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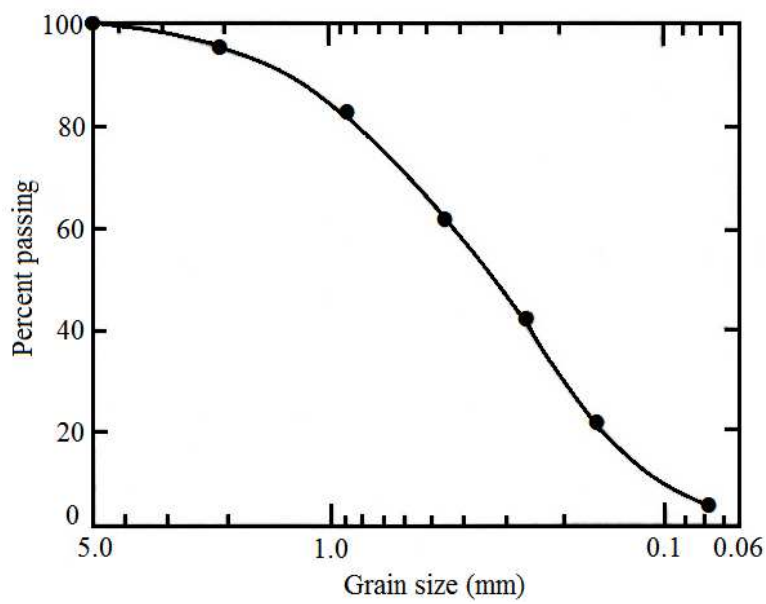
Chapter 2

2.1 a. **True**
b. **False**
c. **True**
d. **True**
e. **True**

2.2 a.

Sieve No.	Mass of soil retained on each sieve (g)	Percent retained on each sieve	Percent finer
4	0.0	0.0	**100.0**
10	18.5	4.4	**95.6**
20	53.2	12.6	**83.0**
40	90.5	21.5	**61.5**
60	81.8	19.4	**42.1**
100	92.2	21.9	**20.2**
200	58.5	13.9	**6.3**
Pan	26.5	6.3	**0**
	Σ421.2 g		

The grain-size distribution is shown.



b. From the graph, D_{60} = **0.4 mm**; D_{30} = **0.22 mm**; D_{10} = **0.12 mm**

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c. $C_u = \frac{D_{60}}{D_{10}} = \frac{0.4}{0.12} = \mathbf{3.33}$

d. $C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})} = \frac{(0.22)^2}{(0.4)(0.12)} = \mathbf{1.01}$

2.3 $C_u = \frac{D_{60}}{D_{10}} = \frac{0.41}{0.08} = \mathbf{5.13}$

$C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})} = \frac{(0.22)^2}{(0.08)(0.41)} = \mathbf{1.48}$

2.4 $C_u = \frac{D_{60}}{D_{10}} = \frac{1.81}{0.24} = \mathbf{7.54}$

$C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})} = \frac{(0.82)^2}{(0.24)(1.81)} = \mathbf{1.55}$

2.5 a.

Sieve No.	Mass of soil retained on each sieve (g)	Percent retained on each sieve	Percent finer
4	0	0	**100**
6	0	0	**100**
10	0	0	**100**
20	9.1	1.82	**98.18**
40	249.4	49.88	**48.3**
60	179.8	35.96	**12.34**
100	22.7	4.54	**7.8**
200	15.5	3.10	**4.7**
Pan	23.5	4.70	**0**
	Σ500 g		

The grain-size distribution is shown on the next page.

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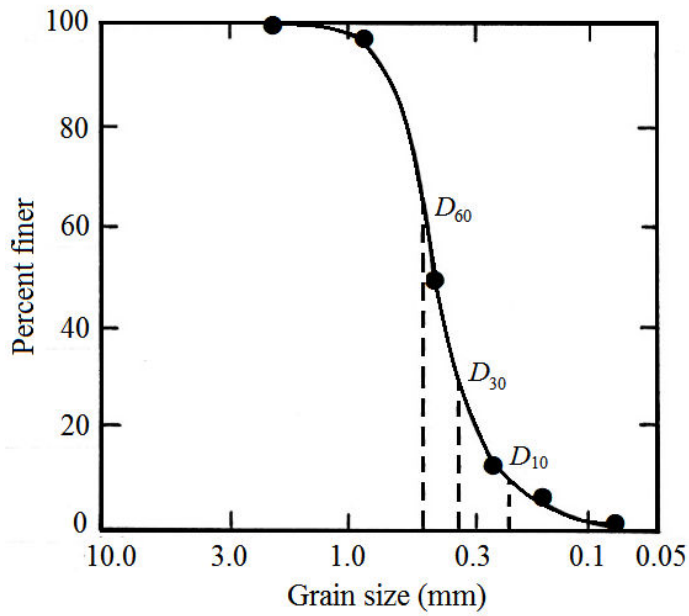

b. From the graph, D_{60} = **0.48 mm**, D_{30} = **0.33 mm**, D_{10} = **0.23 mm**

c. $C_u = \dfrac{0.48}{0.23} = \mathbf{2.09}$

d. $C_c = \dfrac{(0.33)^2}{(0.48)(0.23)} = \mathbf{0.99}$

2.6 a.

Sieve No.	Mass of soil retained on each sieve (g)	Percent retained on each sieve	Percent finer
4	0	0	**100**
10	44	7.99	**92.01**
20	56	10.16	**81.85**
40	82	14.88	**66.97**
60	51	9.26	**57.71**
80	106	19.24	**38.47**
100	92	16.70	**21.77**
200	85	15.43	**6.34**
Pan	35	5.34	**0**
	Σ 551 g		

The grain-size distribution is shown on the next page.

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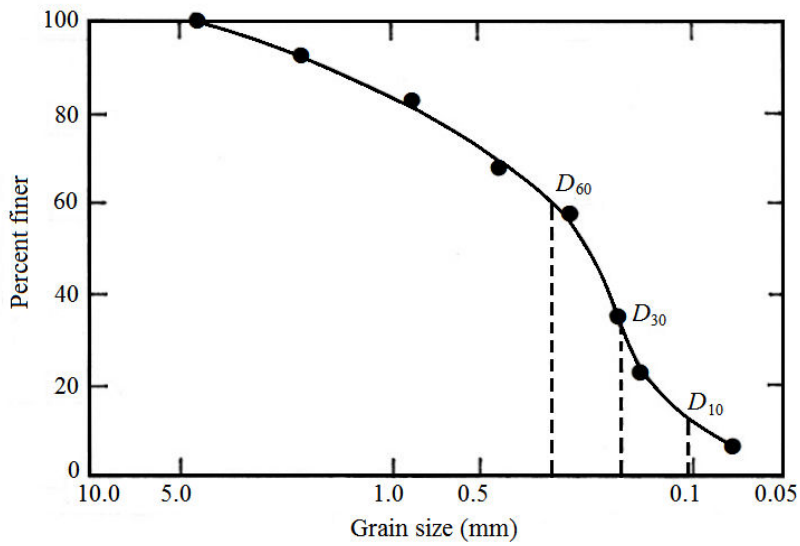
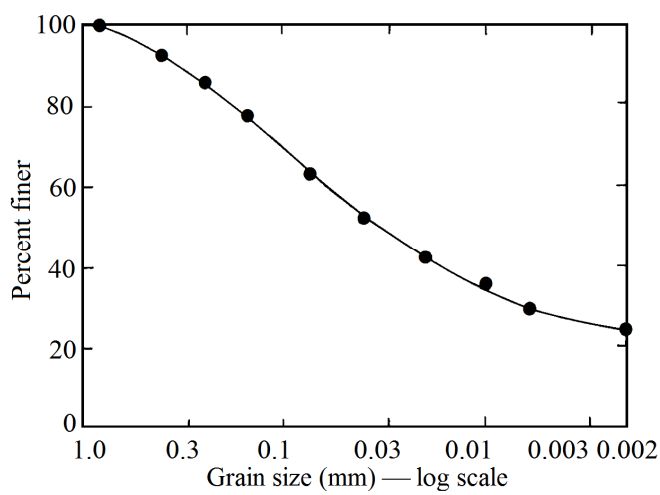


b. From the graph, D_{60} = **0.3 mm**; D_{30} = **0.17 mm**; D_{10} = **0.11 mm**

c. $C_u = \dfrac{0.3}{0.11} = \mathbf{2.73}$

d. $C_c = \dfrac{(0.17)^2}{(0.11)(0.3)} = \mathbf{0.88}$

2.7 The grain-size distribution is shown.



From the graph, percent passing 2 mm = 100%; percent passing 0.06 mm = 58%; percent passing 0.002 mm = 23%. See Table 2.3, so

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Gravel: **0%**
Sand: 100 – 58 = **42%**
Silt: 58 – 23 = **35%**
Clay: 23 – 0 = **23%**

2.8 Refer to the graph for Problem 2.7. From the graph, percent passing 2 mm = 100%; percent passing 0.05 mm = 54%; percent passing 0.002 mm = 23%. See Table 2.3, so

Gravel: **0%**
Sand: 100 – 54 = **46%**
Silt: 54 – 23 = **31%**
Clay: 23 – 0 = **23%**

2.9 Refer to the graph for Problem 2.7 and Table 2.3. From the graph, percent passing 2 mm = 100%; percent passing 0.075 mm = 62%; percent passing 0.002 mm = 23%.

Gravel: **0%**
Sand: 100 – 62 = **38%**
Silt: 62 – 23 = **39%**
Clay: 23 – 0 = **23%**

2.10 G_s = 2.60; temperature = 24°; hydrometer reading = 43; time = 60 min. Referring to Table 2.10, L = 9.2 cm.

Eq. (2.6): $D\,(\text{mm}) = K\sqrt{\dfrac{L\,(\text{cm})}{t\,(\text{min})}}$

From Table 2.9, for G_s = 2.60 and temperature = 24°, K = 0.0132.

$$D = 0.0132\sqrt{\frac{9.2}{60}} = \mathbf{0.0052\ mm}$$

2.11 For G_s = 2.70 and temperature = 23°, K = 0.013 (Table 2.9), L = 12.2 (Table 2.10).

$$D\,(\text{mm}) = K\sqrt{\frac{L\,(\text{cm})}{t\,(\text{min})}} = 0.013\sqrt{\frac{12.2}{120}} = \mathbf{0.0041\ mm}$$

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2.12 In Soil A,

Percent passing 75 mm sieve = 100; i.e., percent of gravel + sand + fines = 100

Percent passing 4.75 mm (No. 4) sieve = 67.5; i.e., percent of sand + fines = 67.5

Therefore, percent of gravel = 32.5

Percent passing 0.075 mm (No. 200) sieve = 8.5

Therefore percent of fines = 8.5 and percent of sand = 59.0

Soil A contains 32.5% gravel, 59.0 % sand and 8.5% fines.

In Soil B, following the same method,

Percent of gravel + sand + fines = 100

Percent of sand + fines = 100

Percent of fines = 0

Soil B consists of 100% sand.

2.13 Percent of gravel + sand + fines = 100

Percent of sand + fines = 63

Percent of fines = 16

Percentages of gravel, sand and fines within the soil are 37, 47, and 16, respectively.

2.14 a. **Soil A has the largest (50%) percentage of gravel**

b. **Soil C is entirely sand, with grains in the size range of 0.2-4.75 mm**.

c. **Only Soil D contains clay fraction (less than 0.002 mm) of about 35%.**

d. **In Soil A, there are no grains in the size range of 0.2–5.0 mm**. It is known as gap graded soil.

CRITICAL THINKING PROBLEM

2.15 a. $n = 0.5$

$$10 = \left(\frac{D_{10}}{D_{\max}}\right)^{0.5} \times 100 \qquad \text{(a)}$$

$$30 = \left(\frac{D_{30}}{D_{\max}}\right)^{0.5} \times 100 \qquad \text{(b)}$$

$$60 = \left(\frac{D_{60}}{D_{\max}}\right)^{0.5} \times 100 \qquad \text{(c)}$$

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$$\frac{\text{Eq. (c)}}{\text{Eq. (a)}} \text{ gives } 6 = \left(\frac{D_{60}}{D_{10}}\right)^{0.5}$$

$$C_u = \frac{D_{60}}{D_{10}} = 36$$

Similarly, $\dfrac{[\text{Eq. (b)}]^2}{[\text{Eq. (a)} \times \text{Eq. (c)}]}$ gives $\dfrac{30 \times 30}{10 \times 60} = \left(\dfrac{D_{30}^2}{D_{10} \times D_{60}}\right)^{0.5}$

$$C_c = \frac{D_{30}^2}{D_{10} \times D_{60}} = 2.25$$

The soil is well graded.

b. $n = 0.5$ and $D_{max} = 19.0$ mm

For percentage of fines, $D = 0.075$ mm; for sand and fines, $D = 4.75$ mm (Unified Soil Classification System).

$$p_{0.075} = \left(\frac{0.075}{19.0}\right)^{0.5} \times 100 = 6.3\% \text{ (per cent of fines)}$$

$$p_{4.75} = \left(\frac{4.75}{19.0}\right)^{0.5} \times 100 = 50.0\% \text{ (per cent of sand and fines)}$$

The soil contains 50% gravel, 43.7% sand and 6.3% fines.

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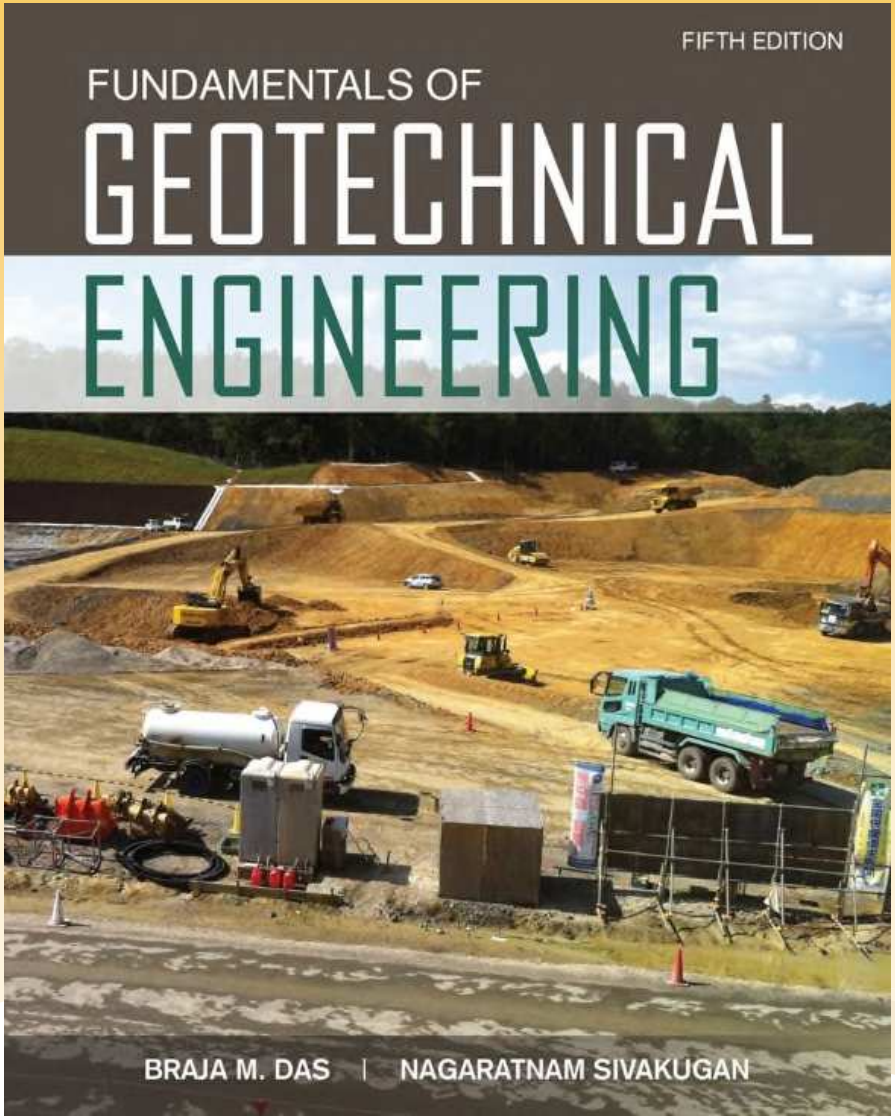

Chapter 2

Soil Deposits–Origin, Grain-Size, and Shape

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2.1 Introduction

During the planning, design, and construction of foundations, embankments, etc., engineers find it helpful to know the origin of the soil deposit that supports the structure.

The physical properties of soil are dictated primarily by the minerals that constitute the soil particles.

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2.2 Rock Cycle and the Origin of Soil

The mineral grains that form the solid phase of a soil aggregate are the product of rock weathering.

Many of the physical properties of soil are dictated by the size, shape, and chemical composition of the grains.

On the basis of their mode of origin, rocks can be divided into three basic types: igneous, sedimentary, and metamorphic.

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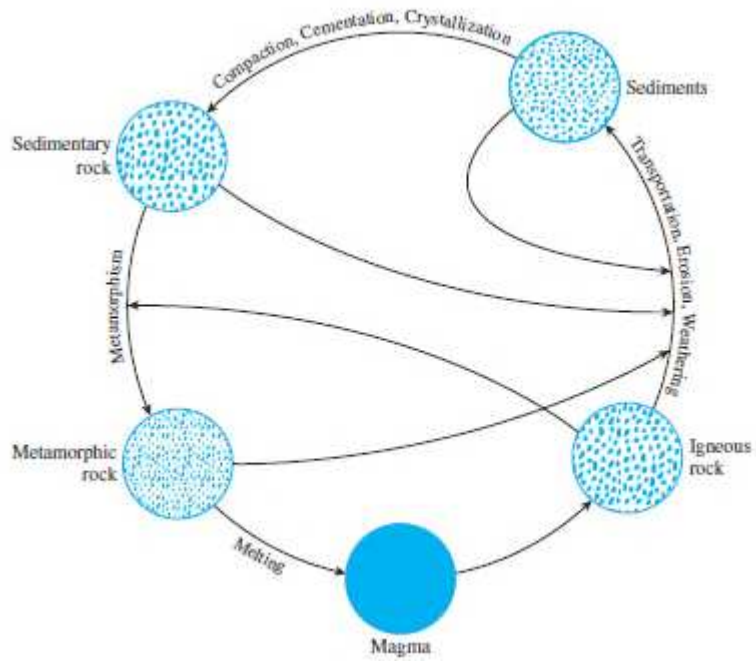
2.2 Rock Cycle and the Origin of Soil

The figure below is a demonstration of the rock cycle and shows the formation cycle of different types of rocks and the processes associated with them.



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2.2 Rock Cycle and the Origin of Soil

Roughly 65% of the earth's crust is made up of igneous rocks.

Igneous rock originates from magma. Magma is molten rock below the surface of the earth that moves above the surface due to volcanic eruption.

The types of igneous rock formed by the cooling of magma depend on factors such as composition of the magma and the rate of cooling associated.

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2.2 Rock Cycle and the Origin of Soil

Bowen's reaction principle describes the sequence by which new minerals are formed as magma cools.

Bowen classified the cooling rate reactions by the definitions below:

* Discontinuous ferromagnesian reaction series: Minerals formed are different in their chemical composition and crystalline structure.
* Continuous plagioclase feldspar reaction series: The minerals formed have different chemical compositions with similar crystalline structures.

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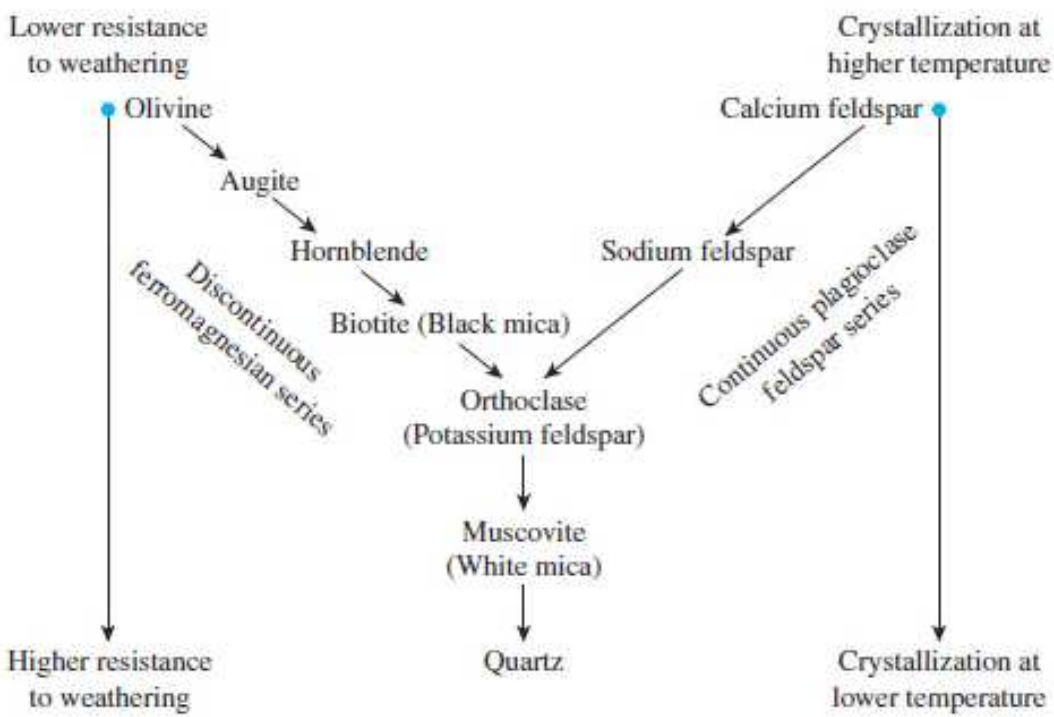
2.2 Rock Cycle and the Origin of Soil

The figure below shows Bowen's reaction series.



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2.2 Rock Cycle and the Origin of Soil

The chemical compositions of minerals are given in the table below.

Table 2.1 Composition of Minerals Shown in Bowen's Reaction Series

Mineral	Composition
Olivine	$(Mg, Fe)_2SiO_4$
Augite	$Ca, Na(Mg, Fe, Al)(Al, Si_2O_6)$
Hornblende	Complex ferromagnesian silicate of Ca, Na, Mg, Ti, and Al
Biotite (black mica)	$K(Mg, Fe)_3AlSi_3O_{10}(OH)_2$
Plagioclase: calcium feldspar	$Ca(Al_2Si_2O_8)$
Plagioclase: sodium feldspar	$Na(AlSi_3O_8)$
Orthoclase (potassium feldspar)	$K(AlSi_3O_8)$
Muscovite (white mica)	$KAl_3Si_3O_{10}(OH)_2$
Quartz	SiO_2

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2.2 Rock Cycle and the Origin of Soil

The table below shows the general composition of some igneous rocks.

Table 2.2 Composition of Some Igneous Rocks

Name of rock	Mode of occurrence	Texture	Abundant minerals	Less abundant minerals
Granite Rhyolite	Intrusive Extrusive	Coarse Fine	Quartz, sodium feldspar, potassium feldspar	Biotite, muscovite, hornblende
Gabbro Basalt	Intrusive Extrusive	Coarse Fine	Plagioclase, pyroxines, olivine	Hornblende, biotite, magnetite
Diorite Andesite	Intrusive Extrusive	Coarse Fine	Plagioclase, hornblende	Biotite, pyroxenes (quartz usually absent)
Syenite Trachyte	Intrusive Extrusive	Coarse Fine	Potassium feldspar	Sodium feldspar, biotite, hornblende
Peridotite	Intrusive	Coarse	Olivine, pyroxenes	Oxides of iron

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2.2 Rock Cycle and the Origin of Soil

Weathering: Process of breaking down rocks by mechanical and chemical processes into smaller pieces.

Mechanical weathering may be caused by the expansion and contraction of rocks from the continuous gain and loss of heat, which results in ultimate disintegration.

It must be stressed that in mechanical weathering, large rocks are broken down into smaller pieces without any change in chemical composition.

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2.2 Rock Cycle and the Origin of Soil

In chemical weathering, the original rock minerals are transformed into new minerals by chemical reaction.

An example is water and carbon dioxide from the atmosphere forming carbonic acid, which reacts with the existing rock minerals to form new minerals and soluble salts.

The chemical weathering process changes solid rock masses into fragments of various sizes ranging from large boulders to very small clay particles.

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2.2 Rock Cycle and the Origin of Soil

The products of weathering may stay in the same place or may be moved via ice, water, wind, and gravity.

Residual Soils: Soils formed by the weathered products at their place of origin.

For residual soils, it should be noted that the grain size of soil increases with depth.

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2.2 Rock Cycle and the Origin of Soil

Transported soils may be classified into several groups depending on mode of transportation and deposition.

1. Glacial Soils – Formed by transportation and deposition of glaciers.

2. Alluvial Soils – Transported by running water and deposited along streams.

3. Lacustrine Soils – Formed by deposition in quiet lakes.

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2.2 Rock Cycle and the Origin of Soil

4. Marine Soils – Formed by deposition in the seas.

5. Aeolian Soils – Transported and deposited by wind.

6. Colluvial Soils – Transported and deposited by gravity.

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2.2 Rock Cycle and the Origin of Soil

Deposits of gravel, sand, silt, and clay formed by weathering may become compacted by overburden pressure and cemented by agents like iron oxide and quartz.

Cementing agents are generally carried in solution by groundwater. The cementing agents fill the spaces between particles and form sedimentary rock.

Rocks formed this way are called detrital sedimentary rocks.

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2.2 Rock Cycle and the Origin of Soil

All detrital rocks have a clastic texture.

In the case of conglomerates, if the particles are more angular, the rock is called breccia. In sandstone, the particle sizes may vary between 1/16 mm and 2 mm.

Chemical sedimentary rock: Sedimentary rock formed by chemical processes.

Chemical sedimentary rocks can have clastic or nonclastic textures.

Sedimentary rock may undergo weathering to form sediments or may be subjected to the process of metamorphism to become metamorphic rock.

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2.2 Rock Cycle and the Origin of Soil

Metamorphism: The process of changing the composition and texture of rocks by heat and pressure.

During metamorphism, new minerals are formed, and mineral grains are sheared to give a foliated-texture to metamorphic rock.

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2.4 Residual Soil

Residual soils are found where the rate of weathering is more than the rate at which the weathered materials are carried away by transporting agents.

The rate of weathering is higher in warm and humid regions compared to cooler and drier regions and, depending on the climatic conditions, the effect of weathering may vary widely.

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2.4 Residual Soil

The nature of a residual soil deposit will generally depend on the parent rock.

Hard rocks like granite and gneiss that undergo weathering are likely to remain in place.

In contrast to hard rocks, some chemical rocks have large amounts of soluble materials, which are carried away by groundwater and leave behind the insoluble fraction of the rock.

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2.5 Gravity-Transported Soil

Residual soils on a steep natural slope can move slowly downward. This process is known as creep.

When the downward soil movement is sudden and rapid, it is called a landslide.

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2.5 Gravity-Transported Soil

Colluvium are soil deposits formed by landslides.

Mud flows are gravity transported soil that consist of highly saturated, loose sandy residual soils on relatively flat slopes moving downward like a viscous liquid.

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2.6 Alluvial Deposits

Alluvial deposits derive from the action of streams and rivers and can be divided into two major categories:

1. Braided-stream deposits

2. Meander belt deposits

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2.6 Alluvial Deposits

Braided streams are high-gradient, rapidly flowing streams that are highly erosive and carry large amounts of sediment.

Because of the high bed load, a minor change in the velocity of flow will cause sediments to deposit.

By this process, the streams may build up a complex tangle of converging and diverging channels, separated by sandbars and islands.

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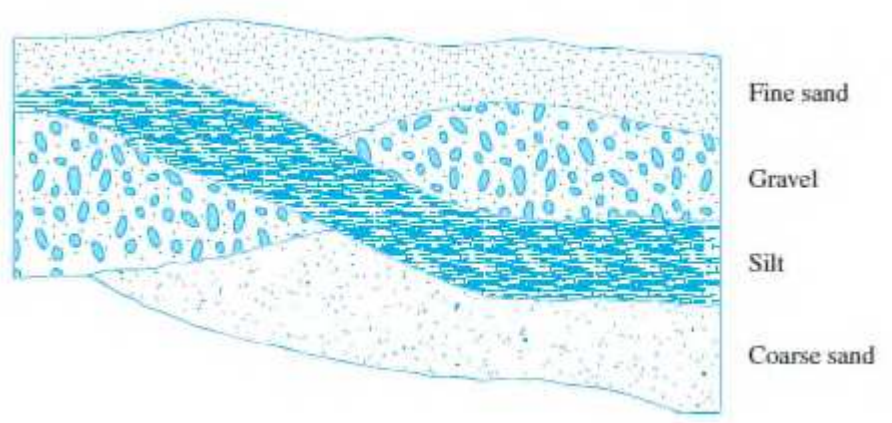
2.6 Alluvial Deposits

The deposits formed from braided streams are highly irregular in stratification and have a wide range of grain sizes.

The figure below shows a cross section of such a deposit.



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2.6 Alluvial Deposits

Deposits from braided streams share several characteristics:

1. The grain sizes usually range from gravel to silt. Clay-sized particles are generally not found in deposits from braided streams.

2. Although grain size varies widely, the soil in a given pocket or lens is rather uniform.

3. At any given depth, the void ratio and unit weight may vary over a wide range within a lateral distance of only a few meters.

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2.6 Alluvial Deposits

A meandering river in a valley curves back and forth.

The valley floor in which a river meanders is referred to as the meander belt.

In a meandering river, the soil from the bank is continually eroded from the points where the river is concave and deposited at points where the bank is convex.

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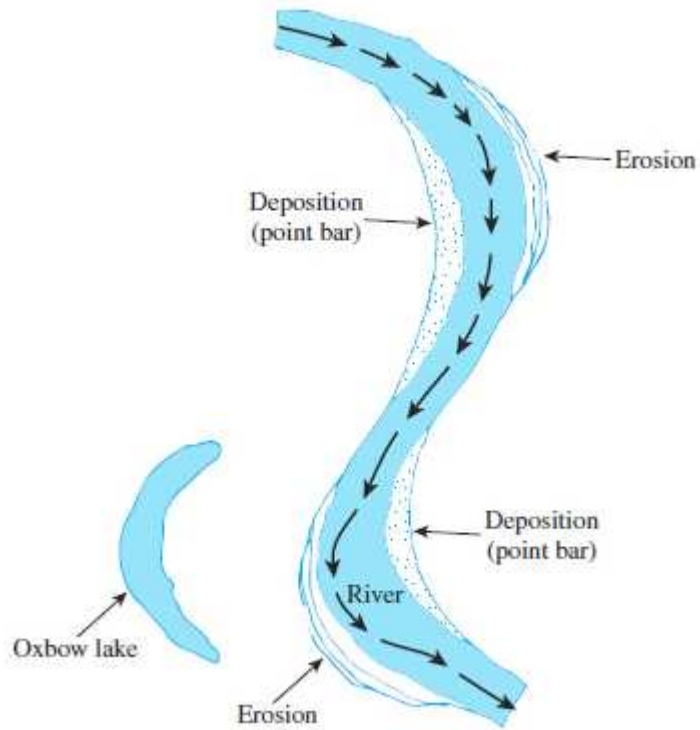
2.6 Alluvial Deposits

The figure below shows a meandering river with eroding and depositing as described previously.



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2.6 Alluvial Deposits

The deposits left by a meandering river are called point bar deposits and usually consist of sand and silt-sized particles.

Sometimes during erosion and deposition, the river abandons a meander and cuts a shorter path. The abandoned meander, when filled with water, is called an oxbow lake.

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2.6 Alluvial Deposits

During floods, rivers overflow low-lying areas.

The sand and silt-size grains carried by the river are deposited along the banks to form ridges known as natural levees.

Finer soil particles consisting of silts and clays are carried by the water farther onto the floodplains.

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2.7 Lacustrine Deposits

Lacustrine deposits result from springs and rivers flowing into lakes.

Coarse grains and fine grains are carried into the lake and are deposited onto the lake bottom in alternate layers of coarse and fine grains.

The deltas formed in humid regions usually have finer grained soil deposits compared to those in arid regions

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2.8 Glacial Deposits

When glaciers move, they also carry large amounts of sand, silt, clay, gravel, and boulders.

Drift: Deposits laid down by glaciers.

Till: Unstratified deposits laid down by melting glaciers.

Moraines: Landforms that developed from the deposits of till.

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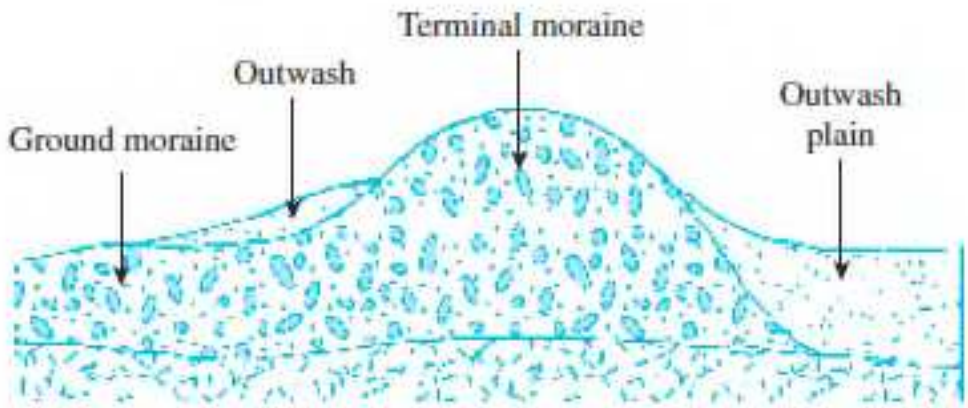
2.8 Glacial Deposits

Below is a figure of a terminal moraine which marks the maximum limit of a glacier's advance.



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2.8 Glacial Deposits

Recessional moraines are ridges of till developed behind the terminal moraine at varying distances apart.

Recessional moraines are the result of temporary stabilization of the glacier during the recessional period.

The till deposited by the glacier between the moraines is called the ground moraine.

The sand, silt, and gravel that are carried by the melting water from the front of the glacier are called outwash.

In a pattern similar to the braided-stream deposits, the melted water deposits the outwash, forming outwash plains/glaciofluvial deposits.

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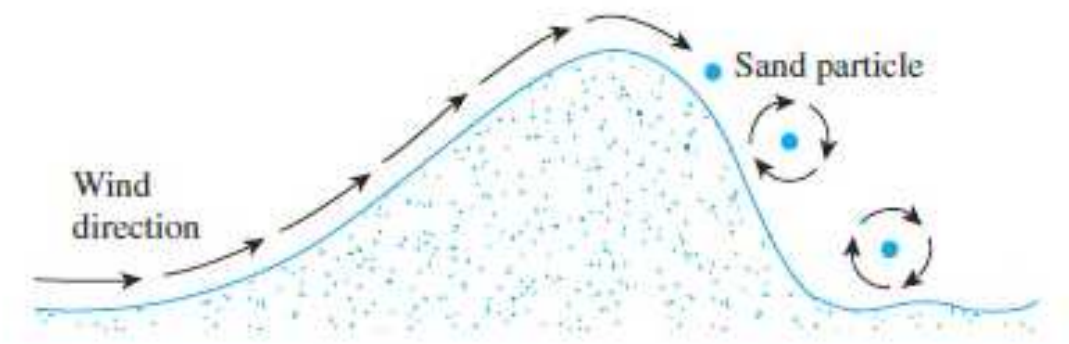
2.9 Aeolian Soil Deposits

Wind is also a major transporting agent leading to the formation of soil deposits.

Deposits of windblown sand generally take the shape of dunes (shown below).



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2.9 Aeolian Soil Deposits

As dunes are formed, the sand is blown over the crest by the wind.

Beyond the crest, the sand grains roll down the slope.

This process forms a compact sand deposit on the windward side and a loose deposit on the leeward side.

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2.9 Aeolian Soil Deposits

Some of the characteristics of the sand dune are:

1. The grain-size distribution of the sand at any particular location is surprisingly uniform. This uniformity can be attributed to the sorting action of the wind.

2. The general grain size decreases with distance from the source, because the wind carries the small particles farther than the large ones.

3. The relative density of sand deposited on the windward side of dunes may be as high as 50 to 65%, decreasing to 0 to 15% on the leeward side.

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2.9 Aeolian Soil Deposits

Loess is an aeolian deposit consisting of silt and silt-sized grains.

The cohesion of loess is generally derived from a clay coating over the silt-sized grains, which contributes to a stable soil structure in an unsaturated state.

Loess is a collapsing soil, because when the soil becomes saturated, it loses its binding strength between grains.

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2.10 Organic Soil

Organic soils are usually found in low-lying areas where the water table is near or above the ground surface.

The presence of a high water table helps in the growth of aquatic plants that, when decomposed, form organic soil.

Organic soils have the following characteristics:

1. Their natural moisture content may range from 200 to 300%.

2. They are highly compressible.

3. Laboratory tests have shown that, under loads, a large amount of settlement is derived from secondary consolidation.

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2.11 Soil-Grain Size

Soils are generally called gravel, sand, silt, or clay depending on the predominant size of grains within the soil.

To describe soils by their grain size, several organizations have developed soil-separate-size limits.

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2.11 Soil-Grain Size

Grain size classifications for various organizations are provided in the table below.

Table 2.3 Soil-Separate-Size Limits

Name of organization	Grain size (mm)			
	Gravel	Sand	Silt	Clay
Massachusetts Institute of Technology (MIT)	>2	2 to 0.06	0.06 to 0.002	<0.002
U.S. Department of Agriculture (USDA)	>2	2 to 0.05	0.05 to 0.002	<0.002
American Association of State Highway and Transportation Officials (AASHTO)	76.2 to 2	2 to 0.075	0.075 to 0.002	<0.002
Unified Soil Classification System (U.S. Army Corps of Engineers; U.S Bureau of Reclamation; American Society for Testing and Materials)	76.2 to 4.75	4.75 to 0.075	Fines (i.e., silts and clays) <0.075	

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2.11 Soil-Grain Size

Gravels are pieces of rocks with occasional grains of feldspar and other minerals.

Sand grains are made of mostly quartz and feldspar. Other mineral grains may also be present at times.

Silts are the microscopic soil fractions that consist of very fine quartz grains and some flake-shaped grains that are fragments of micaceous minerals.

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2.11 Soil-Grain Size

Clays are mostly flake-shaped microscopic and submicroscopic grains of mica, clay minerals, and other minerals.

Clays are defined as those grains "which develop plasticity when mixed with a limited amount of water."

Non-clay soils can contain grains of quartz, feldspar, or mica that are small enough to be within the clay size classification.

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2.12 Clay Minerals

Clay minerals are complex aluminum silicates composed of one of two basic units:

1. Silica tetrahedron

2. Aluminum octahedron

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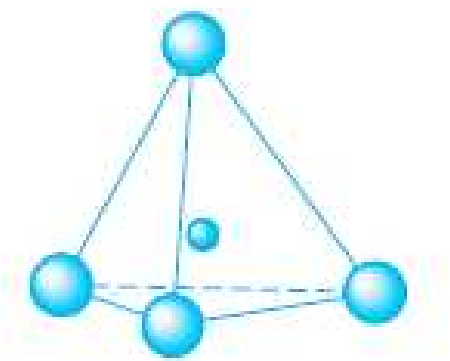
2.12 Clay Minerals

Each tetrahedron unit consists of four oxygen atoms surrounding a silicon atom.



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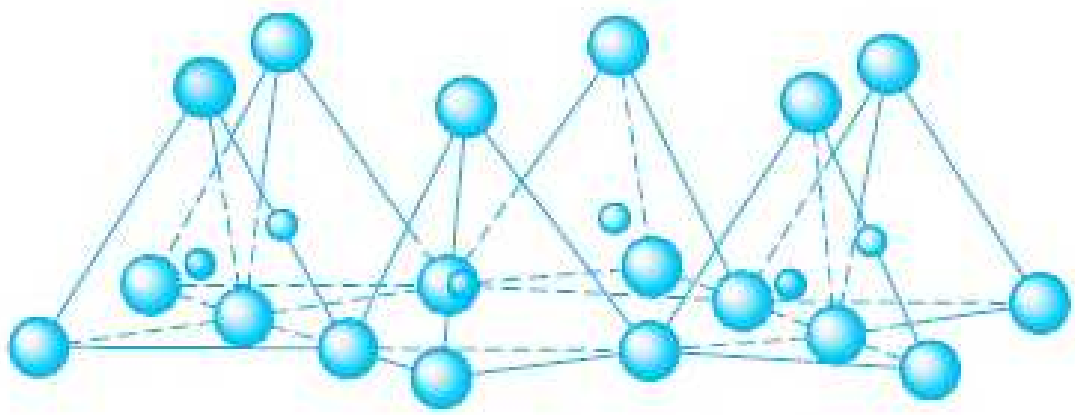
2.12 Clay Minerals

The combination of tetrahedral silica units gives a silica sheet.



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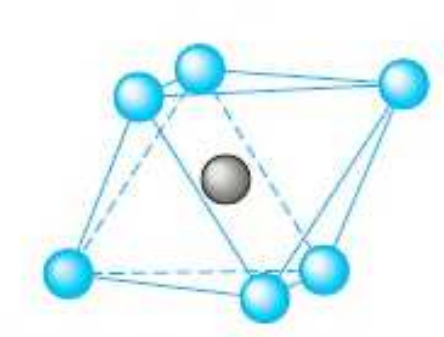
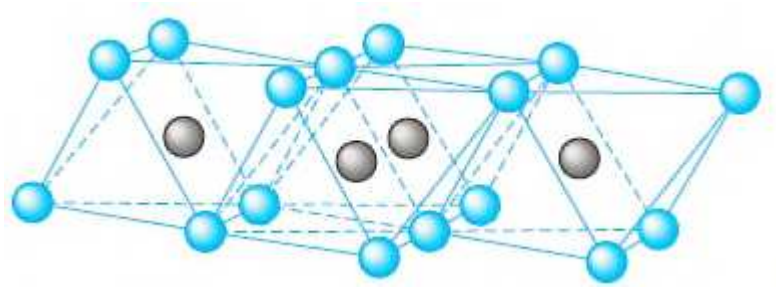
2.12 Clay Minerals

The octahedral units consist of six hydroxyls surrounding an aluminum atom.



The combination of the octahedral aluminum hydroxyl units give an octahedral sheet.



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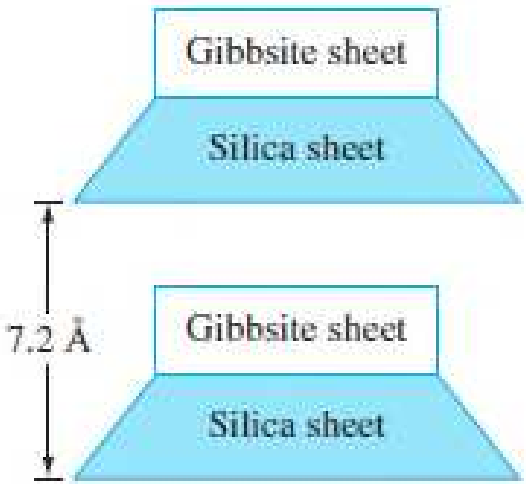
2.12 Clay Minerals

Kaolinite consists of repeating layers of elemental silica-gibbsite sheets, as shown in the figure below.



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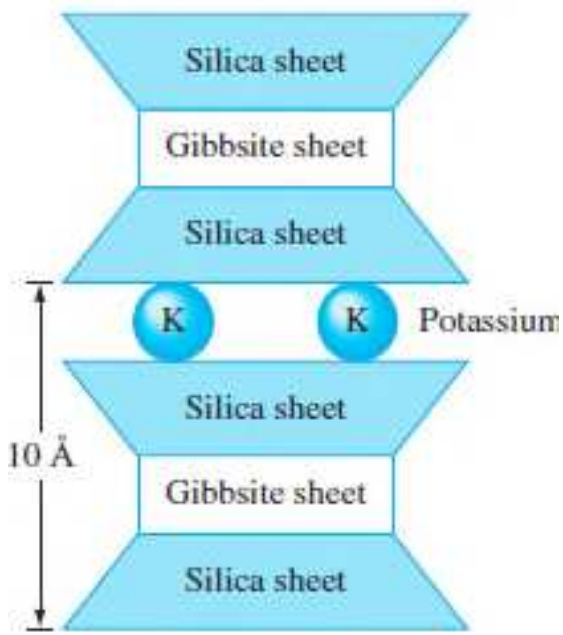
2.12 Clay Minerals

Illite consists of a gibbsite sheet bonded to two silica sheets—one at the top and another at the bottom.



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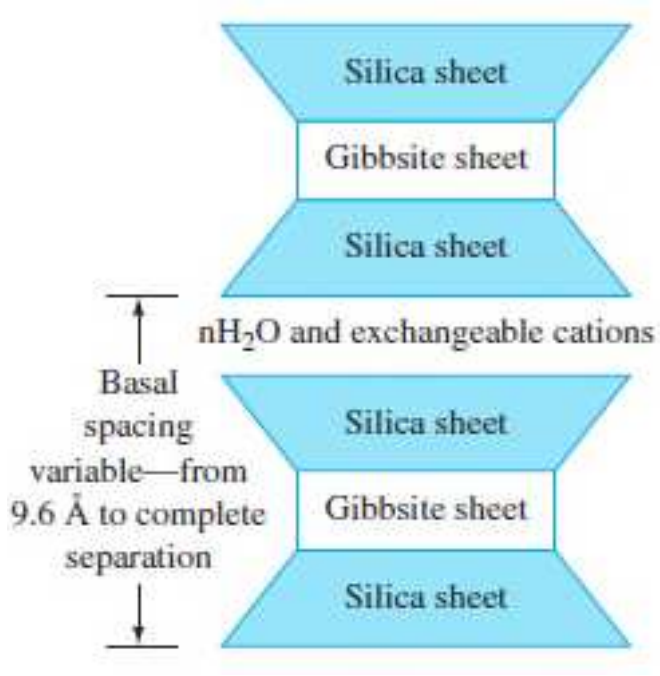
2.12 Clay Minerals

Montmorillonite has a similar structure to illite—that is, one gibbsite sheet sandwiched between two silica sheets.



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2.12 Clay Minerals

Clay grains carry a net negative change on their surfaces.

In dry clay, the negative charge is balanced by exchangeable cations surrounding the grains being held by electrostatic attraction.

When water is added to clay, these cations and a small number of anions float around the clay grains. This is referred to as diffuse double layer.

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2.12 Clay Minerals

Water molecules are dipoles, meaning they act like small rods with positive charges at one end and negative charges at the other end.

The dipolar water is attracted both by the negatively charged surface of the clay grains, and by the cations in the double layer.

A third mechanism by which water is attracted to the clay grains is hydrogen bonding. This is when hydrogen atoms in the water molecules are shared with oxygen atoms on the surface of the clay.

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2.12 Clay Minerals

All of the water held to clay grains by force of attraction is known as double-layer water.

The innermost layer of double-layer water, which is held very strongly by clay, is known as absorbed water.

Absorbed water cannot be easily removed and is more viscous than free water.

The orientation of water around the clay grains gives clay soils their plastic properties.

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2.13 Specific Gravity (G_s)

Specific gravity of a material says how heavy that material is compared to water.

It is the ratio of the density of the material to the density of water.

Specific gravity of the soil solids is used in various calculations in soil mechanics.

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2.13 Specific Gravity (G_s)

The table below shows the specific gravity of some common minerals found in soils.

Table 2.4 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

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2.14 Mechanical Analysis of Soil

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

Two methods are generally used to find the grain-size distribution of soil:

1. Sieve analysis—for grain sizes larger than 0.075 mm in diameter.

2. Hydrometer analysis—for grain sizes smaller than 0.075 mm in diameter.

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2.15 Sieve Analysis

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

Table 2.5 U.S. Sieves by Size Designation

100.0 mm	25.0 mm
75.0 mm	19.0 mm
63.0 mm	16.0 mm
50.0 mm	12.5 mm
45.0 mm	9.5 mm
37.5 mm	8.0 mm
31.5 mm	6.3 mm

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2.15 Sieve Analysis

The opening for the *i*th sieve given in Table 2.6 in the book can be approximately given as

$$\text{Opening for the } i\text{th sieve} = \frac{\text{Opening for the } (i-1)\text{th sieve}}{(2)^{0.25}}$$

Several other countries have their own sieve sizes which are commonly referred to by their aperture sizes.

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2.15 Sieve Analysis

The following are the steps showing the calculation procedure for a sieve analysis:

1. Starting from the top sieve determine the mass of soil retained on each sieve (i.e., M_1, M_2, . . . M_n) and in the pan (i.e., M_p).

2. Determine the total mass of the soil:

$$M_1 + M_2 + \cdots + M_i + \cdots + M_n + M_p = \Sigma M$$

3. Determine the cumulative mass of soil retained above each sieve.

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2.15 Sieve Analysis

4. The mass of soil passing the *i*th sieve is

$$\sum M - (M_1 + M_2 + \ldots + M_i)$$

5. The percent of soil passing the *i*th sieve is

$$F = \frac{\sum M - (M_1 + M_2 + \ldots + M_i)}{\sum M} x100$$

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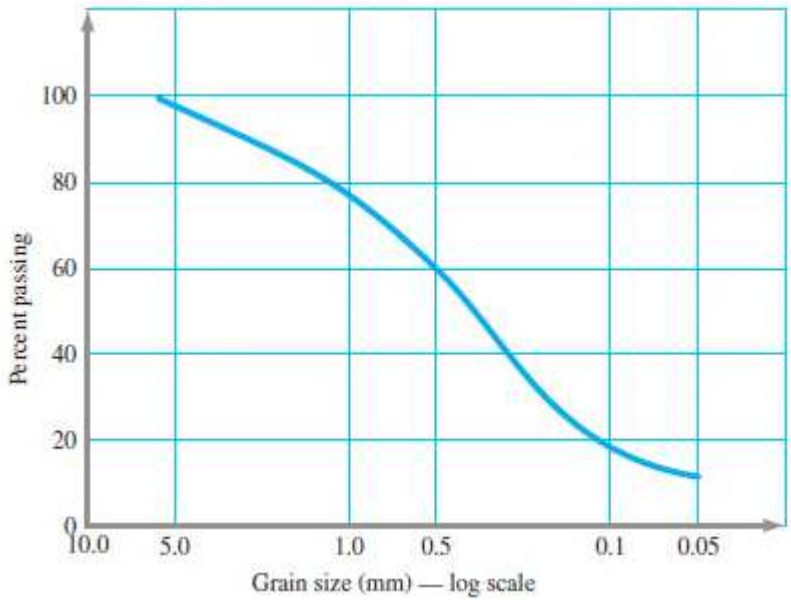
2.15 Sieve Analysis

Once the percent finer for each sieve is calculated, the calculations are plotted on semilograrithmic graph paper with percent finer as the ordinate and sieve opening size as the abscissa.



This plot is known as the grain-size distribution curve.

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2.16 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 grains settle at different velocities, depending on their shape, size, and weight.

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2.16 Hydrometer Analysis

For simplicity, it is assumed that all the soil grains are spheres, and the velocity of soil grains can be expressed by Stoke's law, which is

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

v = velocity

ρ_s = density of soil grains

ρ_w = density of water

η = dynamic viscosity of water

D = diameter of soil grains

g = acceleration due to gravity

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2.16 Hydrometer Analysis

If we use ρ_w equal to 1 g/cm^3, we get

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

with

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

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2.16 Hydrometer Analysis

When a hydrometer is placed in the soil suspension at a time t, measured from the start of sedimentation, it measures the specific gravity in the vicinity of its bulb at a depth L.

The specific gravity is a function of the amount of soil grains present per unit volume of suspension at that depth.

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

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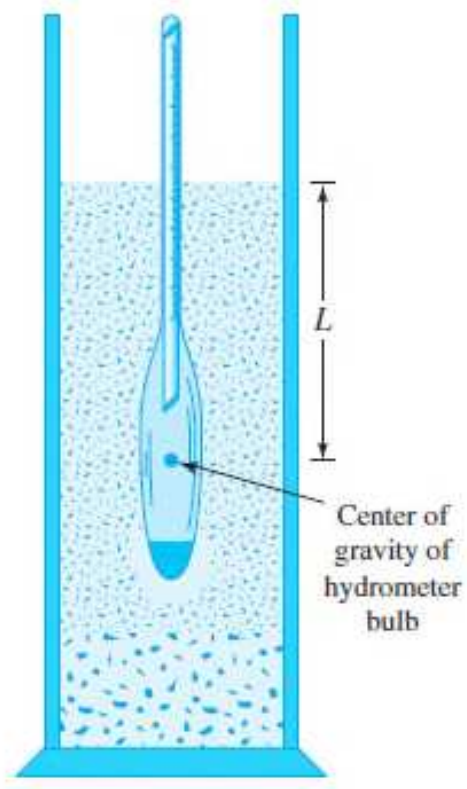
2.16 Hydrometer Analysis



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2.16 Hydrometer Analysis

The larger grains would have settled beyond the zone of measurement. Hydrometers are designed to give the amount of soil, in grams, that is still in suspension.

By knowing the amount of soil in suspension, L, and t, we can calculate the percentage of soil by weight finer than a given diameter.

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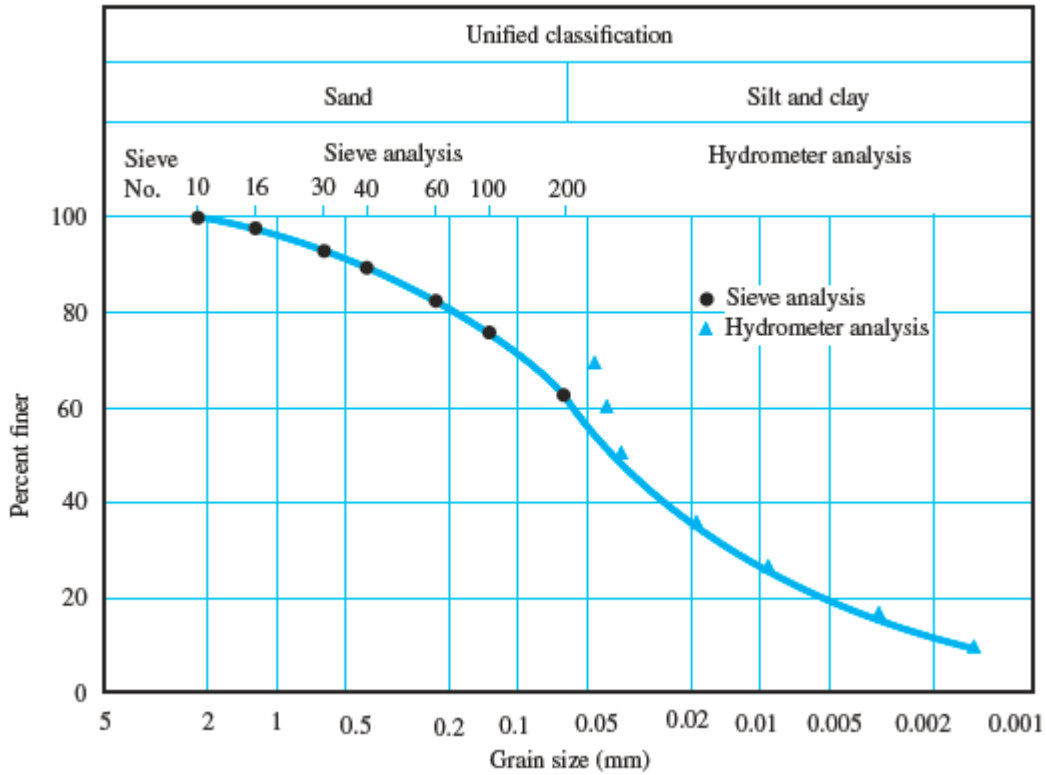
2.16 Hydrometer Analysis

In many instances, the results of sieve analysis and hydrometer analysis for finer fractions for a given soil are combined on one graph like that shown below.



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2.16 Hydrometer Analysis

When these results are combined, a discontinuity generally occurs in the range where they overlap.

This discontinuity occurs because soil grains are generally irregular in shape.

Sieve analysis gives the intermediate dimensions of a grain.

Hydrometer analysis gives the diameter of an equivalent sphere that would settle at the same rate as the soil particle.

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2.16 Hydrometer Analysis

The percentages of gravel, sand, silt, and clay-size grains present in a soil can be obtained from the grain-size distribution curve.

According to the Unified Soil Classification System, the soil in the previous figure has the following percentages:

Gravel (size limits – greater than 4.75 mm) = 0%

Sand (size limits – 4.75 to 0.075 mm) = percent finer than 4.75 mm diameter – percent finer than 0.075 mm diameter = 100 – 62 = 38%

Silt and clay (size limits – less than 0.075 mm) = 62%

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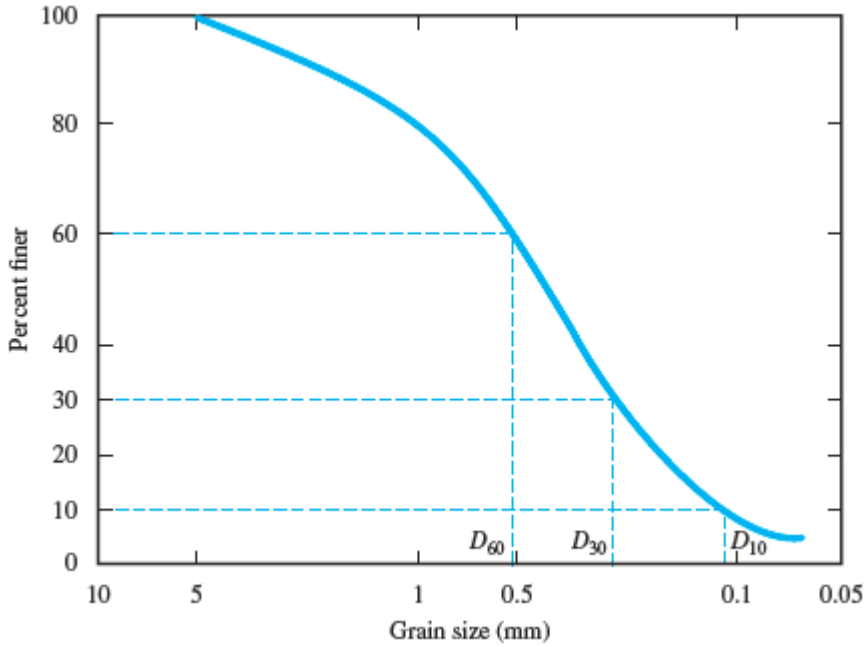
2.17 Effective Size, Uniformity Coefficient, and Coefficient of Gradation

The grain-size distribution curve below can be used to compare different soils.



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2.17 Effective Size, Uniformity Coefficient, and Coefficient of Gradation

Three basic soil parameters can be determined from these curves, and they can be used to classify granular soils.

The three soil parameters are:

1. Effective grain size

2. Uniformity coefficient

3. Coefficient of gradation

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2.17 Effective Size, Uniformity Coefficient, and Coefficient of Gradation

The diameter in the grain-size distribution curve corresponding to 10% finer is defined as the effective grain size, or D_{10}.

The uniformity coefficient is given by the relation

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

C_u = uniformity coefficient

D_{60} = diameter corresponding to 60% finer in the particle-size distribution curve

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2.17 Effective Size, Uniformity Coefficient, and Coefficient of Gradation

The coefficient of gradation (coefficient of curvature) may be expressed as

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

C_c = coefficient of gradation or coefficient of curvature

D_{30} = diameter corresponding to 30% finer

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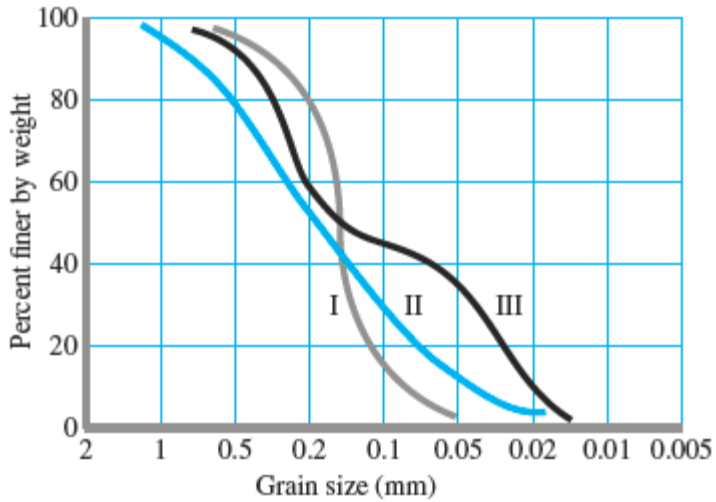
2.17 Effective Size, Uniformity Coefficient, and Coefficient of Gradation

The grain-size distribution curve also shows the distribution of various size grains.

Three curves are shown in the figure below.



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2.17 Effective Size, Uniformity Coefficient, and Coefficient of Gradation

Curve I represents a type of soil in which most of the soil gains are the same size. This is called poorly graded soil.

Curve II represents a soil in which the grain sizes are distributed over a wide range and is termed well graded.

A well-graded soil has a uniformity coefficient greater than about 4 for gravels and 6 for sands, and a coefficient of gradation between 1 and 3.

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2.17 Effective Size, Uniformity Coefficient, and Coefficient of Gradation

A soil might have a combination of two or more uniformly graded fractions.

Curve III represents such a soil, termed gap graded, which has a gap in the grain size.

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2.18 Grain Shape

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

Not much attention is paid to grain shape because it is more difficult to measure.

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2.18 Grain Shape

The grain shape generally can be divided into three major categories:

1. Bulky

2. Flaky

3. Needle shaped

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2.18 Grain Shape

Bulky grains are formed mostly by mechanical weathering of rock and minerals.

Terms associated with bulky grains include angular, subangular, subrounded, and rounded.

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2.18 Grain Shape

Flaky grains have very low sphericity, usually 0.01 or less.

These grains are predominantly clay minerals.

The sphericity of grains is defined as

$$S = \frac{D_e}{L_p} (range\ 0\ to\ 1)$$

D_e = equivalent diameter of the grain = $\sqrt[3]{\frac{6V}{\pi}}$

V = volume of grain

L_p = length of grain

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2.18 Grain Shape

Needle-shaped grains are much less common than the other two grain types.

Examples of soils containing needle-shaped grains are some coral deposits and atta-pulgite clays.

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