Chapter 1

Origin of Soils and Clay Mineralogy

CHAPTER HIGHLIGHTS

- *Introduction*
- *Soil formation and soil types*
- *Commonly used soil designation*
- *Soil structure and clay mineralogy*

Introduction

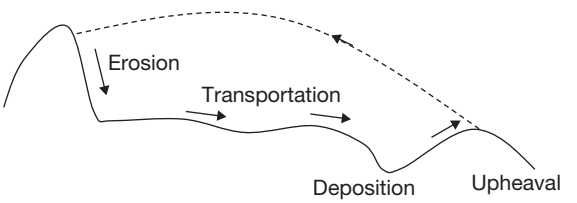
This chapter outlines the concept of the formation or the origin of soils and their geometric arrangement known as soil structure and also minerals present in soils.

Definition of Soil

The term 'soil' is defined as an unconsolidated material, composed of solid particles, produced by the disintegration of rocks.

Soil Formation and Soil Types

- On the basis of geological origin, soils may be organic or inorganic types.
- Organic soils are extremely compressible and their use as a foundation material is avoided.
- Peat, muck and humus are organic soils. Organic oil also known as *cumulose* soil.
- Inorganic soils are formed by weathering of rocks due to mechanical disintegration or chemical decomposition.
- Physical disintegration or mechanical weathering occurs due to the effects temperature changes, wedging action of ice, spreading of roots of plants and abrasion.
- Due to physical disintegration, there is no change in chemical composition.
- Coarse grained soils, such as gravel and sand are formed by the process of physical disintegration.
- Chemical decomposition or chemical weathering of rocks occurs due to hydration, carbonation, Oxidation, solution and hydrolysis.
- Due to chemical decomposition, original minerals are transformed into new minerals by chemical reactions.
- Chemical decomposition of rocks results in formation of clay minerals.
- Soils are obtained from geologic cycle, which goes on continuously in nature.
- The geologic cycle consists of erosion, transportation, deposition and upheaval of soil.



Geologic cycle

- Soils formed at the place of their origin are known as residual soil.

  Examples: Black cotton soils, laterite soils.
- Soils deposited at a place away from the place of their origin, are called transported soil.
- The soils formed at a place may be transported to other place by agents of transportation, such as water, wind, ice and gravity.

Source of Transportation	Type of Soil
River	Alluvial soils
Lakes	Lacustrine soils
Sea	Marine soils
Wind	Aeolian soils **Examples:** Sand dunes, loess.
Gravitation	Colluvial soils **Example:** Talus
Glacier	Glacier-deposited soils **Examples:** Drift, till.

Commonly Used Soil Designation

1. **Bentonite:** Decomposed volcanic ash containing a high percentage of clay mineral (i.e., montmorillonite).
2. **Black cotton soil:** It contains the mineral montmorillonite mineral, and exhibits large swelling and shrinkage.
3. **Loam:** It is a mixture of sand, silt and clay-size particles approximately in equal proportions.
4. **Moorum:** It is gravel mixed with red clay.
5. **Varved clay:** It is clay and silt of glacial origin, especially a lacustrine deposit.

NOTES

1. Gravitational forces are predominant in gravels and sands.
2. Surface forces, electrical forces, chemical forced are predominant in clays.

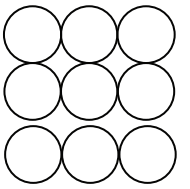
Soil Structure and Clay Mineralogy

Soil Structure

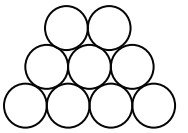
- Geometric arrangement of soil particles with respect to one another is known as soil structure.
- Depending upon the particle size and mode of formation, the following types are found.

Single Grained Structure

- Found in coarse grained soils, like gravel, sand.
- The major cause for formation is gravitational force. Here the surface forces are negligible.
- Under the influence of gravitational forces, the grains will assume a particle to particle contact referred to as single grained structure.
- Single grained structure may be loose or dense as shown below.



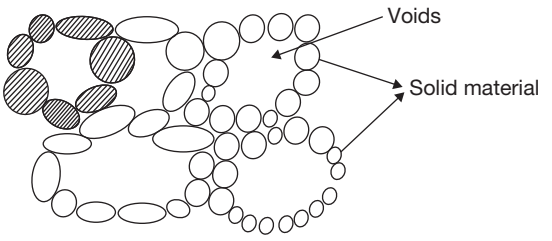
(a) Loosest state



(b) Densest state

Honey-comb Structure

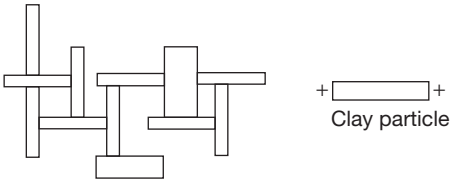
- It is possible for fine sands or silts.
- Both gravitational force and surface force are responsible.
- Such a structure can support loads, only under static conditions.
- Under vibrations and shocks, the structure collapses and large deformations take place.



Honey-comb structure

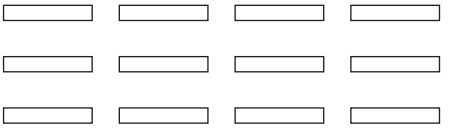
Flocculated Structure

- This structure occurs in clays.
- Clay particles have a negative charge on surface and a positive charge on edges and flocculated structure occurs when there is an edge-to-face orientation.
- A flocculated structure is formed when there is a net attractive force between the particles.
- Soils with flocculent structure have a high void ratio and water content and, also have a low compressibility, a high permeability and high shear strength.



Flocculated structure

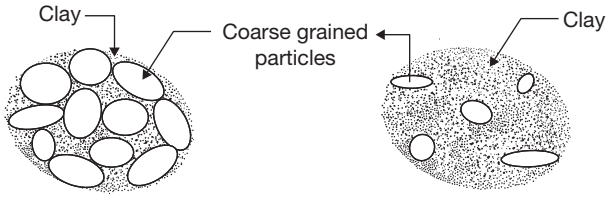
Dispersed Structure



- A dispersed develops in clays that have been reworked or remolded.
- Remoulding converts 'edge-to-face' orientation to 'face-to-face' orientation.
- Dispersed structure is formed when there is a net repulsive force between particles.
- Have low shear strength, high compressibility and low permeability.

Composite Structure

A composite structure in the form of coarse grained skeleton or clay-matrix is formed when soil contains different types of soil particles.



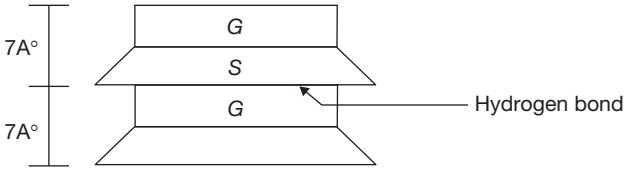
Composite structure

Clay Mineralogy

- Important clay minerals kaolinite, Illite, montmorillonite and halloysite, are present in clays.
- In coarse grained soils, like gravel, sand, rock minerals like quartz, feldspar, mica, etc., are present.

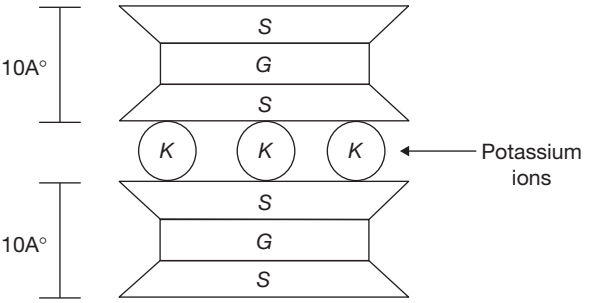
Kaolinite Mineral

- One molecule of kaolinite mineral is made of one silica sheet and one gibbsite sheet.
- Various such molecules are joined by hydrogen bonds.
- These show less change in volume due to changes in moisture content.
- Kaolinite is thus the least active of clay minerals.
  Example: China clay



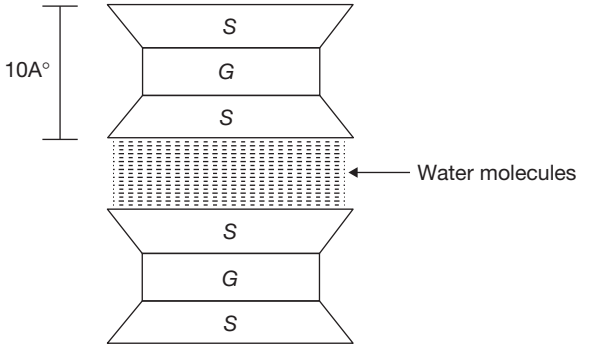
Illite Mineral

- One molecule of Illite is made of two silica sheets and one gibbsite sheet, but in silica sheet, silicon atom is replaced by aluminum atom.
- Various such molecules are joined together by ionic bond (potassium ion).
- These shows medium swelling and shrinkage properties.
  Example: Alluvial soil.



Montmorillonite Mineral (Also Called 'Smectite')

- One molecule of montmorrilonite mineral is made of two silica sheets and one gibbsite sheet.
- Gibbsite sheet is sandwiched between silica sheets.
- Various such molecules are loosely bonded through water.
- These soils show high volume changes on moisture variation (i.e., large swelling and large shrinkage).
  Example: Black cotton soils, bentonite soil.



Diffuse Double Layer and Adsorbed Water

- Clay particles usually carry a negative charge on their surface.
- Because of net negative charge on the surface, the clay particles attract cations, such as potassium, calcium and sodium, from the moisture present in the soil to reach equilibrium.
- The layer extending from the clay particle surface to the limit of attraction is known as a diffuse double layer.
- The water held in the zone of the diffuse double layer is known as adsorbed water or oriented water.
- The plasticity characteristics of clay are due to the presence of adsorbed water.
- Clays using non-polar liquid, such as kerosene in place of water, does not show any plasticity characteristics.
- The thickness of adsorbed water layer is about 10–15A° for colloids, but may be up to 200A° for silts.

Exercises

1. Match List I (Type of soil) with List II (Mode of transportation and deposition) and select the correct answer using the codes given below the lists:

	List I		List II
a.	Lacustrine soils	**1.**	Transportation by wind
b.	Alluvial soil	**2.**	Transportation by running water
c.	Aeolian soils	**3.**	Deposited at the bottom of lakes
d.	Marine soils	**4.**	Deposited in sea water

Codes:

	a	b	c	d		a	b	c	d
(A)	1	2	3	4	(B)	3	2	1	4
(C)	3	2	4	1	(D)	1	3	2	4

2. Consider the following statements in the context of aeolian soils:
I. The soil has low density and low compressibility.
II. The soil is deposited by wind.
III. The soil has large permeability.

Which of these statements are correct?
(A) I, II and III (B) II and III
(C) I and III (D) I and II

3. **Assertion (A):** Black cotton soils are clays and they exhibit characteristic property of swelling.

Reason (R): These clays contain montmorillonite which attracts external water into its lattices structure.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not a correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

4. The collapsible soil is associated with
(A) dune sands
(B) laterite soils
(C) loess
(D) black cotton soils

5. The predominant mineral responsible for shrinkage and swelling in black cotton soils is
(A) illite
(B) kaolinite
(C) mica
(D) montmorillonite

6. Consider the following clay minerals:
I. Kaolinite
II. Montmorillonite
III. Illite

What is the correct sequence in an increasing order of their plasticity index?
(A) I–II–III (B) III–II–II
(C) I–III–II (D) III–I–II

7. Consider the following statements:
I. Peat and muck are organic soils.
II. Peat is an inorganic soil whereas muck is an organic soil.
III. Indurated clay is a type of clay which does not soften under prolonged wetting.

Which of these statements is/are correct?
(A) I, II and III (B) II only
(C) III only (D) I and III only

8. Consider the following statements:
I. Mica is a clay mineral.
II. The shape of clay particle is usually flaky.
III. A particle of kaolinite is electrically charged.

Which of these statements is/are correct?
(A) I, II and III (B) I and III only
(C) II and III only (D) II only

9. When the product of rock weathering is not transported as sediment but remains in place, is called
(A) alluvial soil. (B) glacial soil.
(C) residual soil. (D) aeolian soil.

10. Aeolian soils are
(A) residual soils.
(B) wind deposits.
(C) gravity deposits.
(D) water deposits.

11. Black cotton soil exhibits large swelling and shrinkage due to the presence of the following clay mineral:
(A) Kaolinite
(B) Illite
(C) Montmorillonite
(D) Halloysite

12. The shape of clay particle is usually
(A) angular
(B) flaky
(C) tubular
(D) rounded

13. Some of the structural strength of a clayey material that is lost by remolding is slowly recovered with time. This property of soils to undergo an isothermal gel-to-soil-to-gel transformation upon agitation and subsequent to rest is termed
(A) isotropy
(B) anisotropy
(C) thixotropy
(D) allotropy

14. Deposit with flocculated structure is formed when
(A) clay particles settle on sea bed.
(B) clay particles settle on fresh water lake bed.
(C) sand particles settle on river bed.
(D) sand particles settle on sea bed.

15. Identify the incorrect pair from the following:
(A) Alluvial soils–Transported by running water
(B) Lacustrine soils–Deposited at the bottom of lakes
(C) Talus–Soil transported by gravitational force
(D) Loess–Soil transported by glaciers

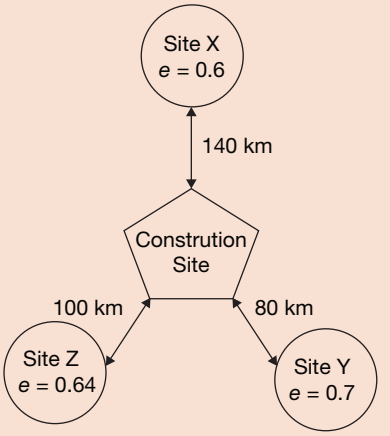
16. Which one among the following clay minerals has the maximum swelling tendency?
(A) Montmorillonite
(B) Kaolinite
(C) Illite
(D) Halloysite

17. Inorganic soil with high compressibility are represented by
(A) CL
(B) ML
(C) MH
(D) SH

Previous Years' Questions

1. The clay mineral primarily governing the swelling behavior of black cotton soil is **[GATE, 2014]**
(A) halloysite
(B) illite
(C) kaolinite
(D) montmorillonite

2. An earth embankment is to be constructed with compacted cohesionless soil. The volume of the embankment is 5000 m^3 and the target dry unit weight is 16.2 kN/m^3. Three nearby sites (see the given figure) have been identified from where the required soil can be transported to the construction site. The void ratios (e) of different sites are shown in the figure. Answer the specific gravity of soil to be 2.7 for all three sites. If the cost of transportation per km is twice the cost of excavation per m^3 of borrow pits, which site would you choose as the most economic solution? (Use unit weight of water = 10 kN/m^3) **[GATE, 2015]**



(A) Site X
(B) Site Y
(C) Site Z
(D) Any of the sites

3. The relationship between porosity (η), specific yield (S_y) and specific retention (S_x) of an unconfined aquifer is **[GATE, 2015]**
(A) $S_y + S_x = \eta$
(B) $S_y + \eta = S_x$
(C) $S_x + \eta = S_y$
(D) $S_y + S_x + \eta = 1$

Answer Keys

Exercises

1. B	**2.** B	**3.** A	**4.** C	**5.** D	**6.** C	**7.** D	**8.** D	**9.** C	**10.** B
11. C	**12.** B	**13.** C	**14.** A	**15.** D	**16.** A	**17.** C			

Previous Years' Questions

1. D **2.** B **3.** A