



ECIV 3302

Engineering Geology

CHAPTER 2

ORIGIN OF SOIL AND GRAIN SIZE

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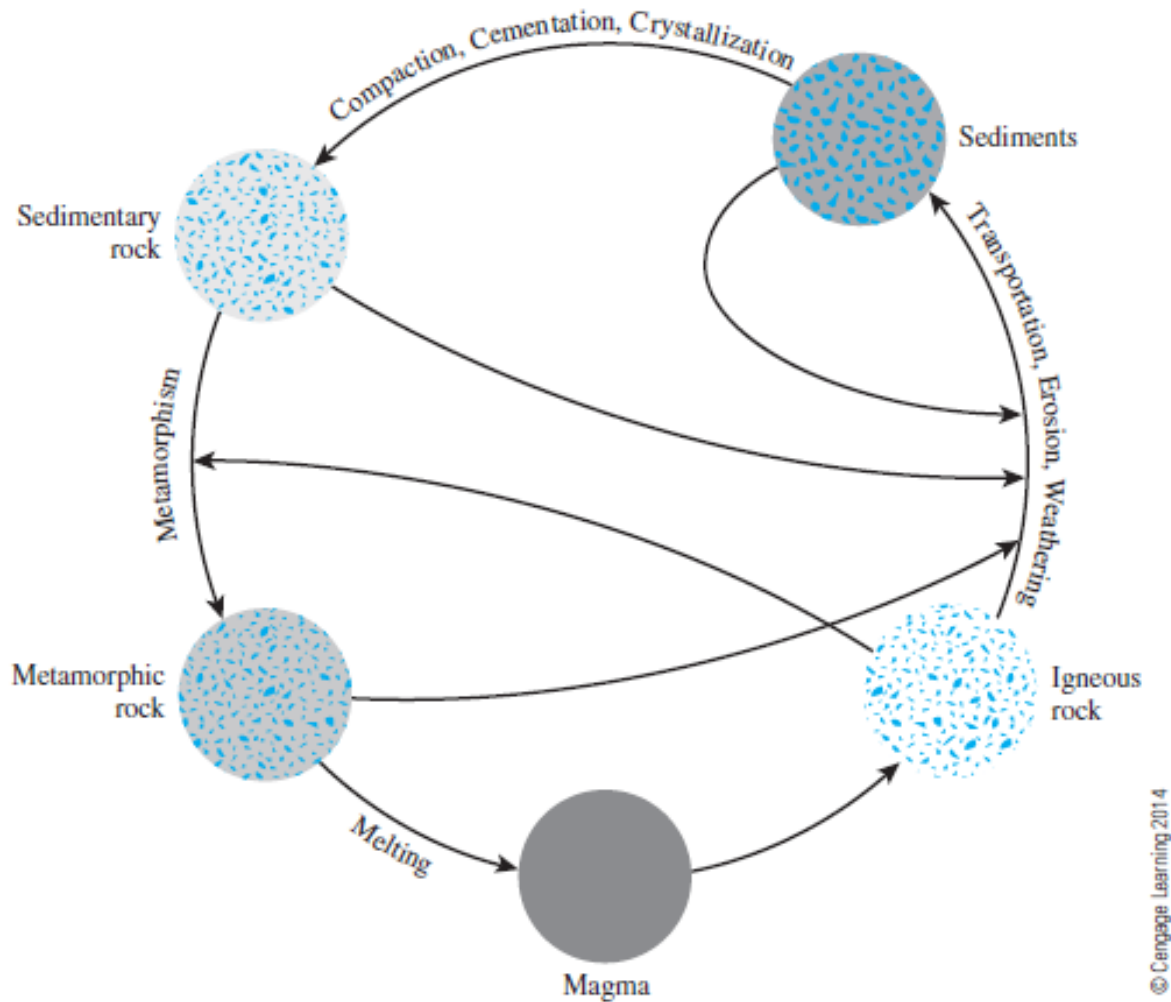
Islamic University of Gaza, Palestine

The materials are mostly adapted from the presentation of Ahmed Abu Foul

According to Terzaghi (1948):

“**Soil Mechanics** is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles produced by the mechanical and chemical disintegration of rocks regardless of whether or not they contain an admixture of organic constituent.”

Rock Cycle and the Origin of Soil



The final products due to weathering are **soils**

Figure 2.1 Rock cycle

Soil Formation

Parent Rock

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graph TD; A[Parent Rock] --> B[Residual soil]; A --> C[Transported soil]
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Residual soil

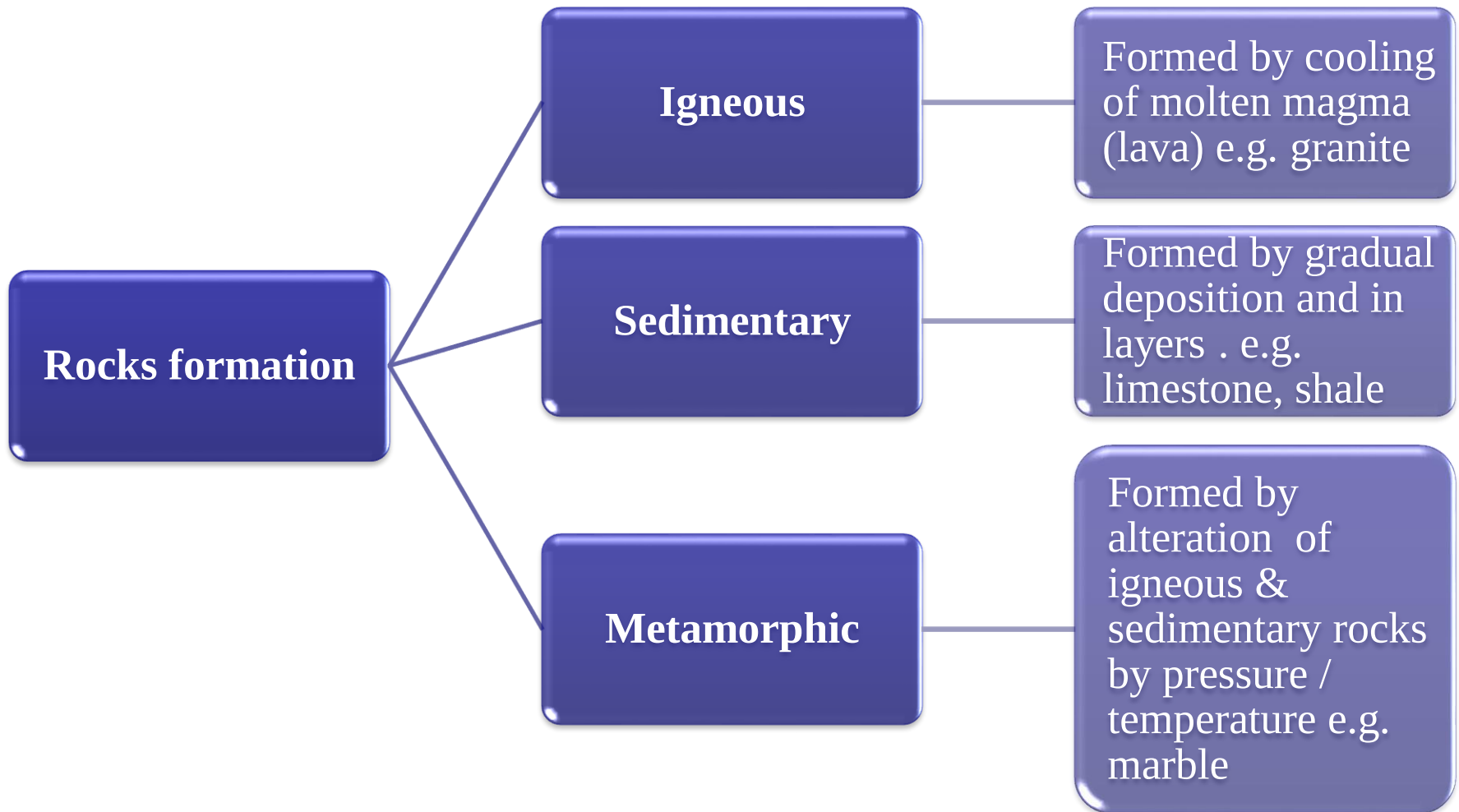
~ in situ weathering (by physical & chemical agents) of parent rock

Transported soil

~ weathered and **transported** far away

by wind, water and ice.

Parent Rocks



Specific Gravity (Gs)

Definition

Specific gravity is defined as the ratio of the unit weight of a given material to the unit weight of water.

$$\text{Specific gravity} = \frac{\text{Weight of a Substance}}{\text{Weight of an Equal Volume of Water}}$$

Unit weight of Water is:

$$W = 1 \text{ g /cm}^3 \text{ (strictly accurate at } 4^\circ \text{ C)}$$

$$W = 62.4 \text{ pcf}$$

$$W = 9.81 \text{ kN/m}^3$$

Specific Gravity (Gs)

Table 2.2 Specific gravity of important minerals

Mineral	Specific gravity, G_s
Quartz	2.65
Kaolinite	2.6
Illite	2.8
Montmorillonite	2.65–2.80
Halloysite	2.0–2.55
Potassium feldspar	2.57
Sodium and calcium feldspar	2.62–2.76
Chlorite	2.6–2.9
Biotite	2.8–3.2
Muscovite	2.76–3.1
Hornblende	3.0–3.47
Limonite	3.6–4.0
Olivine	3.27–3.37

Mechanical Analysis of Soil

Mechanical analysis is the determination of the **size range** of particles present in a soil, expressed as a **percentage** of the total **dry weight**.

Two methods that generally utilized to determine the particle size distribution of soil:

1. **Sieve Analysis** (for particle sizes $> 0.075\text{mm}$ in diameter)
2. **Hydrometer Analysis** (“ “ “ $< 0.075\text{mm}$ “ “)

Sieve analysis

Sieve analysis consists of shaking the soil sample through a set of sieves that have progressively smaller openings.



Standard Sieves

Sieve Number	Opening Size (mm)
4	4.750
6	3.350
8	2.360
12	1.680
16	1.180
20	0.850
30	0.600
40	0.425
50	0.300
60	0.250
80	0.180
100	0.150
140	0.106
200	0.075
270	0.053

Particle Size Distributions and Soil Particle Characteristics

Particle size distribution **curve** is a representation in **graphical or tabular** form of the various (diameter) grain sizes in a soil, determined through sieving and sedimentation.

The **particle diameters** are plotted in **log scale**, and the corresponding **percent finer** in **arithmetic scale**.

Particle-size distribution curve

1

- Determine the mass of soil retained on each sieve (i.e., $M_1, M_2, \dots, M_n$) and in the pan (i.e., M_p)

2

- Determine the total mass of soil :
 $M_1 + M_2 + \dots + M_i + \dots + M_n + M_p = \sum M$.

3

- Determine the cumulative mass of soil retained above each sieve . For the i th sieve, it is $M_1 + M_2 + \dots + M_i$

4

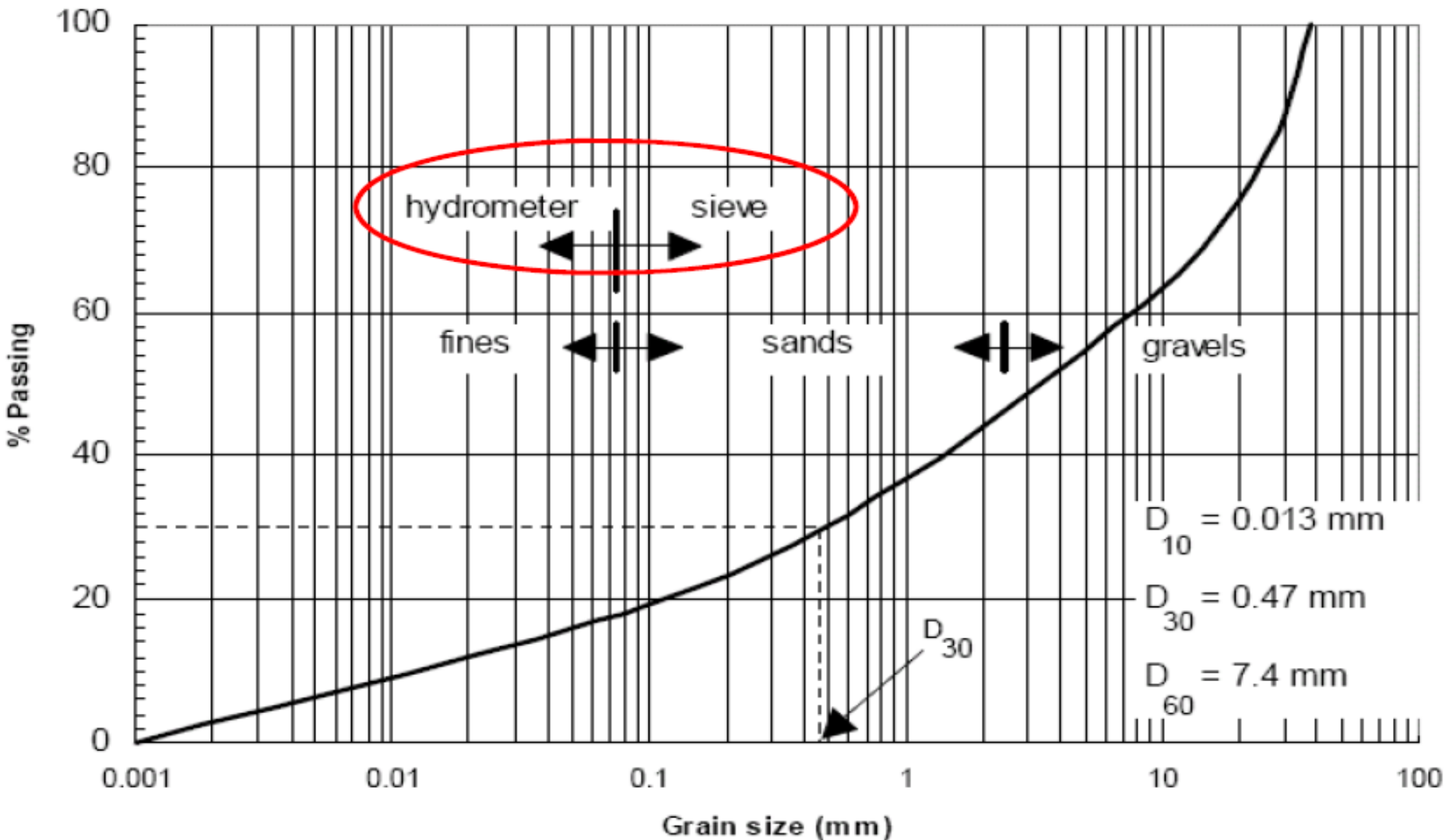
- The mass of soil passing the i th sieve is $\sum M - (M_1 + M_2 + \dots + M_i)$

5

- The percent of soil passing the i th sieve (or percent finer) is

$$F = \frac{\sum M - (M_1 + M_2 + \dots + M_i)}{\sum M} * 100$$

Particle Size Distribution Curve

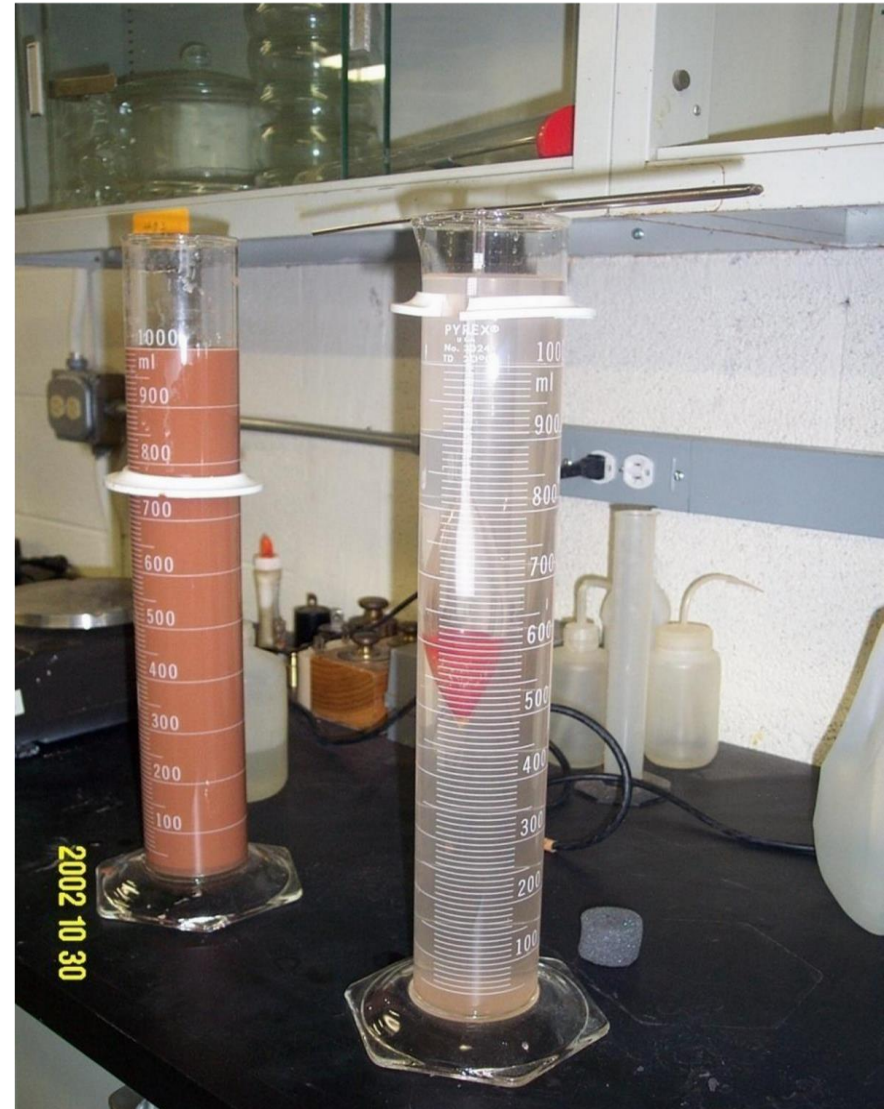


SILT & CLAY

SAND

GRAVEL

Hydrometer Analysis



Hydrometer Analysis

Hydrometer analysis is based on the principle of sedimentation of soil grains in water. When a soil specimen is dispersed in water, the particles settle at different velocities, depending on their shape, size and weight, and the viscosity of the water.

For simplicity, it is assumed that all the soil particles are spheres and that the velocity of soil particles can be expressed by Stokes' law.



Figure 2.28 ASTM 152H hydrometer (Courtesy of ELE International)



Figure 2.29 ASTM 152H type of hydrometer placed inside the sedimentation cylinder (Courtesy of Khaled Sobhan, Florida Atlantic University, Boca Raton, Florida)

Hydrometer Analysis

- Also called Sedimentation Analysis
- Stoke's Law

$$v = \frac{\rho_s - \rho_w}{18\eta} D^2 \quad (2.1)$$

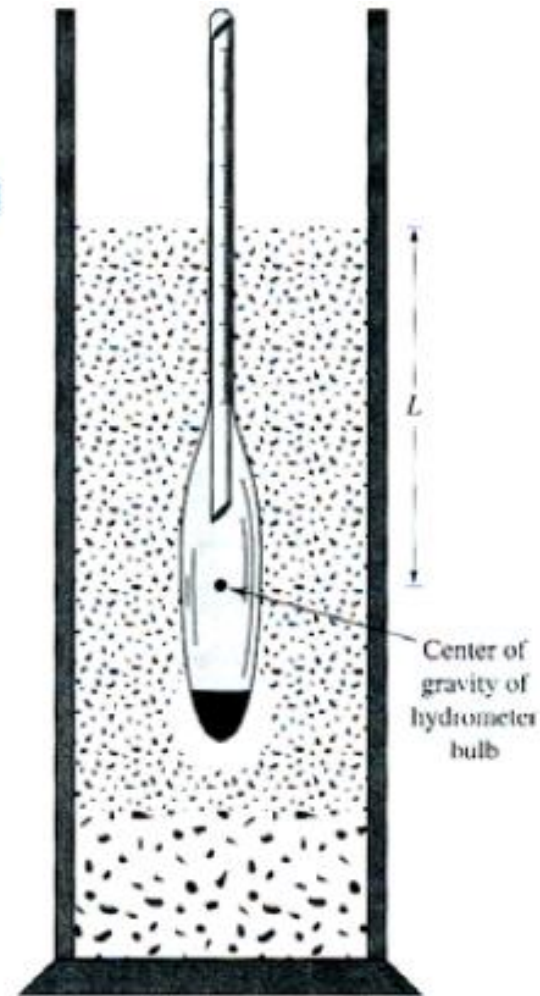
where v = velocity

ρ_s = density of soil particles

ρ_w = density of water

η = viscosity of water

D = diameter of soil particles



$$v = \frac{\rho_s - \rho_w}{18\eta} D^2 \quad (2.1)$$

Thus, from Eq. (2.1),

$$D = \sqrt{\frac{18\eta v}{\rho_s - \rho_w}} = \sqrt{\frac{18\eta}{\rho_s - \rho_w}} \sqrt{\frac{L}{t}} \quad (2.2)$$

where $v = \frac{\text{Distance}}{\text{Time}} = \frac{L}{t}$.

Note that

$$\rho_s = G_s \rho_w \quad (2.3)$$

Thus, combining Eqs. (2.2) and (2.3) gives

$$D = \sqrt{\frac{18\eta}{(G_s - 1)\rho_w}} \sqrt{\frac{L}{t}} \quad (2.4)$$

If the units of η are $(\text{g} \cdot \text{sec})/\text{cm}^2$, ρ_w is in g/cm^3 , L is in cm , t is in min , and D is in mm , then

$$\frac{D(\text{mm})}{10} = \sqrt{\frac{18\eta [(\text{g} \cdot \text{sec})/\text{cm}^2]}{(G_s - 1)\rho_w (\text{g}/\text{cm}^3)}} \sqrt{\frac{L (\text{cm})}{t (\text{min}) \times 60}} \quad D = \sqrt{\frac{18\eta}{(G_s - 1)\rho_w}} \sqrt{\frac{L}{t}}$$

or

$$D = \sqrt{\frac{30\eta}{(G_s - 1)\rho_w}} \sqrt{\frac{L}{t}}$$

Assume ρ_w to be approximately equal to $1 \text{ g}/\text{cm}^3$, so that

$$D (\text{mm}) = K \sqrt{\frac{L (\text{cm})}{t (\text{min})}} \quad (2.5)$$

where

$$K = \sqrt{\frac{30\eta}{(G_s - 1)}} \quad (2.6)$$

Note that the value of K is a function of G_s and η , which are dependent on the temperature of the test. Table 2.6 gives the variation of K with the test temperature and the specific gravity of soil solids.

Table 2.6 Values of K from Eq. (2.6)^a

Temperature (°C)	G_s							
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.01323
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01225	0.01208	0.01191
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01169

^aAfter ASTM (2004). Copyright ASTM INTERNATIONAL. Reprinted with permission.

Some commonly used measures are:

Effective size: (D_{10}) It is the diameter in the particle size distribution curve corresponding to 10% finer. (maximum size of the smallest 10% of the soil). The effective size of a granular soil is a good measure to estimate the hydraulic conductivity and drainage through soil.

Uniformity Coefficient: $C_u = D_{60}/D_{10}$

It is the ratio of the maximum diameter of the smallest 60% to the effective size. A **well graded soil** will have

- $C_u > 6$ for **sands**
- $C_u > 4$ for **gravels**

Some commonly used measures are:

Coefficient of Curvature:

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}}$$

D_{30} = Diameter corresponding the 30% finer

Clay Fraction: (CF)

It is the percentage by dry mass of particles smaller than 0.002mm (2 μ m), and is an index property frequently quoted relation to fine grained soils (soils with 50% or more finer than 63 μ m). It has a strong influence on the engineering properties of fine grained soils.

Some commonly used measures are:

Sorting Coefficient (S_0):

This parameter is another measure of uniformity and is generally encountered in geologic works and expressed as:

$$S_0 = \sqrt{\frac{D_{75}}{D_{25}}}$$

Definitions

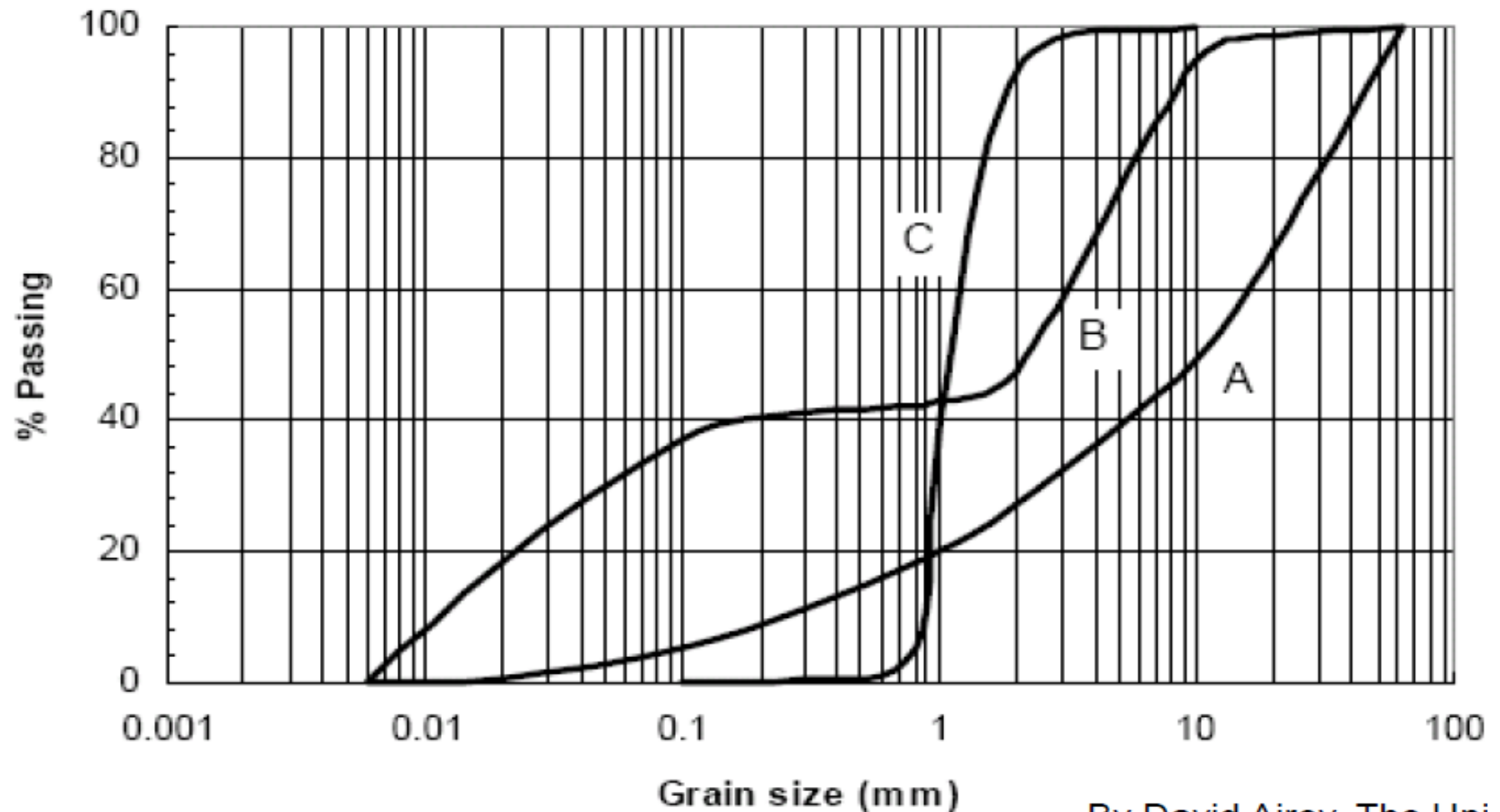
Well – Graded Material

Contains particles of a wide range of sizes. The smaller particles fill the spaces left between the larger particles; therefore the soil has greater strength than a poorly graded soil, and lower permeability.

Poorly – Graded Material

Contains a large portion of uniformly sized particles. This particular soil has larger voids in its structure and poor strength along with high permeability.

Definitions



Soil A: Well Graded

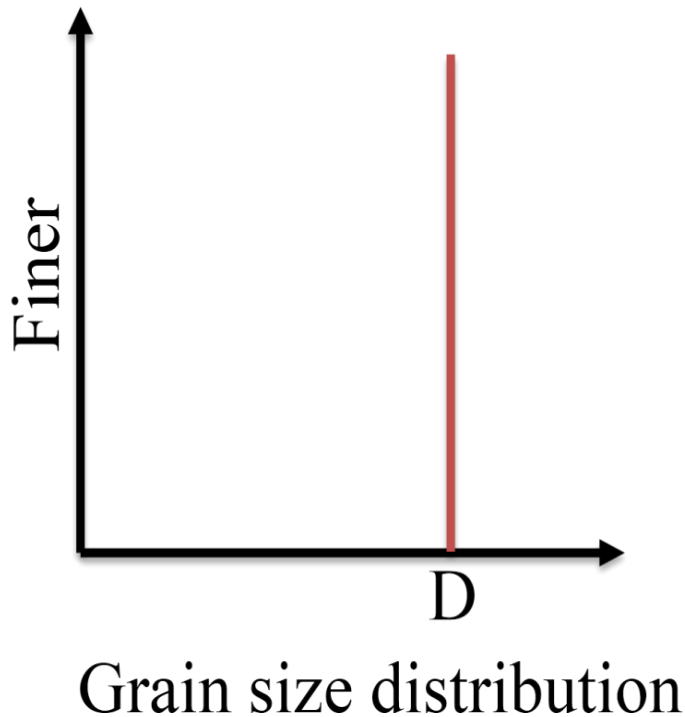
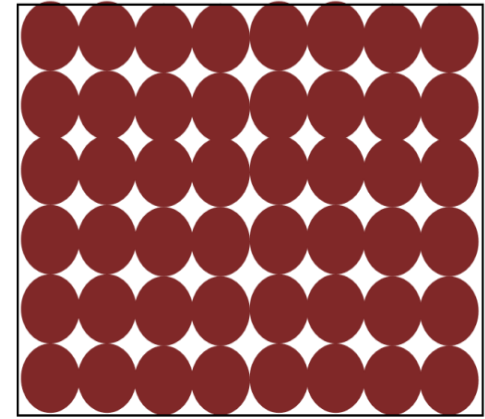
Soil B: Poorly Graded

Soil C: Uniform

By David Airey, The Uni

Question

What is the C_u for a soil with only one grain size?



Uniformity Coefficient (C_u)

$$C_u = \frac{D_{60}}{D_{10}} = 1$$

Example

The results of a particles size analysis are shown in the table below (***Given:** The total mass 469g*)

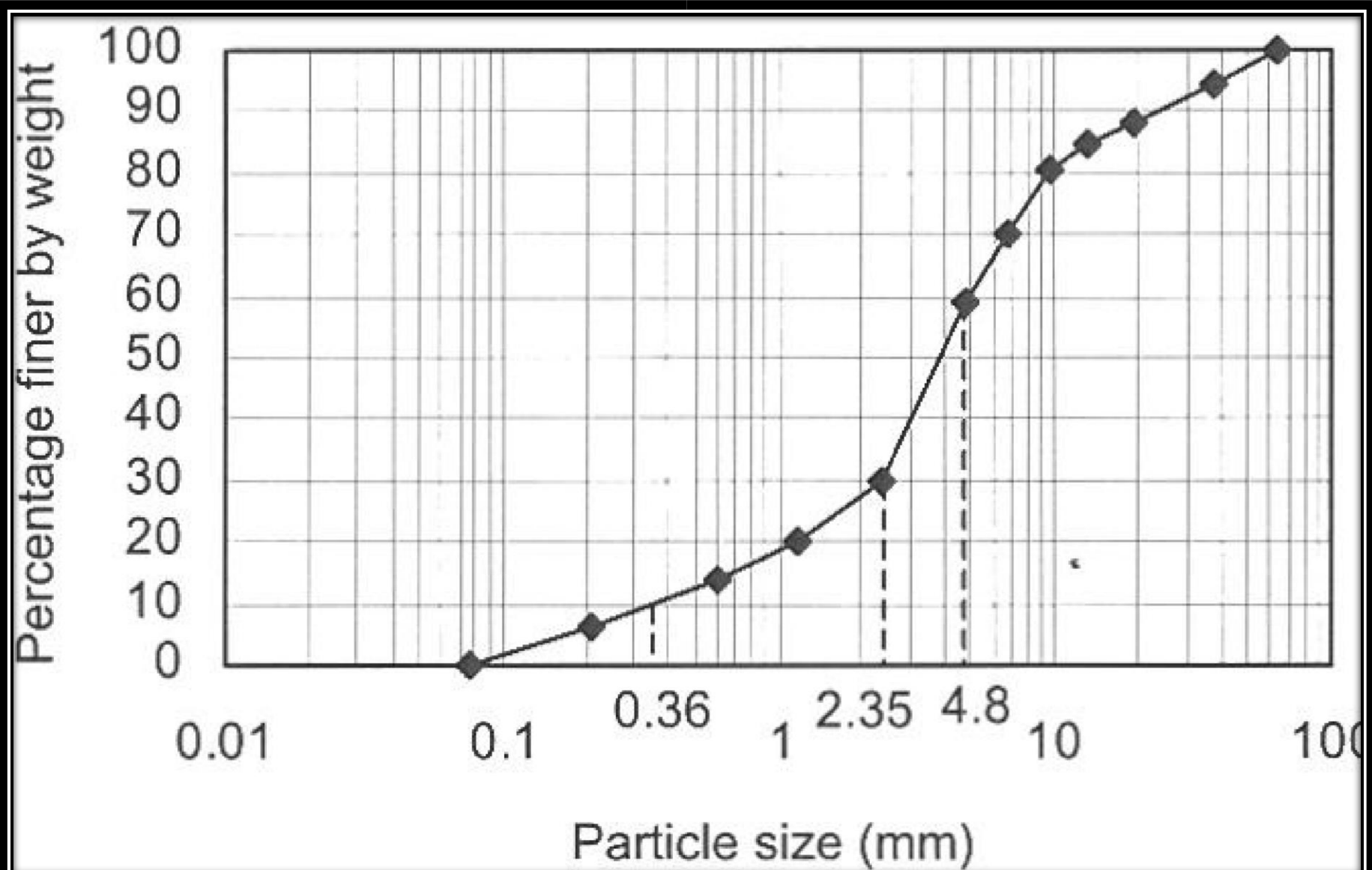
Sieve size (mm)	Mass retained (g)	Sieve size (mm)	Mass retained (g)
63	0.0	4.75	50
37.5	26	2.36	137
19.0	28	1.18	46
13.2	18	0.6	31
9.5	20	0.212	34
6.7	49	0.075	30

- 1-Plot the particle size distribution curve
- 2-Determine the coefficient of uniformity
- 3-Determine the coefficient of gradation

The calculations are summarized in the table below

Particle size (mm)	Individual mass retained (g)	Individual percentage retained	Cumulative percentage retained	Cumulative percentage finer
63	0.0	0.00	0.00	100.00
37.5	26	5.54	5.54	94.46
19	28	5.97	11.51	88.49
13.2	18	3.84	15.35	84.65
9.5	20	4.26	19.61	80.39
6.7	49	10.45	30.06	69.94
4.75	50	10.66	40.72	59.28
2.36	137	29.21	69.93	30.07
1.18	46	9.81	79.74	20.26
0.6	31	6.61	86.35	13.65
0.212	34	7.25	93.60	6.40
0.075	30	6.40	100.00	0.00

Particle size distribution curve



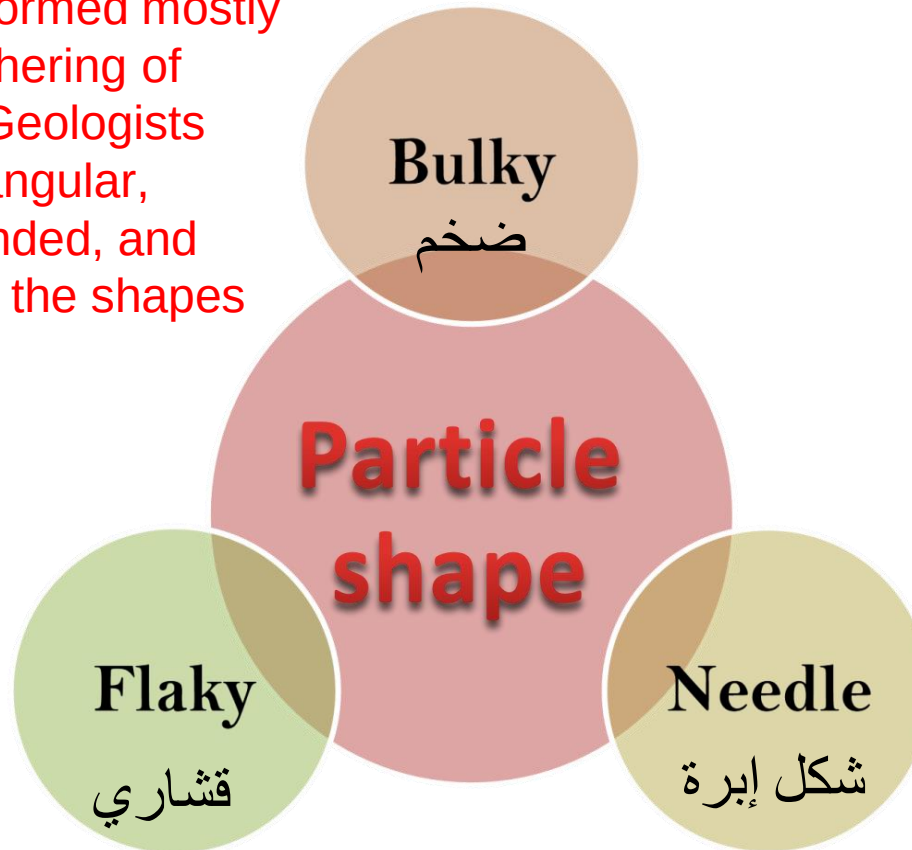
The coefficient of uniformity = $C_U = \frac{D_{60}}{D_{10}} = \frac{4.8}{0.36} = 13.3$

The coefficient of gradation = $C_c = \frac{D_{30}^2}{D_{60}D_{10}} = \frac{2.35^2}{4.8 * 0.36} = 3.2$

Particle shape

The shape of particles present in a soil mass is equally as important as the particle-size distribution because it has significant influence on the physical properties of a given soil.

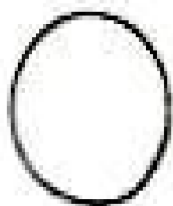
Bulky particles are formed mostly by mechanical weathering of rock and minerals. Geologists use such terms as angular, subangular, subrounded, and rounded to describe the shapes of bulky particles.



Needle-shaped particles are much less common than the other two particle types. Examples of soils containing needle-shaped particles are some coral deposits and attapulgite clays.

Flaky particles have very low sphericity. These particles are predominantly clay minerals.

Rounded



Spherical



Irregular



**Highly
irregular**

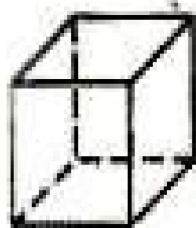


**Flat or
oblate**

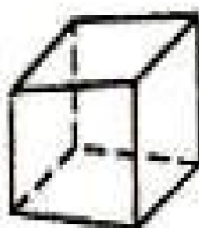


**Elongated
(needle-like)**

Angular



Cubical



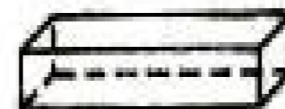
**Irregular
(chunky)**



**Highly
irregular**



**Flat or
flaky**



**Elongated
(prismatic)**

H.W

**All Problems page 63-65 related to
issues discussed on the class**