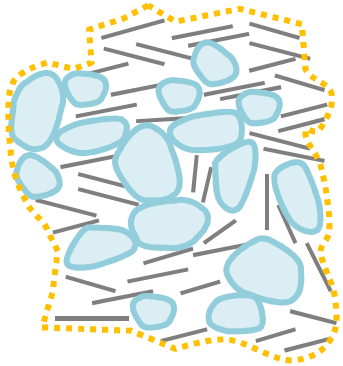
Classification of particle size

# PSD - Coarse Fraction

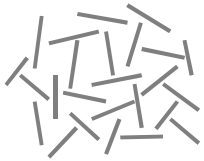
**Dry Sieving** Suitable ONLY for soils containing *insignificant* quantities of silt and clay

**Wet Sieving** Used on essentially *cohesionless* soils



**Agglomeration of silt and clay**



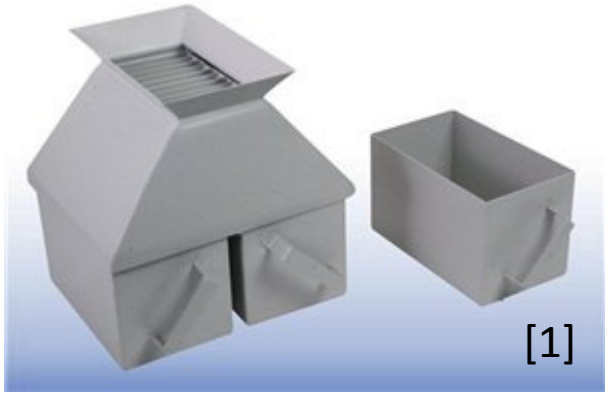
**Clay floc**

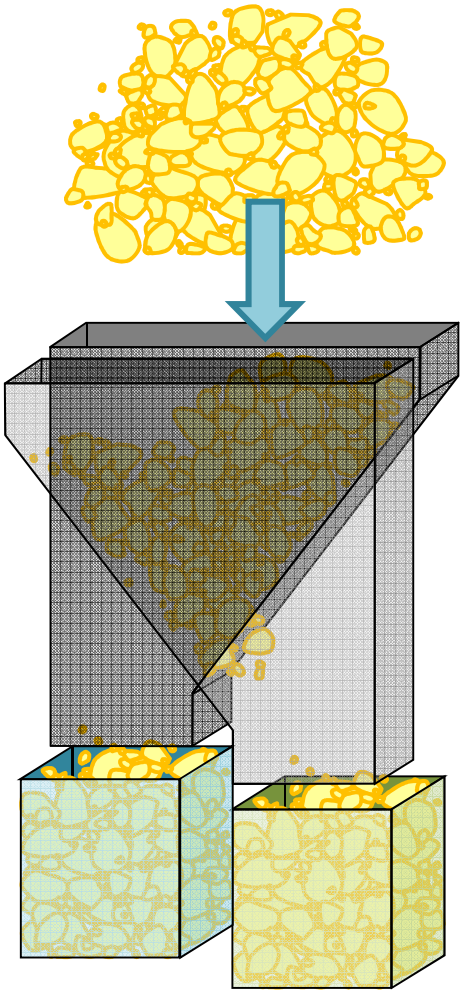
BSI (1990) BS 1377-2 *Methods of test for soils for civil engineering purposes – Part 2: Classification tests.* London, British Standards Institution.

# PSD - Coarse Fraction

**Riffling**

Splitting the soil sample into smaller (or appropriate) representative units



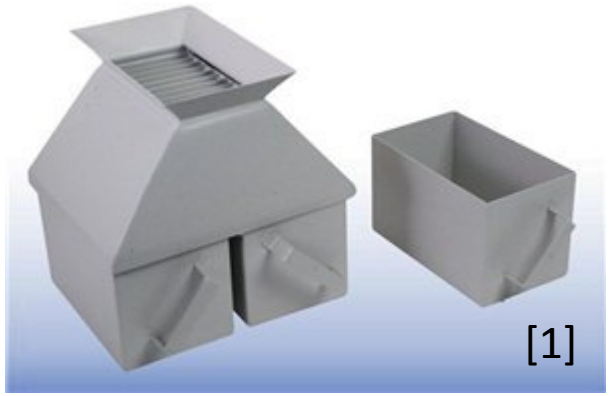



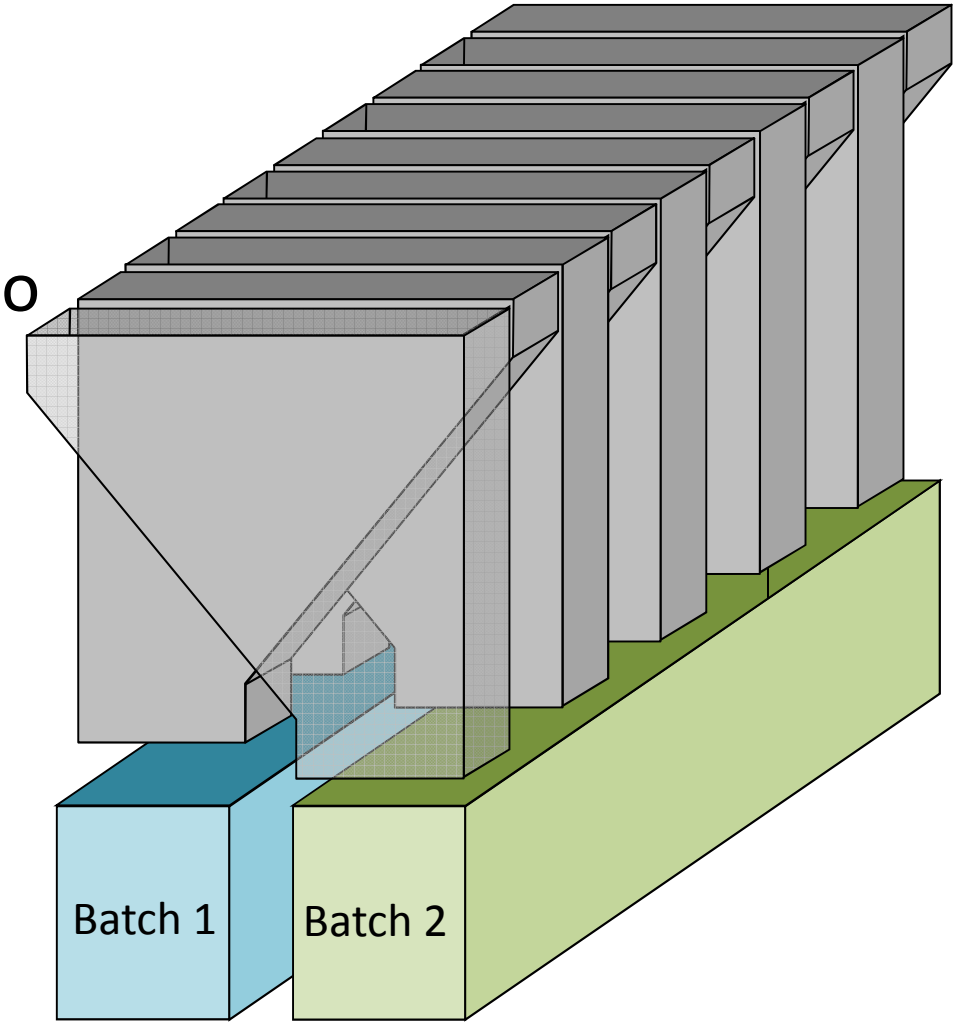
[1] vjtech (2013) VJT0017 - Riffle Box (Slot Width 13 mm, 12 Slots) [Online], Available from: http://www.vjtech.co.uk/Products/SoilRock/ClassificationTesting/tabid/205/ProdID/402/CatID/83/Riffle_Boxes.aspx [Accessed: 9th Aug 2013].

# PSD - Coarse Fraction

**Riffling**

Splitting the soil sample into smaller (or appropriate) representative units

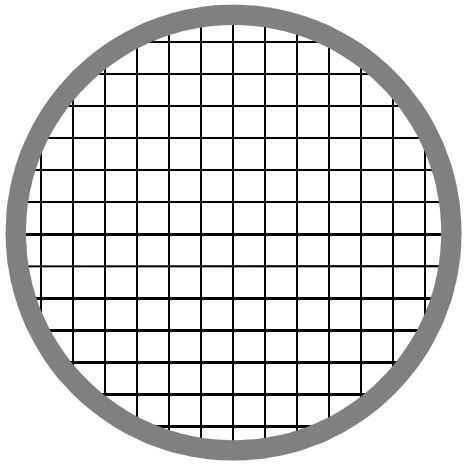


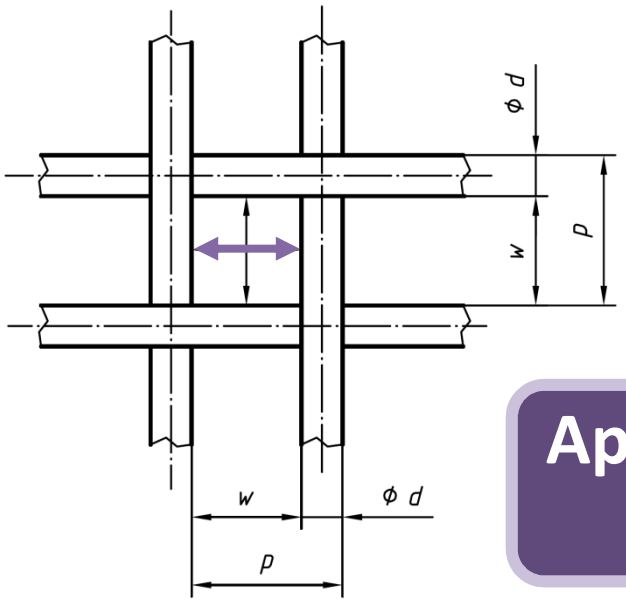




[1] vjtech (2013a) VJT0017 - Riffle Box (Slot Width 13 mm, 12 Slots) [Online], Available from: http://www.vjtech.co.uk/Products/SoilRock/ClassificationTesting/tabid/205/ProdID/402/CatID/83/Riffle_Boxes.aspx [Accessed: 9th Aug 2013].

# PSD - Coarse Fraction


**Plan view**





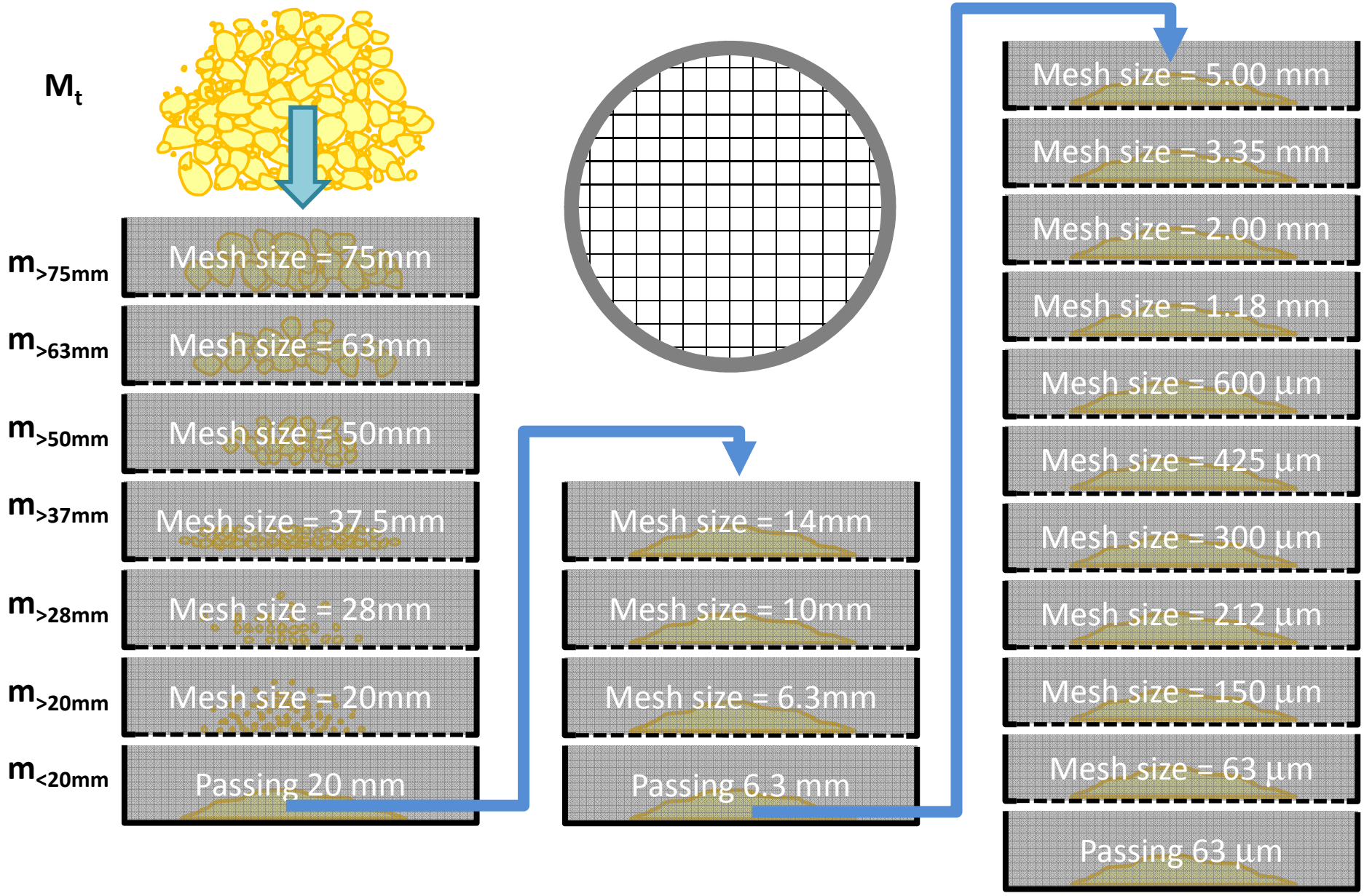

**Aperture Size**

$w$ = aperture size
$d$ = wire diameter
$p$ = pitch ($w + d$)

[3]

[2] vjtech (2013b), [3] BSI 410-1:2000

# Particle Size Distribution [PSD]



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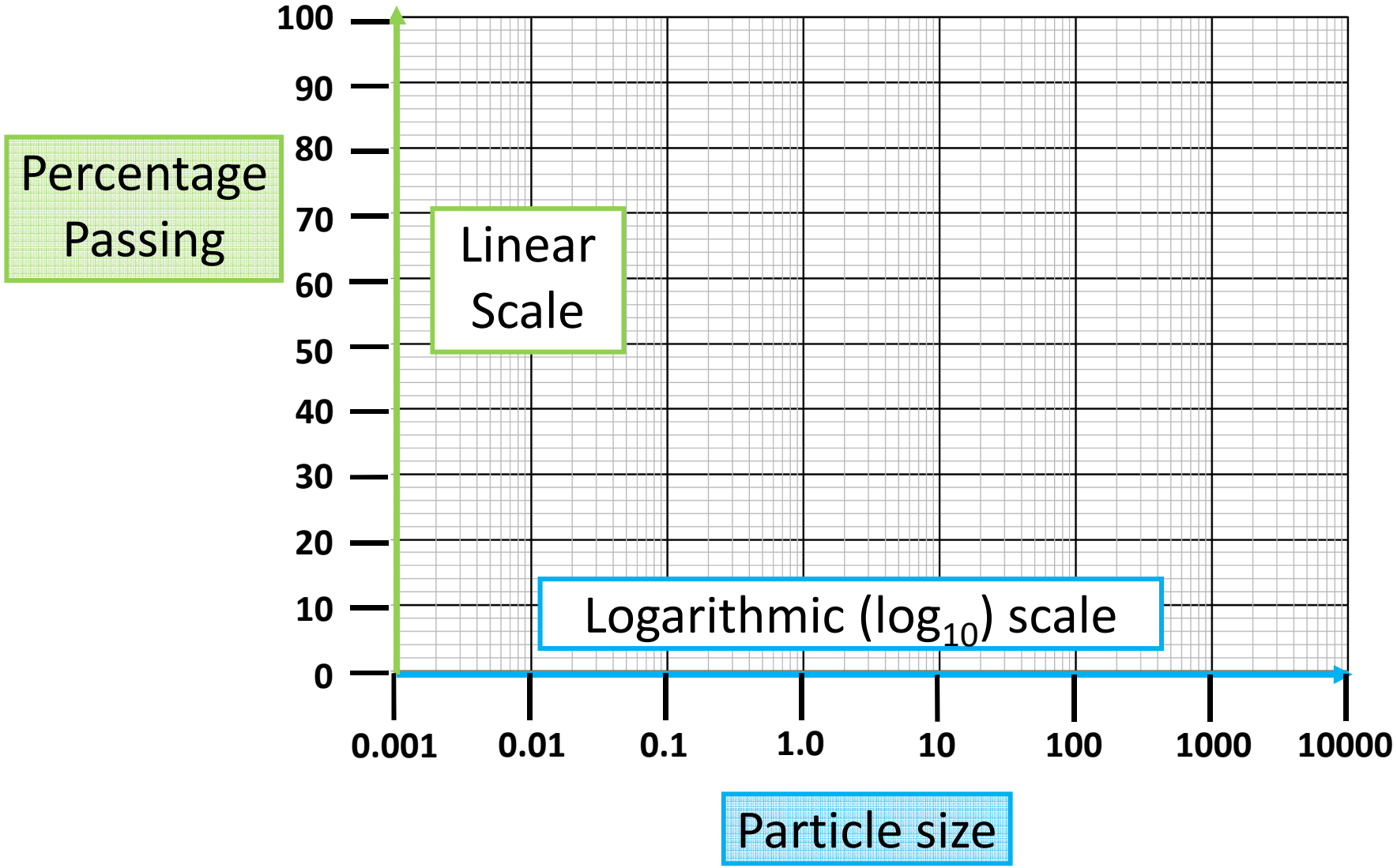
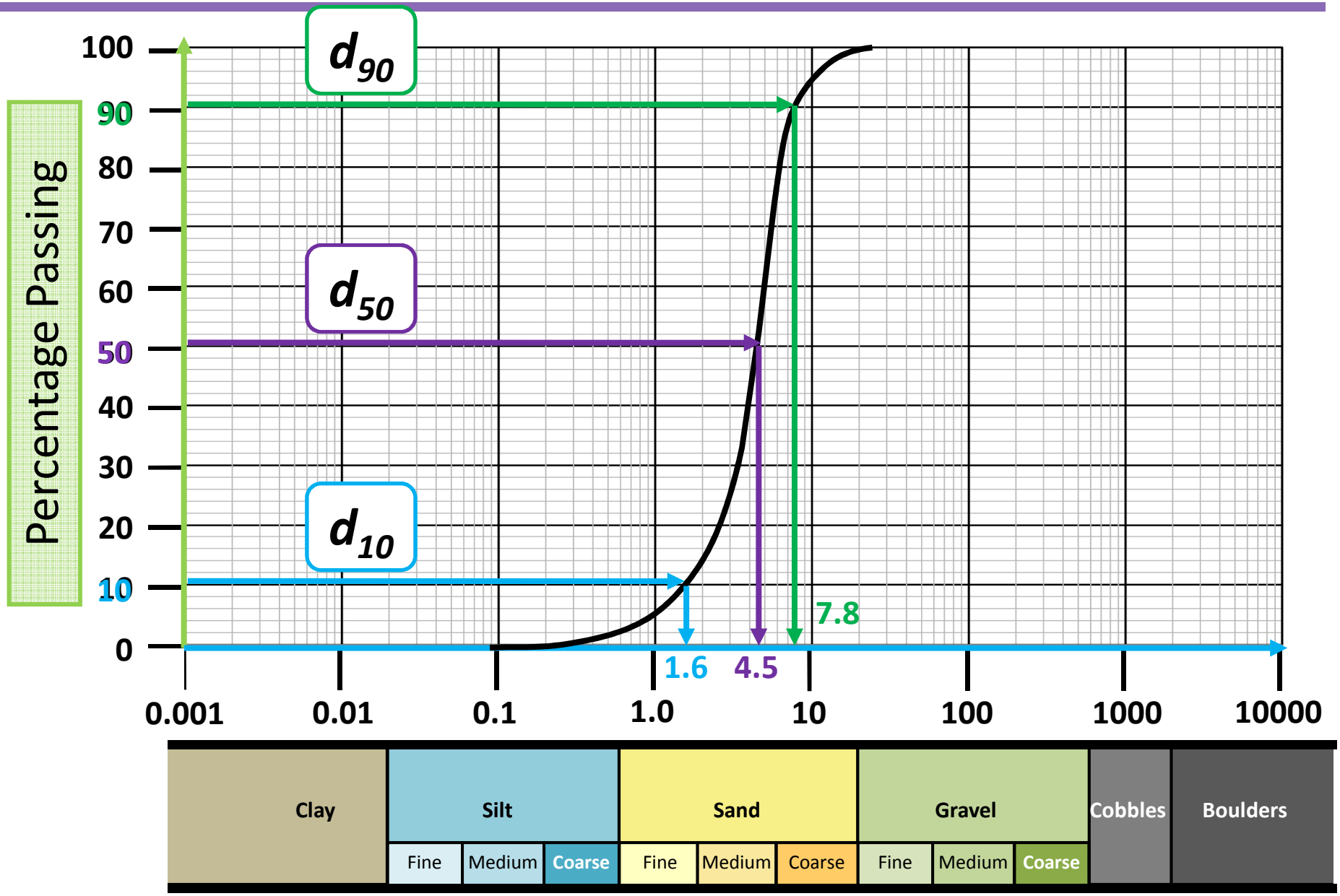
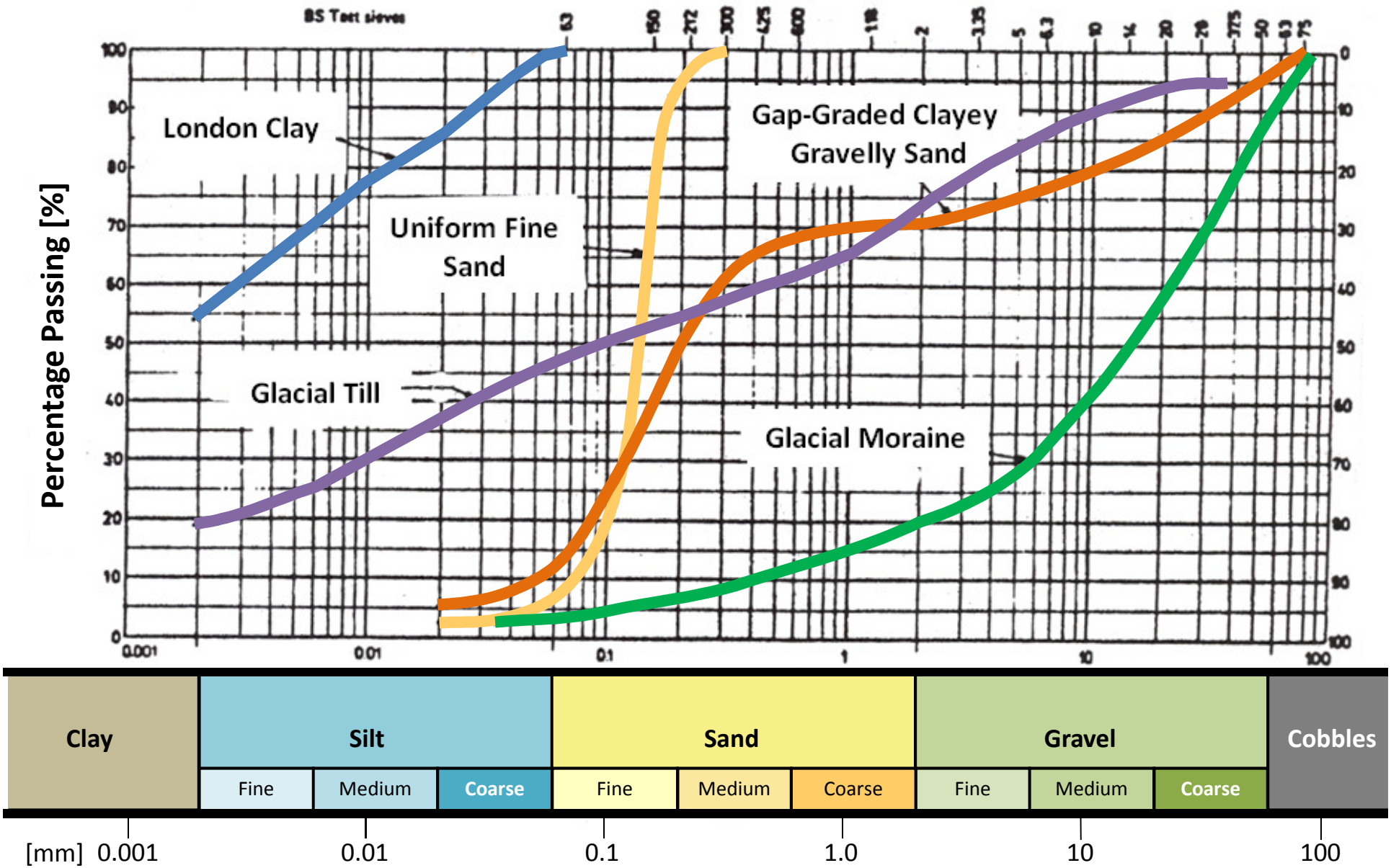


# Particle Size Distribution [PSD]



# Particle Size Distribution [PSD]



# PSD – grading descriptions

**Well Graded**

**Silty Clayey SAND**

**Glacial Till**

**Poorly Graded**

**Uniformly Graded**

**Clay**

**Gap-Graded**

# PSD – parameters

## $d_{50}$

- The diameter at which 50% of grains are smaller than

## Coefficient of Uniformity, $C_u$

$$C_u = \frac{d_{60}}{d_{10}}$$

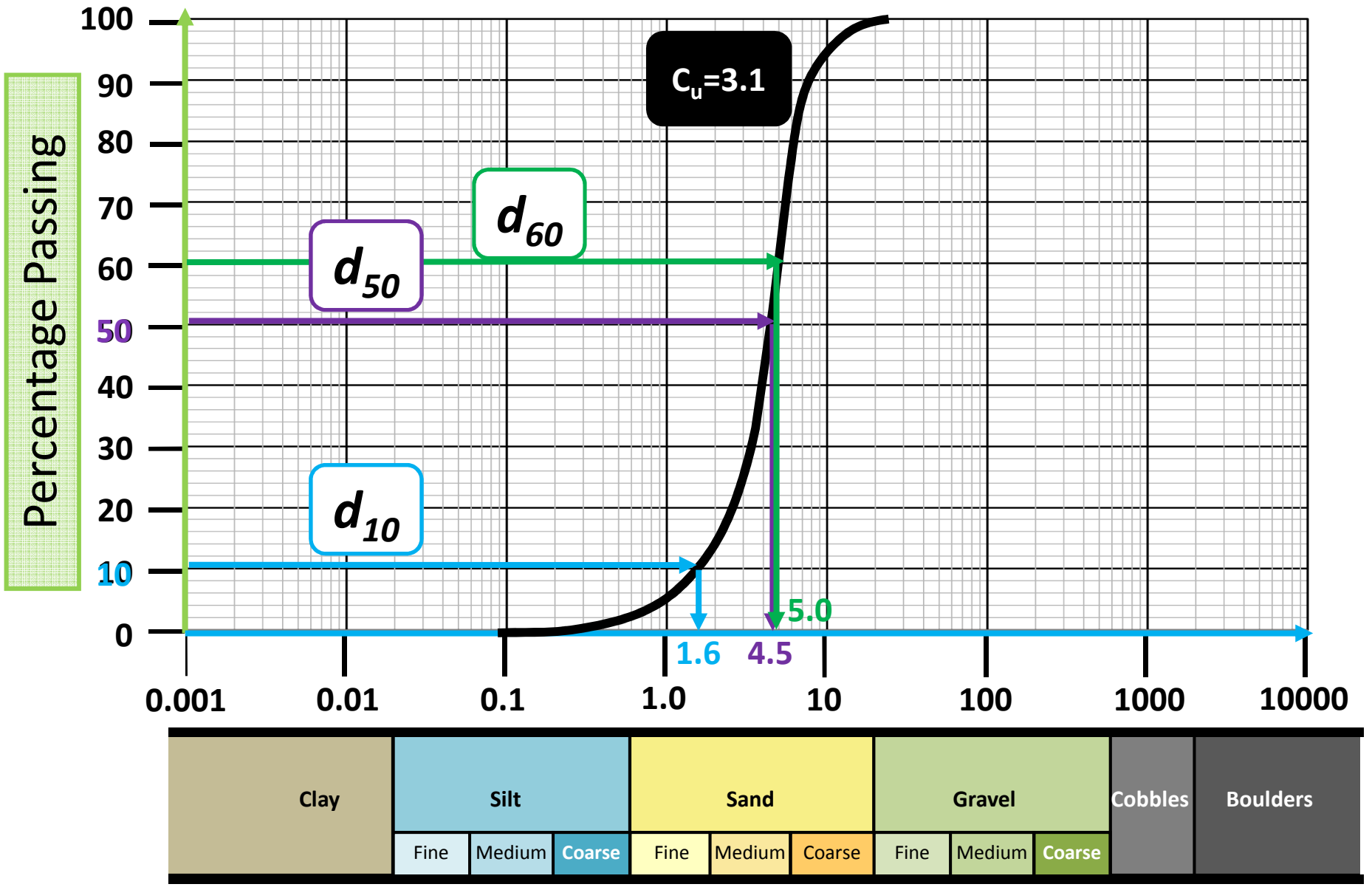
- $d_{60}$, The diameter at which 60% of grains are smaller than
- $d_{10}$, The diameter at which 10% of grains are smaller than

## Coefficient of Curvature, $C_z$

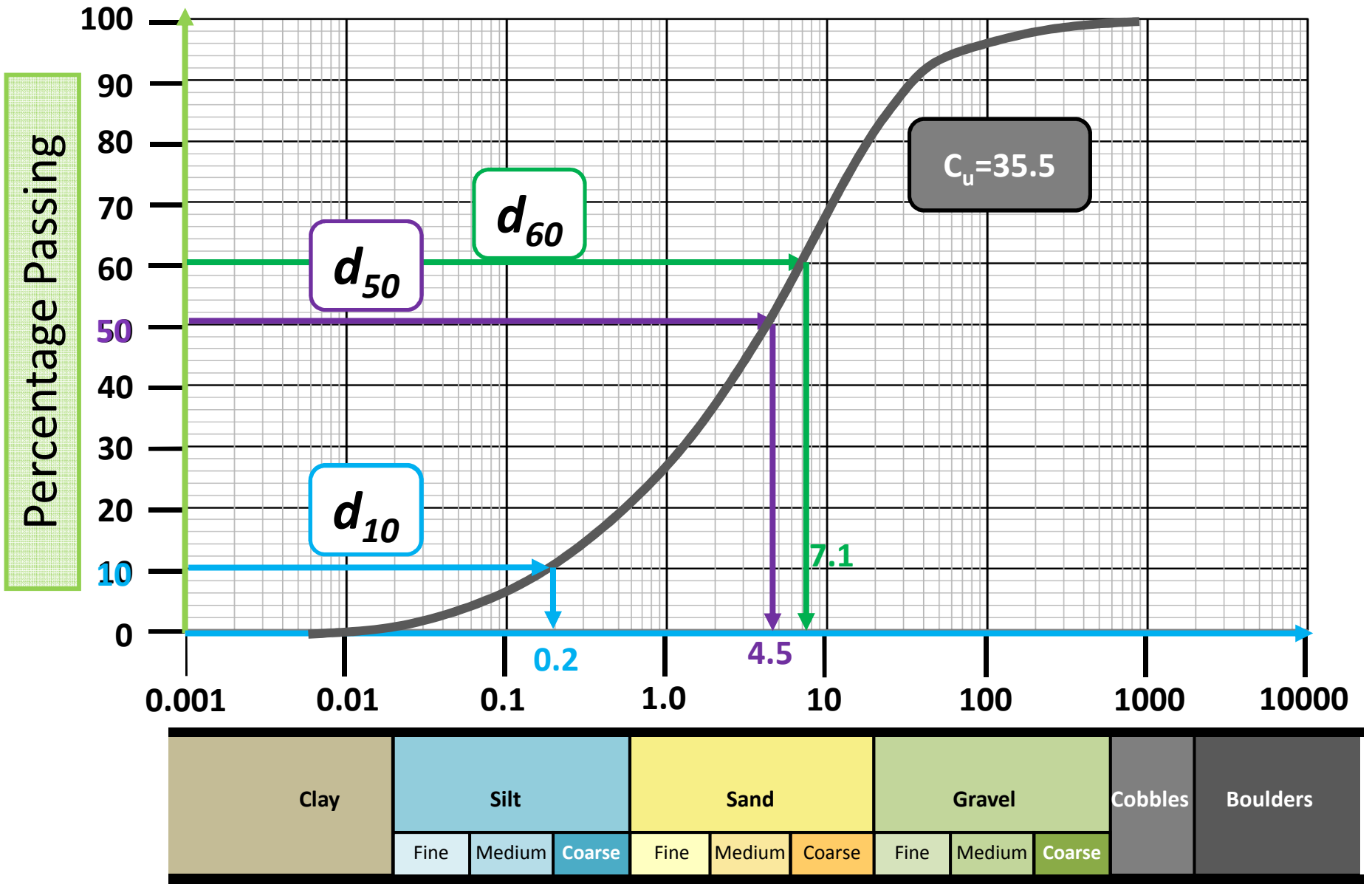
$$C_z = \frac{(d_{30})^2}{d_{60} \cdot d_{10}}$$

- $d_{30}$, The diameter at which 30% of grains are smaller than

# Particle Size Distribution [PSD]



# Particle Size Distribution [PSD]



# PSD – parameters

## Coefficient of Uniformity, $C_u$

⇧ $C_u$ ⇧ *range of sizes*

$$C_u = \frac{d_{60}}{d_{10}}$$

## Coefficient of Curvature, $C_z$

$1 < C_z < 3$

***Well graded***
***Poorly sorted***

$$C_z = \frac{(d_{30})^2}{d_{60} \cdot d_{10}}$$

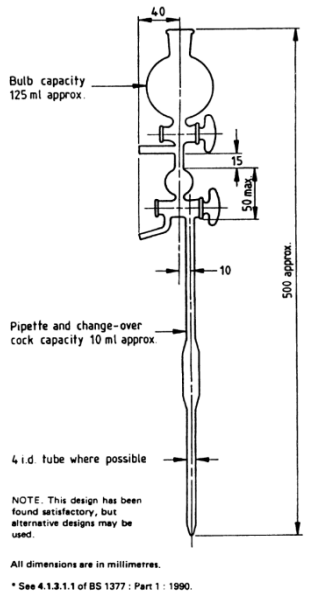
# Fine fraction

Classification of particle size

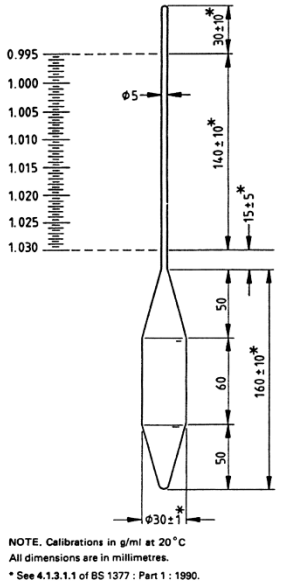
# Sedimentation

Methods to determine the particle size distribution of fine particles (< 425 microns) involve sedimentation analysis

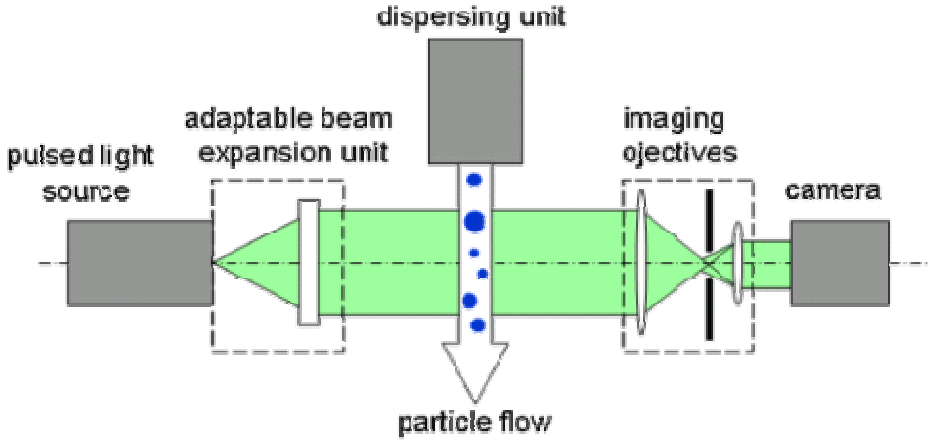
## Pippette




## Hydrometer




## Laser diffraction




(Above) Sympatec (2013) *Sympatec's Image Analysis Overview and Concept*. [Online]

**Settling Velocity:**
**The speed with which particles of a certain diameter settle out from a fluid**

**Dispersing Agent:**
**Added to soil/water solution to prevent particles from sticking together**

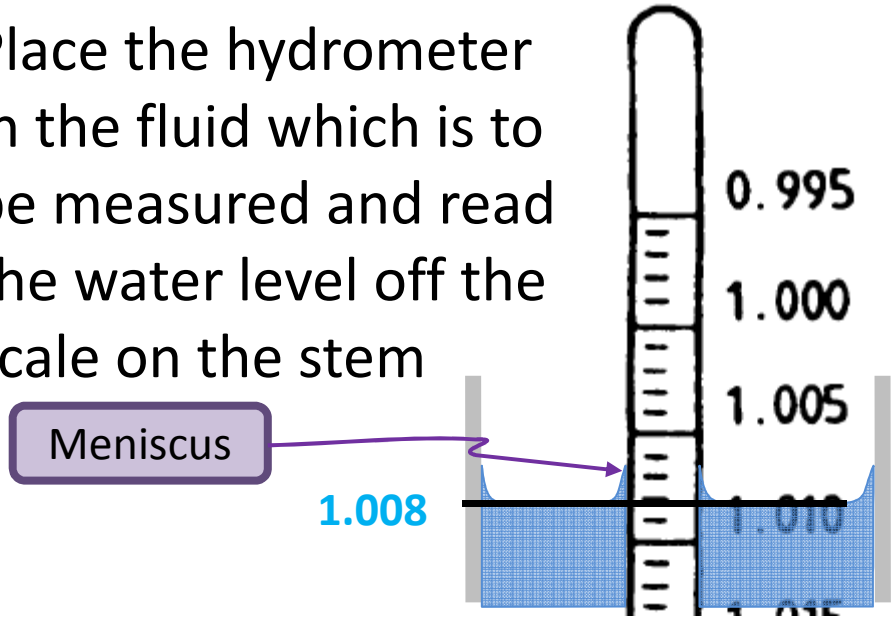
# Hydrometer

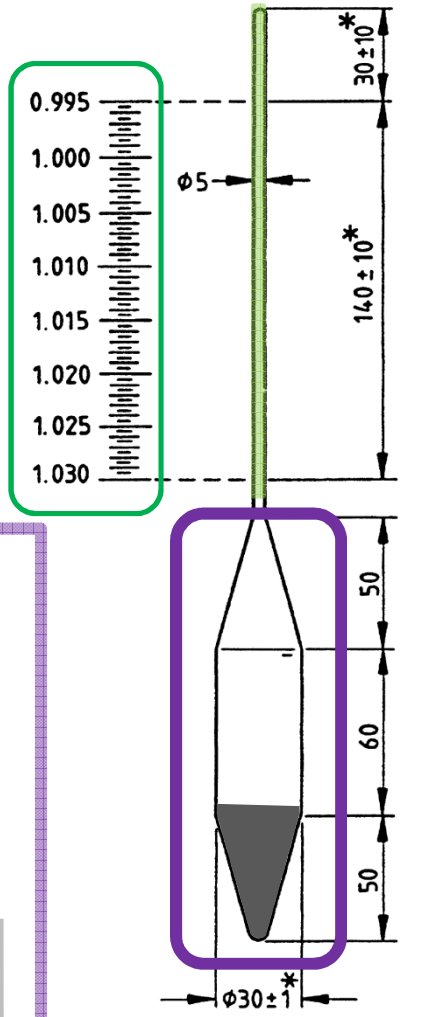
A device to measure the density of a fluid.

Consists of:

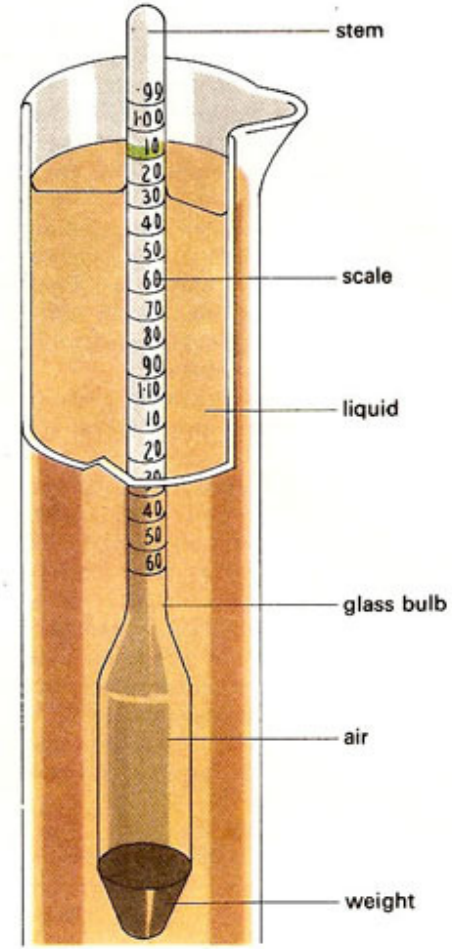
- graduated stem
- glass bulb

Place the hydrometer in the fluid which is to be measured and read the water level off the scale on the stem




NOTE. Calibrations in g/ml at 20 °C
All dimensions are in millimetres.
* See 4.1.3.1.1 of BS 1377 : Part 1 : 1990.



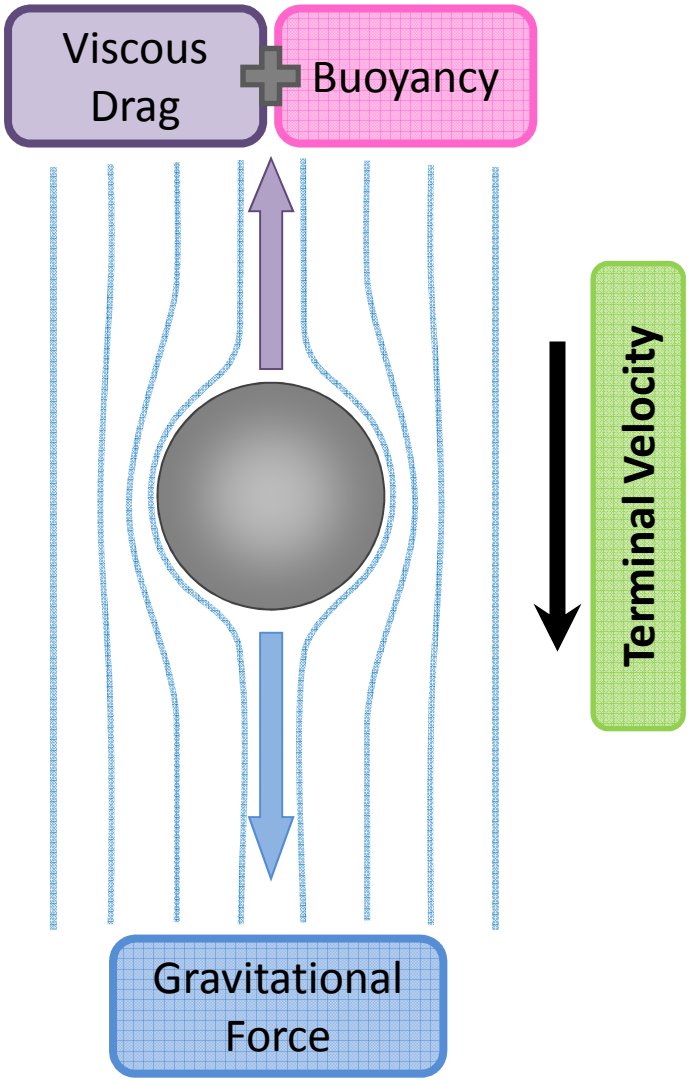

(above) daviddarling (2013) *Hydrometer*. [Online]
(Left) BSI (1990) BS 1377-2

# Hydrometer

## Stokes Law:

- Smooth spherical particles
- Laminar flow
- Not applicable to particles <0.2 microns in diameter

***Brownian Motion***




## Real Soils:

- A range of particle roughness's
- Non-spherical particles!

**Elongated**

**Platy**

# Nature and State

**Sands**

## Nature;

The essential characteristics or basic qualities of the soil

- Particle Size Distribution
- Max Void Ratio $e_{max}$
- Min Void Ratio $e_{min}$
- Mineral Composition

## State;

The physical condition in which the soil exists

- Insitu Void Ratio $e_{insitu}$
- Natural Water Content, w
- Relative Density $D_r$
- Grain Structure

# Learning Outcomes

# Learning outcomes

1. Explain how particle size distributions (PSD) are measured for soils
2. Explain the terms:
   a) Well graded,
   b) Gap graded,
   c) Poorly graded,

   …and sketch their typical PSD's
3. Write down the definitions for:
   a) Void Ratio, $e$,
   b) Specific Volume, $v$,
   c) Porosity, $n$,
   d) Water Content, $w$,
   e) Degree of Saturation, $S_r$
   f) Coefficient of Uniformity, $C_u$

# Learning outcomes

4. Sketch phase diagrams for:
   a) Dry,
   b) Fully Saturated,
   c) Partly Saturated soils

5. Working from the definitions of e, v and the phase relationships show:
   a) $v = e + 1$ b) $e = \frac{n}{1-n}$ c) $n = \frac{e}{1+e}$
   d) $\rho = G_s \cdot \rho_w \cdot \left( \frac{1+w}{1+e} \right)$

6. Plot and interpret a PSD, on semi-log graph paper, from sieve data

# Learning outcomes

7. Read $d_x$ (eg. $d_{10}$, $d_{50}$, $d_{90}$) data from PSD curves.

8. Calculate $C_u$ and $C_z$ values from PSD curves.

9. Understand and explain the difference between *nature* and *state*, giving examples of parameters which give and indication of each of the properties.

# References


Atkinson, J. H. (2007) *The Mechanics of Soils and Foundations.* 2nd Ed., London, Taylor & Francis. Section 5.1.

Barnes, G.E. (2000) Soil Mechanics: Principles and Practice. 2nd Ed., Houndmills, Palgrave.

BSI (1990) BS 1377-2 *Methods of test for soils for civil engineering purposes – Part 2: Classification tests.* London, British Standards Institution.

BSI (1999) BS 5930:1999 + A2:2010 *Code of practice for site investigations.* London, British Standards Institution.

BSI (2000) BS 410-1:2000, ISO 3310:2000 *Test sieves. Technical requirements and testing. Test sieves of metal wire cloth. London*, British Standards Institution.

Gasparre, A (2005) *Advanced laboratory characterisation of London Clay*. PhD thesis, Imperial College London.

Knappett, J.A. & Craig, R.F. (2012) *Craig's Soil Mechanics*. 8th Ed, Abingdon, Spon Press.

Schneider et al. (2011) Insights into pore-scale controls on mudstone permeability through resedimentation experiments. *Geology* **39** (11): 1011-1014.

**For interest:**

Head, K.H. (1980). *Manual of Soil Laboratory Testing. Vol.1, Soil Classification and Compaction Tests,* Pentech Press, London.

# Image references

daviddarling (2013) *Hydrometer*. [Online] Available from: http://www.daviddarling.info/encyclopedia/H/hydrometer.html , [Accessed: 14/08/2013], [Modified: 18/06/2013]

Sympatec (2013) *Sympatec's Image Analysis Overview and Concept*. [Online] Available from: http://www.sympatec.com/EN/ImageAnalysis/ImageAnalysis.html [Accessed: 14/08/2013], [Modified: 05/08/2013]

[1] vjtech (2013) VJT0017 - Riffle Box (Slot Width 13 mm, 12 Slots) [Online], Available from: http://www.vjtech.co.uk/Products/SoilRock/ClassificationTesting/tabid/205/ProdID/402/CatID/83/Riffle_Boxes.aspx [Accessed: 9th Aug 2013].

[2] vjtech (2013b) VJT-200W-xx.xxMM - Stainless Steel Mesh Sieve (200 mm Diameter - selected mm apertures) [Online], Available from: http://www.vjtech.co.uk/Products/SoilRock/ClassificationTesting/tabid/205/ProdID/380/CatID/83/Stainless_Steel_Mesh_Sieve_200_mm_diameter__selected_mm_apertures.aspx [Accessed: 9th Aug 2013].