Investigation on Selected Khulna Soils as a Potential Base liner for Sanitary Landfills

by

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Declaration

This is to certify that the thesis work entitled "Investigation on Selected Khulna Soils as a Potential Base Liner for Sanitary Landfills" has been carried out by Salma Akhter in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work has not been submitted anywhere for any award of degree or diploma.

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ABSTRACT

Environmental protection is now one of the goals parallel to economic growth in the development policies throughout the world. Waste and its associated environmental problems specially in the urban areas have raised significant concern in both Government and Public authorities of Bangladesh.

Among the several methods of solid waste management, landfilling method of waste disposal is considered as the cheapest and most prevalent solution in the majority of the countries.

The most important part of the design of a sanitary landfill is the impervious liner. This type of design is practical when clay layer is present nearby or on the construction site within limited financial, technical and human resources. Some representative Khulna soils have been investigated for its workability, geotechnical properties including mineral identification.

A series of laboratory tests was conducted on selected soil samples, which are widespread and readily available over a considerable part of Khulna, to assess whether it could be compacted as hydro-geological barrier in waste disposal landfills.

Index properties, compaction characteristics, and hydraulic conductivity of most of the investigated soil samples indicate that it is inorganic, plastic, inactive, moderately expansive (due to presence of Montomorillonite and Vermiculite) and of fair attenuation capacity for inorganic/organic contaminants. The results of hydraulic conductivity tests illustrate that hydraulic conductivity lower than 1×10^{-7} cm/s can be achieved using a broad range of water contents and compactive efforts.

These findings suggest that the selected Khulna soil can be potentially utilized as compacted soil liner material. It is of special interest for Khulna zone, in Bangladesh, because there are no alternative mineral raw materials for liners of landfills.

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Units of Measurements

gm	:	Gram
kg	:	Kilogram
km	:	Kilometer
km^2	:	Square Kilometer
Kg/m^3	:	Kilogram per Cubic Meter
KJ/kg	:	Kilojoule per Kilogram
kg/day	:	Kilogram per Day
kg/cap/day	:	Kilogram per Capita per Day
l/day	:	Liter per Day
mm	:	Millimeter
m	:	Meter
m^3	:	Cubic Meter
ml	:	Milliliter
mg	:	Milligram
mg/l	:	Milligram per liter
nm	:	Nanometer
ppm	:	Parts per million

CHAPTER ONE

INTRODUCTION

1.1 General

The amount of waste generated in Bangladesh has been rapidly increasing in recent years. Waste and its associated environmental problems have raised significant concerns for both the government and the Local authorities. Environmental protection is now one of the goals that are required to be given the highest priority, parallel to economic growth and the development policies of the country.

In the Least Developed Countries (LDCs) like Bangladesh waste characteristics, climate conditions, operational capacity, technical resources, workforce, financial situation, environmental awareness, social and cultural standard are quite site specific. In order to set up adequate measures, It is required to develop own technologies and standards. Internationally accepted technologies may be modified according to the local conditions and accommodated to the level of acceptance.

Among the many other methods of solid waste management, landfilling is of particular attention including the issues of landfill siting, construction and operation. Implementation of waste reduction, recycling, and transformation technologies has decreased waste burdens, but landfills remain an important component of an integrated solid waste management strategy. It has been considered as the most economical and environmentally accepted method of waste disposal in the world. Based on the in-depth feasibility study conducted in Bangladesh and Nepal, Waste Safe team considers properly planned engineered landfill to be only affordable option for safe disposal of the majority of the Municipal Solid Waste (MSW) in the Least Development Asian Countries (LDACs) for the foreseeable future (Waste Safe 2005).

Landfill is a carefully designed structure built into or on top of the ground in which trash is isolated from the surrounding environment (groundwater, air, rain). This isolation is accomplished with a bottom liner and daily covering of soil. MSW landfills contain waste collected from residential, commercial, and industrial sources. These landfills may also accept construction and demolition debris, but not hazardous waste. Sanitary Landfill is a controlled method of waste disposal on land. It is an engineered containment system. It is so designed to aim at minimizing the impact of solid waste on the health and environment. As the landfill leachate is a potential threat to the soil and ground water contamination, increasing concern about landfill practices have come under increasing scrutiny in recent decades. Leachate is the water and water soluble compounds in the solid waste. When solid wastes deposited in a landfill and as water moves through the wastes, Leachate, viewed as Garbage juice accumulates. The water may be in the form of rainfall or from waste itself. The liner system is the most important component of the landfill design. It isolates and separates solid waste from the surroundings, acts as a barrier against seepage and diffusive transport of leachate solutes and thus prevents contamination of the native soil and ground water.

An adequate lining system is a necessary component for any sanitary landfill. Extra cares in waste-disposal site designs are given to the base liner to ensure protection of groundwater resources. A variety of natural and industrial materials have been developed and used for the base liner of landfills. Investigations have proven that clays are important natural resources for such applications (e.g., Emcon Associates 1983; Mundell & Bailey 1985; Quigley & Rowe 1986). As a consequence the use of natural soil as a base liner/barrier in order to retard the leachate produced from landfill sites has become very popular in recent years. Liners may be described as single, composite, or double liners. Single liners may be a clay liner, a geosynthetic clay liner, or a geomembrane liner. A composite liner consists of a geomembrane in combination with a clay liner. Composite liners are mostly used in landfill, which contains municipal solid waste (MSW). A double liner consists of either two single liners, two composite liners, or a single and a composite liner. The upper (primary) liner usually functions to collect the leachate, while the lower (secondary) liner acts as a leak-detection system and backup to the primary liner. Double-liner systems are used in some municipal solid waste landfills and in all hazardous waste landfills.

The major consideration deciding on a material for the liner is its permeability, and type of leachate will be exposed if the liner leaks. Compacted natural soil liners has been found most popular for many years for its suitability, cost effectiveness and simplest type of construction process. It can be handled with local expertise and equipment to compact and place to achieve practical imperviousness. High clay content was considered useful not only for low permeability but also for potential contaminant retardation. It is learnt that clay has an ability to attenuate many of the chemical constituents found in leachates. It is further learned that Shrink-Swell type of clays usually contains clay mineral named montomorillionite is found to best suited as liner material. Natural soil may contain a wide variety of clay minerals including montomorillionite.

Khulna is a divisional town in the southwest region of Bangladesh. There is no sanitary landfill at present within this region. The solid waste burden has been continuing mounting, directly and indirectly every day. Option for Sanitary landfills are an indispensable aspect for maintaining sanitary living conditions on a priority basis. Eventually an engineered burial facility for the solid waste needs to be located, designed, constructed, and operated in order to contain and isolate the solid waste in order to make it certain that it does not pose a substantial hazard to human health or the environment in and around Khulna city.

A deposit of silt highly compressible organic soil of low strength is common Khulna region again patches of large clay deposit, expansive in nature is found in and around this area. However primary information reveals that optimization of naturally occurring Khulna soil can be achieved without much change in geotechnical properties and its variation with time and waste degradation. Keeping in view of the availability and economy, it is essential to explore the potentiality of Khulna soil as a natural base liner material for the construction of sanitary landfills. The study was carried out to this destination.

1.2 Background of the study

The question "where should we put our garbage?" comes every quite often particularly in the country like Bangladesh where systematic garbage disposal system is far reaching. NIMBY/ LULU's (Not in My Back Yard / Locally Unwanted Land Uses) syndrome is not a matter to be just avoided. Again there is considerable misinformation on the public health and environmental benefits of the reduction, reuse, recovery and recycling (4R's) of municipal solid wastes.

The need for waste containment systems is under question due to the performance to contain liquids and gases generated in the landfill. The generated leachate moves downwards due to gravity and also towards the lesser density liquids by diffusion. If containment unit is not provided with liner system, leachate would continue to migrate out of the unit, through the vadose zone. It would ultimately be a threat to groundwater quality and, at some locations, nearby surface-water quality.

Not only the quantity and quality of leachate are of concern, for MSW landfills, the biodegradation of organics in the waste would create landfill gas. This gas works as an added source of groundwater contamination, explosion hazards and air pollution.

Historically, the use of liners to protect groundwater quality has been practiced for some types of landfills in some parts of the USA from about the mid 1970s. It is learnt that, the use of waste containment systems has become widespread since then and the capabilities of these systems have progressively improved.

Modern landfill sites are expected to prevent the leakage of leachate into the surrounding groundwater. So the containment unit must be lined to provide an impermeable barrier to the gas and leachate. Investigations have demonstrated that optimisation of landfill barrier design can not be achieved without specific geotechnical properties and time dependent variations in these properties as the waste degrades.

However, till to date, landfills have been the most economical and environmentally acceptable method of disposing of residual solid waste. The use of clay as a barrier or liner in order to retard the leachate produced from landfill sites has become very popular in recent years.

In the case of Khulna, Bangladesh where the research will focus, the use of clay materials as a barrier or liner in waste disposal landfill sites has not been used yet, and no research has been conducted on the use of clays in the area of landfill sites. All industrial and domestic waste is dumped in large collection sites without protection. These waste sites have started causing severe problems to the environment and to groundwater.

The aim of this research is be to find out how much contribution can be obtained from the natural soils in Khulna for constructing Sanitary landfill, particularly, because there are large clay deposits that could be utilised as an appropriate clay liner.

1.3 Objectives

The main objective of this research is to investigate and examine experimentally the suitability of some selected Khulna soil to function as a natural base liner material based on its physical, mineralogical and chemical characterization. It can be outlined as

1) To evaluate soil types and suitability of the selected khulna soil as base liner with respect to the physical properties of the collected soil samples

2) To assess the range of seepage quantities for liners constructed with Khulna soils,

3) To investigate the clay mineralogy of selected soil sample with respect to the liner requirement and recommend alternatives for reducing seepage

4) To evaluate the compaction properties of Khulna soils and the transport characteristics of leachate through the reconstituted Soils of the selected sites.

5) To examine the performance of the khulna soil in transmitting and releasing organic chemicals by employing compacted clay specimens in using clean and pre-contaminated clay materials of the selected soil sample.

1.4 Scope and Limitation of the Study

The use of natural soil as a base liner/barrier in order to retard the leachate propagation from landfill sites has become very popular in recent years. With expansion of urbanization in Bangladesh, consequent increasing waste producing society and greater public concern for waste containment facility, there is a regional need to investigate the issues related to the engineering behaviour of the landfill liner made of natural / partly modified Khulna soil.

Since there is no sanitary/ engineered landfill in this region, results from such an investigation can provide guidance for evaluation of potential solution, risk assessment and mitigation strategies, those are feasible under given condition of Khulna soils This research will also be an informative basis regarding material properties and effectiveness of the natural Khulna soils, as a natural base liner material for the construction of solid waste containment barrier in this region.

It is expected that this study will be helpful to the concerned researcher, designers, operators, regulators and related organizations to evaluate and work for the improvement measures of the existing open dumping sites. In addition, it will be beneficial for the local Authorities to use local natural resources as cost effective landfill facilities for any future attempts for constructing sanitary landfills in this region.

However, to properly use these materials as a base liner, more theoretical and experimental research is necessary to delineate material-leachate interactions and mass-transport processes.

1.5 Approach and Methods

Soils from four selected sites of in and around Khulna city were acquired for this study. The sites are Fultala, Rupsa, KUET backyard, Rajbandh municipal waste disposal site of Khulna City Corporation. The soils collected from these sites upto a considerable depth were thoroughly characterized and clearly profiled for their engineering properties.

Several natural liner specimens prepared from the collected soil have been tested in the laboratory to determine permeability, migration profile, and to investigate factors controlling the waste-barrier interaction including liner thickness, optimum moisture content, mass transfer characteristics of liner material, range of seepage quantities through compacted clays. In particular, the compaction characteristics of the soils were determined using the Proctor compaction method. The permeabilities of the compacted specimens with respect to water were determined using compaction permeameters. A subset of the samples was subsequently permeated with collected leachate from the waste disposal site of KCC. The effects of organic chemicals on physical properties of the clay has been examined. The identification of the leachate sample were also thoroughly examined for its physical and chemical constituents.

Mineralogical tests on the collected soils on strata basis were evaluated from the Bangladesh Atomic Energy commission in order to evaluate its compatibility as base liner characteristics. Investigation had been made whether any modification of the clay constituents can provide better performance of the liner system. Attempts had also been made to correlate compaction criteria to hydraulic conductivity, swell index, volumetric index upon drying and other relevant parameter.

A review of the literature related to this project was done in order to determine the state-of-the-art on research in soil liner barrier to bring together the existing knowledge base in concerned areas and to identify the areas where new research could be applied. In addition a review of international guidelines and specification for landfill liners was carried out.

1.6 Organisation of the Thesis

This report is organized in five main chapters, and is meant to provide understanding of Khulna Soil as base liner material through investigation of theory, presentation of experimental procedures and results, and introduction to possible design applications. The Content of each chapter as appeared sequentically are described in the following:

Chapter 1 includes general introduction, background, objectives, scope and limitations of the study.

Chapter 2 provides an understanding of MSW compositions, Possible hazard identification, General features of a Sanitary Landfills, Liner system, Evaluation of waste containment facilities, Typical Leachate characteristics, Contaminant Transport in soils: Waste containment principal, Influence of clay liner on leachate etc. This chapter also reviews the basic concepts of engineering parameter of clay liner, performance of compacted earthen linings, practical aspect of clay as liner material.

Chapter 3 provides a review of the state-of-the-art on issues of waste containment facilities of the study area. This chapter also represents overview of study areas including general information and provides analyses and discussions of a database for waste disposal facilities.

Chapter 4 includes requirement design criteria of a clay liner, factors controlling the waste/barrier interaction. Chapter 4 discusses the various soil physical characteristics and parameter found in collected soil samples . This chapter evaluates responses of different testing parameters for base liner.

Chapter 5 consists of mineralogy testing of selected soil sample. XRD identification of the soil samples, interpretation, evaluation of percentage mineral content in the analysed soil samples

Chapter 6 gives the brief review of the contaminant transport through compacted soil liner. It contains the details of the chemical analyses performed to characterize the chemical stability of the soil samples under investigation.

Chapter 7 summarizes the study findings with some specific considerations and provides suggestions for beneficial use of Khulna soil as soil liner as landfill component for the site specific zone of Khulna area. A number of recommendations for future research are placed in this chapter.

Appendixes, references and bibliography are cited at the end of the report.

CHAPTER TWO

Literature review

2.1 General

From the beginning of the social culture, human have been taking care of the resources and dispose of wastes. The useless and unwanted materials are usually thrown away. It is learnt that the problem with the disposal of wastes, usually solids can be traced from the time when human first began to congregate in tribe, villages, and communities and accumulation of waste became a consequence of life. In early times these wastes deposited outside of their places/residences, which eventually because of odour, rodent, nuisance etc. the practice of open dumping of garbage usually located in a nearby low value land. In the beginning, this practice did not pose a significant problem as for less population, there existed large land spaces for the assimilation of waste. Due to rapid growth of population, industrialization and urbanization, the generation of waste increased sharply. In US alone, the 1988 figure for the number of contaminated sites was 52000. In Germany suspected registered contaminated sites were 362,689 (www.icss-uba.de).

2.2 Evaluation of Waste Containment Facilities

The first recorded regulation to control municipal waste were implemented during the Minoan civilization, which flourished in Greece from 3000 to 1000 B.C.E. Solid waste from the capital Knossos, were placed in large pits and covered with layers of earth in intervals. The basic method of landfilling has remained relatively unchanged until these days. Early seventies most of the landfill site were chosen near the lakes or rivers or in close proximity to ground water aquifers, without concern of the environmental impact. As a consequence contaminants out of these landfills caused greater contamination of ground and surface water. It is learnt that this problem came into view in 1970s and necessitated safe containment facilities. The concept of the containment landfill, where the body of waste material is completely encapsulated within a supposedly impermeable barrier, has therefore been developed and used for a much wider range of waste types. In addition, the containment landfills need to have incorporated systems for the collection, handling and management of gas and leachate. Eventually, careful design and operation lead to a highly sophisticated engineered system day by day.

Table 2.1: Evolution of waste containment facilities (after Bouzza et al, 2002)

Date	Development	Problems	Improvements
1970s	Sanitary Landfills	Health, nuisance i.e. odour, fires, litter	Daily cover, better compaction, engineered approach to containment
Late 1980-early1990s	Engineered landfills, recycling	Ground and groundwater contamination	Engineered liner, cover, leachate and gas collection system, increasing regulation, financial assurance
Late 1990s	Improved sitting and containment , waste diversion and reuse	Stability gas migration	Incorporation of technical , socio-political factors into sitting process, development of new lining material , new cover concept, increased post closure care
200s	Improved waste treatment		Increasing emphasis on mechanical and biological waste pre-treatment, leachate recirculation and bioreactors, smart landfills.

2.3 Types of Waste Containment Facilities

The term Landfill is used to describe the physical facilities for waste containment in the surface of soils. In one form or another, Landfills, have been found most economical and environmentally acceptable method for disposal of solid wastes throughout the world. Waste is termed Non hazardous, when it may release constituents that are in excess in concentration of the acceptable water quality criteria established by recognized authority. Hazardous waste landfills are called secure landfills. Landfills for individual waste constituents such as combustion ash, asbestos and other similar wastes are known as monofills.

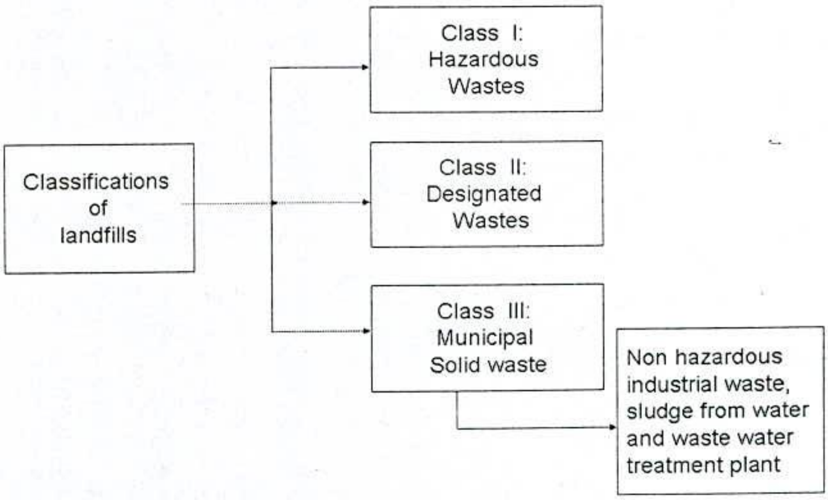


Fig 2.1: Classification of Landfills

2.4 Sanitary Landfill

Sanitary landfills are well-engineered, well controlled method of waste disposal on land. Public concerns such as odor, unsightliness, insects and birds problems are well taken care of in the design and construction phase of a landfill. These landfills provide environmentally sound disposal of waste that cannot be reduced, recycled, composted, combusted, or processed in some other manner. At least once a day the wastes are covered with layers of earth, (synthetic foam and other types of daily covers are available these days), and then compacted again. The site of the landfill must also be suitable in terms of geological, hydrological and environmental conditions. Substantial provisions are made in terms of design, construction, and operation to ensure proper containment and decomposition of the waste. One of the important features of a landfill is that it does not pollute the native soil and ground water beneath. Sanitary landfills receive solid waste from various sources as follows:

- Municipal solid waste (MSW) consists of waste generated by residential and commercial sources. With no recycling nearly half consists of paper and another one-third consists of organic waste, including food and yard sweeping. The remainder includes glass, plastics, metals and many other materials.
- Industrial solid waste produced from industrial processes, depending on the type of industry. These may include hazardous chemicals.
- Agricultural solid waste includes plant and animal materials generated in farms and food processing plants
- Sewage sludge is produced by sewage treatment plants.
- Combustion by –product from burning coal include ash from furnaces.
- Various by-product of mining operations coarse grained mining waste called as trailing, fine grained wastes called slimes, which are useless in compare to trailing (used as construction aggregates) etc are the mining solid waste.

Table 2.2: Typical composition of MSW

Component	Percent by mass	
	Range	Typical
Food waste	6-26	14
Paper	15-45	34
Cud board	3-15	7
Plastics	2-8	2
Textiles	0-4	0.5

Rubber	0-2	0.5
Garden trimmings	0-2	12
Wood	0-20	2
Miscellaneous organics	0-5	4
Glass	4-16	4
Tin cans	2-8	4
Non ferrous metals	0-1	4
Ferrous metals	1-4	4
Dirt, ashes, brick etc.	0-10	4

Source: Peavy, Rowe, Tchanoglous, Environmental Engineering, 1985.p. 577, McGraw Hill book co.

2.4.1 General features of Sanitary Landfills

Sanitary landfills, as discussed above, are aimed to prevent migration of the deleterious chemicals produced as "garbage juice" called "leachate" and landfill gas, into the surrounding soil, to nearby ground and surface water and to the air. There are four critical elements in a sanitary landfill: a bottom liner, a cover, a leachate collection system, and the natural hydrogeologic setting. The natural setting can be selected to minimize the possibility of wastes escaping to groundwater beneath a landfill. The other three elements must be engineered. Each of these elements is critical to success.

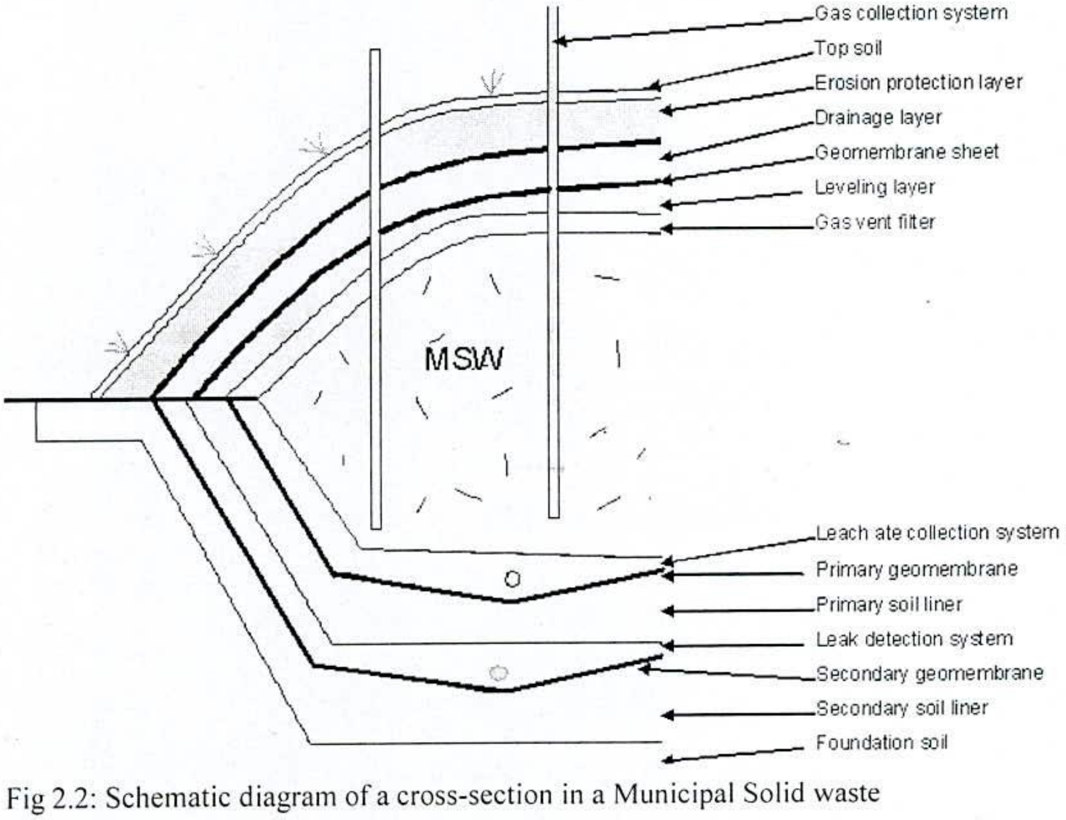


Fig 2.2: Schematic diagram of a cross-section in a Municipal Solid waste

2.4.2 Leachate

Leachate extracts dissolved and suspended materials as it percolates through solid waste. Depending on the type of wastes and the reactions between the percolated water and wastes, the leachate may become highly contaminated and concentrated "chemical soup". It may be so concentrated that small amounts of leachate can pollute large amounts of groundwater consequently make it unsuitable for domestic water supply.

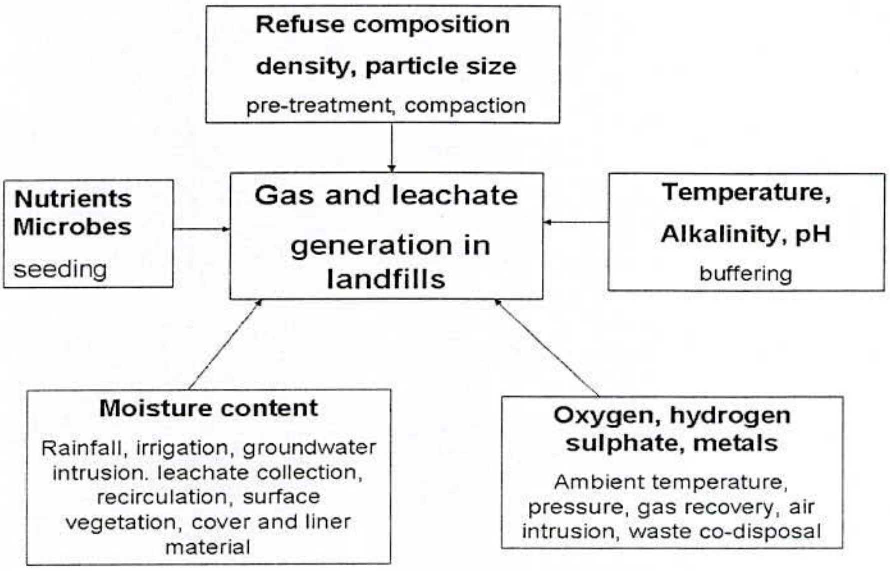


Fig 2.3: The main factors influencing gas and leachate generation in landfills (El-Fadel et al. 1995)

In normal conditions, Moisture within a landfill percolates down through the waste materials picking up a variety of contaminants from any rotting waste and other components present. Leachate rates at a landfill site are controlled by seasonal factors or by a decline in source strength as components of the waste such as organics, biodegrade (Domenico & Schwartz, 1998). Leachate contains a wide variety of Physical, Chemical and biological constituents in it. Typical Leachate characteristics are shown below:

Table 2.3 : Typical Leachate characteristics

Physical	Organic constituents	Inorganic constituents	Biological
Appearance pH Oxidation-Reduction potential Conductivity	Organic chemicals Phenols Chemical Oxygen Demand (COD) Total Organic Carbon (TOC)	Suspended solids (SS), Total Dissolved solids (TDS) Volatile Suspended Solids (VSS), Volatile Dissolved solids (VDS) Chloride Sulphate	Biological Oxygen Demand (BOD), Coliform Bacteria

Colour Turbidity Temperature odour	Volatile acids Tannins, Lignin Oprganic –N Ether soluble (oil & grease) Methylene Blue Active substances (MBAS) Organic functional group as required Chlorinated hydrocarbon	Phosphate Alkalinity and Acidity Nitrate –N Nitrite –N Amminia-N Sodium Potassium Calcium Magnesium Hardness Heavy metals (Pb, Cu, Ni, Cr, Zn, Cd, Fe, Mn, Hg, Ba, Ag) Arsenic, Cyanide, Fluride, Selenium	(Total, Fecal, local Streptococci) Standard Plate Count

Many factors influence leachate composition including the types of wastes deposited in the landfill, the amount of precipitation in the area and other site-specific conditions. The common reaction process occurring within the wastes are:

- Dissolution of certain solid forms of waste and subsequent precipitation
- Decomposition and disintegration of the solids
- Reactions between the original liquids contained in the waste and percolating water

The rates of biological and chemical activities taking place in the landfill can also affect leachate quality by altering the way that waste dissolves in or migrates with leachates (Lee, 1996). The loading history describes how the concentration of a contaminant or its rate of production varies as a function of time at the source.

Table 2.4: Concentration Ranges for Components of Municipal Landfill Leachate

Parameter	**"Typical" Concentration Range**	**"Average"***
BOD	1,000 - 30,000	10,500
COD	1,000 - 50,000	15,000
TOC	700 - 10,000	3,500
Total volatile acids (as acetic acid)	70 - 28,000	NA
Tota Kjeldahl Nitrogen (as N)	10 - 500	500
Nitrate (as N)	0.1 - 10	4
Ammonia (as N)	100 - 400	300
Total Phosphate (PO_4)	0.5 - 50	30
Orthophospate (PO_4)	1.0 - 60	22
Total alkalinity (as $CaCO_3$)	500 - 10,000	3,600
Total hardness (as $CaCO_3$)	500 - 10,000	4,200
Total solids	3,000 - 50,000	16,000
Total dissolved solids	1,000 - 20,000	11,000
Specific conductance (mhos/cm)	2,000 - 8,000	6,700
pH	5 - 7.5	63
Calcium	100 - 3,000	1,000
Magnesium	30 - 500	700

Sodium	200 - 1,500	700
Chloride	100 - 2,000	980
Sulphate	10 - 1,000	380
Chromium (total)	0.05 - 1	0.9
Cadmium	0.001 - 0.1	0.05
Copper	0.02 - 1	0.5
Lead	0.1 - 1	0.5
Nickel	0.1 - 1	1.2
Iron	10 - 1,000	430
Zinc	0.5 - 30	21
Methane gas	60%	
Carbon dioxide	40%	

All values mg/L except as noted
NA - not available
*After: Lee et al. (1986) *From CH2M Hill based on 83 landfills (1989)*

Table 2.5: Phased activity of Leachate production:

Phase no.	***Name of phase***	***Activity***
Phase i	Initial adjustment	biological decomposition occurs under aerobic conditions
Phase ii	Transition phase	Oxygen is depleted and anaerobic conditions began to develop, pH starts to drop due to production of organic acids and CO_2 production
Phase ii	Acid phase	excessive organic acid production due to microbial activity (pH 5 or lower), Heavy metal will be solubilized
Phase iv	Methane fermentation phase	microbial converting of acetic acids and hydrogen into CO_2 and CH_4
Phase v	Maturation phase	biodegradation of previously unavailable materials with water supply , leachate contains humic and fulvic acids.

Table 2.6 : Time scale for different decomposition phases (Pacey and Augestein, 1991)

	Phase	**Time scale**
I	Oxygen and nitrate reduction phase	Hours -1 week
II	Acid phase	1-6 months
III	Unstable methane- generation phase	3 months-3 years
IV	Methane generation phase	8-40 years
V	Humus-generation phase	1 at least 40 years

2.4.3 Landfill Gases

In addition to leachate, almost all landfills will generate potentially toxic, explosive and asphyxiating landfill gas through the decomposition of organic waste materials. It is learnt that the anaerobic decomposition of organic materials in a municipal solid waste landfill will generate a combination of gases (collectively called landfill gas) at a rate of approximately 0.15 cubic feet per pound of waste per year. In the past, the potential for leachate pollution and gas migration was not valued to the extent that it is today. Landfill gas can migrate considerable distances underground. Predominantly methane and carbon dioxide, the underground migration of landfill gas can pose serious safety risks in nearby structures when the gas accumulates at concentrated levels. At smaller landfills, the gas venting layer allows for the effective collection and dispersion of landfill gas which is passively released through cane-like vents installed in a landfill's cover system

Table 2.7 : Typical composition of a stabilized MSW landfill gas (waste volume <0.46 million cubic yard)

Parameter	*Percentage or concentration*
Methane	30-53%
Carbon dioxide	34-51%
Nitrogen	1-21%
Oxygen	1-2%
Benzene	ND-32 ppm[a]
Vinyl Chloride	ND-44 ppm[a]
Toluene	150 ppm[a]
t-12 Dichloroethane	59 ppm[a]
$CHCL_3$	0.69 ppm[a]
1,2- Dichloroethane	19 ppm[a]
1,1,1-Trichloroehane	3.6 ppm[a]
CCL_4	0.011 ppm[a]
Trichloroehane	13 ppm[a]
Perchloroehane	19 ppm[a]
[a] *maximum concentration from a survey of 20 landfills , ND= not detected*	

Source : Bagchi, Amalendu, Design ,Construction and Monitoring of Sanitary Landfill,P.47, John Willey & Sons Inc.

At larger landfills, the gas venting layer is often eliminated and the gas is actively collected via horizontal trenches and gas collection wells and burned in flares or utilized in projects that make use of the energy value of the methane component of the landfill gas.

2.5 Waste Containment Patterns

Landfills are complex civil engineering structure and require a lot of additional factors to be considered. The selection of an appropriate site for a new landfill is of utmost importance. It is dependent on various factors like, Geology /hydrogeology of the site, Nature of the barrier, Geometry and the nature of the site ,Climate, Type of waste. The evaluation of the design for a waste disposal facility involves making a quantities prediction of potential impact of contaminants on the environment. Four aspects to be considered:

- Identification of the controlling mechanism
- Formulation or selection of a theoretical model

- Determination of the relevant input parameters
- Solving the governing equation.

The deposition of waste in a landfill has a major influence on the chemical reactions and conditions in the landfill. Waste deposited in compacted horizontal layers has low permeability, there is low infiltration and percolation of liquids, anaerobic condition will prevail and leachate concentration will be high. One of the first questions a landfills designer must address is whether the landfill will be above ground where leachate can be drain by gravity and it is easy construction. Below ground or above and below which can contain large volume, excavated materials can be used as cover and it has wide range of use.

2.6 Liners

Once a contaminant has escaped into the ground, it flows from pore to pore through the soil, sometimes traveling several kilometers. The manner and rate of transport depend on many factors including:

- Whether the soil is saturated or unsaturated
- The type of soil
- The type of material flowing through the soil, especially its solubility in water and its specific gravity
- The velocity and direction of natural ground water flow
- The rate of infiltration from the source.

For all except the most toxic wastes, it was felt that leachate should be allowed to disperse into surrounding soils where its toxicity would be naturally reduced (attenuated) through physico-chemical and microbiological mechanisms. In general, the extend of this action depends on the characteristics of the soil, especially clay content.

Almost invariably, new landfills are now required to incorporate some form of impermeable lining material *(liner)* entirely covering the floor and sides of the excavated area. The purpose of the liner is to prevent the migration of gas or leachate from the landfill into the surrounding environment, and to prevent the migration of groundwater into the landfill. The liner may be constructed from compacted clay soil *(mineral liner)*, or from synthetic plastic sheeting (*geomembrane*), or from a combination of the two (*composite liner*).

2.6.1 Liner Components

Landfill liners are so designed and constructed as to create a barrier between the waste and the environment and to drain the leachate to collection and treatment facilities. Barriers are intended to limit and control contaminants escaping from the landfills. Now a day's barrier include one or more of the components:

- Natural clayey soil and /or re-compacted clayey soil liners
- Natural bedrock
- Cut-off walls
- Artificial liners

Liner Components are as follows:

Clay : To protect the ground water from landfill contaminants, clay liners are constructed as a simple liner that is two- to five-feet thick. In composite and double liners, the compacted clay layers are usually between two- and five-feet thick, depending on the characteristics of the underlying geology and the type of liner to be installed. It is required that the clay used can only allow water to penetrate at a rate of less than 1.2 inches per year. The effectiveness of clay liners can be reduced by fractures induced by freeze-thaw cycles, drying out, and the presence of some chemicals.

In theory, one foot of clay is enough to contain the leachate. The reason for the additional clay is to safeguard the environment in the event of some loss of effectiveness in part of the clay layer. The efficiency of clay liners can be maximized by laying the clay down in four- to six-inch layers and then compacting each layer with a heavy roller.

The efficiency of clay liners is impaired if they are allowed to dry out during placement. Desiccation of the clay during construction results in cracks that reduce the liner efficiency. In addition, clays compacted at low moisture contents are less effective barriers to contaminants than clays compacted at higher moisture contents. Liners that are made of a single type of clay perform better than liners constructed using several different types.

Geomembranes: Geomembranes are also called flexible membrane liners (FML). These liners are constructed from various plastic materials, including polyvinyl chloride (PVC) and high-density polyethylene (HDPE). The preferred material for use in MSW and secure landfills is HDPE. This material is strong, resistant to most chemicals, and is considered to be impermeable to water. Therefore, HDPE minimizes the transfer of leachate from the landfill to the environment.

Geotextiles: In landfill liners, geotextiles are used to prevent the movement of small soil and refuse particles into the leachate collection layers and to protect geomembranes from punctures. These materials allow the movement of water but trap particles to reduce clogging in the leachate collection system.

Geosynthetic Clay Liner (GCL): Geosynthetic clay liners are becoming more common in landfill liner designs. These liners consist of a thin clay layer (4-6 mm) between two layers of a geotextile. These liners can be installed more quickly than traditional compacted clay liners, and the efficiency of these liners is impacted less by freeze-thaw cycles.

Geonet: A geonet is a plastic net-like drainage blanket which may be used in landfill liners in place of sand or gravel for the leachate collection layer. Sand and gravel are usually used due to cost considerations, and because geonets are more susceptible to clogging by small particles. This clogging would impair the performance of the leachate collection system. Geonets do, however, convey liquid more rapidly than sand and gravel.

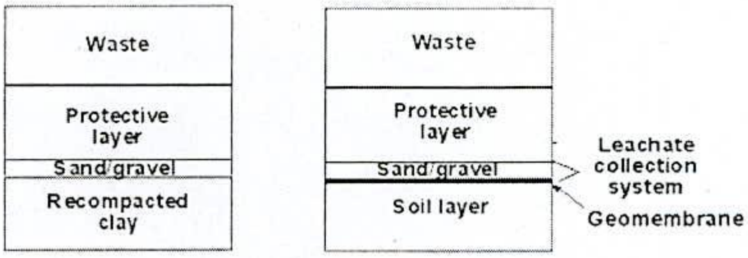
2.6.2 Liner system

Different type of liner system is required for different categories of Landfills depending on the potential threat of the waste in consideration. There are single, composite, or double liners.

Single-Liner Systems

Single liners consist of a clay liner, a geosynthetic clay liner, or a geomembrane. Single liners are sometimes used in landfills designed to hold construction and demolition debris results from building and demolition activities and includes concrete, asphalt, shingles, wood, bricks, and glass. These landfills are not constructed to contain paint, liquid tar, municipal garbage, or treated lumber; consequently, single-liner systems are usually adequate to protect the environment.

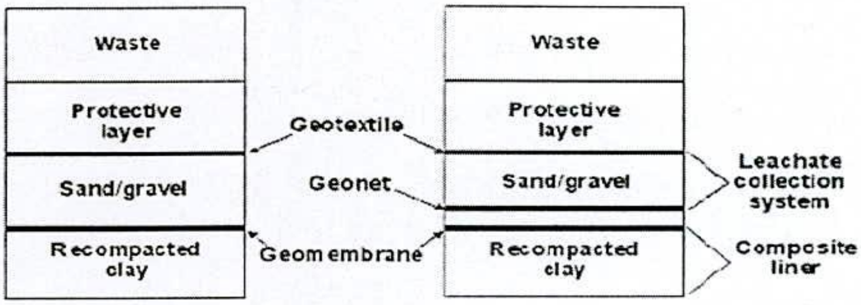
Single liner system



Composite-Liner Systems

A composite liner consists of a geomembrane in combination with a clay liner. Composite-liner systems are more effective at limiting leachate migration into the subsoil than either a clay liner or a single geomembrane layer. Composite liners are required in municipal solid waste (MSW) landfills.

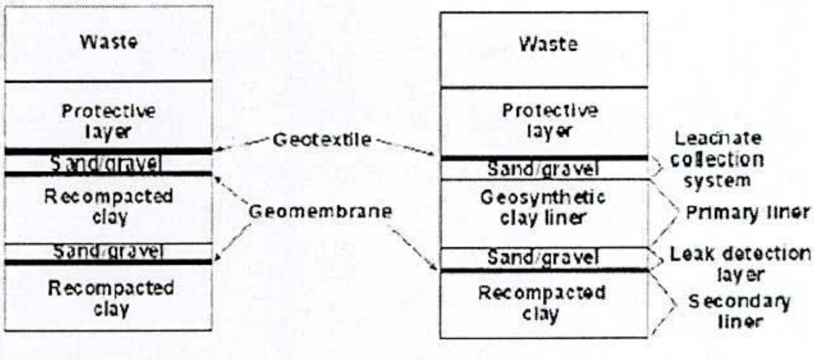
Composite liner system



Double-Liner Systems

A double liner consists of either two single liners, two composite liners, or a single and a composite liner. The upper (primary) liner usually functions to collect the leachate, while the lower (secondary) liner acts as a leak-detection system and backup to the primary liner. Double-liner systems are used in some municipal solid waste landfills and in all hazardous waste landfills.

Double liner system



2.6.3 Basic Liner Specifications

Natural soil liner are relatively impervious geologic formations such as aquitards or aquicludes. An aquitard is a geologic formation that transmit water at a very slow rate relative to aquifer whereas an aquicludes is a geologic formation which is so impervious that it completely obstruct the flow of ground water. Natural soil liner, made of native soil are having some common criteria:

1. $K = 10^{-9}$ m/s or less
2. Clay ($< 20^{-60}$ m) content > 15 -20 %
3. Plasticity Index I_p (PI) > 7%
4. Minimum CEC of 10 meq (milliequivalants) / 100 gr.Soil
5. Leachate compatibility (no k- value increase)
6. Minimum thickness for MSW : 1.0 m, 0.6 m with geomembrane
7. Minimum thickness for industrial /toxic waste 3-4 m (15 m), alternatively Multiple Composite Liner Systems.

Table 2.8 Basic Characteristics of Liner Soils

Type of soils	*Dry strength*	*Dilatancy*	*Plastiicity*	*Toughness*	*Remarks*
Silt	None to low	Slow to rapid	None to low	Low or thread can not be formed	Lean clay is only slightly plastic, whereas fat clay is highly plastic. Dilatancy is increased in volume when soil is compressed
Lean clay	Medium to high	None to slow	Low to medium	Medium	
Elastic silt	Low to medium	None to slow	Medium	Low to medium	
Fat clay	High to very high	None	High	High	

2.7 Engineering Parameters of Clay Lining Materials

The use of clay as lining materials is the preferential method of reducing or eliminating of percolation of leachate from landfills for its ability to adsorb and retain many of the chemical constituents and resistance to flow. If suitable earthen material is available near the site of construction, or is in-situ, a lining of compacted earth is an inexpensive and efficient means of controlling seepage. This type of lining, especially a thick compacted lining, has proved better than other types of earthen linings and has been used extensively.

2.7.1 Hydraulic Conductivity

A critical parameter of a landfill liner to isolate leachate from the subsurface environment is hydraulic conductivity. Of all the landfill liner parameters investigated by researchers, hydraulic conductivity has been received the most attention when designing and analyzing the performance of a landfill (Yanful et al. 1990, Fernandez and Quigley 1985 and Quigley et al. 1987). The hydraulic conductivity of soil generally decreases with an increasing amount of he fine grained soil. Lambe (1958) suggested that the soil with a flocculated structure (i.e. at dry of optimum moisture content) exhibits greater hydraulic conductivity than soil having an equal density and moisture content but a dispersed structure (i.e. at wet of optimum moisture content).

2.7.2 Moisture Content & Plasticity

Natural moisture content and plasticity should be carefully established as these are two key parameters in governing the ability of a soil to produce a well engineered and impermeable liner. For a given soil sample there is a unique compactive effort at which the density ceases to increase. The higher the moisture content, the lower the compactive effort beyond which no further increase in density occurs. A minimum Plasticity Index of 10% is normally required / stipulated as soils with a lower plasticity index are unlikely to achieve a sufficiently low permeability.

2.7.3 Plasticity Characteristics

Plasticity characteristics describe a material's ability to behave as a plastic or moldable material. Soils containing clay are generally categorized as plastic. Soils that do not contain clay are non-plastic and typically considered unsuitable materials for compacted clay liners, unless soil amendments such as bentonite clay are introduced. Plasticity characteristics are quantified by three parameters: liquid limit, plastic limit, and plasticity index. The liquid limit is defined as the minimum moisture content (in percent of oven-dried weight) at which a soil-water mixture can flow. The plastic limit is the minimum moisture content at which a soil can be molded. The plasticity index is defined as the liquid limit minus the plastic limit and defines the range of moisture content over which a soil exhibits plastic behavior. When soils with high plastic limits are too dry during placement, they tend to form clods, or hardened clumps, that are difficult to break down during compaction. As a result, preferential pathways can form around these clumps allowing leachate to flow through the material at a higher rate. Soil plasticity indices typically range from 10 percent to 30 percent. Soils with a plasticity index greater than 30 percent are cohesive, sticky, and difficult to work with in the field. Common testing methods for plasticity characteristics include the methods specified in ASTM D-4318, also known as Atterberg limits tests.

2.7.4 Percent Fines and Percent Gravel

Typical soil liner materials contain at least 30 percent fines and can contain up to 50 percent gravel, by weight. Common testing methods for percent fines and percent gravel are specified in ASTM D-422, also referred to as grain size distribution tests.5 Fines refer to silt and clay sized particles. Soils with less than 30 percent fines can be worked to obtain hydraulic conductivities below 1 x 10-7 cm/sec (4 x 10-8 in./sec), but use of these soils requires more careful construction practices. Gravel is defined as particles unable to pass through the openings of a Number 4 sieve, which has an opening size equal to 4.76 mm (0.2 in.). Although gravel itself has a high hydraulic conductivity, relatively large amounts of gravel, up to 50 percent by weight, can be uniformly mixed with clay materials without significantly increasing the hydraulic conductivity of the material. Clay materials fill voids created between gravel particles, thereby creating a gravel-clay mixture with a low hydraulic conductivity.

As long as the percent gravel in compacted clay mixture remains below 50 percent, creating a uniform mixture of clay and gravel, where clay can fill in gaps, is more critical than the actual gravel content of the mixture. Similar to gravel, soil particles or rock fragments also can create preferential flow paths. To help prevent the development of preferential pathways and an increased hydraulic conductivity, it is best to use soil liner materials where the soil particles and rock fragments are typically small (e.g., ¾ inches in diameter).

Table 2.9: Typical Soil Properties

Soil Type	***Hydraulic Conductivity K (cm/s)***	***Total Porosity*** ***n (%)***	***Effective Porosity*** ***n_e (%)***	***Bulk Density*** ***d (g/cm^3)***
Clayey	10^{-9} - 10^{-6}	40-60	0-5	1.2-1.8
Silty	10^{-7} - 10^{-3}	35-50	3-20	1.1-1.8
Sandy	10^{-5} - 10^{-1}	20-50	10-35	1.3-1.9
Gravelly	10^{-1} - 10^{2}	25-40	12-30	1.6-2.1

Where a compacted clay liner functions as a bottom layer to a geosynthetic, gravel can cause puncturing in geosynthetic materials. Controlling the maximum particle size and angularity of the gravel should help prevent puncturing, as well as prevent gravel from creating preferential flow paths.

2.7.5 Compaction Requirement

Lower hydraulic conductivity in the liner can be maintained by proper remoulding and compaction of the soil. A compaction curve is developed by preparing several samples of soil at different water content and then subsequently compacting each of the samplesinto a mold of known volume with specifies compaction procedure. The reason for developing a compaction curve is to determine the optimum water content and maximum dry density weight for a given soil and compaction procedure. If the soil's specific gravity of solids (Gs) changes, the zero air voids curve will also change. Theoretically, no points on a plot of *dry* unit weight versus water content should lie above the zero air voids curve, but in practice some points usually lie slightly above the zero air voids curve as a result of soil variability and inherent limitations in the accuracy of water content and unit weight measurements (*Schmertmann, 1989*).

Several methods for laboratory compaction are commonly employed. The two common method are Standard compaction (ASTM D 698) and Modified compaction (ASTM D 1557). The soil is placed into a mould of 9.4×10^{-4} m^3 (1/30 cu ft). the number of lifts , weight of hammer, weight of fall are listed in the following table. Standard Proctor (ASTM D 698) produces maximum dry unit weights approximately equal to field dry unit weights for the soils samples that are well compacted using modest sized compaction equipment (i.e compactors with a mass of 9-20 Mg [weight of 10-12 tons]) whereas Modified Proctor (ASTM D 1557) produces maximum dry unit weights approximately equal to field dry unit weights for soils that are well compacted using heaviest compaction equipment available (i.e compactors with a mass of 32-36 Mg [weight of 35-40 tons]).

Table 2.10 : Compaction tests details

Compaction procedure	*Number of lifts*	*Weight of hammer*	*Weight of fall*	*Compaction energy*
Standard	3	24.5 N (5.5 lb)	305 mm (12 in.)	594 kN-m/m^3 (12.375 ft-lb/cu ft)
Modified	5	44.5 N (10 lb)	457 mm (18 in.)	2.693 kN-m/m^3 56.250 ft-lb/cu ft

(after Daniel & Koerner)

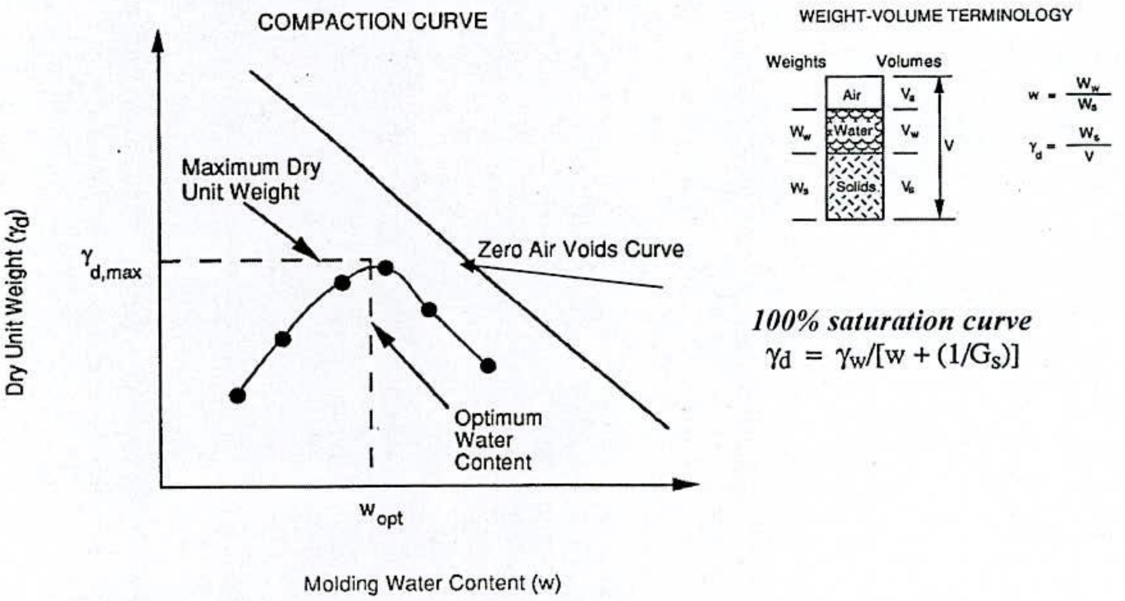


Figure 2.4 - Compaction Curve (reproduced from EPA_QA-QC for Waste Containment Facilities)

2.8 Performance of Compacted Earthen Linings

Wetting and drying of soil can affect the soil properties. Freezing and thawing in colder areas can also cause changes in performance (Kraatz, 1977), although, studies indicate that some linings exhibit no significant change in density. The greatest decrease in density was approximately 7%, which was concentrated near the lining surface. This lining still achieved reduced seepage rates of 10 to 30L/m^2/day (USBR, 1976). Field and laboratory tests on typical soils in selected US compacted earthen channel linings demonstrate long-term physical changes. The unit weight, a property affecting permeability, was found to vary significantly from one test site to the other and from year to year. The unit weight tended to decrease from the top of the lining to the bottom, although the reverse also occurs. The changes in unit weight were largely attributed to frost action. There was less change in unit weight in soils that did not have a significant gravel fraction. Loss of unit weight was attributed to wetting and drying in some instances. It was concluded that soil changes found did not significantly affect the expected performance of the channels in controlling seepage (Jones, 1987).

2.8.1 Seepage reduction

A number of studies have attempted to quantify seepage reduction due to installation of compacted earthen linings and results are summarised in the table below. A properly installed clay liner is estimated to have a seepage reduction effectiveness of 70% with an estimated life of 30 years (Sinclair Knight Merz, 1998).

Table 2.11 : Seepage rate through liner with time

Material		*Seepage rate (L/m^2/day) with time*							*Remark*
Natural soil	*Lining*	*Pre-lining*	*Post-lining*	*4 yrs*	*5 yrs*	*6 yrs*	*10yrs*	*Seepage Reduction*	
Lean clay and sand	Compacted clay, soil and gravel cover	1338	27				55	98-96%	Pohjakas et al, 1967
Clay & sand over silt and gravel	Compacted clay (500mm)	610	30	76				95 -88%	Pohjakas et al, 1967
Clay and silt	Compacted clay (300mm)	354	30		79			92-78%	Pohjakas et al, 1967
Clay, silt and sand	Compacted clay (500mm)	125	40			73		68-42%	Pohjakas et al, 1967
Not specified	Lean clay lining (300mm)	122	21					83%	USBR, 1963
Not specified	Compacted clayey limestone material (500mm)	671	85					87%	ICID, 1957
Not specified	Compacted (300 to 900mm)	122	21					83%	USBR, 1977

The hydraulic properties of compacted clay liners can be adversely affected by desiccation cracking. Initial results using soil additives (such as lime, cement, and sand) for crack reduction, indicated that soil shrinkage was reduced. However, it is learnt, in many cases, the additives resulted in an increased hydraulic conductivity and decrease in soil plasticity.

2.8.2 Evaluation of a Potential Source for Clay Lining

Clay deposits can be found in estuaries, coastal plains, continental shelves, and offshore islands of various parts of the world. These geographic zones are usually the economic, industrial, commercial, and residential hubs of regions. In the recent decades, many waste landfill facilities have been constructed on the coastal and offshore clay deposits, in view of their strategic locations. The clay deposits found in these zones have been regarded as excellent natural hydraulic barriers. In addition, exposure to the marine environment during initial deposition gave the clays favorable geochemical properties such as high alkalinity and acid buffer capacity for heavy metal immobilization (Lim, 1998).

Clay deposits, besides serving as excellent hydraulic barriers, can attenuate contaminant migration via geochemical processes such as adsorption, precipitation, and co-precipitation. The actual modes of heavy metal retention depend on the species of heavy metal, soil constituents, leachate pH and composition, redox conditions, and numerous physical parameters of the soil–waste system. pH has been regarded as a master variable regulating the mobility of metals. A large volume of literature is available on the influence of pH on metal sorption in various natural soils and synthetic soil constituents (e.g., Harter, 1983; Yong et al., 1993; Holm and Zhu, 1994; Lee et al., 1998; Papini et al., 1999; Coles et al., 2000). To evaluate a **potential source for clay** lining the following suite of tests is recommended and should be carried out in accordance with BS 1377 (1990).

Natural moisture content
Atterberg limit (Liquid / Plastic Limits)
Particle size grading
Organic content
Compaction curves (dry density / optimum moisture content relationship)
Moisture Condition Value (MCV)
Permeability

It is highlighted that a potential borrow source may contain variations in fines content (e.g. possibly reducing with depth) lenses of fine sands, fluvioglacial gravel horizons etc. Hence the importance of assessing these variations so that accurate quantities can be determined. Ideally, a number of samples from the borrow source should be obtained so that the aforementioned suite of geotechnical parameters can be determined. Groundwater plays an important role in borrow pit and source evaluation. Where boreholes are sunk, either piezometers or standpipes should be installed to establish equilibrium water levels. This is particularly important where horizons or lenses of sands or gravels are present within boulder clay deposits as they may give rise to sub-artesian conditions.

2.8.3 Sampling & Laboratory Testing

For borrow pit source evaluation, trial pits are recommended in conjunction with boreholes as they will provide a clearer indication of stone content and sizes. They also permit more accurate sampling and provide larger sized samples for compaction tests. A minimum of 20kg of representative soil is required to carry out the classification and performance laboratory tests. A three week programme should be allowed to complete the suite of laboratory tests, particularly the triaxial cell permeability test which for very low or 'impermeable' clay liner soils typically takes 10 to 12 working days.

The rapid (i.e. results within two to three days of sampling) and cheaper laboratory tests include moisture content, grading, Atterberg Limit and MCV. The particle size grading provides an excellent initial appraisal of the potential suitability of a soil for the construction of an impermeable liner.

From the grading curve, an approximation of permeability can be made using either the Hazen or Sherard equations. The fines proportion, plasticity and moisture content essentially control the likely permeability of the soil and can be determined from the aforementioned inexpensive laboratory tests.

2.8.4 Permeability measurement

Permeability is predominantly measured by taking undisturbed samples (U100's) of the compacted clay liner or re-compacting disturbed samples in the Proctor mould to an equivalent in-situ density. In-situ density is measured (by nuclear method or sand replacement) and this allows the soil to be re-compacted in the mould to a known density.

In-situ permeability measurement is by use of either lysimeter or ring infiltrometer. Both of these methods are of long duration (3 to 6 months) and very expensive. Hence, determination of permeability by laboratory methods is regarded as being the most practical and cost effective. The triaxial cell test is regarded as the preferred method (to permeameter) in determining laboratory permeability on either undisturbed or remoulded samples. The advantages of the triaxial cell methods are principally as follows:

- Sample can be saturated under back pressure thus reducing or eliminating obstructions due to air bubbles or entrainment
- Saturation can be achieved more quickly, particularly for compacted soils
- Small rates of flow can be measured easily and the test is carried out under effective stress and at pore pressures which relate to field conditions

2.9 Practical Aspect of Clay as Liner Material

2.9.1 Compaction

Compaction is a process of reducing the void ratio of a soil by mechanical kneading. The soil is laid out in layers and then subjected to momentary application of load (via rolling, tamping or vibration). The expulsion of air from the voids occurs without significant change in moisture content. The compaction process creates a denser soil mass and the effect of compaction can be quantitatively described in terms of dry density. Optimum moisture content (OMC) is obtained from compaction testing and this allows comparison with the natural value and provides a maximum dry density (MDD).

Compaction reduces soil pore sizes by displacing air and water. Reduction in void size, increases the density, compressive strength and shear strength of the soil and eventually reduces permeability. This is accompanied by a reduction in volume and settlement of the surface. Proper compaction is essential to increase the stability, to decrease erosion, seepage losses and frost resistance (*where required*).

Compaction can generally be achieved by one of four principal means (McCann and Kelly, 1998)

Pressure – The static weight of a smooth drum or tyre rollers compresses the upper levels of the material.

Kneading – The concentrated contact area of a sheep-foot roller kneads material in its plastic state, but only in the upper levels of the material.

Vibration – The oscillation drum of a vibratory roller re-orientates the particles and reduces the void spaces, but only in material within 400mm of the surface.

Impact – The high-intensity compression and shear waves generated deep in soil by dynamic action of an impact roller compacts soil to effective depths of 2.5m or more

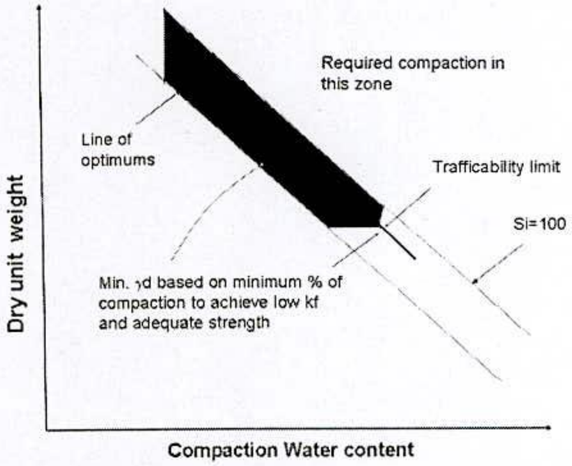


Fig 2.5 : compaction curve

Low permeability of the soil in a compacted state is of prime importance in seepage reduction. The water loss of a proposed lining can be estimated from the results of laboratory permeability tests on compacted soil specimens, the thickness of the proposed lining and the water depth. Maximum density and optimum moisture content should be determined in the laboratory before using soils for compaction. Compacted earthen lining can be effective. A well-compacted earthen lining can be highly impermeable, reducing seepage losses to 20L/m^2/day, and is almost comparable to good concrete lining (ICID, 1967). Usually the thickness and material components are planned so that seepage loss is less than 30L/m^2/day. Losses up to 60L/m^2/day are tolerated if natural subgrade soils are very pervious and better lining materials are not economically available (Kraatz, 1977).

2.9.2 In-situ Compaction

The simplest and least expensive compacted earthen lining involves compaction of the existing bed and slopes in-situ using appropriate compaction equipment. Compaction improves the impermeability of the existing material and achieves varying degrees of seepage remediation depending on the properties of the in-situ soils.

2.9.3 Compaction of Imported Material

Compacted liners, also called compacted clay liners, generally consist of an imported mixture of clay and soil with lower permeability and better erosion resistance than the in-situ soils. The imported material is compacted to an appropriate thickness within the channel to further improve the soil characteristics.

Table 2.12: Degree of compaction related to the soil type (from Brandi, 1992)

Soil Type	*Compaction degree (%)*
Widely graded	≥ 100
Clayey silt, silty clay	≥ 97 (*95)
Clean clay	≥ 95 (*92)

* local areas difficult to access

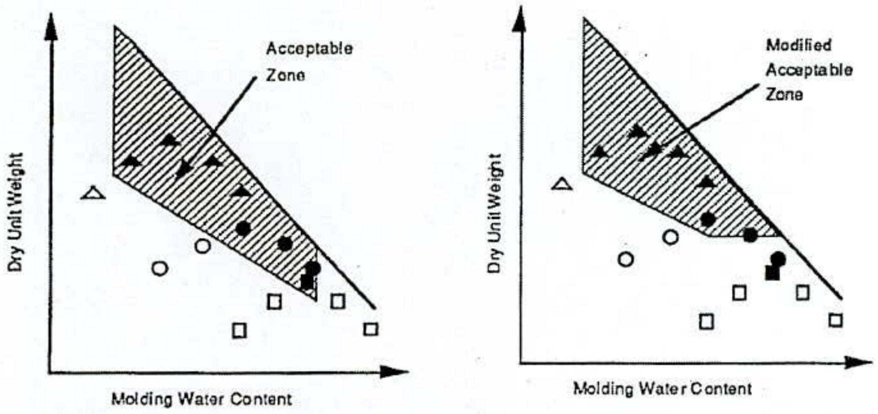


Fig 2.6 - Recommended Procedure to Determine Acceptable Zone of Water Content/Dry Unit Weight Values Based Upon Hydraulic Conductivity Considerations (after Daniel and Benson, 1990).

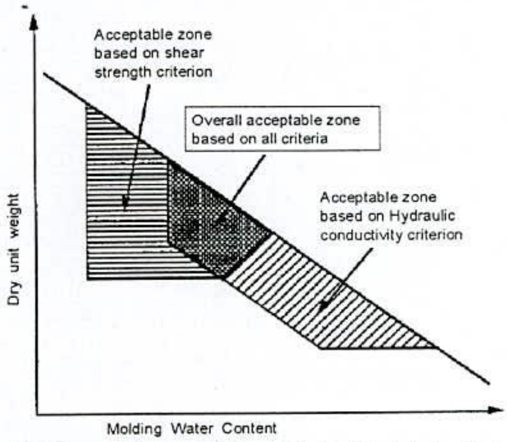


Fig 2.7 : Acceptable Zone of Water Content/Dry Unit Weights Determined by Superposing Hydraulic Conductivity and Shear Strength Data (after Daniel and Benson, 1990).

The **main issues** to be considered in the use of a compacted clay liner are (Sinclair Knight Merz, 1998):

Availability of suitable clay close to the site
Effect of weed growth, wind and water erosion
Future maintenance needs and costs
Avoidance of damage by machinery or animals
Conditioning of clay to required moisture content.

Suitable materials are (Neville and Chant, 1998):

- Soils with 60% clay content, slightly dispersive, with a coarse grain to allow high bulk density to be achieved
- Dispersive soils with more than 60% clay content, to which lime and coarse grain material is added
- Soils with low permeability and shrinkage characteristics

Compacted material required to be adequate for lining:

Must have very low permeability (10^{-9} m/s is often expected)
Should be free from excessive shrinking or swelling
Should have low dispersion properties
Should resist erosion from flowing water or wave action
Should have good slope stability characteristics.

A well-graded sand and gravel with a clay binder is considered the best material for a compacted earthen lining, followed by clayey gravel soils and sand with clay binder. Silty or sandy clay soils with low plasticity are not considered suitable. Fat clays (i.e. inorganic clays of high plasticity) may not be suitable (because of swelling and shrinking due to wetting and drying), unless the lining is protected by a gravel-sand cover. Suitable soils can be blended on site from different sources to produce the optimum mix.

2.9.4 Placing of Clay Liners

Prior to placing and compacting clay fill liners, screening is often required to remove oversized constituents (typically > 75mm). This is usually carried out by table shakers or trommels where the as-dug clay fill is fed into a hopper and screened. The screened clay fill is thus referred to as 'processed' and is spread out by dozer to the required thickness.

In most cases of clay liner construction, the soils are placed in 'lifts'. This usually entails four (225mm thickness) or three (300mm thickness) lifts, each compacted with a pad foot or grid roller. A (conservative) rule of thumb is that the compacted layer thickness should be less than the penetrative depth of the feet of the pad or grid roller. The surface of the final lift (100mm) should be smooth and free from cracks as it is overlain by a flexible membrane liner.

The use of a pad foot or grid roller is strongly advised as this allows *kneading* of the lumps or clods. The effect on permeability of kneading the clods is very important for clay liners as it produces a reduction in clod sizes. It is important in the field to knead the soil repetitively to reduce the clods and interclod macropores.

For placement of liners on side slopes, consider the angle and length of the slope.Placing continuous lifts on a gradually inclined slope will provide better continuity between the bottom and sidewalls of the liner. Since continuous lifts might be impossible to construct on steeper slopes due to the difficulties of operating heavy compaction equipment on these slopes, materials might need to be placed and compacted in horizontal lifts. When sidewalls are compacted horizontally, it is important to avoid creating seepage planes, by securely connecting the edges of the horizontal lift with the bottom of the liner. Because the lift needs to be wide enough to accommodate compaction equipment, the thickness of the horizontal lift is often greater than the thickness specified in the design. In such cases, you should consider trimming soil material from the constructed side slopes and sealing the trimmed surface using a sealed drum roller. It is common for contractors to use several different types of compaction equipment during liner construction. Initial lifts might need the use of a footed roller to fully penetrate a loose lift. Final lifts also might need the use of a footed roller for compaction, however, they might be formed better by using a smooth roller after the lift has been compacted to smooth the surface of the lift in preparation for placement of an overlying geomembrane.

2.9.5 Number of Passes

The number of passes made by a compactor over clay materials can influence the overall hydraulic conductivity of the liner. The minimum number of passes that is reasonable depends on a variety of site-specific factors and cannot be generalized. In some cases, where a minimum coverage is specified, it might be possible to calculate the minimum number of passes to meet such a specification. At least 5 to 15 passes with a compactor over a given point are usually necessary to remold and compact clay liner materials thoroughly.

2.9.6 Lift Thickness

Appropriate thickness (as measured before compaction) of each of the several lifts that will make up the clay liner is to be determined. The initial thickness of a loose lift will affect the compactive effort needed to reach the lower portions of the lift. Thinner lifts allow compactive efforts to reach the bottom of a lift and provide greater assurance that compaction will be sufficient to allow homogenous bonding between subsequent lifts. Loose lift thicknesses typically range between 13 and 25 cm (5 and 10 in.). Factors influencing lift thickness are: soil characteristics, compaction equipment, firmness of the foundation materials, and the anticipated compaction necessary to meet hydraulic conductivity requirements.

2.9.7 Bonding between Lifts

Since it is inevitable that some zones of higher and lower hydraulic conductivity, also known as preferential pathways, will be present within each lift, lifts should be joined or bonded in a way that minimizes extending these zones or pathways between lifts. If good bonding is achieved, the preferential pathways will be truncated by the bonded zone between the lifts. At least two recommended methods exist for preparing proper bonds. The first method involves kneading, or blending the new lift with the previously compacted lift using a footed roller. Using a roller with feet long enough to fully penetrate through the top lift and knead the previous lift improves the quality of the bond. A second method involves using a disc harrow or similar equipment to scarify, or roughen, and wet the top inch of the recently placed lift, prior to placing the next lift.

2.10 Leakage Theory

There is no such thing as an impermeable barrier. All liners leak. The issue is that we minimise the leakage through good design and construction quality assurance such that its effect on the environment would not be significant. The mechanisms of leakage are:

Flow through holes in the membrane and/or cracks and fissures in the clay; *and* Permeation through both the flexible membrane liner and through the clay itself. The proper choice of materials will minimise the permeation and good contract quality assurance will minimise leakage through defects both in the liner and in the clay.

Leakage rates through composite liners have been studied by Giroud and Bonaparte, who developed empirical equations that predicted leakage through composite liners for a number of circumstances. Where the hydraulic head above the geomembrane is less than the thickness of the soil component and the hydraulic conductivity of the soil component is less than 10^{-6} m/sec, then the equations are:

$Q=0.21a^{0.1}h^{0.9}k^{0.74}$ (for good contact)

$Q=1.15a^{0.1}h^{0.9}k^{0.74}$ (for poor contact). Where a is the area of a hole, h is the head of leachate on the liner and k is the permeability factor

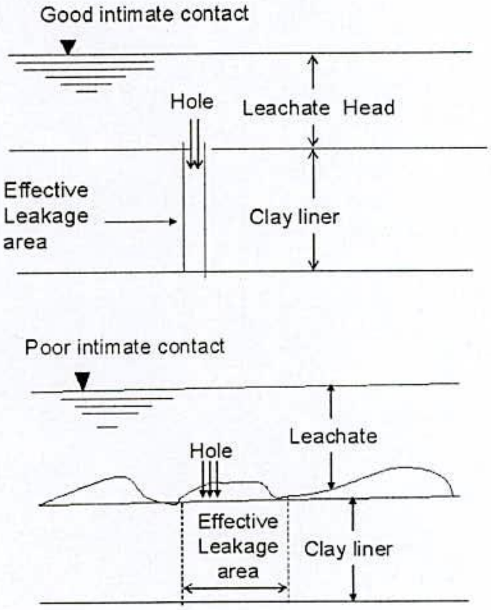


Fig 2.8: Contact vs effective leakage area

If the leachate head on the membrane is greater than the thickness of the soil, then a further factor is introduced known as I_{avg} and the quantity of leakage derived from the above equations is multiplied by this new factor in each instance.

$Q=0.21i_{avg}a^{0.1}h^{0.9}k^{0.74}$ (good contact)

$Q=1.15i_{avg}a^{0.1}h^{0.9}k^{0.74}$ (poor contact)

A simple sensitivity analysis on the above equations suggests that while hole size (a) has little effect on the leakage rate, both hydraulic head and permeability have a much more significant effect. Hydraulic conductivity of compacted soils can vary considerably (up to 1 order of magnitude) depending on how the soils are treated. It is concluded that the engineering of the compacted clay liner is the most important factor in minimising leakage.

2.11 Attenuation

It has been demonstrated above that absolute terms such as *total containment, prevention of leachate* and *landfill gas migration,* or *impermeable* are not achievable. It should not be concluded that failure to achieve the above conditions is a reflection of either poor materials or workmanship. All materials have a finite permeability and thus some finite seepage is inevitable. The compacted clay element of the composite lining system fulfils a second role in that it facilitates the attenuation of contaminants that may be present in the leachate as it migrates slowly through the soil. If a material possessing good chemical buffering capability as well as low hydraulic conductivity and high sorption capacity can be secured, this would ensure that a competent containment/attenuation barrier system against leachate transport would be obtained.

This subject has been studied in some depth by Yong *et al.* Studies of the chemical buffering by soils are conducted in a similar manner as in solution chemistry, except that soil suspensions are used in place of solutions in the titration procedure. The titration procedure allows one to study the capacity of the soil to absorb or desorb ions. The ability of the soil to act as an acid (or base) and thus resist pH changes during titration with the contaminant solution will demonstrate the attenuation characteristics of the soil for the selected contaminant. Improved assimilation of actual field conditions can be made using soil column leaching tests. Such tests determine the attenuation characteristics of the compacted soil and distribution of contaminants within the soil as a function of the amount of leachate transported through the soil sample.

A standard method for assessing the attenuation capacity of the soils is not available. Where alternative clays are available, both of which satisfy the permeability requirement, attenuation capacity could be used as a decision making tool. Both physical and chemical characteristics of the soils should be determined to assist in the assessment of the attenuation capacity. The following is a typical list of parameters that might be required:

Natural water content
Specific gravity
Liquid limit
Plasticity index
Percentage clay fraction
Dry density
Optimum moisture content
Permeability
Percentage organics
Specific surface area
Cation exchange capacity

In addition, the chemistry of the pore water and leachate should be known. Parameters such as pore volume can be used to determine the quantity of leachate that might be permeated through a particular sample. Comparison of the break through concentration against the number of pore volumes permeated through the soil will assist in determining the attenuation capacity of the soil.

Leachate attenuation by mineral clays might be improved by the addition of organo-clays to the mineral clay. Some work on this has been undertaken by E.A. Voudrias and others. Their work has shown that the breakthrough time for certain contaminants increases from say 10 years to 50 years as a result of the incorporation of organo clays into the lining systems.

Attenuation theory has been taken to a new level by considering the concept of reactive walls. Work has been done by Bradl and Bartel on the concept that as landfills age and the concentration of contaminants arising reduces, leachate can be directed in a controlled fashion through a designed attenuation layer and traditional leachate treatment can be abandoned.

2.12 Contaminant Transport in soils

The various constituents comprising waste leachate, i.e. the undissolved and dissolved solutes derive from processes of dissolution of buried solid wastes; interact chemically, biologically and physically with the soil material. Liquid wastes of waste streams will also contain dissolved and undissolved solutes and organic substance. The process of accumulation and transport of contaminant in and through the soil will depend on the nature of both contaminants and soil.

Chemical transport is of major concern in connection with the ground water pollution, waste disposal and storage, remediation of contaminated sites, leaching phenomena and soil stabilization. In addition to the above flow types, each driven by own potential gradient, coupled flows may be important under a variety of circumstances.

Gravity causes leachates to move through the landfill, to the bottom and sides, and through the underlying soil until it reaches the groundwater zone or aquifer. The leachates contaminants first enter the unsaturated zone and eventually are transported to the groundwater table in the saturated zone (Schnoor, 1996). Figure 2.11 gives an overview of the zones that exist underground..

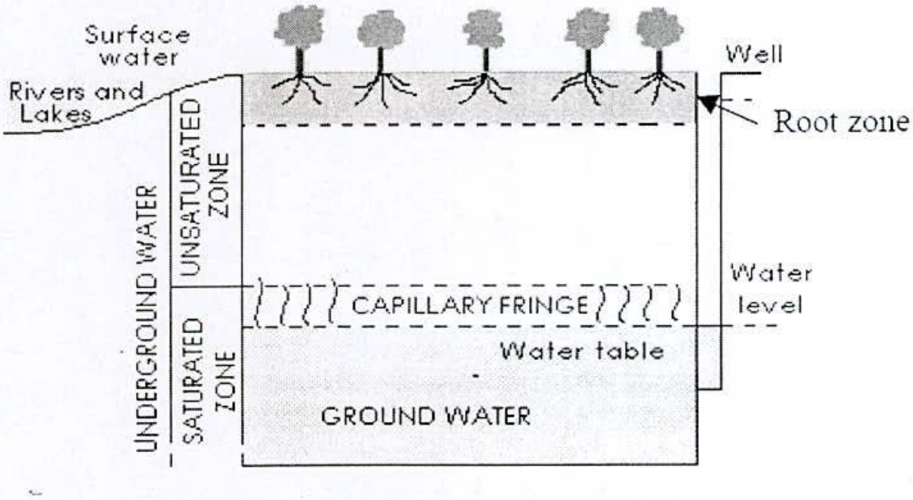


Figure 2.9: Subsurface vertical stratigraphy (www.groundwater.com)

1.12.1 Contaminant-Soil Interaction

The transport of contaminants in the soil by external and internal forces will result in reaction occurring between contaminants and soil constituents these include chemical, physical and biological processes, and are generally identified as contaminant-soil-interactions as a catch all terms.

To a very large extent, the principles used in the development of the soil-water relation also apply to the relationships established between contaminants and soil constituents. The various principles governing ion distribution and exchange, apply in principle to the dissolved ions in the contaminating leachate being transported through the soil. The degree, to which the accumulation process renders the trapped contaminants immobile, is of the vital interest in considerations for design of clay barriers for contaminant retention. In other words, evaluation and analysis of contaminant –soil interaction provide us with an insight into the various processes which control accumulation, transport and fate of the contaminants.

The liquid phase of a soil-water system consists of water and dissolved substances such as free salts, solutes, colloidal materials, and/or organic solutes. All dissolved ions and probably all dissolved molecules are to some extent, surrounded by water molecules. The interaction of ions with water molecules and other ions will affect the concentration-dependent properties such as osmotic pressure and chemical potential. The principal constituents to be considered in the basic interactions include:

Solutes---ions, molecules, substances in the pore fluid
Aqueous phase---pore fluid considered as a solvent
Solid surfaces --- soil solids (minerals, amorphous materials, soil organics etc.)

The process which control the transfer or removal of solutes from the aqueous phase to the solid surfaces occur as a result of interaction between chemically reactive groups which are present in the principal constituents and other chemical, physical and biological interactions.

2.12.2 General Mechanism of Solute Transfer

The general mechanism discussed below to provide and overall view of the processes of solute transfer or removal from the aqueous phase of the contaminant –soil system. This process **Sorption** includes **physical adsorption**, occurring principally as a result of ion-exchange reaction and Van der Waals forces, and **chemical adsorption** which involves short range chemical valence bonds.

In Sorption, the solutes (ions, molecules and compounds) are partitioned between the liquid phase and the soil particle interface. Of the various phenomena that can contribute to sorption, **chemical interaction** is the major subject of interest. When it is difficult to fully distinguish between the mechanism of physical adsorption, chemical adsorption and precipitation the term sorption is used to indicate the general transfer of materials to the interfaces.

The adsorption reactions which occur, are processes by which contaminant solutes in solution become attached of soil solid particles through mechanism which seek to satisfy the forces of attraction from the soil solid surfaces. These processes are governed by the surface properties of the soil solids (inorganic and organic) and the chemistry and physical chemistry of the contaminant leachate and its constituents e.g. cations, anions, and nonionic molecules. The net energy of interactions due to adsorption of a solute ions or a molecule on to soil constituent surfaces is a result of both short range chemical bonding such as covalent bonding and long range forces such as electrostatic forces.

Physical adsorption occurs when the contaminants in the soil solution (aqueous phase pore water) are attracted to soil constituents surfaces because of the unsatisfied charges (attractive forces) of the soil particles. Cations and anions are specifically or non specifically adsorbed by the soil solids. The ion can interact in both the diffuse double layer and in the stem layer.

In non specific cation adsorption, the ions are held primarily by electrostatic forces e.g. the adsorption of most of alkali and alkaline earth cations by the clay minerals. If the cations is considered as a point charge , the adsorption of cation would be related to their valance, crystalline and hydrated radii. From Coulomb's law , the cations with the smaller hydrated size of large crystalline size would be preferentially adsorbed everything else being equal.

Complexation occurs when a metallic cation reacts with an anion that functions as inorganic ligand. As might be expected, the organic component of soil constituents has a high affinity for heavy metal cations because of the presence of ligands or groups that can chelates with metals. The functional groups include carboxyl, phenolic, alcoholic and carbonyl groups. With increasing pH the stabilities of complexes are likely to increase because of the increased ionization of the functional group.

Precipitation is the converse of dissolution, and in case of containment in the aqueous phase, precipitation is to occur when transfer of solutes from the aqueous phase to the inter-phase results in accumulation of a new substance in the form a new soluble solid phase.

These processes generally do not occur as individual process to the mutual exclution of the other processes. These will most likely occur in conjunction with other processes with each process more or less dominant dependent on the local chemical environment. It is very probable that all (or most) of these occur simultaneously. To a greater or lesser degree in the total interaction between contaminants and soil which result in the binding of the solutes to the solid surfaces.

2.12.3 Sorption of Contaminants

In case of landfill we are mostly concerned with the sorption of contaminant solutes such as those contained in waste leachate and waste streams. The migration of leachates containing various types and concentration of contaminants through soil could lead to eventual ground water contamination. Leachate containing inorganic and organic contaminants interact with the solid constituents through process of physisorption, chemisorption, precipitation and /or complexation of the contaminants, resulting in accumulation of contaminants in /by soil. Soil act as a buffer against the transport of contaminants to the ground water. In contaminant interaction the term 'buffer' is used both from viewpoint of a chemical buffering system which means the capability of the system to act as chemical barrier against the transport of the contaminants and also as a physical system where constrictions pore and pore blockage can play major roles.

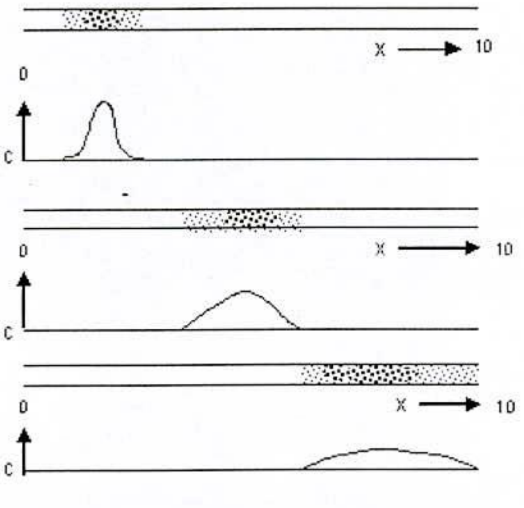


Fig 2.10: Migration from a point source of pollution

Heavy metals form a group of contaminants commonly found in several kinds of wastes including sludge and landfill leachates. They are highly toxic to humans, animals, plants the retention capacity and aquatic life. The retention mechanism of heavy metals in soils are different at different pH the ability of soil to retain heavy metal depend depends on the resistance of soil to a change in pH i.e. buffer capacity. For example heavy metals may be retained inn soils in the form of oxides, hydroxides, carbonates, exchangeable cations and/or bound to organic matter in the soil, depended on the local environmental conditions on the kinds of soil constituents present in soil-water system.

2.12.4 Mass Transport in Saturated Media

It has been established that in the absence of coupled flow processes the migration of contaminants in homogeneous, saturated soil is governed by three transport processes.

Table 2.13: Process associated with dissolved solutes

Process	***Definition***	***Impact on transport***
Advection	Movement of a solute as a consequence of groundwater flow	Most important way of transporting solute away from source
Diffusion	Solute spreading due to molecular diffusion in response to concentration gradients	A second order mechanism in most flow systems where advection and dispersion dominates
Dispersion	Fluid mixing due to effects of unresolved heterogeneities in the permeability distribution	A mechanism that reduces solute concentration in the plume. However, a dispersed plume is more wide spread than a plume moving by advection alone

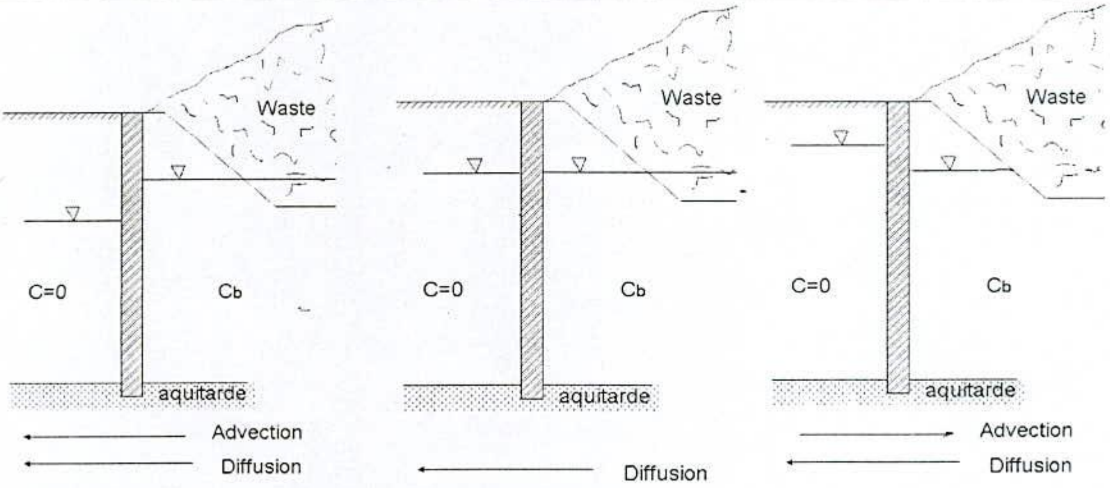


Fig 2.11 : Advective and diffusive contaminant migration

Advection is the process by which moving groundwater carries with it dissolved solutes The amount of solute that is transported is a function of its concentration in the ground water and the quantity of ground water flowing. The process of dispersion acts to dilute the solute and lower its concentration. Advection involves the movement of contaminants with the flowing water. If there were no flow then there were no transport by advection through the barrier.

The movement of contaminants at a speed of the groundwater flow is refer to as Plug flow. The time required for a plug flow of contaminants to travel a certain distance is distance divided by velocity. The mass of contaminants transported by advection per unit area per time is the mass flux, given as

$\mathbf{f = n_e \times v \times c}$ where n_e = effective porosity

v=ground water flow velocity n

c=concentration of a contaminant at a point and time of interest

The contaminant transported into a barrier into a barrier upto a specific time t is simply can be obtained by integrating the muss flux with respect to time:

$$m_a = A_o \int_0^t n_e vc \, dt$$

Diffusion is the process by which both ionic and molecular species dissolved in water move from areas of higher concentration to areas of lower concentration. Diffusive transport involves the transportation of contaminants from high concentration to low concentration. This result in the fact that contaminant transport from a disposal site can occur , even if there is no advective transport or even if the water flows towards the landfill. Generally spoken , in the materials with very low permeability, diffusion is mostly the controlling transportation process.

The mass flux f transported by pure diffusion can be written as negative because movement is from high to low concentration.

$f = (-)(n_e)(D)(\delta c/\delta z)$

.D = effective diffusion coefficient

$\delta c/\delta z$ = concentration gradient change in concentration with distance z

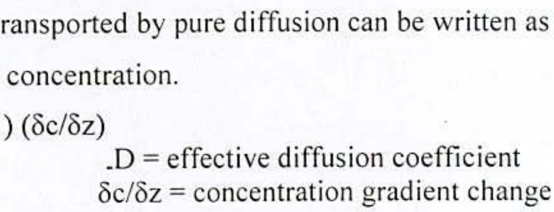


Fig 2.12: Spreading of a solute slug with time due to diffusion

The total mass of contaminant, m_d , transported by diffusion upto a specific time t is obtained by integrating the above equation :

$$m_a = A_o \int_0^t (-n_e D\, \delta c/\delta z)\, dt$$

Diffusion can occur in the same time as Advection, but also any other direction, including opposite direction. Hence it is possible that contaminant can escape from a landfill even if, the water flows into the landfill thus causes hydraulic trap. In case of advective –diffusive transport the mass flux is given by

$$f = n_e vc - nD_e\, \delta c/\delta z$$

The total mass flux m transported from a landfill upto a specific time t is

$$m_a = A_o \int_0^t (n_e vc - n_e D_e\, \delta c/\delta z)\, dt$$

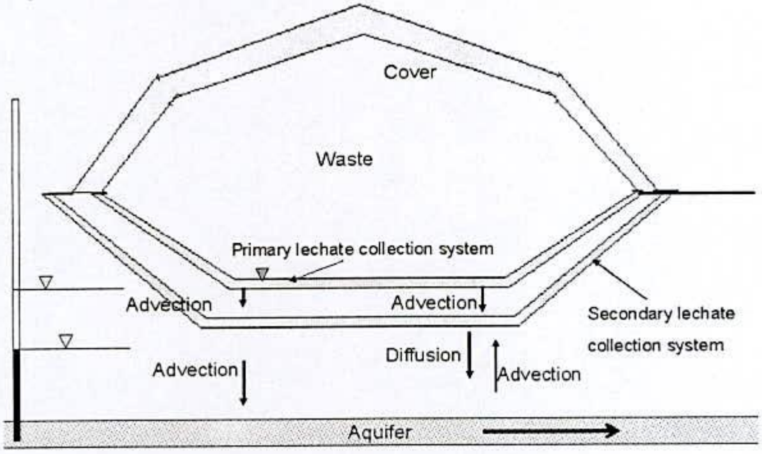


Fig: 2.13 : Schmatic diagram for hydraulic trap

Mechanical Dispersion process involves the mixing that occurs due to local variation of the velocity and direction of flow in the groundwater. This is due to non-homogeneities in the aquifer. The two process are often lumped together as a composite parameter D, which is called the coefficient of hydrodynamic dispersion:

$$D = D_e + D_{md}$$

D_e = effective diffusion coefficient [m^2/sec]
D_{md} = coefficient of mechanical dispersion [m^2/sec]

The mass flux is given by :

$$f = n_e vc - n_e D\, \delta c/\delta z$$

Hydrodynamic Dispersion process of molecular diffusion cannot be separated from mechanical dispersion in flowing ground water. The two are combined to define a parameter called by hydrodynamic dispersion coefficient, D. it is represent by the following formula:

$D_L = a_L v_I + D^*$

$D_T = a_T v_I + D^*$

D_L = hydrodynamic dispersion coefficient parallel to the principal direction of flow

D_T = hydrodynamic dispersion coefficient, perpendicular to the principal direction of flow

$a_L v_I$ = longitudinal dynamic dispersivity

$a_T v_I$ =transverse dynamic dispersivity

Advection is by far the most dominant mass transport process in shaping the plume while hydrodynamic dispersion is usually a second-order process, except in some cases involving fractured rocks. The magnitude and direction of advective transport are controlled by hydraulic conductivity distribution within the flow field, the configuration of the water table, the presence of sources and sinks (e.g. wells), and the shape of the flow domain. All of these parameters are important in controlling the ground water velocity, which drives advective transport.

When there is no dispersion or reactions, the plumes have a uniform concentration equal to the source concentration. A reduction in hydraulic conductivity reduces the extent of the plume by simply reducing the ground water velocity (Domenico & Schwartz, 1998).

On the other hand, dispersion can cause important changes in the shape of a plume. Dispersion mixes the contaminant with an increasing proportion of the uncontaminated water and the plume size increases, the maximum concentration decreases (Domenico & Schwartz, 1998).

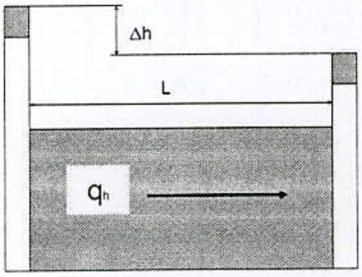
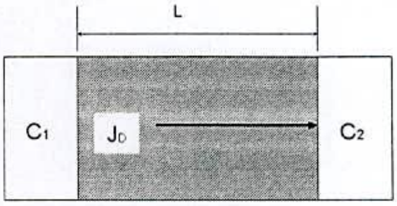
2.12.5 Soil-Water Interaction and Relations

Since water is the transporting agency for contaminants it is important to obtain an understanding of soil-water interaction and the relationships established. The processes involved during the transport of contaminants in and through soil will control:

- the amount of contaminant transported at any one time through a particular control region
- the attenuation of contaminant concentration through adsorption and desorption processes
- the rate and extent of propagation or advance of a contaminant plume

Many of the controlling processes are similar to those involved in soil-water interaction. The manner in which water is held in soils will determine how strongly water is held to the particle system.

Table 2.14 : Direct flow through a soil mass:

Fluid	Chemicals
	
$q_h = K_h \Delta H/L$	$J_h = D \Delta c/L$
Darcy's Law	Fick's Law

2.12.6 Flow Laws and Relationship

Fluids and chemicals do flow through soils. It has been well established thet provided the flow process does not change the fabric and stress state of soil, each flow rate or flux J_i relates linearly to its corresponding driving forces X_i

$J_i = L_{ii} X_i$……………(i)

in which L_{ii} is conductivity coefficient for flow. For a particular flow type the eqn. (i) becomes

water flow: $q_h = K_h i_h$

Chemical flow: $J_D = D i_c$

The coefficient K_h and D are hydraulic conductivity and diffusion coefficient respectively. The driving forces for flows are given by respective hydraulic and chemical gradients I_h and I_c.

2.12.7 Water Movement in Clay Soils

The water content of a soil is rarely static. Water addition from snow melts, rainfall, irrigation, or condensation and water losses from evaporation, transpiration or drainage occur most of the time. Thus the distribution and migration of water in soils are dependent on many fluxes such as those arising from the internal energy of the water itself and from external and surficial mechanisms and driving forces due to thermal ionic, osmotic, gravitational hydraulic and other gradients. The rate of movement or migration of water will depend on the magnitude of the forces and gradient and also the factors determining the transmission coefficient or hydraulic conductivity of soil.

The transport of contaminants in soils is achieved principally through water as a medium i.e. water is the carrier for contaminants. To better understand the transport processes of contaminants, it is important to understand water movement in soils inasmuch as the contaminant transport coefficient for various dissolved and undissolved solutes are to a greater or lesser degree controlled by the same mechanism which will control uncontaminated water movement. Water movement or water transfer in soils may be divided into two particular systems for general consideration:

- the saturated system where all the voids are filled with water
- the partly saturated system where both air and water are present

For partly saturated soils, the mechanism for moisture transfer will depend upon whether the system is relatively dry or wet. In the former vapour transfer is greater than the liquid transfer, whereas in the latter, where the soil system is relatively wet liquid transfer will overweigh vapour transfer. The movement of water in liquid transfer is generally considered as viscous flow and is due primarily due to gradients of metric or capillary potential which arise from differences in water content. The term capillary flow is often used to describe this type of movement and is not restricted to capillary rise of water above a water table, since capillary flow can occur in any direction where there is a gradient for water flow as if the soil is not saturated.

Soil water will also move under the influence of physico-chemical forces associated with the interaction of the surface-active solids in the soil and water. When the concentration of ions in a solution differs from that at another region or point, there is a tendency for the more dilute concentration liquid to diffuse into the region of higher concentration. The potentials existing in clay soils, as discussed in the previous section, produce gradient, which will induce moisture transfer. Thus for example, there is a tendency for water to diffuse into regions of higher ionic concentration to attain more uniform ionic distribution.

2.12.8 Flow in Saturated and Unsaturated Zone

Darcy, studying the rate of flow of water through the sand filter bed, found that the macroscopic flow velocity v was proportional to the hydraulic head or hydraulic gradient:

$V=Q/At=k\ (\Delta h/\Delta x)=ki$

Where

Q=volume of the water flow,
A=cross-sectional area of the bed,
t=time of flow,
k = hydraulic conductivity,
I = hydraulic gradient.

The relationship which is commonly known as referred to as Darcy's law is valid at low flow velocities of water in soils and for granular particles which are relatively smooth and spherical in shape and also uniform in size, where the results obtained by applying Darcy's law are quite reasonable.

Most of water movement in soils occurs when both water and air are present in the voids- i.e. unsaturated flow. This is true even where water moves into the soil from ponded water to at the surface. The value of k is no longer constant but decreases as the water content decreases, or as the soil-water potential ψ (negative) decreases. General consideration of water flow in unsaturated materials take into account both the metric gravitational potentials. For swelling soils, the osmotic potential is also taken into consideration. For soils that are initially in the dry state, the total soil-water potential will need to include the hydration potential.

Vedose zone hydrology is different from saturated zone hydrology because of the air and water in pore space. The relative portion of air and water in the pores can vary and with it can vary the hydraulic properties of the media.

In saturated flow the driving potential for groundwater flow is due to the pore water pressure and elevation above a reference datum (Fetter 1994). However in unsaturated flow the pore water is under a negative pressure caused by surface tension. The capillary fringe is not a regular surface such as water table. The height of the capillary rise will be different in each vertical set of interconnected pores, depending upon the mean pore diameter of the set. Thus capillary fringe has a ragged upper surface.

2.12.9 Multiphase Flow

The movement of liquids that are immiscible with water through the vedose zone as well as below the water table is an important facet of contaminant hydrogeology. Such liquids are often called nonaqueous phase liquids. They may have densities that are greater than water (dense aqueous phase liquids or DNAPLs.) or densities that are less than water (light nonaqueous phase liquids or LNAPLs). They may me partially soluble in water, so that a dissolved phase as well as a nonaqeous phase may be present two phase flow may occur below the water table with water and DNAPL. Three phase flow may occur in the vedose zone with air, water and an NAPL. In the Vedose zone NAPL may partition into the air as a vapour phase (Baehr 1987). There may be multiple compounds in the nonaqueous phase, each with different properties. Flow is independent upon the densities, viscosities and interfacial tensions of the liquids.

In addition to dispersion and diffusion, compounds can undergo adsorption and chemical and biological degradation. These process pose extremely complex hydrological challenges. Common NAPLs include gasoline and diesel fuel. DNAPLs include the chlorinated hydrocarbons.

Capillary pressure occurs when two immiscible liquids are in contact a curved surface will tends to develop at the interface. By measuring the pore pressure near the interface in each phase, it will be found that the pressures are not the same. The difference is the capillary pressure. In the vedose zone capillary pressure has a negative value.

Relative permeability is considered during simultaneous flow of two immiscible fluids, part of available pore space will be filled with one fluid and reminder will be filled with other fluid. For a two phase oil water system, if the water content is less than the irreducible water saturation, oil can flow, but water will be held by capillary forces.

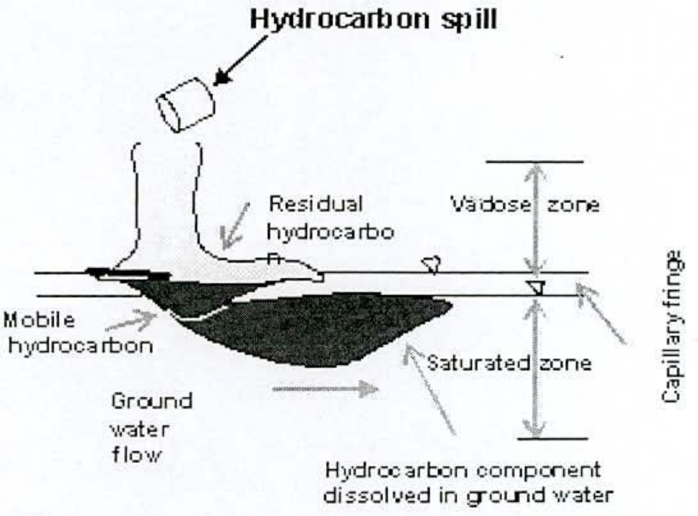


Fig 2.15 : Subsurface distribution of an LNAPL spill

2.12.10 Transformation, Retardation and Attenuation of solute

Solutes dissolved in groundwater are subjected to a number of different processes through which they can be removed from the groundwater. They can be sorbed onto the surfaces of the mineral grains of the aquifer, sorbed by organic carbon that might be present in the aquifer undergo chemical precipitation, be subjected to abiotic as well as biodegradation and precipitate in oxygen reduction reactions. Furthermore radioactive compounds can decay. As a result of sorption process, some solutes will move much slowly through the aquifer than the ground water that is transporting them, this effect is called Retardation. Biodegradation, radioactive decay and precipitation will decrease the concentration of solute in the plume but may not necessarily slow the rate of plume movement.

In the unsaturated zone, both air and water fill the pores between soil particles (Schnoor, 1996). The slow movement of leachates in that zone causes attenuation of certain leachate chemicals. Positively charged lead, zinc, cadmium and mercury metals, are easily attenuated. As leachate containing these metals flows through soil, the metals stick or adsorb to the soil and are removed from the leachate. Other leachate pollutants, such as VOCs and acids, are not easily attenuated, and they move unimpeded through soil, see figure 3.13 (O'Leary &Walsh, 1995).

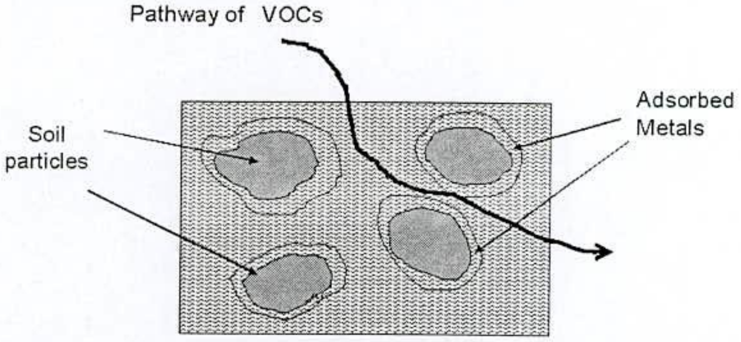


Fig 2.16: Soil attenuation (Reproduced from www.foe.org//ptp)

The composition of a soil and the characteristics of its binding sites affect its attenuation capability. Different soils have different abilities to attenuate and exchange chemicals. Once the binding sites of the soil particles become full, they can hold no more chemicals and henceforth, pollutants will move through the soil towards the groundwater (Domenico & Schwartz, 1998).

As they fill to capacity, the binding sites become choosier. Only preferentially bound chemicals, or those that form tight bonds with soil, will be attenuated, and chemicals that bind loosely to soil will be replaced, refer to figure 2.17.

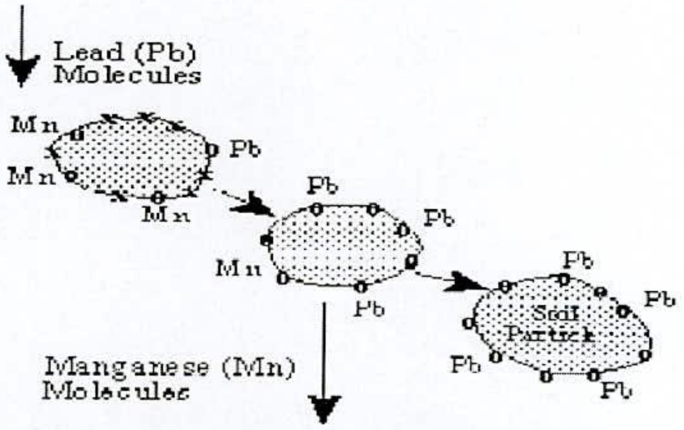


Fig 2.16 : Preferential adsorption of certain chemicals (www.foe.org//ptp)

For example, as leachate flows through soil, lead particles in the leachate can easily replace manganese that is adsorbed on soil because lead is more preferentially bound than manganese. In this situation, lead would be removed from the leachate and stick to the soil, but manganese would leave the soil and re-enter the leachate, posing a continued threat to groundwater.

In general, the more rapidly a reaction removes a contaminant the smaller the plume will be at a given time. Ion exchange can also produce the same dramatic attenuation in concentration. In ion exchange processes, the coefficient of selectivity is a determining factor. When the selectivity (preference among ions), is small, there is no exchange and the contaminant moves due to mass transport alone. However as selectivity increases, the plume becomes smaller as exchange retards spreading. In some instances, the geochemical processes have the capability of immobilising particular contaminants at the source (Domenico & Schwartz, 1998).

2.13 Bioreactor landfills

The ***flushing*** or ***enhanced bioreactor*** concept has been recently devised in an attempt to reconcile landfill of wastes with the concept of sustainable development. The essential theory is that, by introducing water into the landfill and by allowing a continual throughput of water, stabilisation of the waste is achieved more quickly and pollutants are flushed out in leachate for treatment. fitted. This approach contrasts with the hitherto accepted preference for maintaining dry conditions within the landfill in order to minimise leachate. The most fundamental flaw is the problem of the time required for *completion* to occur and the rate of water infiltration required over that time. *Completion* is the state whereby gaseous and liquid emissions from the landfill no longer represent a pollution hazard.

Where an engineered low permeability cap is constructed, necessary for the control of gas releases, then rainfall infiltration into the landfill is likely to be only around 100 mm per annum. At this rate of infiltration, the period required for a single flushing of a typical 30 m deep landfill would be in the region of 100 years. In fact, it is likely that at least 6 complete flushings would be required to achieve completion.

2.14 Alternatives to Compacted Clay Liners

The enhancement of the soil used in compacted clay liners has, from the point of attenuation, been discussed above. If the available soil cannot be compacted to achieve the required permeability ($k \leq 1\text{x}10^{-9}$ m/sec), then it is possible to condition the soil such that it does achieve compliance. There are also synthetic materials available that can be used in lieu of the compacted clay layer, however their use is limited by the requirements of the Directive and by the fact that long term durability of some materials is being questioned.

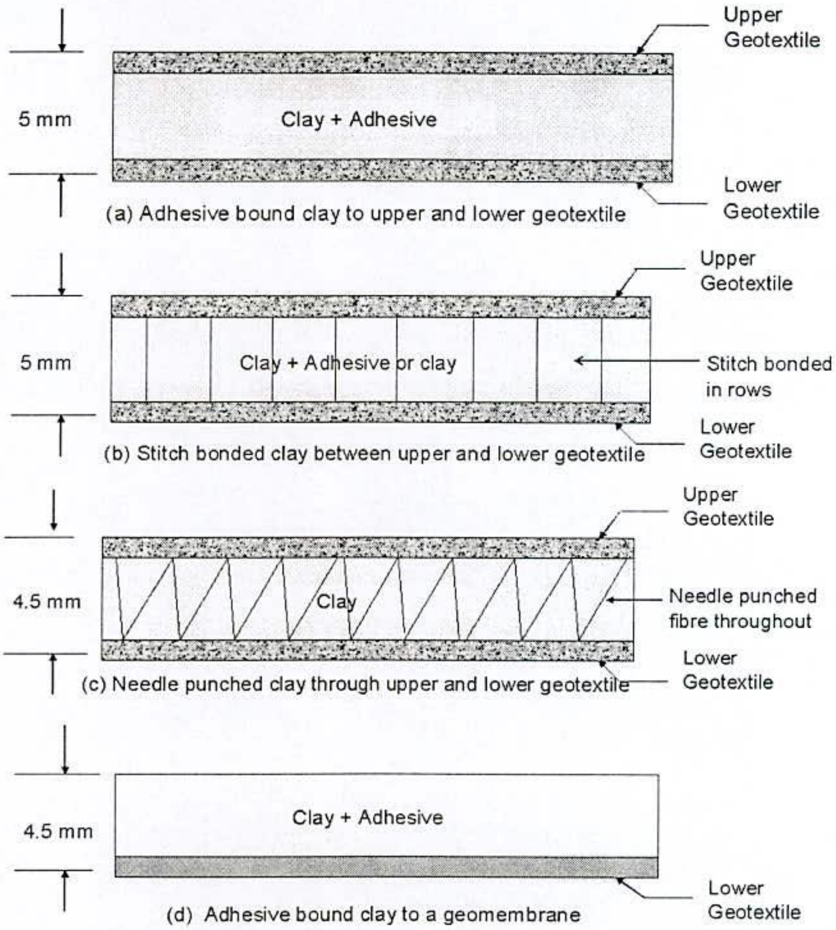


Fig 2.17: Four variations of GCL bonding methods (Source: US. EPA, 1993c)

2.14.1 Bentonite

It is a naturally occurring clay deposit containing montmorillonite group clay materials. The clay occurs naturally in several parts of the world and each deposit varies in chemical composition. Bentonites have particular properties including the ability to absorb large quantities of water molecules and both cat ions and ions into their crystalline structure. The incorporation of Bentonite fines into a naturally occurring soil, e.g. sand, will significantly alter the physical and chemical properties of the soil.

2.15 Future of Land Disposal

Keeping n view of the current technology and waste generation, landfills are and will remain a necessary component of an integrated solid waste management system. Landfills are ultimate disposal. Once the waste is put in the fill, it remains there indefinitely. Although mining is considered a possibility for future recovery of recyclable or reclaimable materials, current technology still identifies the landfill as an ultimate disposal site. As a consequence, the need for landfills will not abate, but with the increase of reduction, reuse, recycling, composting, and incineration alternatives, the need will decline.

2.16 Conclusion

From the above discussion it is clear that the provision of bottom liner is an invariable part of modern landfills. The use of natural clay as a barrier or liner in order to retard the leachate can be a good option in this respect. The low hydraulic conductivity of compacted clayey soils combined with their availability and relatively low cost makes them potential materials to use as liners in landfills for environmental protection. The selected soil is likely to have desirable characteristics to minimize Hydraulic Conductivity to a minimum value of 10^{-7} cm/sec. Percentage of clay (>15%) and percentage of fines (>30%) present in the selected liner soils are of great importance. Other important geotechnical properties are Plasticity Index (>7%) and Activity (≥0.3) of liner Soils. Swelling mineral like Montomorillonite and Vermiculite can contribute to the imperviousness of the liner. It is learnt that more than 10 % swelling mineral is expected in liner soils. It is difficult to identify or categorize the contribution made by each process of contaminant transport. The well-known factors to be considered in contaminant risk assessment are the source, pathway, and receptor or target.

CHAPTER THREE

PHYSICAL PROPERTIES OF THE SELECTED SOIL

3.1 General

Landfilling is the engineered burial facility for waste. This is not the image most people have about landfills, as open dump sites are visible and be the norm for waste disposal in the Khulna region, Bangladesh, where the study is focused on. Liner or barrier is an invariable part of the modern landfills. Using natural clay as liner material in order to retard the percolation of leachate to the surrounding soil, produced from disposed waste is getting popularity in recent years. Hydraulic Conductivity is the governing factor for a base liner property. Again Hydraulic Conductivity can be evaluated from the data of soil composition and compaction conditions. Site specific data for characterization of the soil is essential in this regard.

3.2 Present Scenario of Waste Disposal in Bangladesh

With over 3.3% annual growth in urban population in Bangladesh during 1991-2001 census years, solid waste generation has also increased proportionately with the growth of urban population. As such, most of the urban local bodies are finding it difficult to keep pace with the demand for adequate solid waste management and conservancy services provided by the urban local bodies. Consequently, a backlog between demand and supply for solid waste management in most of the urban local bodies is created. Lack of financial resources, institutional weakness improper choice of technology and lack of public awareness about solid waste management has rendered solid waste management services far from satisfactory. Comprehensive waste characterization studies have not been conducted in Bangladesh. In addition none of waste disposal sites in the country is equipped with weighbridge. Consequently, there is limited reliable information related to quantity of wastes generated in the urban areas of Bangladesh. Due to lack of information, estimates were based on the information available from other countries and cities having similar socio-economic condition to those prevalent in Bangladesh.

Table 3.1 : Urban population versus Waste Generation in Bangladesh

Year	Total Urban Population	**Urban Population (%) Total**	**Waste Rate (kg/cap/day)**	**Total Waste Generation (Tonne/day)**
1991	20872204	20.15	0.49**	9873.5
2001	28808477	23.39	0.5***	11,695
2004	32765152	25.08	0.5***	16,382
2025	78440000	40.0	0.6 **	47,064
** Source: ADBI and ADB, 2000, Zurbrugg 2002,				

Solid waste generation in Bangladesh is growing proportionately with the growth of urban population. Above table shows the growth in solid waste generation over the years.

Table 3.2 : Generation of MSW in six major cities of Bangladesh

MSW Generation	**Dhaka**	**Chittagong**	**Khulna**	**Rajshahi**	**Barisal**	**Sylhet**
Population(millions)	11	3.65	1.5	0.45	0.40	0.50
MSW Generation (tons/day)	5340	1315	520	170	130	215
MSW Generation rate (kg/capita/day)	0.485	0.360	0.346	0.378	0.325	0.430

Source: Integrated Management and safe disposal of MSW in least developed Asian Countries: a feasibility study(Alamgir et al.)

The Solid Waste management system in Bangladesh is not well organized at present. However efforts are being made to improve the organizational structure for Solid Waste management in different cities , towns. Approximately 16, 380 tons/day of waste were generated in the urban areas of Bangladesh in the year 2004 (Alamgir et al). Three systems of Waste management are found to be co-existing in this country. The city authorities are responsible for Solid waste management in the formal system. The Community Initiatives are found organized by different Non-Government Organisations conducting house to house waste collection. Again Informal system represented by large informal labour force involved in the solid waste recycling trade chain (Alamgir et at.).

There have been several positive developments in the country to improve the solid waste management situation in the urban areas of Bangladesh over the last few years, which are as follows:

- Dhaka City Corporation with support from the JICA is preparing a master plan for the solid waste management of Dhaka city

- Two projects on landfill gas recovery along with height increase of Matuail landfill site of Dhaka and establishment of 700 tons/day capacity composting plant has been approved by the National CDM Board of the government. This project will be implemented shortly by private sector using CDM financing and public-private partnership approach.

- UNICEF along with 14 city corporations and municipalities and Department of Public Health Engineering have been implementing community based composting projects and barrel type composting.

- Local Government Engineering Department (LGED) with support form ADB has taken initiative to prepare Solid Waste Management Plan for eight secondary towns of Bangladesh. UNICEF is also initiated a project to establish Recycling Centers in 24 city corporations/municipalities as well as preparation of solid waste management plan.

- Urban Solid Management Handling Rules of Bangladesh' is being prepared under the Sustainable Environment Management Program (SEMP), which is implemented by the Ministry of Environment and Forest (MoEF) and supported by UNDP.

- Bio-medical Waste Handling Rules' is also being prepared under SEMP.

An integrated approach is expected in order to improve solid waste management in the urban areas of Bangladesh.

3.2 Overview of the Khulna Study Area

Khulna is one of its divisional Cities located in south-west region of Bangladesh, lies between 22^0 49′ north latitude and 89^0 34′ east longitudes and its elevation is 2.13 meters above mean sea level (*Environmental maps and workbook for Khulna City, 1999*).

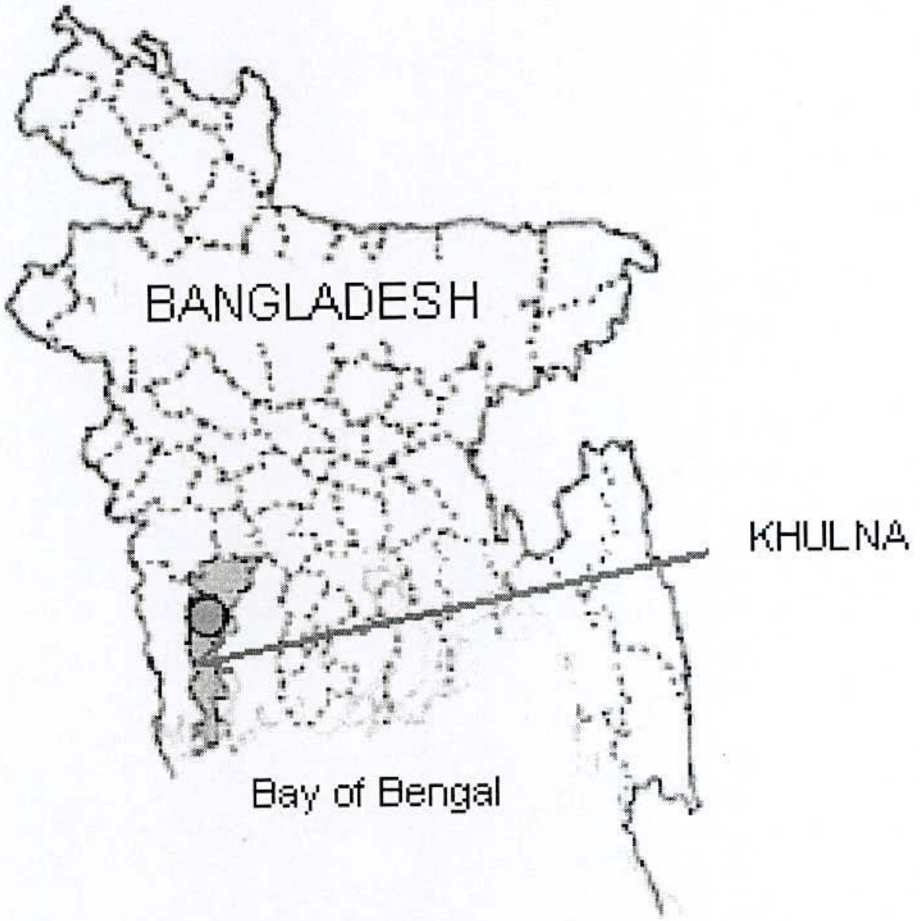


Fig 3.1 Location of Khulna zone in Bangladesh

The city stands on the western bank of the river Bhairab which forms a physical barrier influencing the shape of the growing city. Khulna City Corporation area is of 44.78 sq. km with population around 1.3 million. It is common like all other municipal corporations around the country, Khulna City Corporation (KCC) is in scarce of waste disposal area but the necessity of a sustainable waste management for the generated waste has been going on with its ever increasing trend.

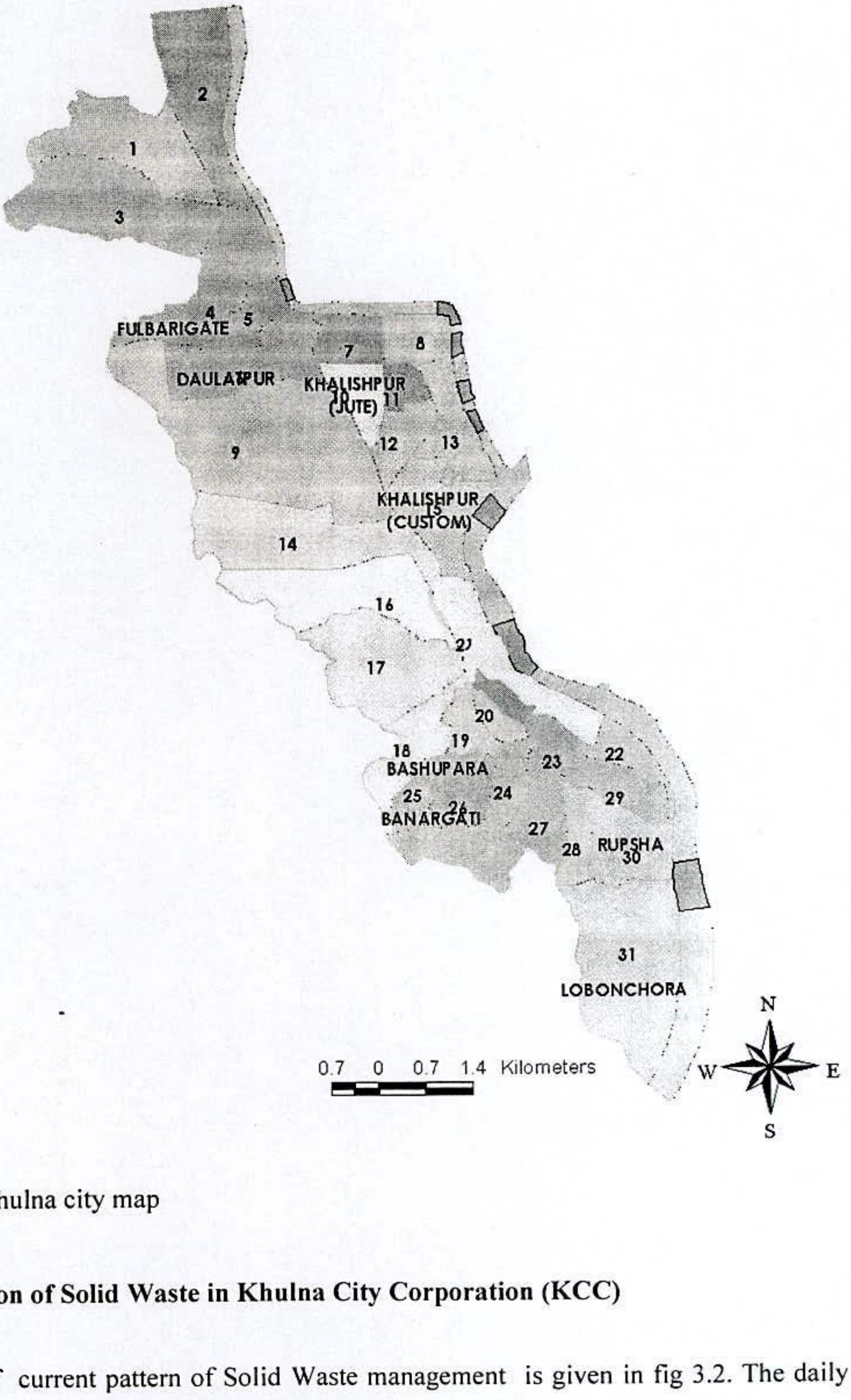


Fig 3.2 : Khulna city map

3.3.1 Generation of Solid Waste in Khulna City Corporation (KCC)

An indication of current pattern of Solid Waste management is given in fig 3.2. The daily waste generation in Khulna city can be estimated to an amount of 520 tons and the volume is equal to 1038 m^3 (as 0.5 tons/m^3) as given in Table 3.3.

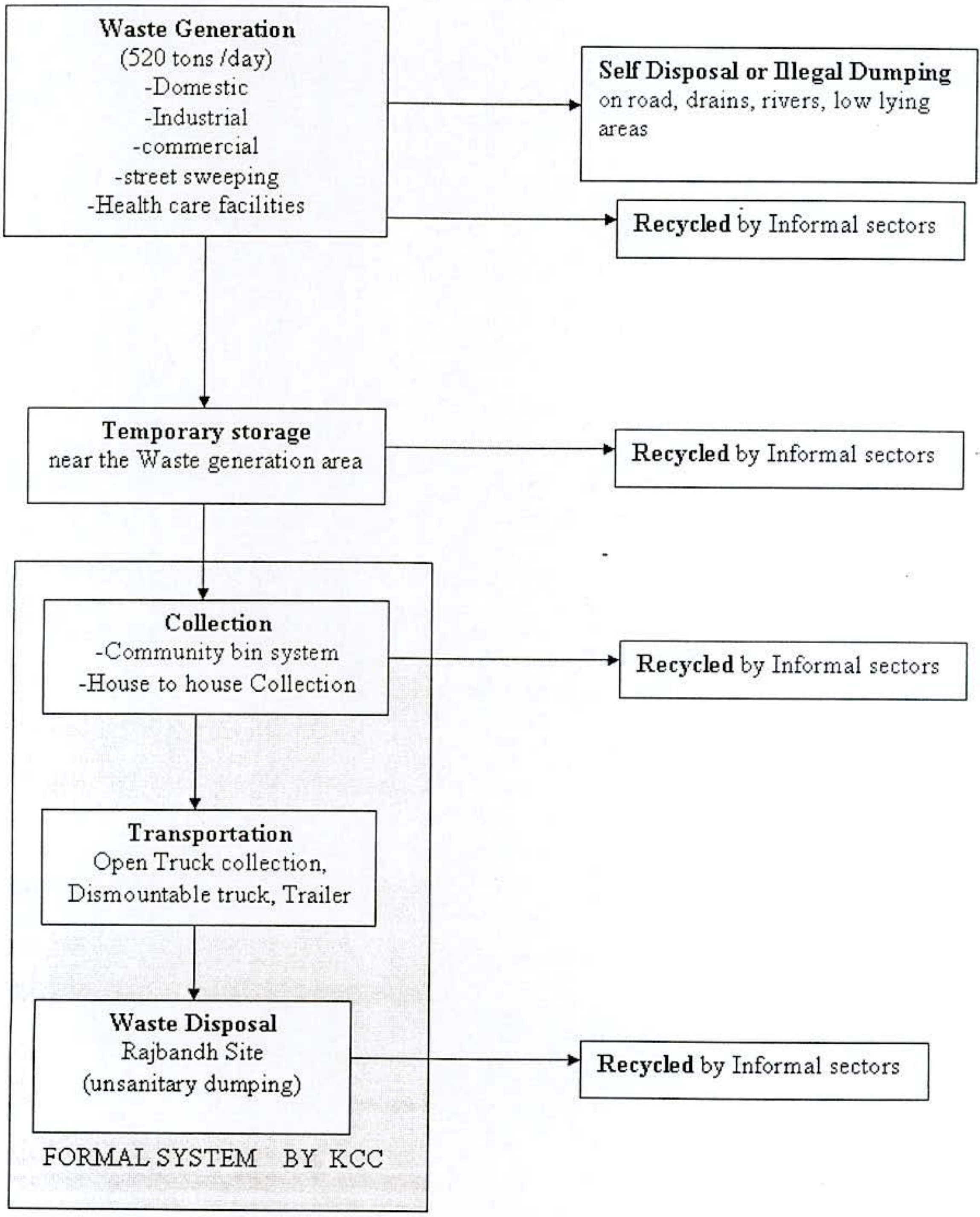


Fig 3.3: Existing Pattern of Solid Waste Management process in Khulna

Residential wastes are the main sources of MSW in Khulna city Corporation contributing 85.87% to the total generation of waste. Commercial wastes comprises of markets, hotels, restaurants, hospital/Clinical, institutions including schools, colleges and government offices, construction & demolition, street sweeping, drain sweeping, and other wastes includes clinical and some industrial wastes have been producing considerable amount of waste everyday.

Table 3.3: Generation of MSW in Khulna city

Sources of generation	*Total generation (tons/day)*	*% of total generation*
Residential area	455.50	85.87
Commercial areas	60.14	11.60
Institutional areas	5.26	1.02
Street sweepings	2.86	0.55
Others	5.00	0.96
Total	518.75 ≈ 520	100

Source: Integrated Management and safe disposal of MSW in least developed Asian Countries: a feasibility study(Alamgir et al.)

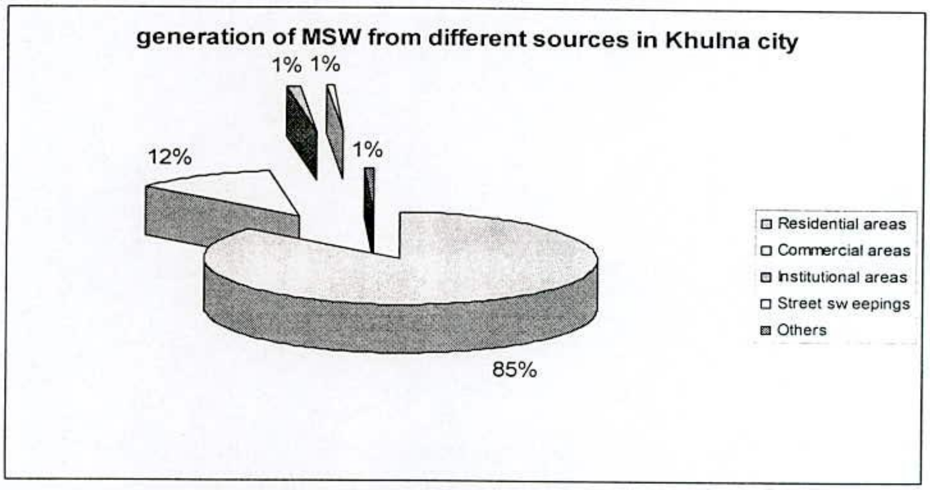


Fig: 3.4 : MSW generation from different sources in Khulna city

In case of Khulna city representative Municipal Solid Waste poses the following physical and chemical composition:

Table 3.4: Physical composition of MSW in Khulna City (in wet weight %)

MSW composition	Residential area	Commercial area	Institutional area	The Whole city
Food & Vegetables	86.0	40.1	16.0	78.9
Paper & Paper products	6.0	27.2	48.0	9.5
Polythene & Plastics	2.0	9.1	14.0	3.1
Textile & Woods	1.0	3.3	3.0	1.3
Rubber & Leathers	0.5	0.8	0.0	0.5

Metal & Tins	1.0	1.6	2.0	1.1
Glass & Ceramics	0.5	0.6	0.0	0.5
Bricks, Concrete & Stones	0.5	1.0	1.0	0.1
Dust, Ash & mud products	2.0	13.9	14.0	3.7
Others (bone, rope, etc.)	0.5	2.4	2.0	1.2
Total	100.0	100.0	100.0	100.0

Source: Integrated Management and safe disposal of MSW in least developed Asian Countries: a feasibility study

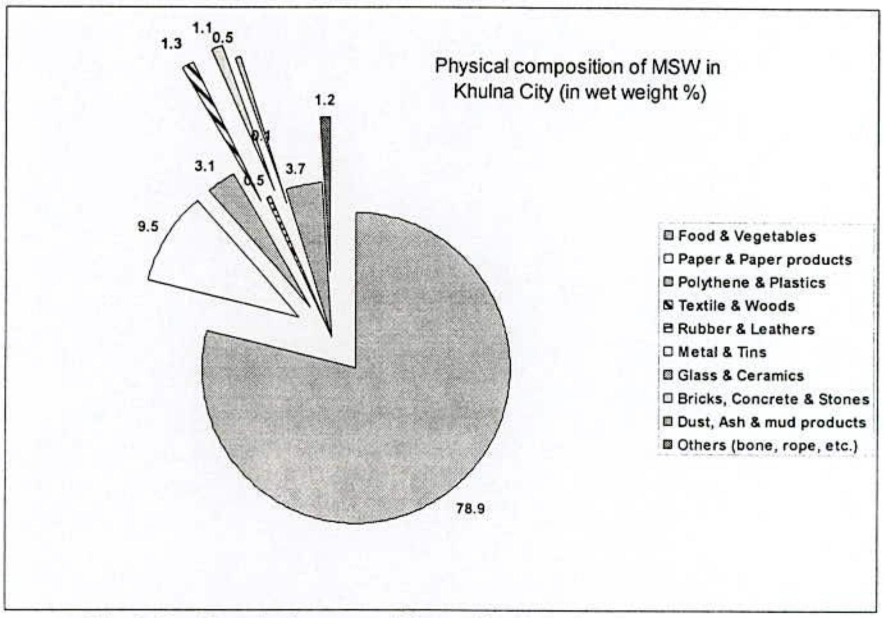


Fig 3.5 : Physical composition of MSW in Khulna city

Table 3.5 : Chemical characteristics of MSW in Khulna city

Carbon (%)	24.93
Nitrogen (%)	1.62
Carbon Nitrogen ratio (%)	16.08
Phosphorous (% P as P_2O_5 =%P × 2.29)	1.37
Potassium (%K as K_2O = %K × 1.20	0.41

Source: Integrated Management and safe disposal of MSW in least developed Asian Countries: a feasibility study (Alamgir et al)

As discussed in Chapter 2, waste containment facilities are made to hold the waste materials with the aim to isolate those from the surrounding environment, providing liners at the bottom of the waste containment system restrict the migration of pollutant to the neighboring soils, surface water and groundwater.

Compacted soil with low hydraulic conductivity has been successfully used for a long time as barrier in such structures as it is naturally available and relative low costing. A series of laboratory tests was conducted on the Khulna soil, to assess whether it could be compacted as hydraulic barriers in waste disposal landfills.

3.4 Location of the Borrow Pit

As the geotechnical is an essential part for investigation of soil and its appropriateness as liner materials an extensive field trip was made in and around Khulna City corporation area. Finally four locations were selected to conduct geotechnical investigation.

Name of the place	*Location of borrow pit/ landfill*
Fultala	In the open space nearby office of the BEST brick field.
Rajbandh	KCC municipal solid waste (MSW) disposal area
Samanta sena	Open place , beside Khulna -Bagerhat old railway line,
KUET campus	It is a swampy area, in the backyard of the KUET campus,

All the places were selected as based on the suitability criteria of a disposal. area and potentiality for future construction of MSW landfill.

Soil samples were collected from various depth at a rate of 3 borehole per site within 50 m diameter of the selected spots. Thus a total number of twelve exploratory boring were drilled down to a depth of 10 m below the existing ground surfaces of the preferred spots. The bore hole were drilled by wash boring method with the help of manually operated rig using a 100 mm diameter cutter. Disturbed and undisturbed soil samples were collected at every 1 m interval from each borehole for subsequent laboratory tests and visual classification. These samples were duly preserved in polythene bags and labeled with detailed job designation (bore hole number, depth and date) for subsequent tests.

3.5 Surface Geology of the Study Areas

3.5.1 Fultala Site

The surface geology of this are consist of silty clay (0 -4.5 ft) underlain by sandy clay (4.5 ft – 6.5 ft), then sandy silt with clay (6.5 ft – 16.5 ft), then silty sand (16.5ft -23 ft), followed by silty clay (23 ft-33 ft). Bore log of three bore hole are given in Table 3.6.

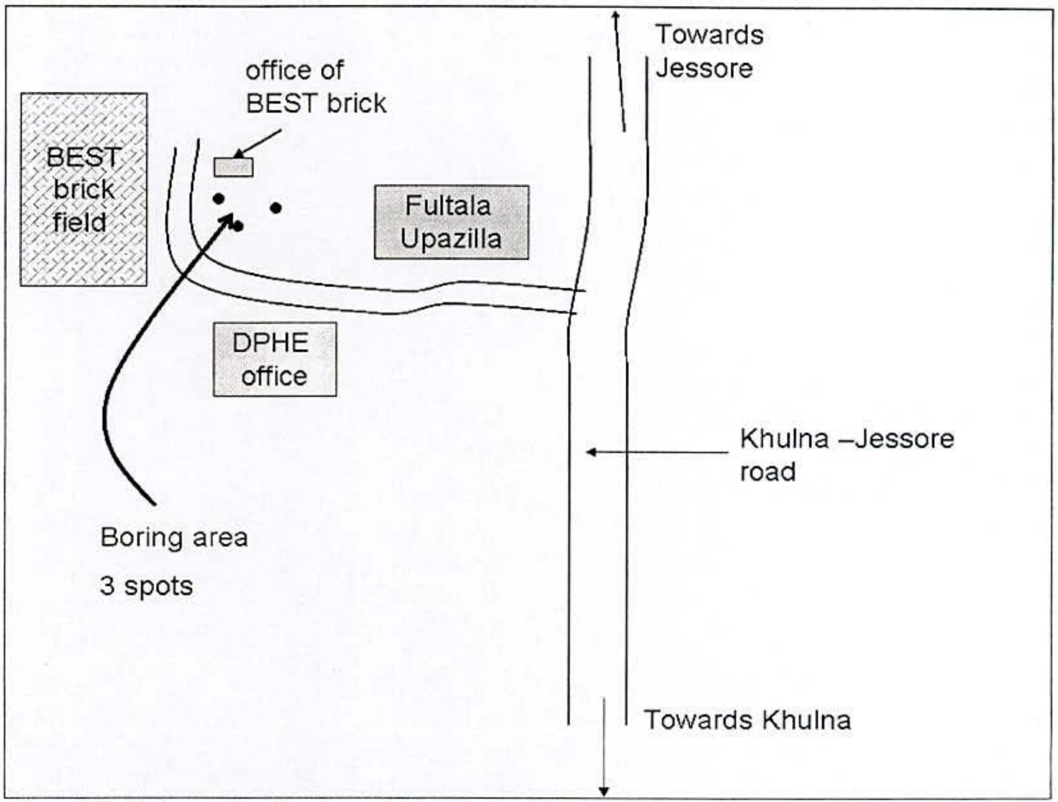


Fig 3.5: Schematic diagram of Fultala location

3.5.2 Rajbandh Site

The present Municipal Solid Waste uncontrolled dumping area of Khulna Municipal Corporation (KCC) is at Rajbandh. The sample was borrow from the adjacent area which may very well be an extended area for the same purpose. It is therefore, better expected to be a controlled landfill area in future.

The surface geology of this area consist of silty clay (0 -6 ft) underlain by sandy silt (6 ft- 18 ft), then clayey sand (18 ft -21 ft), followed by silty sand (21 ft-33 ft). Bore log is at table 3.7.

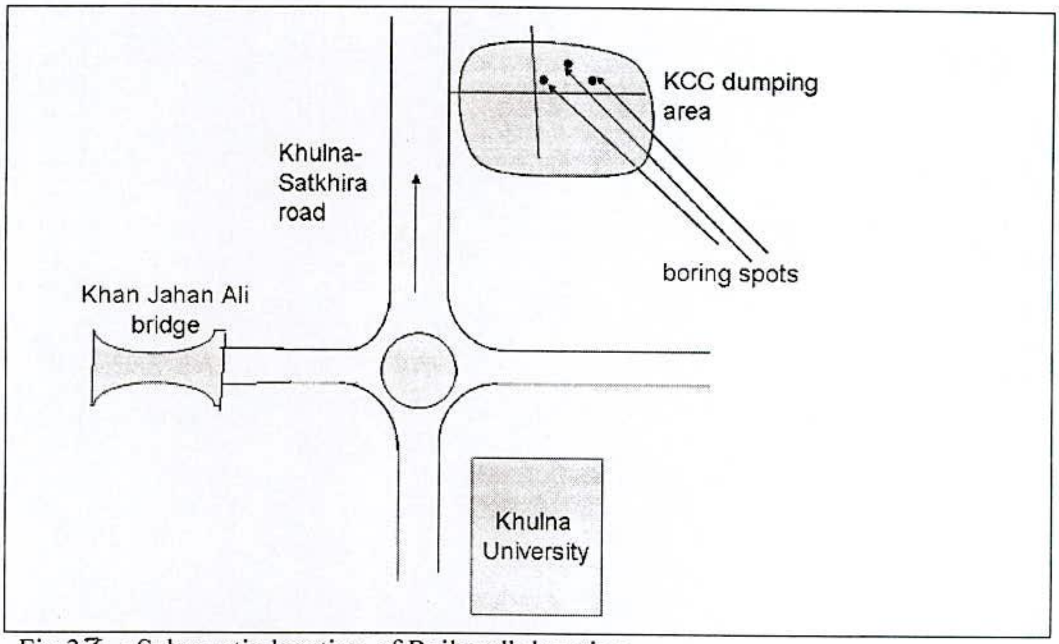


Fig 3.7 : Schematic location of Rajbandh location

3.5. 3 Samanta Sena Site

The surface geology of this are consist of clay (0 -6 ft) underlain by silty clay (3 ft – 9 ft), then silty clay with fine sand (9 ft – 12 ft), then fine sand (12 ft -33 ft) with traces of silty clay. Respective bore log is accommodated in Table 3.8.

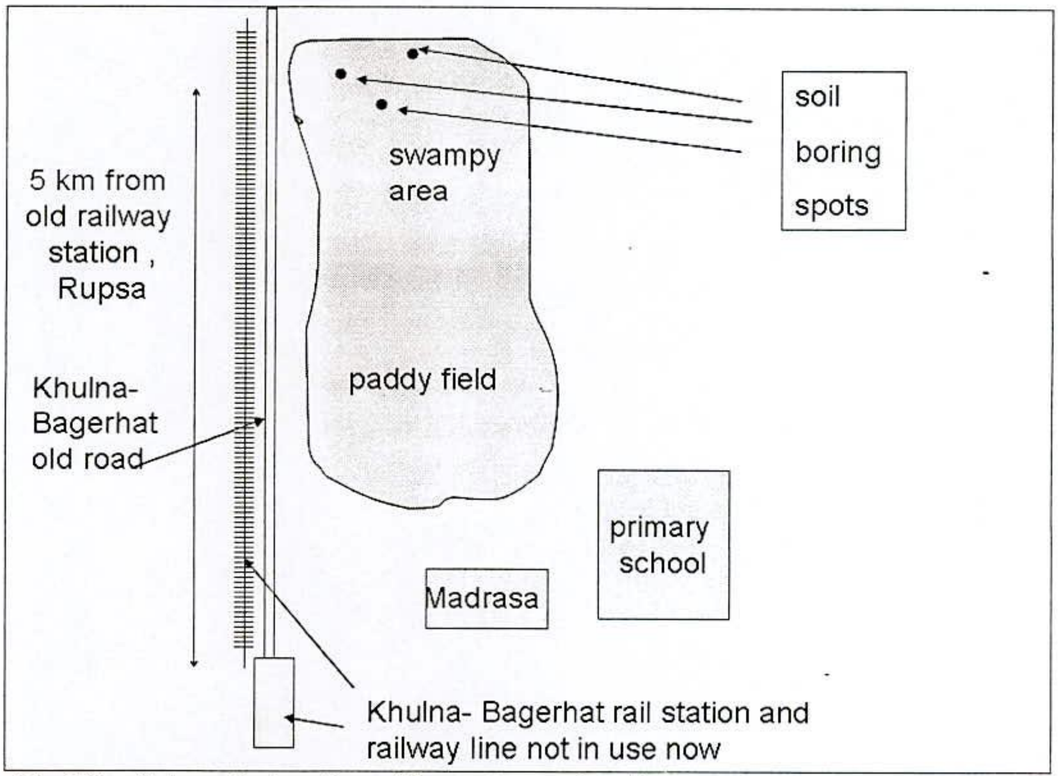


Fig 3.8 : Schematic location of Samanta sena location

3.5.4 KUET Campus Backyard Site

The surface geology of this are consist of Clay, (0 -12 ft) underlain by silty with traces of organic (12-21 ft), followed by silty clay (21 ft -33 ft). Clays are brown to dark gray coloured soils. Clayey layers display traces of organic materials. It also contain lenses of silt sand etc. water generally saturates this lenses.

Ground water table in each borehole was measured and recorded. Various laboratory tests with the collected samples were executed to determine the geotechnical properties of the soil. Bore hole log is submitted at Table 3.9

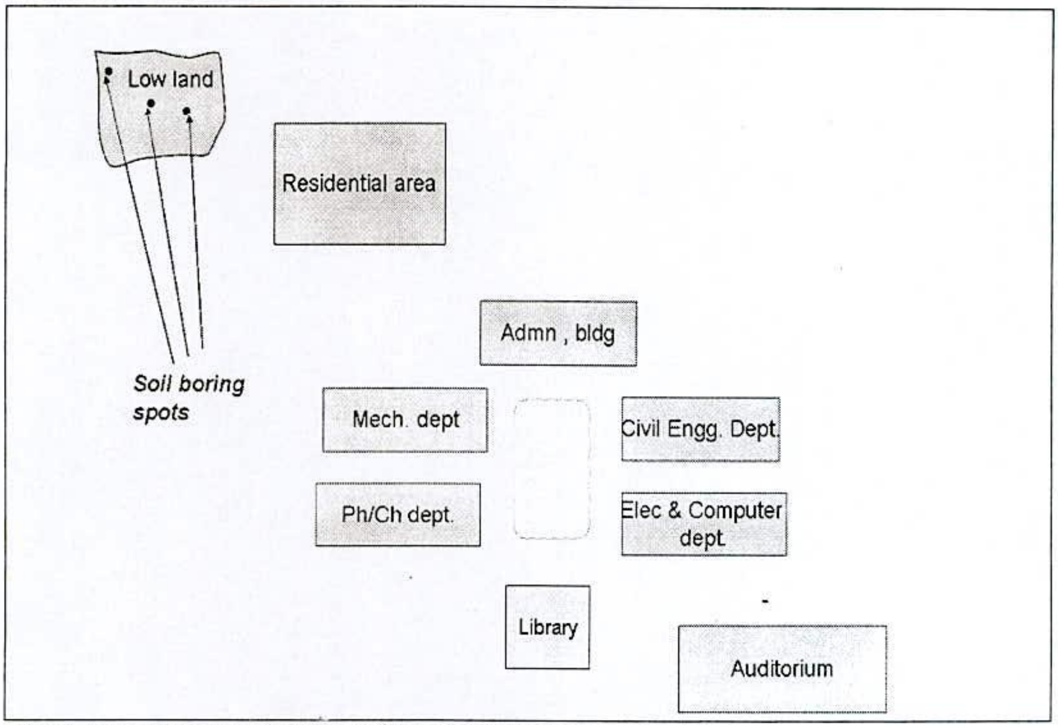


Fig 3.9 : Schematic location of KUET campus backyard location

Table 3.6:: Bore logs of the Fultala site

	Bore hole 1	Bore hole 2	Bore hole 3
Depth in ft	*Type of soil & colour*		
0-1.5	Silty clay, brown	Silty clay, brown	Silty clay, brown
1.5-4.0			
4-6.5	Sandy clay, grey		Sandy clay, brown
6.5-9	Sandy silt with clay grey	Sandy silt with clay grey	Clay , brown
9-11.5			Miss
11.5-13		Silty sand, grey	Sandy silt with clay, grey
13-16.5		Silty clay, dark grey	
16.5-18.5		Silty sand, grey	Sandy clay, grey
18.5-23	Clayey sand, grey	Sandy silt with clay grey	Sandy silt with clay, grey
23-28.5	Silty sand, grey	Silty clay, grey	Silty clay, grey
28.5-33		Sandy clay with silt grey	Sandy clay, grey

Table 3.7: bore log of Rajbandh

	Bore hole 1	Bore hole 2	Bore hole 3
Depth in ft	*Type of soil & colour*		
0-1.5	Silty clay, brown	Silty clay, brown	Silty clay, brown
1.5-4.0			
4-6.5	Sandy clay, grey		Sandy clay, brown
6.5-9	Sandy silt with clay grey	Sandy silt with clay grey	Clay , brown
9-11.5			Miss
11.5-13		Silty sand, grey	Sandy silt with clay, grey
13-16.5		Silty clay, dark grey	
16.5-18.5		Silty sand, grey	Sandy clay, grey
18.5-23	Clayey sand, grey	Sandy silt with clay grey	Sandy silt with clay, grey
23-28.5	Silty sand, grey	Silty clay, grey	Silty clay, grey
28.5-33		Sandy clay with silt grey	Sandy clay, grey

Table 3.8: bore log of Samanta sena

	Bore hole 1	Bore hole 2	Bore hole 3
Depth in ft	*Type of soil & colour*		
0-3	Silty clay, brown	Clay, brown	Silty clay, brown
3-6		Silty clay, brown	Clay , brown
6-9	Sandy clay , gray		Silty clay
9-12	Silty clay with fine sand, grey	Silty sand , grey	
12-15	Fine sand, light grey	Fine sand, grey	Silty clay with silty sand, grey
15-18		Clayey silt, grey	Sandy silt with clay, grey
18-21		Fine sand, grey	
21-24			
24-27			
27-30			
30-33		Silty sand, grey	

Table 3.9: bore log of KUET campus backyard

	Bore hole 1	Bore hole 2	Bore hole 3
Depth in ft	*Type of soil & colour*		
0-3	Clay, grey	Silty clay ,brown	Clay, grey
3-6	Clay, brown	Clayey silt, brown	Clay, brown
6-9	Clay, brown		Clay, brown
9-12	Clay, grey	Clay, brown	Clay, grey
12-15	Organic Clay, dark grey	Organic ,black	Organic clay, black
15-18	Silty clay ,grey		
18-21		Organic clay, black	
21-24	Clayey silt, dark grey	Silty clay , dark grey	Clay with trace of organic, dark grey
24-27	Silty clay , dark grey		Silty clay, grey
27-30			
30-33		Silty sand, grey	

3.6 Material Selection

The soil liner material are to be selected so that it posses low hydraulic conductivity after the soil is remolded and compacted. The soil parameter those are best indicator for hydraulic behaviour of the soil, the parameter related to soil composition and structure, are given concentration in analysing the soil samples.

More over, liquid limit plastic limit, plasticity Index, percent fines percent of gravels in the soil liner material are also examined as their allowances for soil liner is limited. To determine the properties of the borrow from the 4 selected sites, laboratory analysis of the soils were performed. The test conducted on the samples are in Table 3.11.

Table 3.10 : Standard used for characterization tests

Tests	Tests Standards
Moisture content	ASTM D-2216
Particle size distribution	ASTM D-422
Atterberg limits	ASTM D 4318
Standard Proctor test	ASTM D-698
Modified Proctor Test	ASTM D-1557
Clay content	ASTM D 422
Hydraulic Conductivity	ASTM D 5084

3.7 Testing procedure for clay liners

Design Objectives for Compacted Soil Liner is to maintain Low hydraulic conductivity to minimize leakage ($K \leq 10^{-7}$ cm/sec) of leachate, adequate shear strength to maintain liner stability and minimal shrinkage potential to minimize desiccation cracking.

Clay having low permeability is of main interest in constructing soil liner. Due to clay chemistry, large sodium molecules between clay particles cause clay to swell and plates to disperse which leads to high sodium clays have lowest K. Again double layer holds water which reduces K. To determine the suitability of a specific soil as liner material the following comparative analysis:

i) Determine compaction vs. water content

ii) Determine permeability vs. water content

iii) Determine shear strength vs. water content

iv) Determine shrinkage vs. water content

v) Allowable ranges of K, shear strength,

vi) Shrinkage to find water content and compaction

3.8 Percent of Fines

Fines are defined as the fraction of a soil on a dry weight basis that passes through the openings of the No. 200 sieve (opening size 0.075mm). Soil with adequate fines having higher percentage of silt and clay sized materials can produce suitability low hydraulic conductivity. Daniel; (1990) recommended that the liner material contain at least at least 30% fines. Data from Benson et al (1992) suggests that a minimum of 50% fines might be appropriate requirement for many soils as liner.

Collected soils samples has shown the following percent fines when examined. All the samples except a few samples of Samanta sena are having very high percentage of fines. Percentages of gravel were not a concern for the selected sites.

Table 3.11 : Particle size distribution of the collected samples

Location	*Sample collected from depth*	*% Clay*	*% Silt*	*% Sand*
Fultala	1.5-4	28.41	69.79	1.8
	4-6.5	35.1	63.1	1.8
	6.5-9	28.57	67.63	3.8
	9-11.5	17.35	75.45	7.2
	11.5-13	22.09	70.91	7
	13-16.5	29.25	69.25	1.5
	23-28.5	37.24	61.76	1
	28.5-33	36	59.7	4.3
Rajbandh	0-6	44.32	55.18	0.5
	6—9	42.35	57.15	0.5
	18-21	38.53	61.27	0.2
	21-33	38.3	60.9	0.8

Samanta sena	0-3	39.16	56.91	3.93
	6--9	0.91	91.89	7.2
	9--12	30.34	65.46	4.2
	12--15	22.93	55.32	21.75
	15--18	15.65	35.65	48.7
	18--21	11.65	34	54.35
	25--30	12.65	48.85	38.5
	30—33	16.6	18.9	64.5
KUET backyard	3--6	24.25	74.55	1.2
	6--9	51.85	47.35	0.8
	9--12	36.3	62.8	0.9
	12--15	34.31	65.29	0.4
	15--18	30.33	69.17	0.5
	18--21	48.07	51.43	0.5
	21--24	30.09	68.61	1.3
	24--27	28.14	70.63	1.23
	27--30	42.03	57.17	0.8
	30—33	28.11	71.09	0.8

3.9 Moisture Content

Moisture Content determinations show that Rajbandh soil has got the highest moisture content, having layer of moisture content of 91.27% at 21-24 ft depth followed by KUET campus with layer of moisture content 81.31 at 15-18 ft depth .

High water content is due to presence of organics in the soil. Results of Moisture content are shown in Table 4.12 below. In general the variations in the natural moisture content values are insignificant.

Table 3.12 : Moisture content of the samples

Location	*depth in ft*	*Moisture content*
Fultala	0 - 1.5	28.69
	1.5 - 4	31.27
	4 - 6.5	31.77
	6.5 - 9	30.62
	9 - 11.5	30.40
	11.5 -13	31.20
	13- 16.5	44.61
	16.5-18.5	30.50
	18.5- 23	30.37
	23-28.5	35.76
	28.5-33	36.84

Rajbandh	0-3	32.12
	3-6	90.36
	6-9	39.81
	9-12	76.43
	12-15	84.26
	15-18	84.57
	18-21	39.61
	21-24	91.27
	24-27	39.28
	27-30	45.11
	30-33	43.63
Samanta sena	0 - 3	28.62
	3 - 6	31.05
	6 - 9	36.03
	9 - 12	22.94
	12 - 15	26.77
	15 - 18	36.48
	18 - 21	32.48
	21 - 24	33.39
	24 - 27	26.89
	27 - 30	28.31
	30 - 33	30.45
KUET campus	0-3	35.63
	3-6	27.73
	6-9	31.14
	9-12	56.97
	12-15	41.77
	15-18	81.31
	18-21	31.33
	21-24	30.49
	24-27	33.94
	27-30	35.02
	30-33	48.65

Mean moisture content of the Samanta sena and Fultala site is substantially lower than the other two sites samples. This is attributable to lower clay content.

3.10 Plasticity Characteristics

It is needed to know the Plasticity property of the soil as it plays an important role in selecting the liner materials. In general non-plastic soils are not suitable for liner unless it is otherwise treated. Plasticity is a property of the fine-grained portion of a soil that allows it to deformed beyond the point of recovery without cracking or changing volume appreciably.

Some mineral, such quartz powder can not be made plastic no matter how fine the particles or how much water is added. All clay minerals are plastic and can be rolled into thin threads at a certain moisture content without crumbing. The degree of plasticity is a general index to the clay content of a soil. The plasticity characteristics are quantified by three characteristics:

a) Liquid limit: it is the water content corresponding to the arbitrary limit between the liquid and plastic states of consistency of a soil.

b) Plastic limit: it is the water content corresponding to the arbitrary limit between the plastic and solid states of consistency of a soil.

c) Plasticity index is the numerical difference between liquid and plastic limits.

The collected soils were found having the following plasticity characteristics:

Table 3.13 : Plasticity characteristics of collected samples

Location	Depth (in ft)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Activity (PI /% clay fraction)
Fultala	0-1.5	32.30	26.0	6.3	--
	1.5-4	30.50	25	5.5	0.19
	4-6.5	28.20	26.70	1.5	0.04
	13-16.5	32.5	26.3	6.2	--
	16.5-18.5	34.20	28.50	5.7	0.21
	25.5-33	29.5	23.0	6.5	0.17
Rajbandh	0-3	51.20	31.80	19.4	0.44
	3-6	55.06	48.09	6.97	0.17
	6-9	54.43	29.29	25.14	0.59
	9-12	88.23	31.46	56.77	--
	12-15	53.21	31.78	21.43	--
	15-18	12.88	70.49	42.39	--
	18-21	47.05	31.32	15.73	0.41
	21-24	25.40	13.90	66.40	1.73
	27-30	41.40	24.39	17.01	0.44
	30-33	41.81	32.63	8.77	0.23
Samanta Sena	0-3	36.9	25.61	11.29	0.29
	3-6	43	20	23	--
	6-9	34	26.76	7.24	0.24
	9-12	36.10	24.13	11.97	0.52
	12-15	35.67	27.03	8.64	0.55
	15-18	27.50	25.86	1.64	0.10
KUET Campus	0-3	50	28	22	--
	3-6	55	29	26	1.07
	6-9	80	29	51	0.98
	12-15	62	34	28	0.82

15-18	72	44	28	0.92
18-21	79	45	34	0.71
21-24	54	33	21	0.70
24-27	30	27	3	0.11
27-30	58	41	17	0.40
30-33	33	26	7	0.25

3.11 Clay Content and Activity

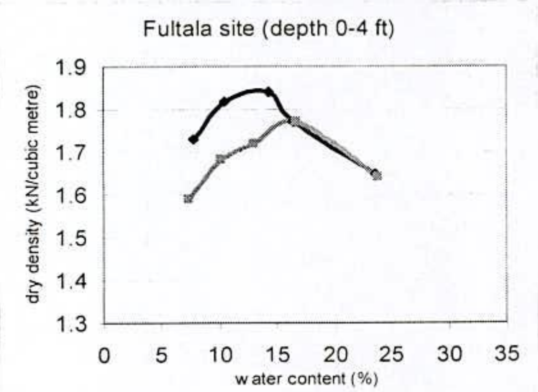
The clay content of the soil may be defined in several ways but it is usually considered to be the percentage of soil that has an equivalent particle diameter smaller that 0.005 mm. The more common definition refers to 0.002 mm. the clay content is measured by sedimentation analysis using a hydrometer (ASTM D 422).

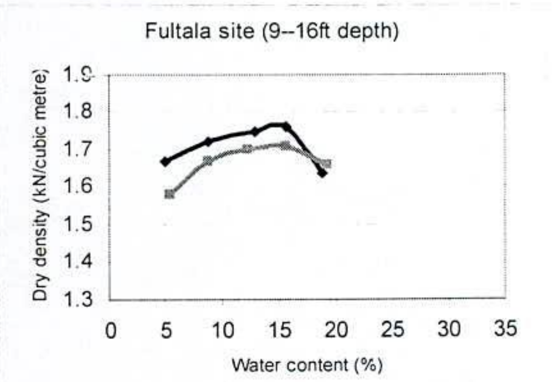
A parameter that is sometimes useful is the Activity of the soil. It is defined as the Plasticity Index (%), divided by the percentage of clay (finer than 0.002 mm).

Table 3.13 above shows all the samples of Rajbandh (38.3 - 44.32) and KUET campus backyard (24.25%-51.85%) are having high percentage of clay. There are certain variation of clay contain in the Fultala and Samantasena. Fultala is within the range of 17% - 37%. Samantasena is within range of 10%-20% except two isolated cases of one sample of almost no clay content (0.91%) and one is having 39.16 % of clay.

Activity in Fultala soil is found within the range of 0.04 to 0.19, Rajbandh in the range of 0.7 to 1.73, Samanta sena in the range of 0.10 to 0.55 and that of KUET campus in the range of 0.11 to 1.07.

3.12 Moisture-Density Relationship


Fultala site (depth 0-4 ft)


Fultala site (9--16ft depth)

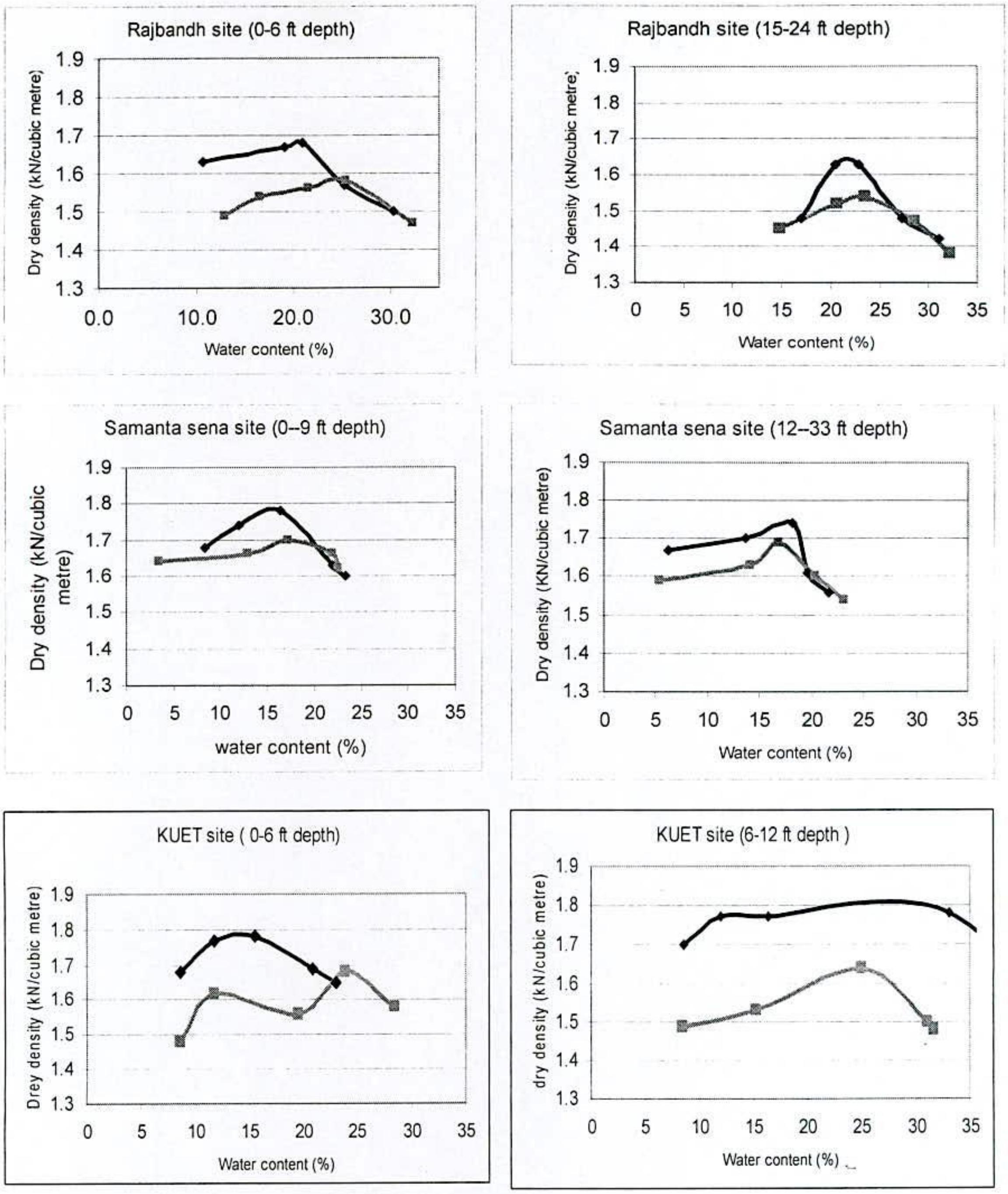


Fig 3.10: Compaction curves of different sites

Laboratory tests were performed to determine the optimum moisture content and the corresponding maximum dry density. They account for the effect of moisture on soil density, establish the soil density to compare the degree of compaction, and result in a moisture-density curve. The most common tests are the standard Proctor test and modified Proctor test.

The maximum dry unit weight and optimum water content measured on the selected 17 soil liner material are having the following ranges:

Table 3.14 : Standard and Modified Proctor test results of collected soil samples

Location	Depth (ft)	Standard Proctor Test		Modified Proctor Test	
		W_{opt} (%)	$(\gamma_d)_{max}$ kN/m^3	W_{opt} (%)	$(\gamma_d)_{max}$ kN/m^3
Fultala	0-4	16.61	1.77	4.28	1.84
	4-9	16.74	1.73	12.84	1.85
	9-16	15.54	1.71	15.60	1.76
	16-33	16.64	1.77	17.84	1.72
Rajbandh	0-6	25.32	1.58	20.82	1.68
	6-12	26.08	1.38	29.04	1.39
	12-15	55.16	0.89	45.10	1.01
	15-24	23.43	1.54	22.83	1.63
	24-30	30.07	1.41	28.57	1.46
	30-33	20.57	1.58	20.38	1.63
Samanta sena	0-9	17.20	1.70	16.44	1.78
	9-12	17.33	1.72	14.48	1.81
	12-33	16.86	1.69	18.19	1.74
KUET campus backyard	0-6	19.50	1.68	15.47	1.78
	6-12	15.30	1.64	16.33	1.77
	12-21	30.64	1.45	22.41	1.64
	21-33	17.40	1.66	19.00	1.78

During placement and compaction of the clay liner, the moisture content of the clay being placed shall be maintained above optimum moisture as determined by the Standard Proctor Test (ASTM D-698) or Modified Proctor Test (ASTM D-1557).

The application of water to the clay shall be accomplished at the borrow areas in so far as practicable. Water may be applied by sprinkling the clay after placement and before compaction of the liner to maintain uniform moisture distribution,

3.13 Consolidation Criteria

Consolidation test were performed for quite a number of samples. In general, the main purpose of consolidation tests is to obtain soil data which is used in predicting the rate and amount of settlement of structures founded on soil. Although some of the settlement of a structure on clay may be caused by shear strain, most of it is normally due to volumetric changes. This is particularly true if the clay stratum is thin compared to the width of the loaded area or the stratum is located at a significant depth below the structure. In engineering practice, reasonably good predictions of a structure's settlements can be made from the results of carefully run laboratory tests. In this experiment the consolidation tests were done to know the site soil condition to give an overview selected soil samples collection site and if these sites are going to be used as landfill sites as well. Typical nature of consolidation curves of the sub-soil are shown in fig 3.11 to 3.21.

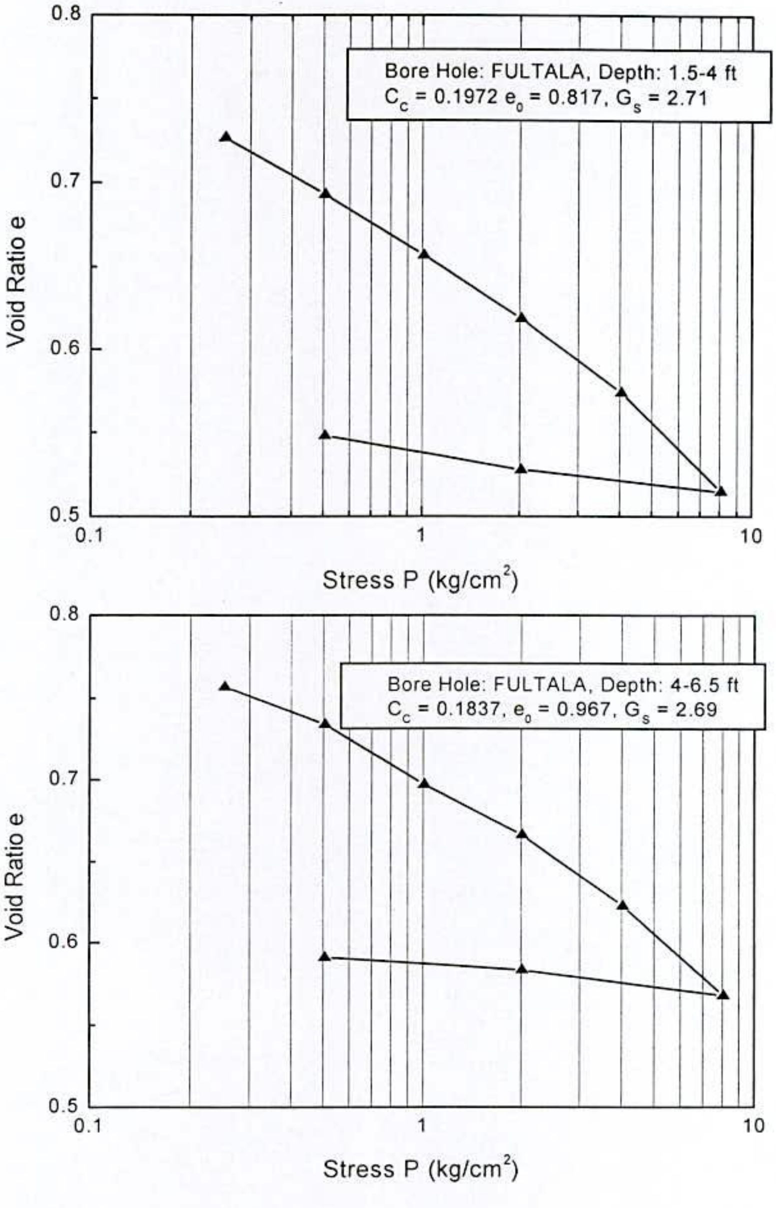


Fig : 3.11 Consolidation curves of Fultala soils (1.5 to 6.5 ft depth)

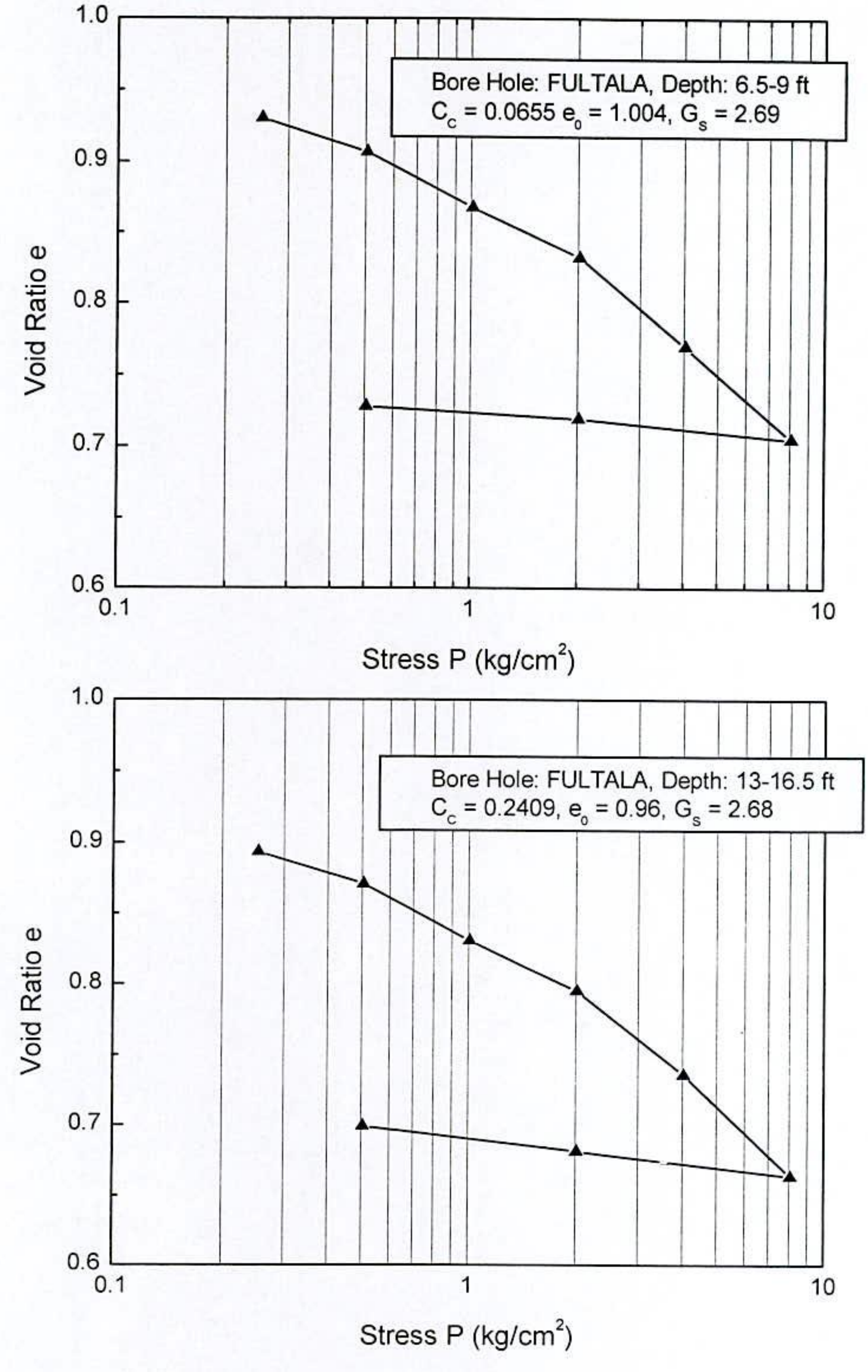


Fig : 3.12 Consolidation curves of Fultala soils (6.5 to 16.5 ft depth)

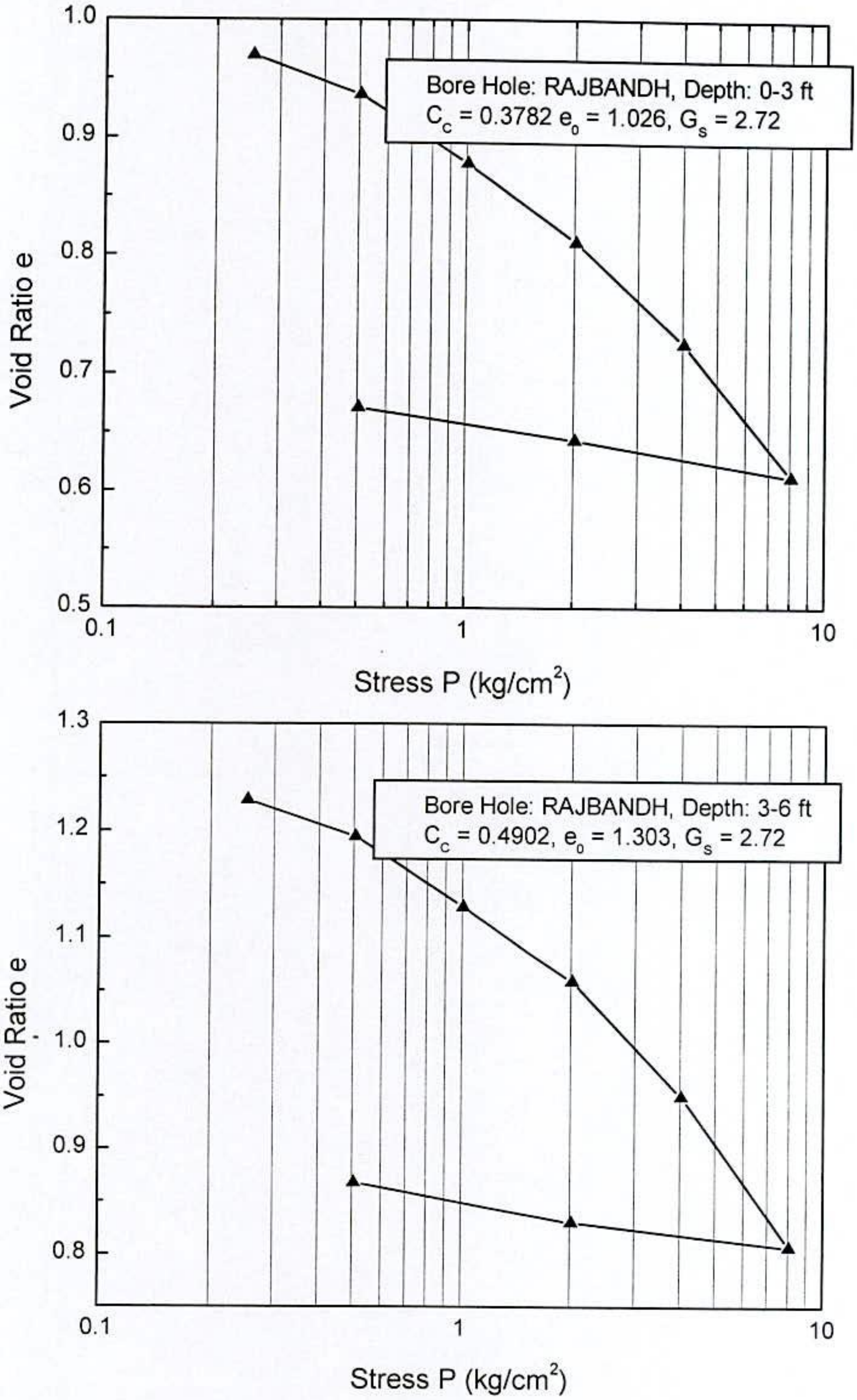


Fig : 3.13 Consolidation curves of Rajbandh soils (0 to 6 ft depth)

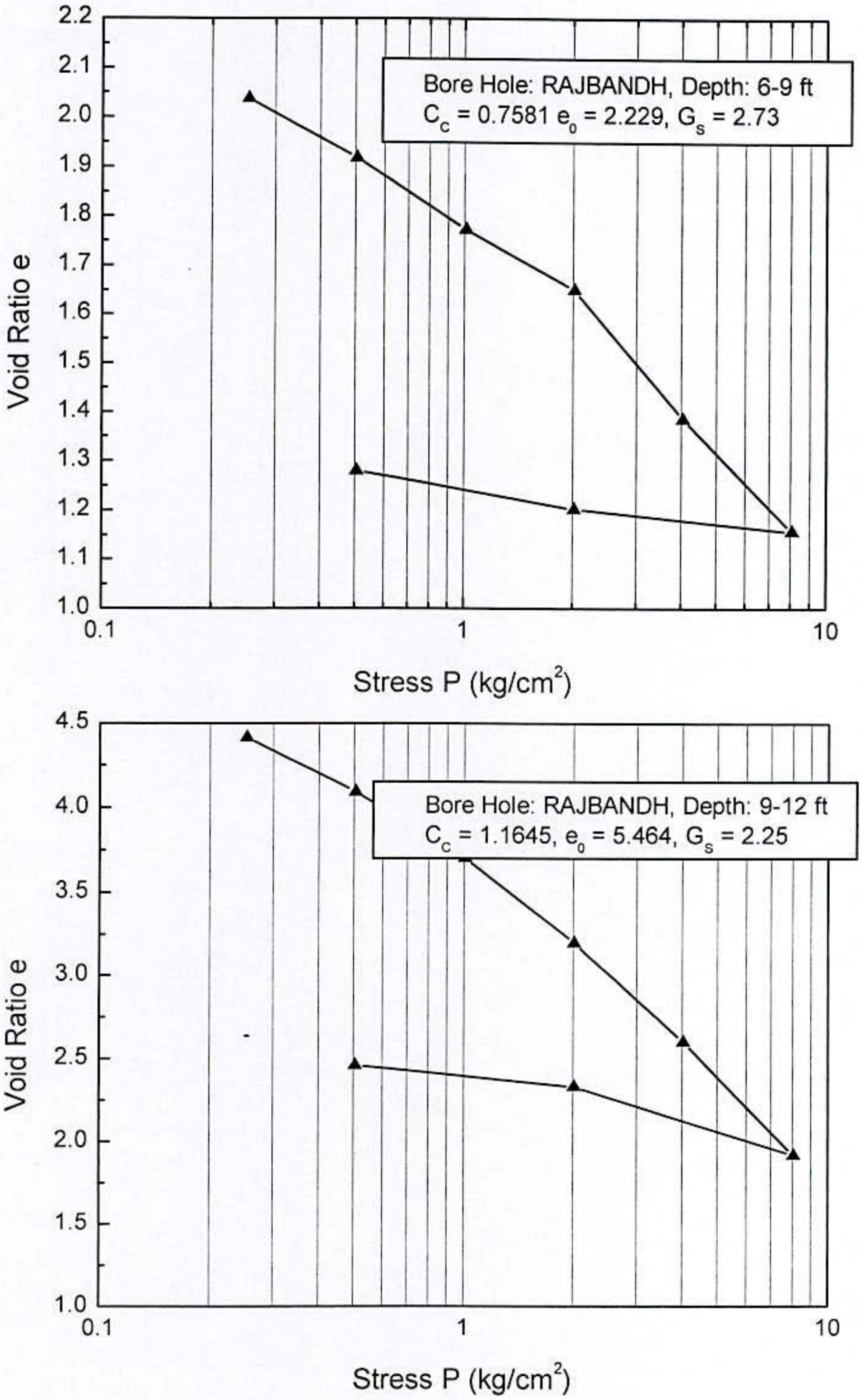


Fig 3.14 : Consolidation curves of Rajbandh soils (6 to 12 ft depth)

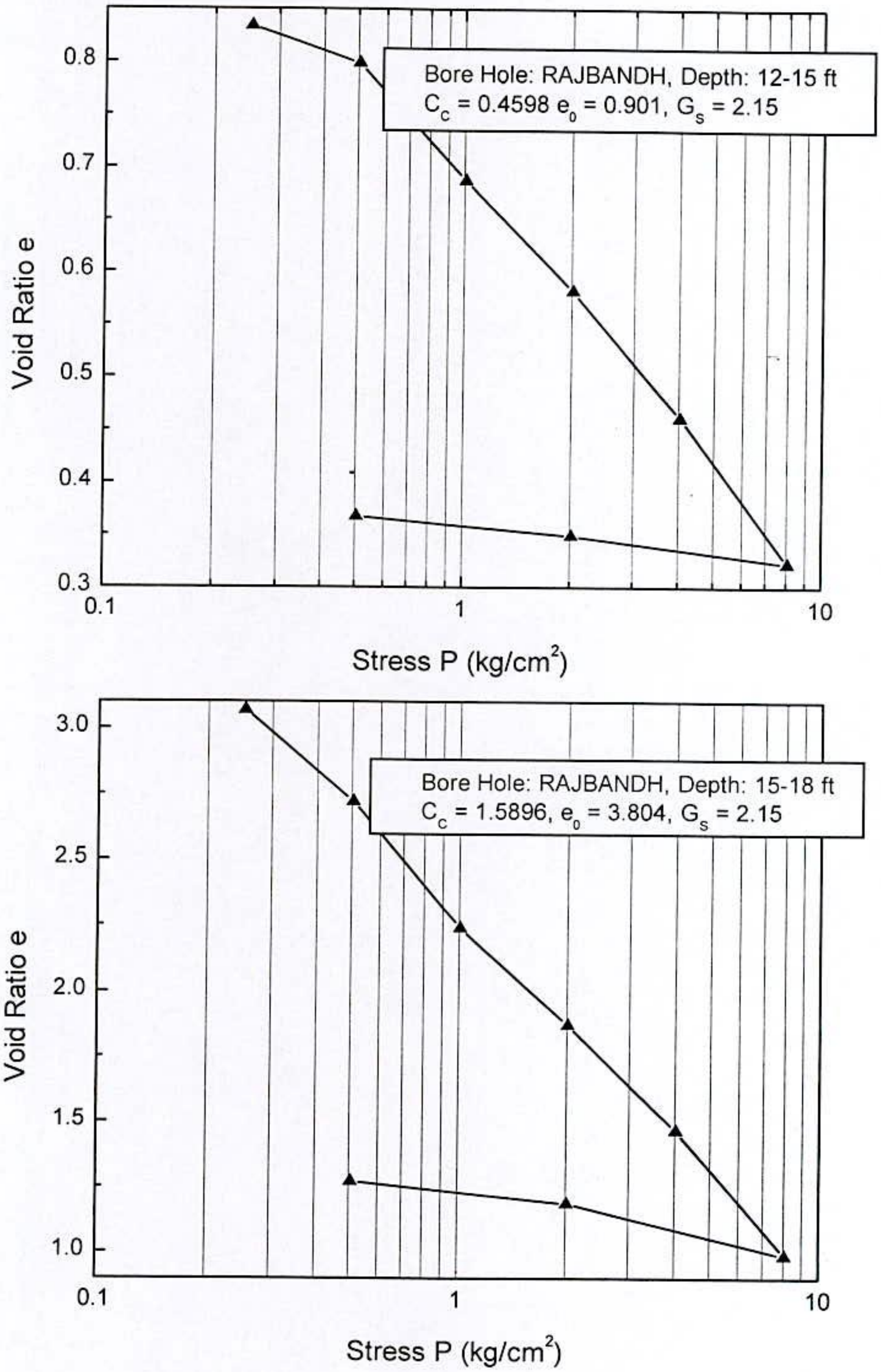


Fig 3.15 : Consolidation curves of Rajbandh soils (12 to 18 ft depth)

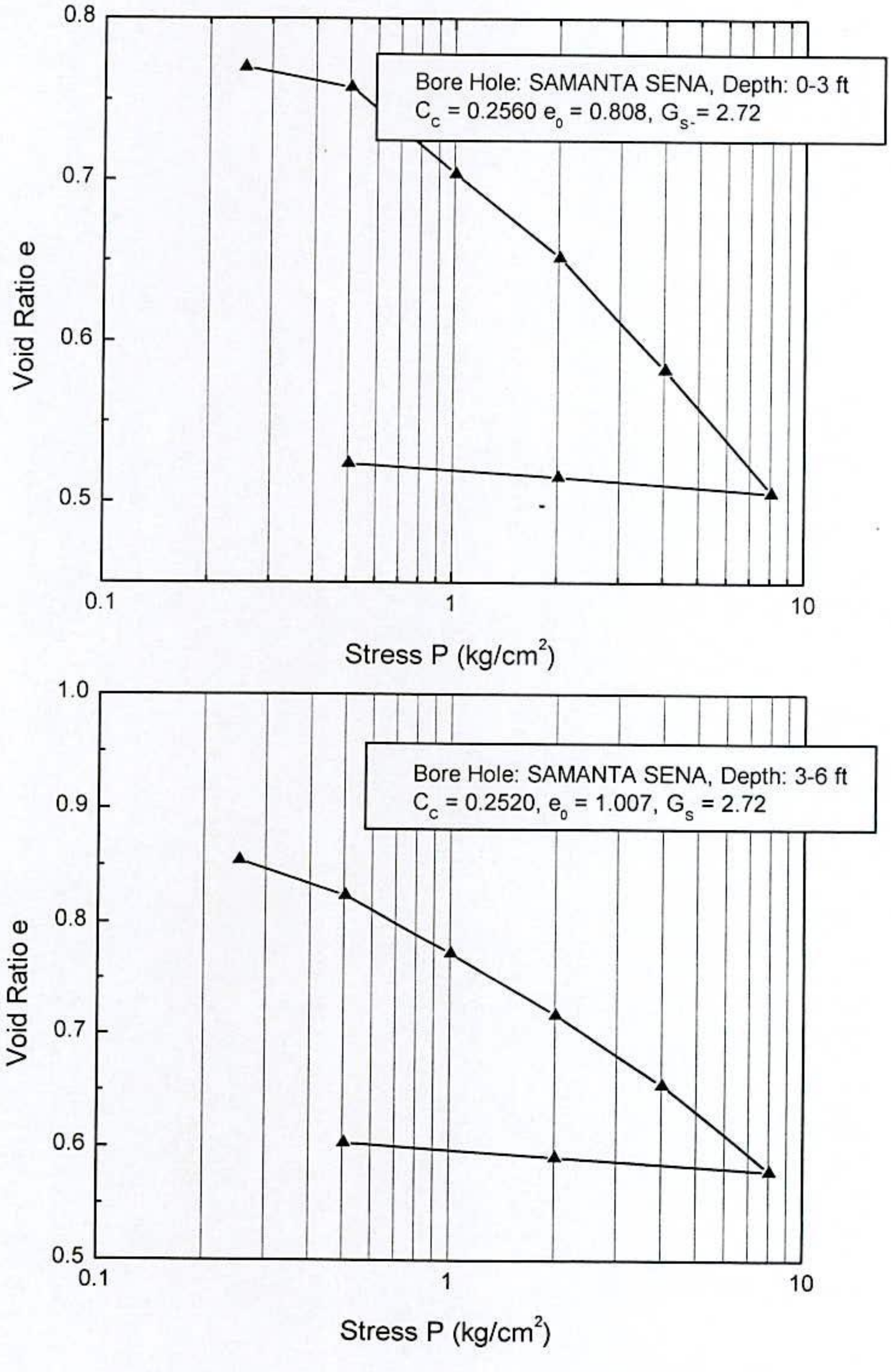


Fig 3.16 : Consolidation curves of Samanta sena soils (0 to 6 ft depth)

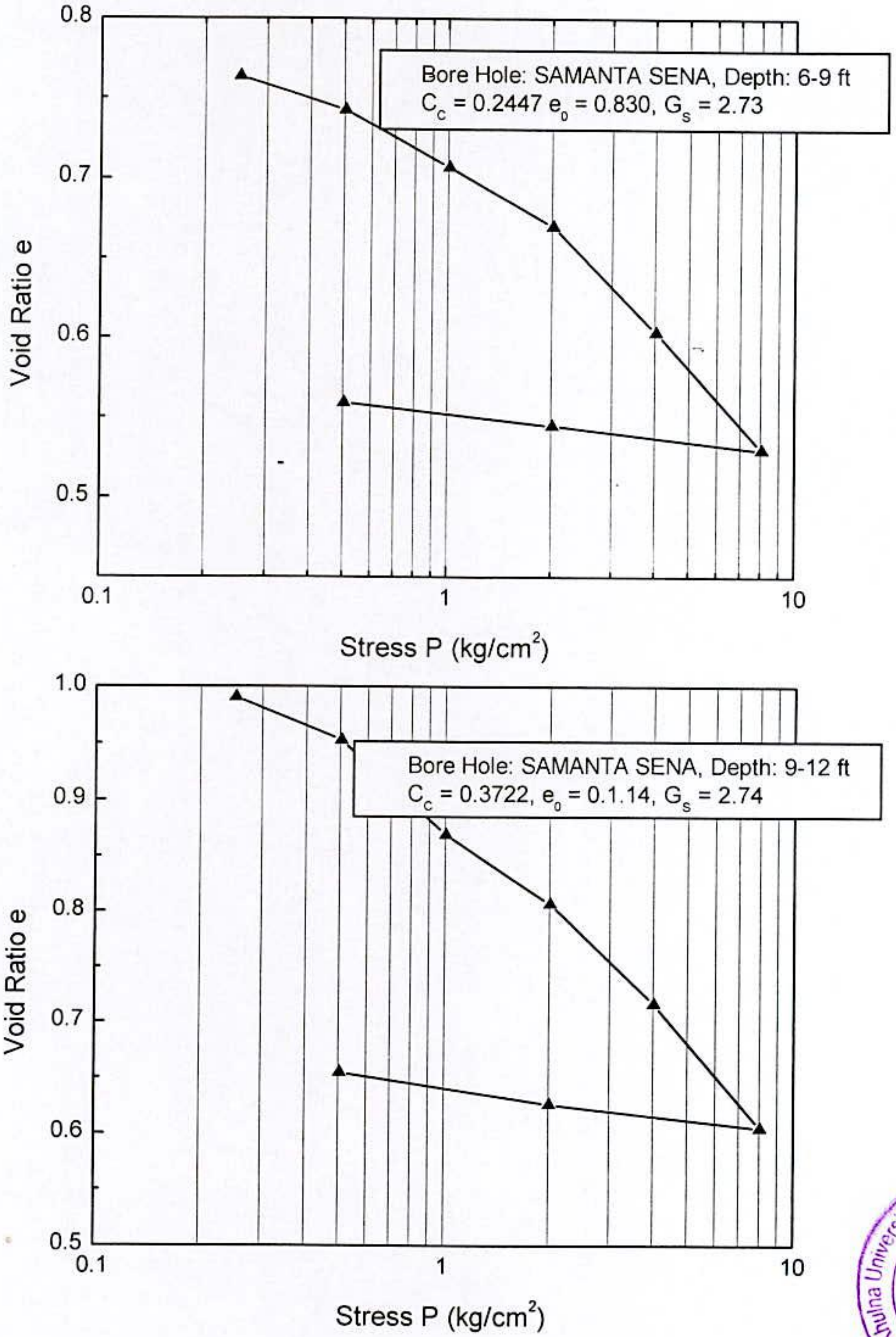


Fig 3.17 : Consolidation curves of Samanta sena soils (6 to 12 ft depth)

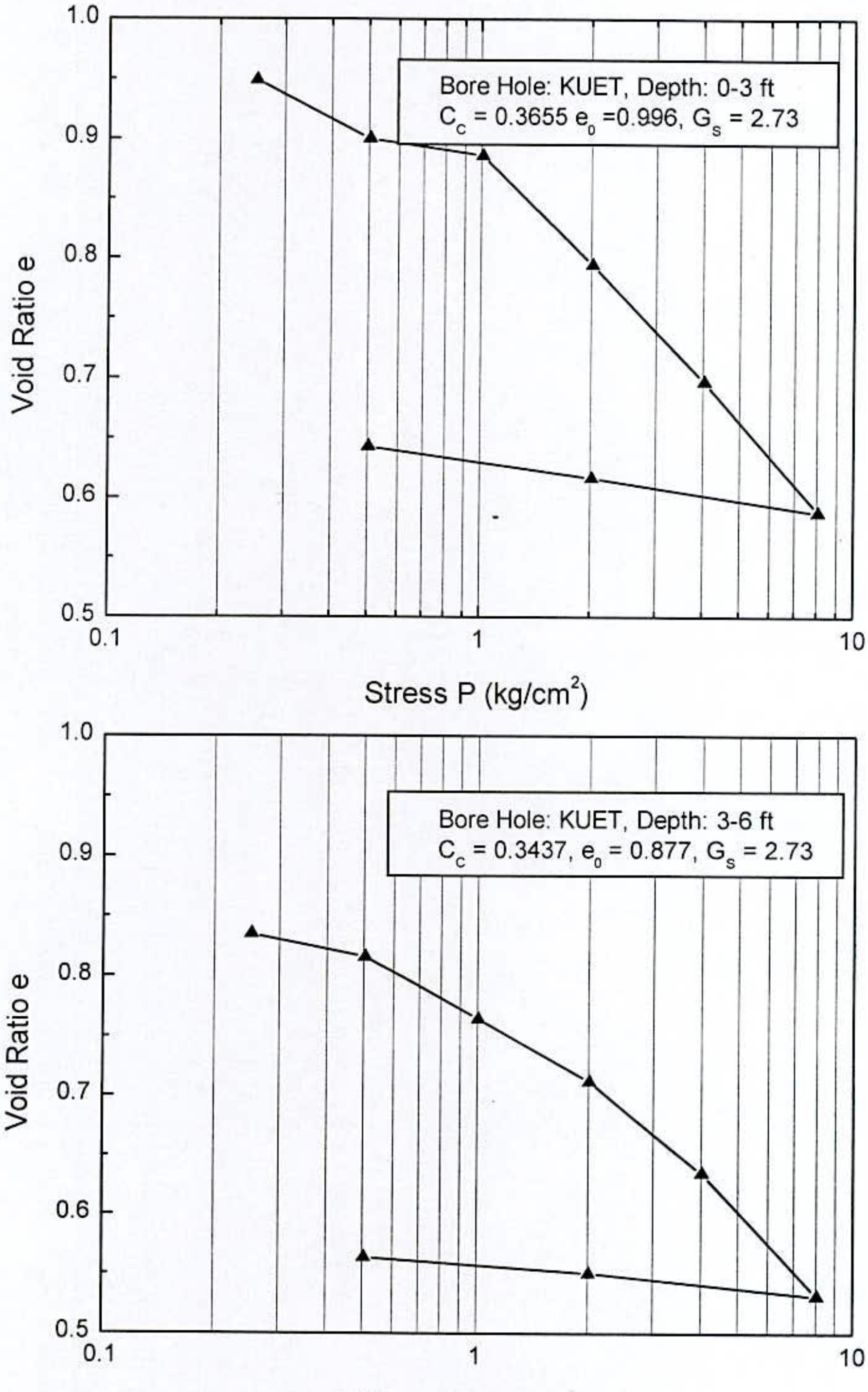


Fig 3.18 : Consolidation curves of KUET campus soils (0 to 6 ft depth)

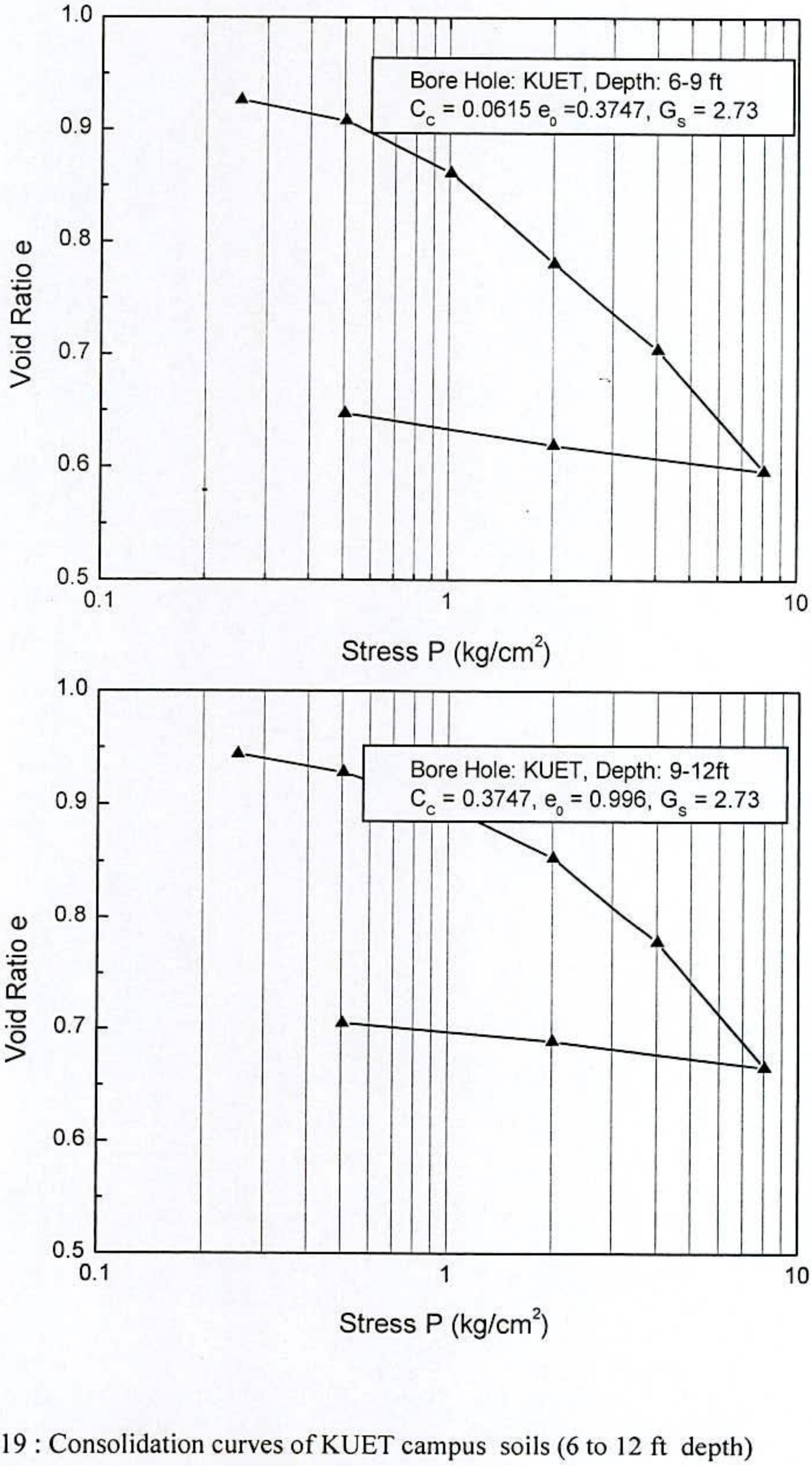


Fig 3.19 : Consolidation curves of KUET campus soils (6 to 12 ft depth)

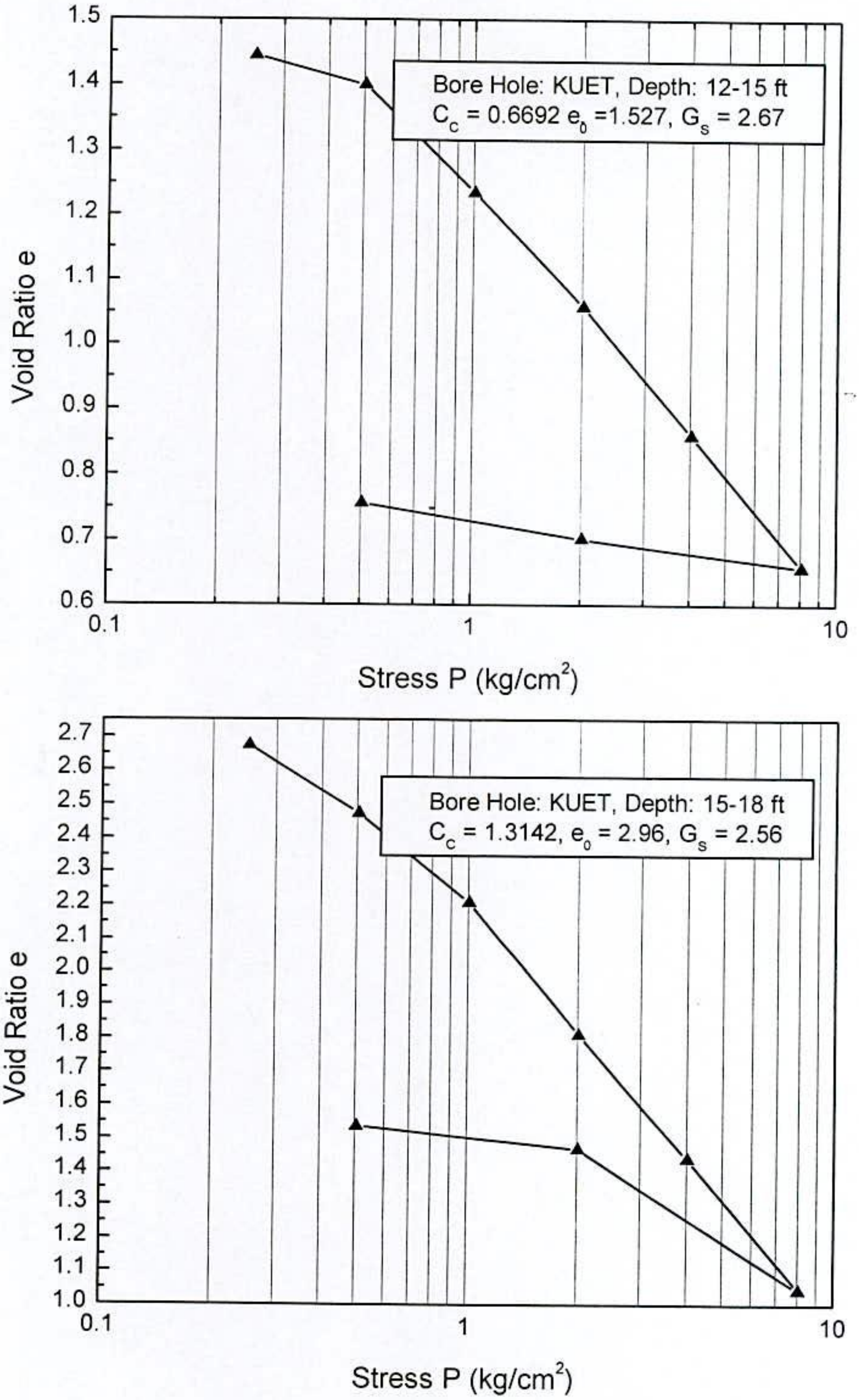


Fig 3.20 : Consolidation curves of KUET campus soils (6 to 12 ft depth)

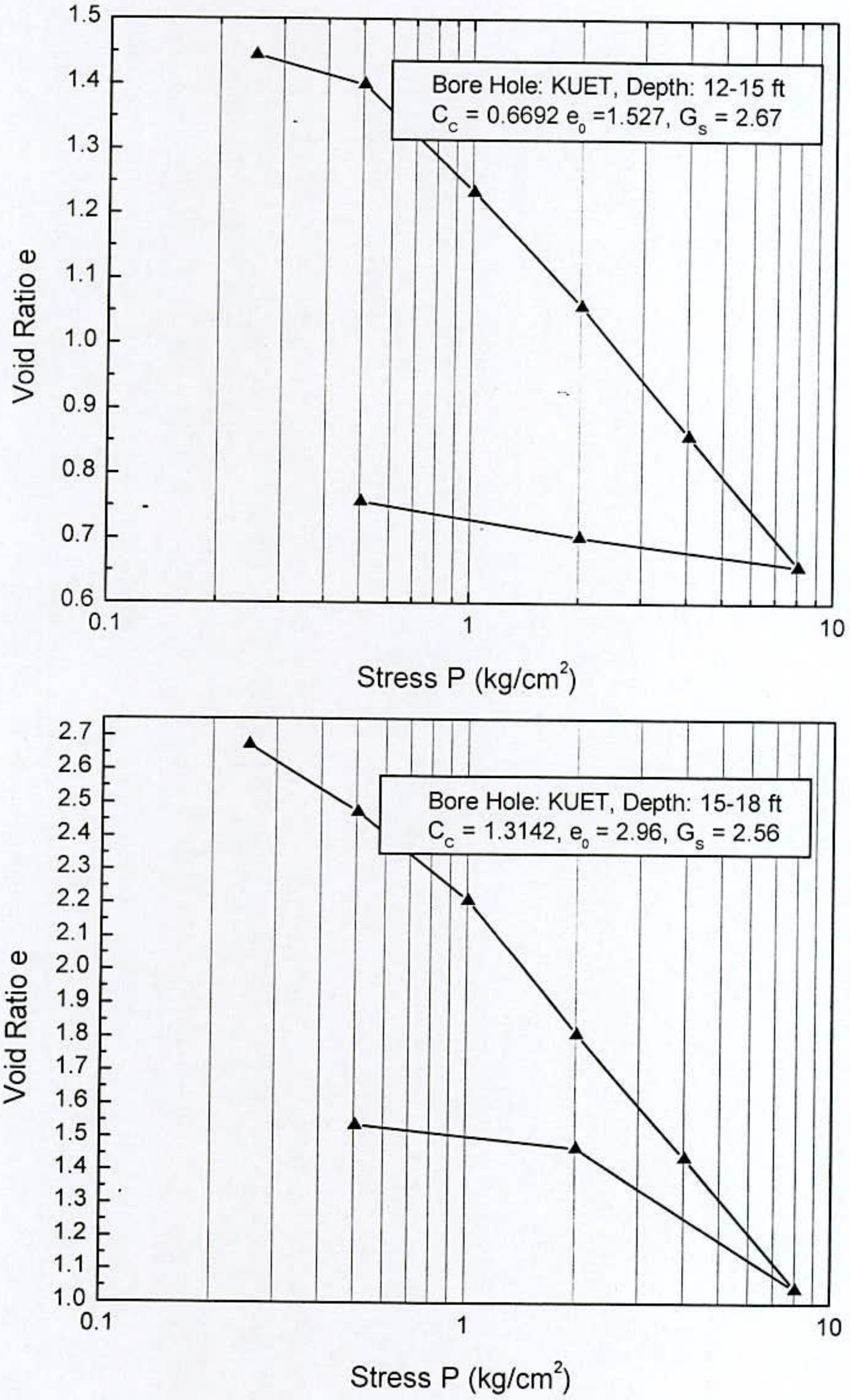


Fig 3.21 : Consolidation curves of KUET campus soils (12 to 18 ft depth)

3.14 Physical Properties of Selected Sub-Soils

Physical properties of the collected soil sample are carefully examined. There are critical variables that usually affect soil liners construction. Some parameters are more important than others. We need to understand how the material properties can influence the performance of a soil liner. The collected soil samples were observed and found to have the following physical properties

Table 3.15: Geotechnical properties of the collected Soil samples

Location	Depth in ft	Hydraulic conductivity (10^{-5} mm/sec)	Natural void ratio e_0	Total Porosity n (%)	Specific gravity	Unit weight γ_d	C_c
FULTALA	0 - 1.5	1.1	-	-	-	-	-
	1.5 - 4	1.5	0.817	44.96	2.71	120	0.0192
	4 - 6.5	4.07	0.967	49.16	2.69	119	0.1837
	6.5 - 9	11.3	1.004	50.10	2.69	108	0.0655
	9 - 11.5	15.8	-	-	-	-	-
	11.5 -13	14.9	-	-	-	-	-
	13- 16.5	5.13	0.96	48.98	2.68	110	0.2409
	16.5-18.5	1.39	1.033	48.98	2.73	108	0.3058
	18.5- 23	1.42	-	-	-	-	-
	23-28.5	1.32	0.996	9.06	2.70	110	0.3058
	28.5-33	9.56	0.897	8.23	2.67	118	0.1935
RAJ BANDH	0 - 3	0.217	1.026	50.64	2.72	108	0.3782
	3 - 6	0.481	1.303	56.58	2.72	95	0.4902
	6 - 9	0.252	2.229	69.03	2.73	68	0.7581
	9 - 12	0.728	5.464	84.53	2.25	28	1.1645
	12 - 15	1.34	0.901	47.40	2.15	91	0.4598
	15 - 18	1.01	3.804	79.20	2.15	36	1.5896
	18 - 21	0.622	1.079	51.90	2.74	106	0.2170
	21 - 24	0.2	1.091	52.18	2.73	105	0.2436
	24 - 27	0.994	0.939	48.43	2.70	112	0.2219
	27 - 30	0.8	-	-	-	-	-
	30 - 33	0.778	1.216	54.87	2.70	98	0.3884
SAMANTA SENA	0 - 3	0.0443	0.808	44.69	2.72	121	0.2560
	3 - 6	0.0804	1.007	50.17	2.72	109	0.2520
	6 - 9	0.0841	0.830	45.36	2.73	120	0.2447

	9 - 12	0.324	1.140	53.27	2.74	103	0.3722
	12 - 15	0.0543	1.015	50.37	2.73	109	0.2141
	15 - 18	0.2	-	-	-	-	
	18 - 21	10.8	-	-	-	-	
	21 - 24	13.4	-	-	-	-	
	24 - 27	2.5	-	-	-	-	
	27 - 30		-	-	-	-	
	30 - 33	0.186	-	-	-	-	
KUET CAMPUS BACK YARD	0 - 3	0.527	0.996	49.90	2.73	110	0.3655
	3 - 6	0.125	0.877	46.72	2.73	117	0.3437
	6 - 9	0.0494	0.954	48.82	2.72	112	0.0615
	9 - 12	0.14	0.996	49.90	2.73	110	0.3747
	12 - 15	0.544	1.527	60.43	2.67	85	0.6692
	15 - 18	0.663	2.96	74.75	2.56	82	1.3142
	18 - 21	1.47	0.912	47.70	2.71	114	0.2170
	21 - 24	5.08	0.915	47.78	2.69	113	0.2436
	24 - 27	1.25	0.889	47.06	2.70	115	0.2204
	27 - 30	2.83	0.949	48.69	2.69	111	0.2377
	30 - 33	0.832	1.119	52.81	2.74	104	0.2605

CHAPTER FOUR

MINERAL IDENTIFICATION

4.1 General

Clay Analysis and Clay Mineral Quantification is extremely important to soil liner selection criteria. X-ray identification is, in principal, better suited to the recognition of structural groups and structural varieties than of chemical species.

Soils are made up of a complex mixture of solids, liquids and gases. The solid fraction of soils are made up of organic and inorganic components. The inorganic component of the soil makes up more than 90% of the soil solids and occurs mainly in limited number of compounds with definite crystalline structure called minerals.

Clay minerals are formed weathering a variety of minerals. The two main processes may involve slight physical and chemical alteration or decomposition and recrystallization. Clay mineral types are normally determined by the types of minerals and acidity of the leaching water.

The clay minerals and soil organic matter are colloids. The most important property of colloids is their small size and large surface area. The total colloidal area of soil colloids may range from $10m^2/g$ to more than 800 m^2/g depending the external and internal surfaces of the colloid.

Soil colloids also carry negative or positive charges on their external and internal surfaces. Two main sources of charge in clay minerals are isomorphous substitution and pH-dependent charges. The presence of charge influences their ability to attract or repulse charge ions to or from surfaces.

Soils colloids play a very important role in the chemical reaction which take play in soil and influence the movement and retention of contaminants, metals, and nutrients in the soil.

4.2 Clay Constituents

Clayey soil and clay minerals are hydrous silicates, and contain significant levels (as opposed to trace levels) of aluminum, magnesium, or iron, which lose adsorbed and constitutional water to potentially yield refractory material at high temperatures (Goldman et al. 1990). Most clay particles fall into the size range that defines larger colloids; particles small enough to have significant interfacial forces that influence the fate of metal species in leachate. Because of their electrochemical surface activity and high specific surface area, clay minerals can profoundly influence the engineering behavior of a soil. Due to their unique interfacial properties, clay materials are important in many areas of scientific endeavor, including environmental science and engineering (Wilson 1994).

On a granulometric basis, clay can be defined as the soil fraction with particles ≤ 5 μm (Bagchi 1989) in size. Clay is of importance in the fate and transport of leachate, since clays have a surface chemistry different from that of the larger granulometric materials. Due to high specific surface area and surface charge per mass as compared to silt or sand, clay materials have a greater propensity to undergo surface phenomena such as adsorption and ion exchange phenomena. Such surface phenomena by colloidal suspended particles or sediments in the aquatic environment has been an interesting topic, and many researchers have studied such phenomena with respect to interacting with metal species under a wide range of conditions associated with the aquatic environment (Mellah and Chegrouche 1997, Kayabali and Kezer 1998, Cells et al. 2000, Eick and Fendorf 1998)

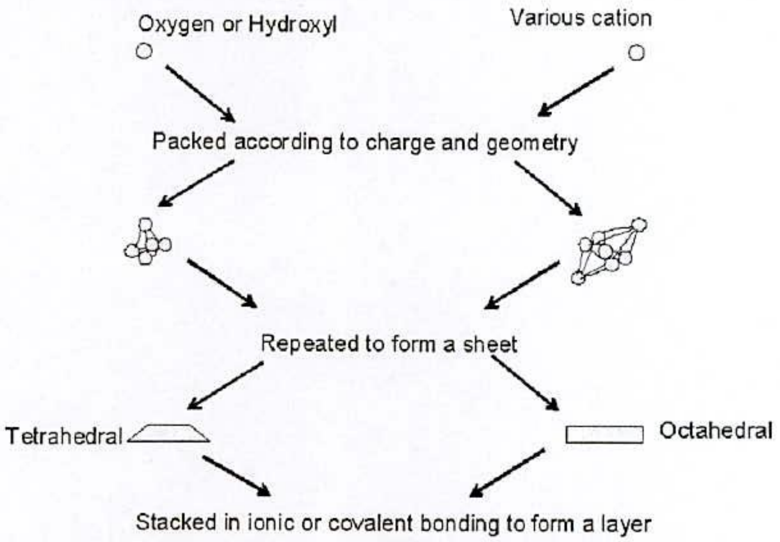


Fig 4.1 Synthetic pattern for clay minerals (Michell 1993):

4.3 Clay Mineralogy

4.3.1 Types of Clay minerals

There are four major types of Clay minerals. These include the layer **silicates, the metal oxides and hydroxides and oxy-oxides, amorphous and allophanes, and crystalline chain silicates**.

The silicate clays are layers of tetrahedral and octahedral sheets. The Si+4 cation occurs in tetrahedral coordination with oxygen whilst the Al3+ is generally found in octahedral coordination. Layer silicate minerals are sometimes defined on the basis of the number of certain positions occupied by cations. When two-thirds of the octahedral positions are occupied , the mineral is called dioctahedral; when all 3 positions are occupied it is called trioctahedral. When one octahedral sheet is bonded to one tetrahedral sheet a 1:1 clay mineral results. Presence of surface and broken - edge OH groups gives the kaolinite clay particles their electro-negativity and their capacity to absorb cations. In 2:1 clay mineral an octhehedral sheet is bonded to two tetrahedral sheets. The octahedral sheet is generally sandwiched between the two tetrahedral sheets.

The 2:1 clays can be classified into expanding (smectites) and non-expanding clays (Illite and micas) on the basis of the sheet where isomorphous susbstitution is taking predominantly taking place. In the 2:1:1 lattice clays, a positively charge brucite sheet sandwiched between layers restricts swelling, decreases effective surface area, and decreases the effective CEC of mineral.

Table 4.1: Silicate Clay Mineral Groups

Group	Layer Type	Layer Charge (x)	Type of Chemical Formula
Kaolinite	1:1	<0.01	$[Si_4]Al_4O_{10}(OH)_8.nH_2O$ (n= 0 or 4)
Illite	2:1	1.4-2.0	$M_x[Si_{6.8}Al_{1.2}]Al_3Fe.025Mg_{0.7}5O20(OH)_4$
Vermiculite	2:1	1.2-1.8	$M_x[Si_7Al]AlFe.05Mg0.5O_{2}0(OH)_4$
Smectite	2:1	0.5-1.2	$M_x[Si_8]Al_{3.2}Fe_{0.2}Mg_{0.6}O_{2}0(OH)_4$
Chlorite	2:1:1	Variable	$(Al(OH)_{2.55})4[Si_{6.8}Al0_{1.2}\}Al_{3.4}Mg_{0.6})20(OH)_4$

Adapted from Sposito1989. The Chemistry of Soils. Oxford University Press.

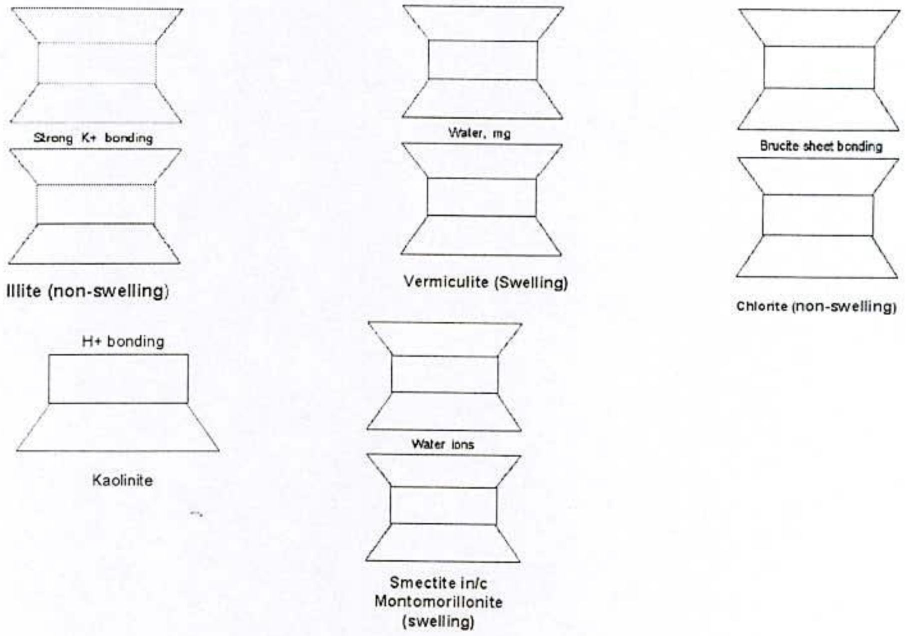


Fig 4.2: Some important clay structures

Metal Oxides and Hydrous Oxides are also found in finer component. These tend to form in soils as Si is depleted by leaching. Gibbsite is the most common Al oxide mineral and is often found in highly weathered soils such as oxisoils in tropical areas. The most common iron oxides are Goethite (FeO(OH) and Hematiite (Fe_2O_3) These are also found in highly weathered soils and gives many red soils their color.

The metal oxides gibbsite and goethite tend to persist in the environment because Si is readily leached than Al, or Fe and significant amount of soluble organic matter is present. Manganese oxides are also quite common in soils. Apart from being an essential plant nutrient, they are an natural oxidant to certain metals such as As^{3+} and Cr^{3+}. Birnessite(MnO_2) is the most common Mn oxide found in soils. Most of the charges developed on the metal oxides are pH-dependent.

Allophanes and Imogolite are structurally disordered aluminosilicates. They are normally derived from volcanic ash materials and constitute a major component of volacnic soils. Allophane is is often associated with clay minerals of the kaolinite group.

Carbonate and Sulfate Minerals are highly soluble compared to the alumino-silicates and are more prevalent in arid and semi arid regions. The major carbonate minerals are calcite ($CaCO_3$) and Dolomite ($CaMg(CO_3)_2$. The major sulfate mineral is gypsum.

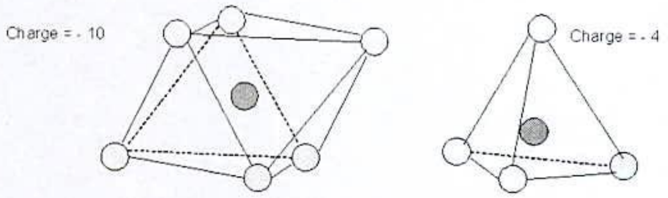


Fig 4.3: The basic structural units of aluminosilicate clay minerals: a tetrahedron of oxygen atoms surrounding a silicon ion (right), and an octahedron of oxygens or hydroxyls enclosing an aluminum ion (left).

Adapted from: Hillel, D. Environmental Soil Physics. San Diego, California: Academic Press, 1998.

4.3.2 Mineral Classification

Clays are again divided into 3 principal groups – kaolinite-serpentine, illite, and smectite. There are about 30 minerals included in the 3 clay groups. Certain other minerals are included with the clays as a group and may consist of a clay mineral regularly interstratified on an atomic level with sheet-type non-clay minerals, usually micas.

Most clay minerals are the result of weathering of some pre-existing rock. The bulk of clay present in sedimentary rocks was derived by the weathering of silicate minerals composing igneous rocks. Some clay minerals are hydrothermal in origin (dickite, rectorite, and halloysite), whereas others form from the alteration of other types of clay (example–nontronite).

Kaolinite-Serpentine Group	Illite Group	Smectite Group
Antigorite	Illite	Beidellite
Dickite		Montmorillonite
Halloysite		Nontronite
Kaolinite		
Nacrite		

4.4 Some Important Characteristics of Clay Mineral

4.4.1 Surface Area of Clay Minerals

- **External surface area:** based on the amount of N_2 adsorbed by the clay surface (BET -

Brunauer-Emmett-Teller Method)

- **Internal surface area***:* based on the amount of ethylene glycol, or similar organic molecule, adsorbed by the clay

Importance of surface area:

- Surface area of clays is large compared to other minerals due to play habit and fairly large intra-crystal (internal) surface area
- Influences CEC (cation exchange capacity)
- Influences water-holding ability
- More sites for adsorption
- Organic carbon accumulation in oceans

4.4.2 Cation Exchange Capacity (CEC)

It is important in quantifying how much organic or inorganic component (Pollutants, Nutrients, fertilizers, pesticides) can be held by the clay as follows:

- Measure of capacity of a clay to exchange cations (*Units: meq/100g of clay)*)
- "Equivalent" of an ion = mw/valence
- Measure of concentration of unfixed cations in interlayer and on surface
- Function of total layer charge (structural and surface)
- Varies with pH (therefore measured at pH of 7)

Table 4.2 : CEC Values for different Clay minerals

Clay	*Meq/100g*
Smectite	80 -150
Vermiculite	120 - 200
Illite	10 - 40
Kaolinite	1 - 10
Chlorite	< 10

4.5 Basic Mineral Requirement for Liner

Metal species in leachate are an important group of constituents of concern. The occurrence and potential threat of metal species in landfill leachate have been well understood. Since the migration of leachate is often a slow process and the dangerous effects of heavy metal will typically become evident after a long period of time, the prediction of the fate of heavy metal in the leachate is challenging.

Physical and chemical characteristics of clays, such as surface charge, protonation, deprotonation and specific surface area play an important role in determining metal species speciation and surface interactions. For example, the adsorption capacity of minerals is proportional to their surface areas and surface-site densities (Langmuir 1997). Langmuir (1997) examined the properties of materials that exhibit significant surface interactions, as such properties influence adsorption-desorption reactions. The properties included particle size, surface area, surface charge, surface-site density, and Cation Exchange Capacity (CEC). Langmuir results indicated that the size effect was most important for kaolin and decreasingly important for illite and smectite.

Smectite It is a special kind of clay, a mineral, that absorbs water and swells substantially. Each crystal of the mineral is made up of a system of sheets of alternating aluminum-oxygen and silicon-oxygen molecules. Between the sheets the air is charged with an electrostatic force that sucks in water, so that the crystal swells up to 8 times its original size.

In addition to metal species, clay minerals and the fate and transport of organic matter compounds such as pesticides are influenced by surface interactions (Cox et al. 1998). Cox et al. found that surface interactions were important for the clay fraction containing a high content of montmorillonite and relatively high organic carbon content.

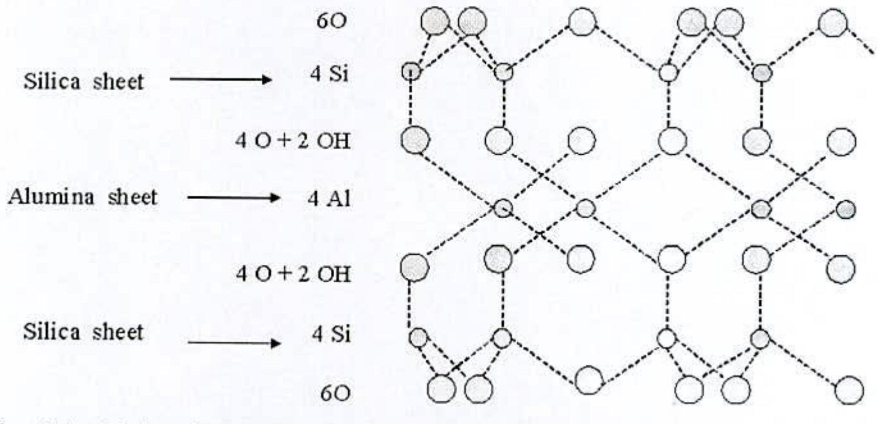


Fig 4.4 : Molecular structure of Montomorillonite

Adapted from: Hillel, D. Environmental Soil Physics. San Diego, California: Academic Press, 1998.

4.6 Examination of Clay Mineral in Khulna Soil

Nine clay minerals have been reported in the analysed samples of Khulna Soils as below. Each type of clay from Khulna has been discussed on the basis of actual use, rather than by mineralogy alone.

4.6.1 Sample Processing and Calculation

Proper sample preparation is one of the most important requirements in the analysis by X-ray diffraction (XRD). It is leant that for soils and clays that contain finely divided colloids, which are poor reflectors of x-rays. Also the soil may contain other types of materials as well i.e iron oxide coatings and organic materials that make characterization by XRD more difficult. Sample preparation includes not only the right sample treatments to remove undesirable substances, but also appropriate techniques to obtain desirable particle size, orientation, thickness, etc.

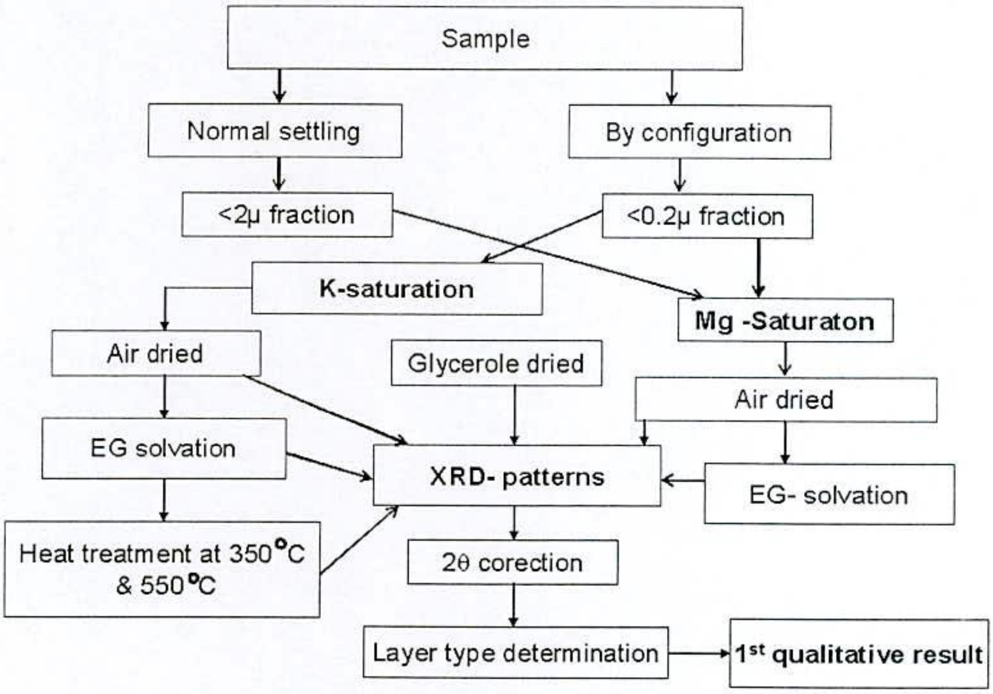


Fig 4.5: Flow chart showing the process of XRD examination

Twenty representative sample collected from different layers of four different sites of Khulna town were carried to Dhaka Atomic Energy centre for mineralogy Identification with the aim to find suitable mineral (if any) are present in the selected Khulna soil samples. As mentioned earlier, X-ray diffraction (XRD) was used to examine the mineralogy of the clay materials. Diffractogram results are a very sensitive analytical method for the clay mineral groups.

Several methods for clay minerals using semi- quantitative powder X ray diffraction (XRD) analysis produces unique results due its preparation procedure and XRD devices *(McManus,1991,More and Reynolds, 1989).* Filtration method and air dry method are used to prepare specimens of clay fraction for XRD with the samples of Khulna as usual. XRD measurements were carried out. Then the specimens were exposed in ethylene glycole vapour for more than 24 hours. After saturation of ethylene glycole molecule, each glycolated scan was measured. The specimen were then put under heat treatment at 350^0 C and 550 ^{0} C for monitoring and tracking the changes in mineral reflection. Then d- value, peak intensity, peak area of the specimen were counted.

In brief the whole procedure for mineral identification took five steps as below:

i) The air dried natural soil sample of Khulna was undergone X ray examination, the result of which is shown in Table 4.7.

ii) The clay content of each of the soil sample is isolated after separation of heavy minerals like quartz by filtration and put under X-ray examination. The results is put up in Table 4.8.

iii) The clay is the processed through Glycolation, for further examination, the result is placed at Table 4.9.

iv) The clay was the brought under heat treatment at 350^0C for 1 hour and the reflections are given at Table 4.10

v) The same samples is then treated with 550^0C for 1 hour and minerals of each samples are identified at Table 4.11.

The identification of the clay mineral was based on the values of d-spacing and the percentage of each mineral in the clay fraction is calculated based on following equation:

$$\% \text{ of mineral } i = A_i / \Sigma A_i$$

In this equation Ai is the peak area of mineral i and ΣAi is the total peak area. The peak areas were determined through discrete summation of differential areas.

4.6.2 X-Ray Diffraction Identification

To identify the composition of the clay materials X-Ray Diffraction (XRD) technology was employed. The analysis was carried out in the Bangladesh Atomic Energy Centre, Dhaka. The machinery used for the purpose was a Philips TW 3040 X Pert Pro X-ray diffractometer. X-ray diffraction can determine the percentage of a mineral in a soil sample within a range of ± 2% (Moore and Reynolds 1989).

An XRD pattern gives the following information:

Peak position	convert °2Θ to d Å
Peak intensity	peak height
Peak shape	sharp vs broad
Peak breadth (FWHM)	full-width at half-maximum peak height above background

Peak position can be obtained from the following equation :

n l = 2dsinq................................(Bragg's law)

For the basal reflection d = (001) (*e.g.*, d(001) illite =10Å), Also = 1.54059Å
let n = *l* (the order of the reflection (1,2,3,...n)

d-spacings occur in an integral series
10/1 = 10Å, 10/2 = 5Å, 10/3 = 3.3Å, ...10/n

Table 4.3: Peak list having the distinctive reflections which are most readily used for mineral identification.

d-spacing (Å)	*Intensity (%)*	*Name of the Mineral*
3.34	100%	Quartz *Silicon Oxide* (SiO_2)
7.1	100%	Kaolinite *Aluminum Silicate Hydroxide* $Al_2O_3 .2SiO_2. 2H_2O$
15.3 4.46 3.05 2.60 1.49	100%	Montomorillonite *Aluminum Iron Magnesium Silicate* $Si_{3.74} Al_{2.03} Fe_{0.03}Mg_{0.02}. O_{11}$
14.1	100%	Vermiculite *Magnesium Aluminium Iron Silicate Hydrate* $22 MgO. 5 Al_2O_3 . Fe_2O_3 . 22SiO_2 .40H_2O$
14.0 6.8 3.5	100%	Chlorite *Aluminum Iron Silicate Hydroxide* $Al. Fe. SiO_2. O$
9.96 4.47 3.32	100%	Illitle *Potassium Aluminium Silicate Hydroxide* $KAl_2 Si_3 AlO_{10} (OH)_2$
7.04	100%	Chlorite –Surpentine *Magnesium Aluminium Iron Silicate* Hydroxide $(Mg,Al)_6(Si,Al)_4O_{10}(OH)_8$
3.2	100%	Albite *Sodium Aluminum Silicate* $Na Al Si_3O_8$
3.24	100%	k-feldspar

Table 4.4 : Changes in low angle reflection (00l) of discrete clay minerals with ethylene glycol and thermal treatments. Positions of d-spacing (A) are approximate.

Mineral	Air-dried	Ethylene Glycol	*300–350 °C	*Temperature of collapse	Comments
Imogolite	20-12	20-12 A	19 A	300-450° C	Broad band
Kaolinite	7.15 A	7.15 A	7.15 A	500-550° C	
Halloysite	10 A	10 A	7.2 A	450-520° C	Dehydrates irreversibly to 7A at 50° C
Serpentine	7.1 A	7.1 A	7.1 A	575-700° C	Broad 11-14A reflection at 550-600° C
Illite	10 A	10 A	10 A sharpens	700 – 900° C	
Na-Smectite	12.5 A	17 A	10 A	800-1000° C	Trioctahedral may be stable up to 1000°
Ca-Smectite	15 A	17 A	10 A	800-1000° C	Trioctahedral may be stable up to 1000°
Mg-Chlorite	14 A	14 A	14 A	800° C	14 A increases at 500° C
Fe-Chlorite	14 A	14 A	14 A	550-600° C	14 A increases at 500° C
Vermiculite	14 A	14 A	10 A	800-1000° C	
Palygorstite	10.5 A	10.5 A	10.5, 9.5 A	700-800° C	10.5 A intensity increase 150°C
Sepiolite	12.2 A	12.2 A	12.2, 10.5	700-800° C	

** Temperatures where changes occur are dependent upon such factors as crystal sizes, the duration of heating, and chemical substitutions.*

4.6.3 Interpretation of XRD Data

The received data from XRD result sheet were interpreted as follows:

- Random - (*hkl*) reflections
    - Polytype (*i.e.*, stacking order and disorder)
    - Impurities (quartz, carbonates, etc).
- Oriented - basal (00*l*) reflections
    - Interlayer composition
    - Layer charge
    - Intra-layer composition

The following Clay Minerals were found from the analysis

a) **Illite**

Dioctahedral : It is a 2:1 (~10Å) structure similar in composition to muscovite, buts differs by having more Si, Mg, Fe and H_2 O and less K. Often reported with a layer charge of 0.75. This an average value and it is likely that there is a range of layer charges within any one sample.

Paragenesis: Illite forms authigenically during hydrothermal alteration and during burial diagenesis of smectite-rich shales (including bentonites). Degraded muscovite (formed during weathering) also takes on the XRD characteristics of illite.

Polytypes:

- 1-dimensional form of polymorphism
- Different structures result from different stacking sequences of similar layers
  (e.g., muscovite and illite have several polytypes that are thought to form under very different geological conditions)
- Mica polytypes: 1Md (very disordered), IM, $2M_1$, $2M_2$, 3T
- $2M_1$: has unique reflections at 2.99Å, 2.87Å, and 2.80Å
- 1M: has unique reflections at 3.66Å and 3.07Å

b) **Kaolinite**

The Kaolinite Group of minerals includes kaolinite, halloysite, dickite, nacrite, "endellite", allophane, and additional commercial clay types such as ball clay and flint clay.Kaolinite is a 1:1 phyllosilicate and an acid pH mineral. It is low temperature from ambient to ~250ƒC, with dickite and nacrite closer to 285ƒC, and is stable from about pH 3-8. It is common as a hydrothermal alteration product in many types of deposits. It can be an acid ground water alteration product of illite. *Spectrally*, kaolinite has two very distinctive doublets at 1400 and 2200 nm. The minima are directly linked to the orientation of different octahedral layer structural components, and change in intensity and profile as the octahedral layer bonds and composition vary.

- 1:1 clay mineral
- 7Å d-spacing in air, glycol and after heating to 375°C (12.4° 2□)
- After treatment to 550°C, the 7Å kaolinite peak disappears as the structure dehydroxylates (chlorite 14Å peak will increase in intensity)

- Poorly crystalline kaolinite may have some broader peaks; well crystallized kaolinite, very sharp.

c) Smectites (Montomorillonite)

Smectite Group is the most diverse of the 2:1 groups. Very fined grained (no large crystals known to exist). Small layer charge allow exchange of interlayer cations. The weak bonding between structural units allow water molecules to coexist. The spacing between layers is therefore variable (10Å to 18Å) depending on the size of the 1) interlayer cation, 2) the hydration energy of the cation (function of size, electron shell configuration and valance state), 3) associated organic molecules, and 4) the relative humidity.

d) Dioctahedral smectites

Montomorillonite Tetrasilisic, therefore, layer charge derived from octahedral sheet.
"low-charge" Montmorillonite - Wyoming type (Na)
$Na_{0.3}Al_{1.7}Mg_{0.3}Si_4O_{10}(OH)_2$
"high-charge" Montmorillonite - Cheto type (Ca)
$Ca_{0.3}Al_{1.6}Mg_{0.3}Si_4O_{10}(OH)_2$

- 2:1 layer silicates
- "Expandables" ...
  - in air, may have peaks in the 14 -15Å range
  - in glycol will expand to 17Å
  - heating to 375°C will collapse structures to 10Å
  - heating to 550°C collapses structures irreversibly to 10Å
  - water layers ~ 2.5Å .. peak position will depend on humidity level

e) Chlorite

Differentiating between chlorite and kaolinite

- kaolinite (002) at 3.58Å (24.9°2□)
- chlorite (004) at 3.54Å (25.1°2□)
- heat to 550°C: (001) of kaolinite disappears (becomes amorphous); (001) of chlorite increases in intensity (but Fe-chlorite may become unstable)
- chlorites soluble in 2N HCl (1 hr)

- kaolinite shows no reaction in acid

f) Vermiculite: Trioctahedral and/or Dioctahedral

$[Mg_{0.5}4H_2O]\ (Mg,Fe^{+2})_3Si_3\ Al\ O_{10}(OH)_2$

Paragenesis: Alteration of pyroxene, biotite, chlorite, phlogopite in the hydrothermal and weathering environment.

Because vermiculite inherits its interlayer and structural chemistry and charge distribution from so many possible parent sources, it's properties can be quite variable. Repeat distance for vermiculite with hydrated Mg in the interlayer site is about 14.5Å. The fact that the layer charge comes from the tetrahedral sheet causes the hydrated layer to stay at this 14.5 Å thickness (as opposed to other 2:1 structures with lower layer charge that, as we will see, can expand to 18Å thickness).

Due to the high hydration energy of Mg in the interlayer site, the sphere of water is difficult to remove. Vermiculite grabs free water readily and is often used as a soil amendment to help hold moisture. Hydroxyl Al-interlayer (HIV) varieties are "incomplete" chlorites where the brucite-like interlayer sheets may be discontinuous - They do not undergo collapse upon heating to 300° C.

- Operationally defined: layers expand to 14.5Å after Mg-saturation and solvation with glycerol

  (rather than ethylene glycol).. Under these conditions smectite expands to ~ 17Å (i.e. the vermiculite accepts one layer of glycerol, smectite two)
- It is to be noted that, these layers don't expand in glycol
- Likely that in the intermediate samples, those that produce a peak between14.5 and 17Å and also collapse to 10Å after K^+ saturation (heated)
- Some dioctahedral vermiculites can look like illite

g) Chlorite –Vermiculite

Intra stratified Vermiculite-Chlorite/ Chlorite-Vermiculite present in the soils are the mixed – layer clay minerals of the secondary weathering product of detrital chlorite. Chlorite-

Vermiculite is identified by the broad basal spacing at 13.83 Å-14.15 Å (001) with decreasing intensity from untreated to heated.

h) Illite vs. glauconite ; Mixed-layer Clays:

- Probably the most difficult to interpret
- Need to look at peak breadth, symmetry, position, intensity, plus look at air dried, glycol and heated runs
- Need to identify:
  - Types of layers involved (e.g., illite, smectite,…)
  - Proportions of each layer
  - Order or lack thereof
- Most are two component systems; multiple component systems are rare
- Most common ones involve illite, smectite, vermiculite, kaolinite, chlorite

Following are the Non clay minerals observed form the analysis:

Quartz :

Quartz is identified by distinctive reflections at 4.24-4.26 Å (100), 3.33 Å-3.34 Å(011), 2.54 Å (110), 2.27 Å-2.28 Å (102), 2.23 Å (111), 2.12 Å (200) and 1.98 Å-2.00 Å (201). Although 3.33 Å-3.34 Å (011) is the principal reflection but in presence of Illite as in the present samples the above reflections interefare and coincide with Illite (003) at 3.34 Å-3.36 Å .

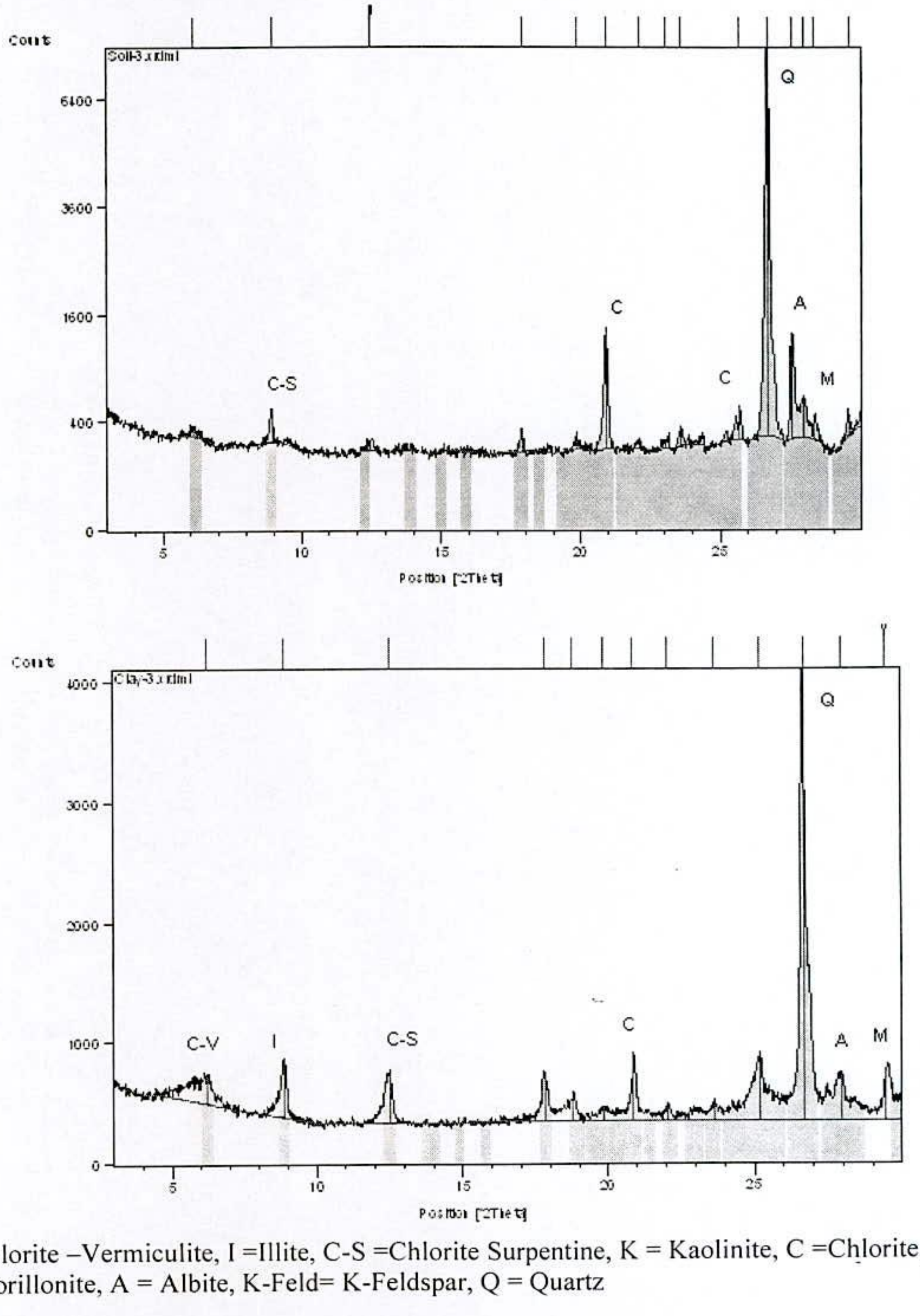
K- feldspar

K- feldspar is most readily identified by principal reflection at 3.23 Å-3.24 Å(040), K feldspar is also shown by (112) and (041) reflection at 3.46 Å-3.48 Å(011), and 2.88 Å(011) in few samples.

4.7 Remarks:

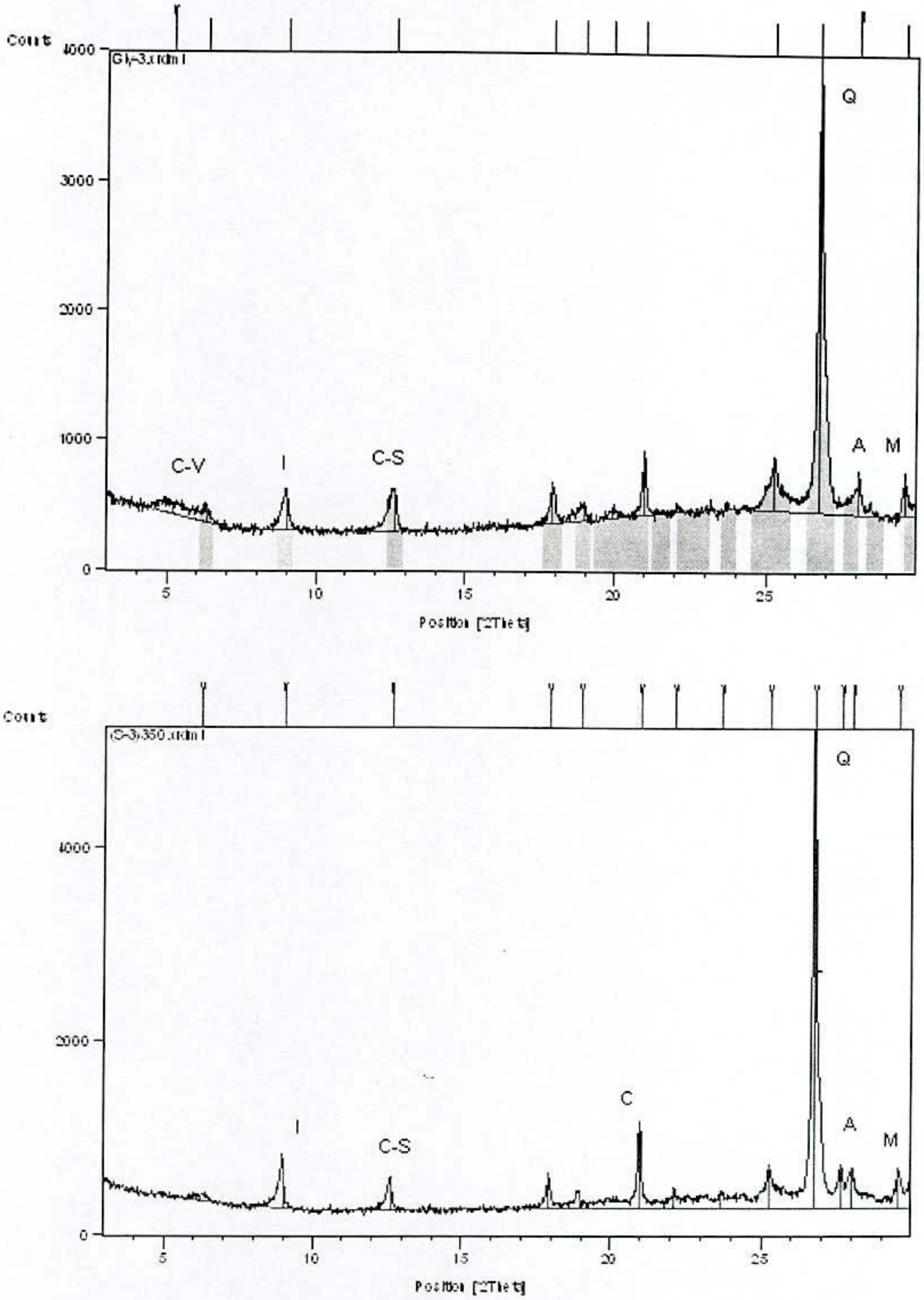
In normal soil, we have about 60% to 70% quartz. Due to presence of high percentage of quartz in soil pecks of the minor minerals are difficult to identify. So we need to separate quartz from soil sample to facilitate identification of minor minerals. Again in soils at d values of 14 Å, 9.98 Å and 7.15 Å, there are two different minerals present in each d values. As such Glycolation and heat treatment of the samples at two different temperatures are required to determine the actual mineral present in the samples e.g at 14Å position Vermiculite or Chlorite may be present. It is seen that Vermiculite has no change after heat treatment but Chlorite will change the intensity. Similarly at 9.98 Å Illite and Mica, at 7.15 Å Kaolinite and chlorite show changes after heat treatment. So careful judgment is a necessity in case of mineral identification.

4.8 XRD Diffraction Patterns



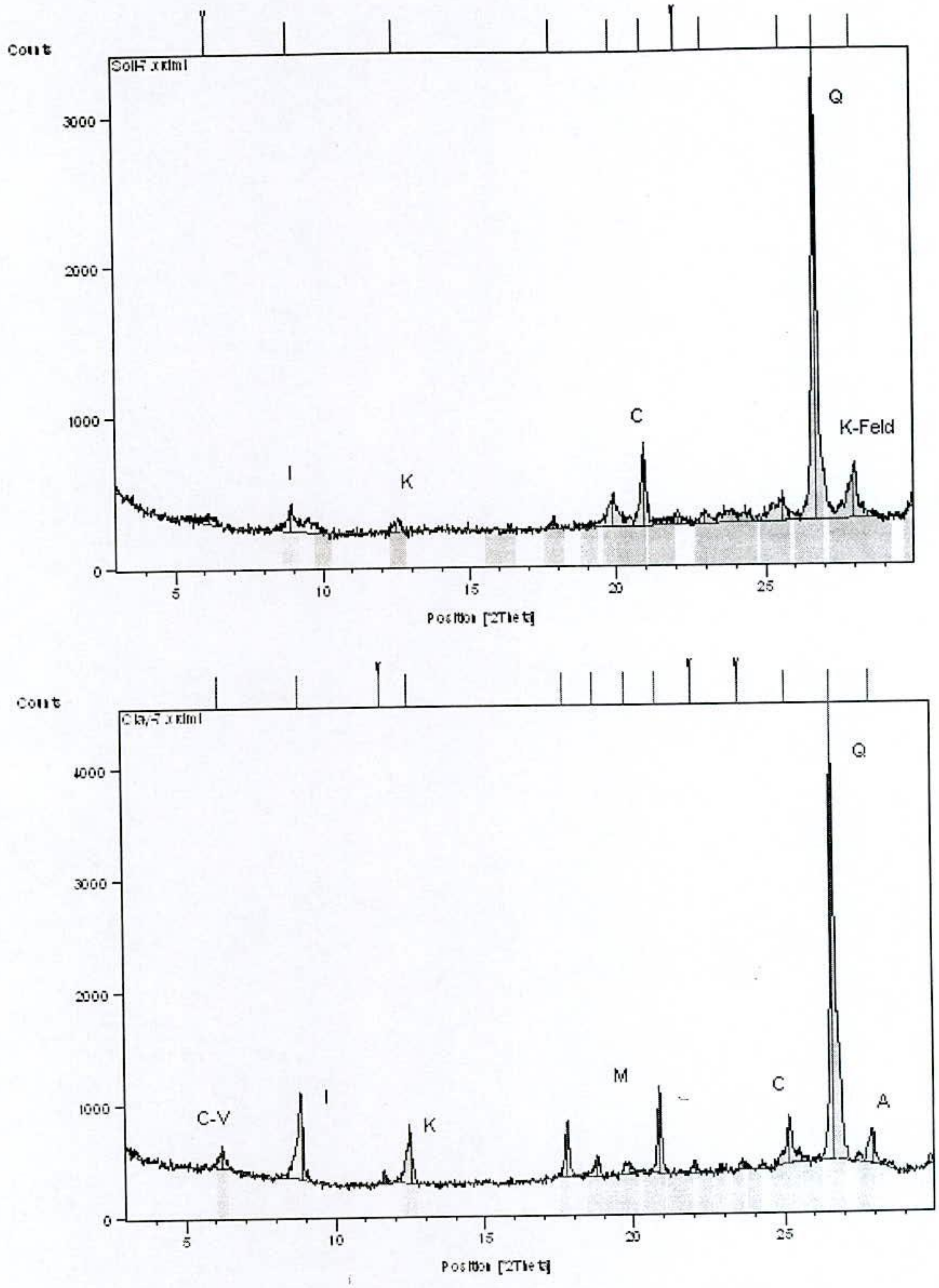
C-V= Chlorite –Vermiculite, I =Illite, C-S =Chlorite Surpentine, K = Kaolinite, C =Chlorite, M= Montomorillonite, A = Albite, K-Feld= K-Feldspar, Q = Quartz

Fig 4.6 (a) & (b): XRD Pattern for soils samples of **FULTALA 6.5 to 16.5 ft** depth,
a) before clay separation (b) after clay separation



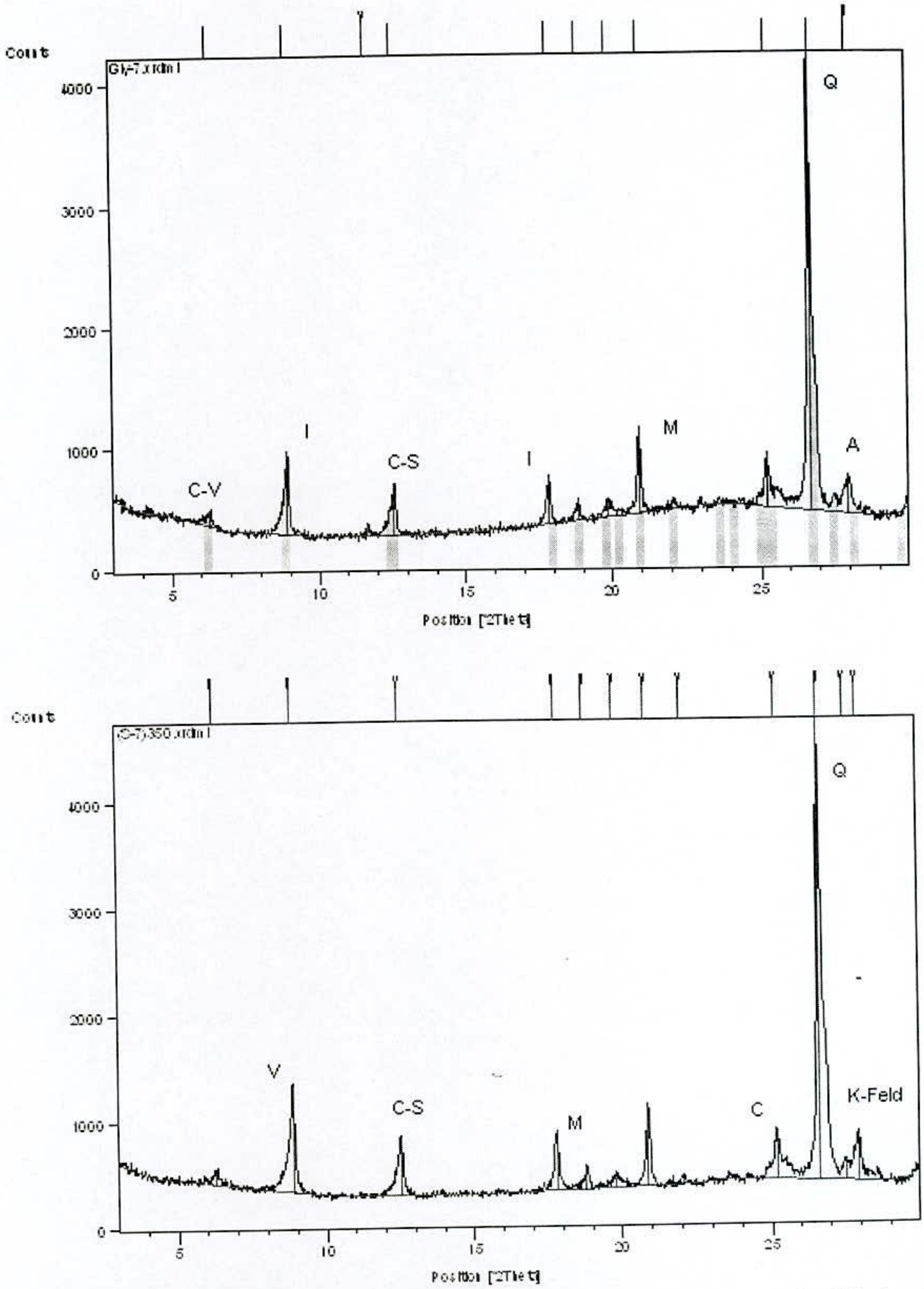
C-V= Chlorite –Vermiculite, I =Illite, C-S =Chlorite Surpentine, K = Kaolinite, C =Chlorite, M= Montomorillonite, A = Albite, K-Feld= K-Feldspar, Q = Quartz

Fig 4.7 (c) & (d): XRD Pattern for soils samples of FULTALA 6.5 to 16.5 ft depth, c) after Glycolation (d) after treated at 350^0 C



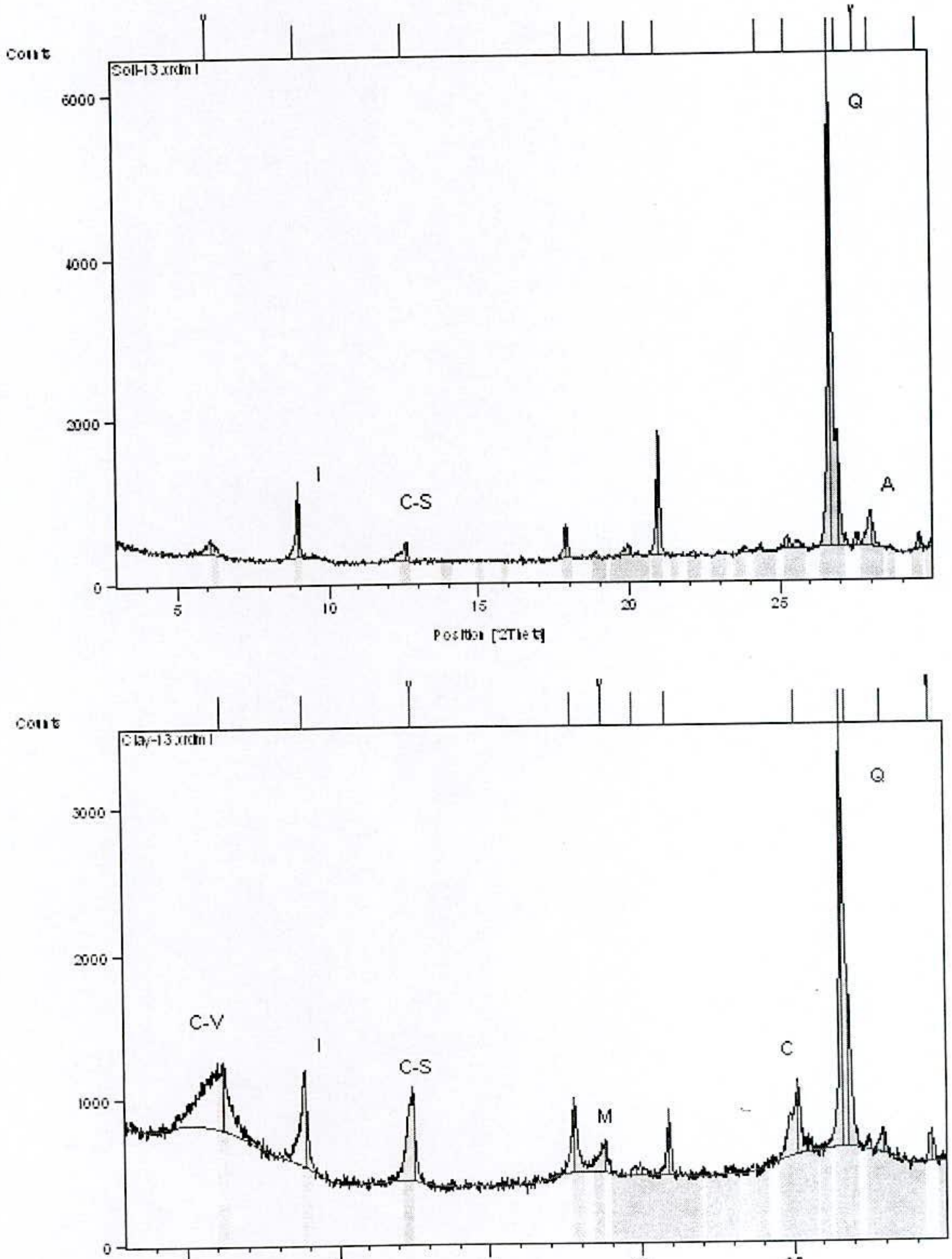
C-V= Chlorite –Vermiculite, I =Illite, C-S =Chlorite Surpentine, K = Kaolinite, C =Chlorite, M= Montomorillonite, A = Albite, K-Feld= K-Feldspar, Q = Quartz

Fig 4.8 (a) & (b): XRD Pattern for soils samples of **Raj bandh 6 to 9 ft depth**, a) before clay separation (b) after clay separation



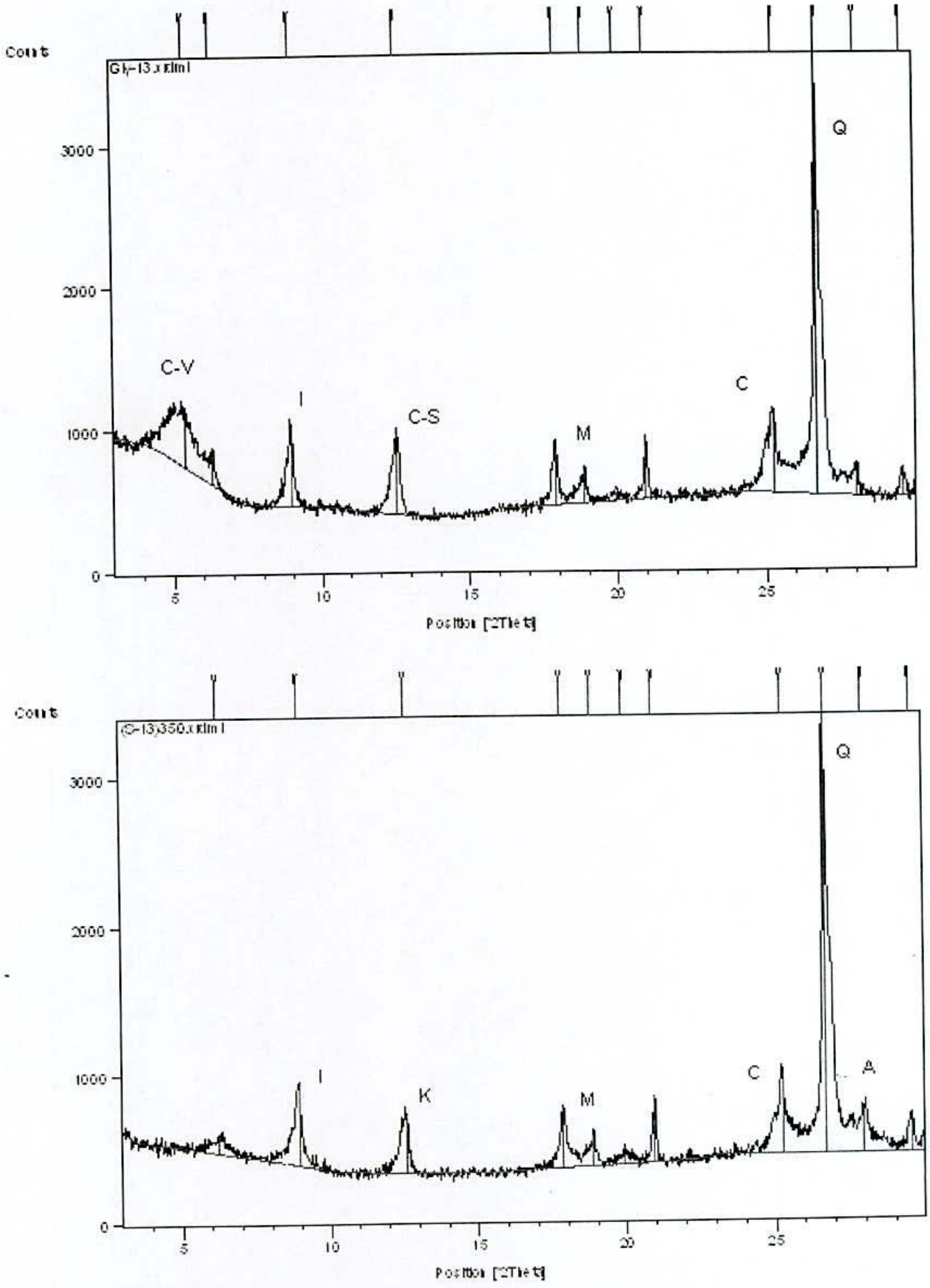
C-V= Chlorite –Vermiculite, I =Illite, C-S =Chlorite Surpentine, K = Kaolinite, C =Chlorite, M= Montomorillonite, A = Albite, K-Feld= K-Feldspar, Q = Quartz

Fig 4.9 (c) & (d): XRD Pattern for soils samples of **RAJBANDH 6 to 9 ft depth,**
c) after Glycolation (d) after treated at 350^0 C



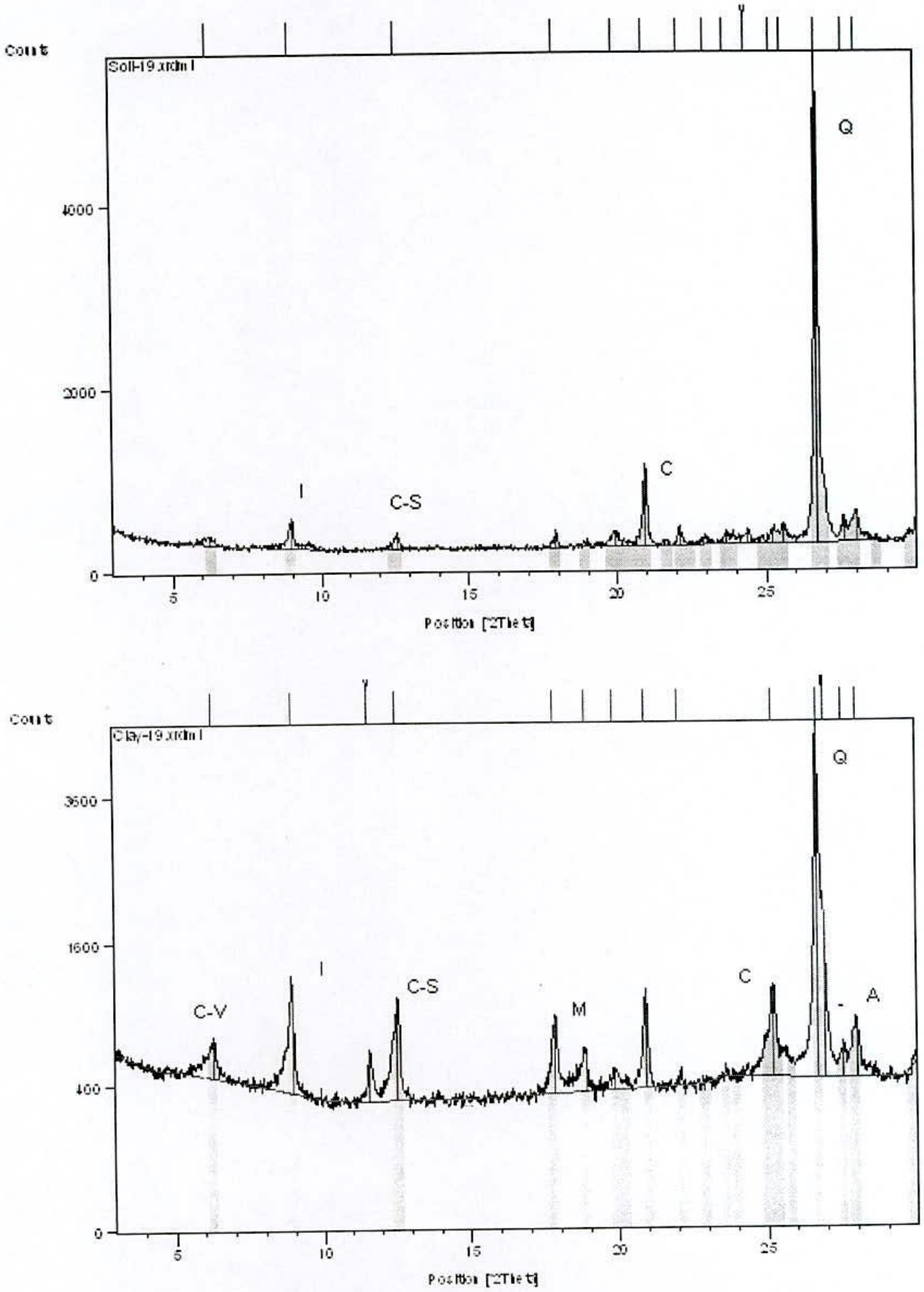
C-V= Chlorite –Vermiculite, I =Illite, C-S =Chlorite Surpentine, K = Kaolinite, C =Chlorite, M= Montomorillonite, A = Albite, K-Feld= K-Feldspar, Q = Quartz

Fig 4.10 (a) & (b): XRD Pattern for soils samples of **SAMANTA SENA 9 to 12 ft depth**, a) before clay separation (b) after clay separation



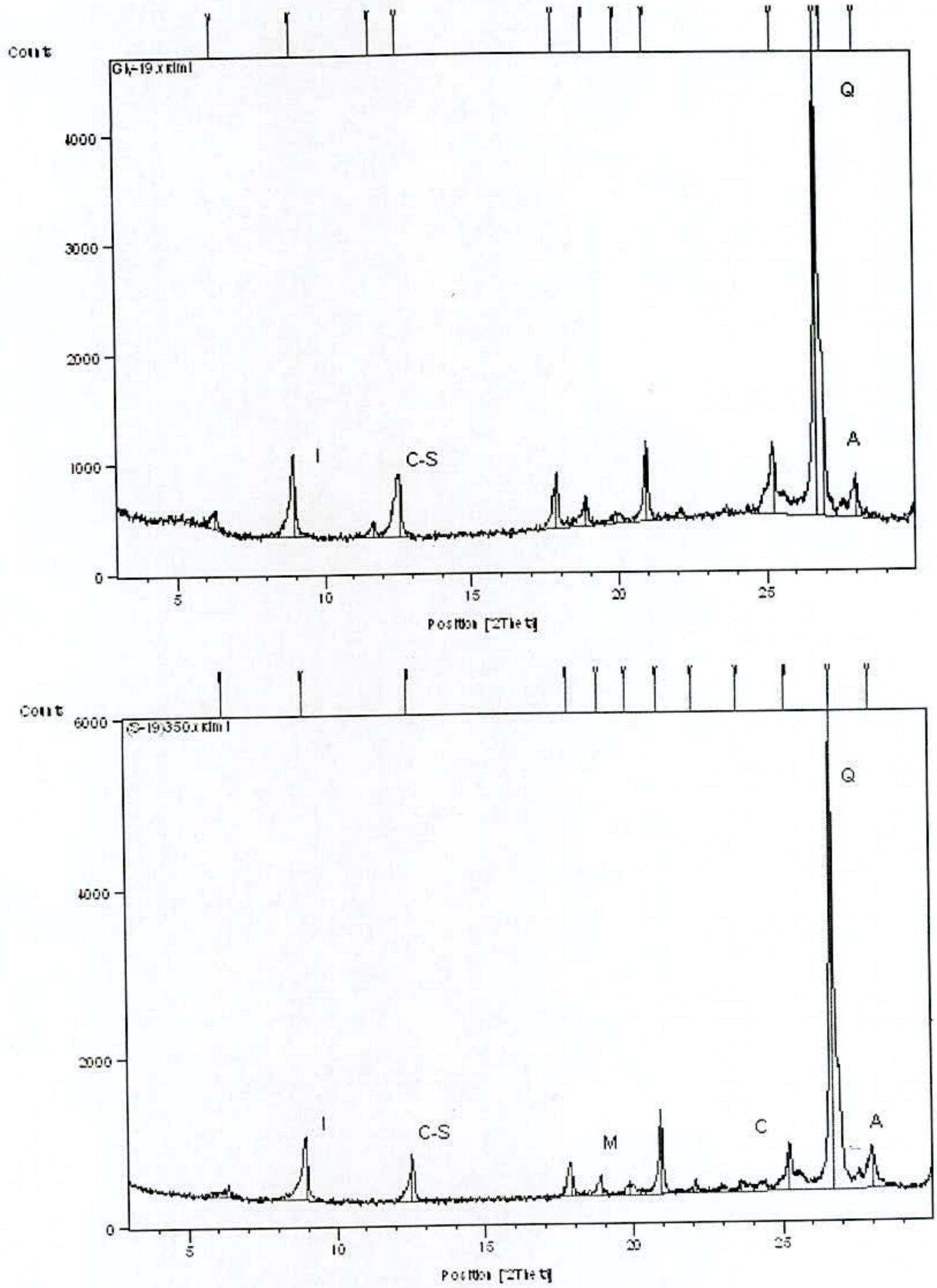
C-V= Chlorite –Vermiculite, I =Illite, C-S =Chlorite Surpentine, K = Kaolinite, C =Chlorite, M= Montomorillonite, A = Albite, K-Feld= K-Feldspar, Q = Quartz

Fig 4.11 (c) & (d): XRD Pattern for soils samples of **SAMANTA SENA 9 to 12 ft depth**, c) after Glycolation (d) after treated at 350^0 C



C-V= Chlorite –Vermiculite, I =Illite, C-S =Chlorite Surpentine, K = Kaolinite, C =Chlorite, M= Montomorillonite, A = Albite, K-Feld= K-Feldspar, Q = Quartz

Fig 4.12 (a) & (b): XRD Pattern for soils samples of **KUET CAMPUS 12 to 21 ft depth**, a) before clay separation (b) after clay separation



C-V= Chlorite –Vermiculite, I =Illite, C-S =Chlorite Surpentine, K = Kaolinite, C =Chlorite, M= Montomorillonite, A = Albite, K-Feld= K-Feldspar, Q = Quartz

Fig 4.13 (c) & (d): XRD Pattern for soils samples of **KUET CAMPUS 12 to 21 ft depth**, c) after Glycolation (d) after treated at 350^0 C

Detailed Calculation for mineral identification is attached at Appendix A. Table 4.7 to 4.11 show the identified minerals in Khulna soils.

Table 4.5: Approximate Mineral Content (%) in the collected soil sample (before Clay separation)

Sample no	*Depth (ft)*	*Chlorite-Vermi culite*	*Vermi culite*	*Illite*	*Chlorite - Surpentine*	*Kaoli nite*	*Chlo rite*	*Quartz*	*Albite*	*Montomori llonite*	*K Feldspar*
Fultala	*0-4.5*	-	-	-	-	-	2.65	77.34	13.19	6.82	
	4.5 -6.5	-	-	2.66	1.71	-	2.54	87.25	4.50	1.33	
	6.5-16.5	-	-	2.86	-	1.49	1.91	77.25	4.73	0.96	10.81
	16.5-23	-	-	2.91	1.79	-	2.67	81.98	4.57	3.43	2.66
	23-33	-	-	2.41	-	0.92	1.70	89.48	3.95	1.54	-
Raj bandh	*0-6*	-	-	3.79	-	2.68	6.91	73.94	12.68	-	-
	6 -9	-	-	3.93	-	2.87	4.49	79.08	9.64	-	-
	9-18	-	12.80	10.72	6.56	-	-	69.92	-	-	-
	18 -21	-	-	3.59	3.30	-	2.47	75.97	13.64	1.03	-
	21 -33	-	2.70	1.44	3.79	-	2.91	82.59	6.57	-	-
Samanta sena	*0-3*	-	-	2.85	1.40	-	2.56	74.15	1.91	7.13	-
	0-3	-	-	3.42	1.23	-	1.1	92.67	-	0.98	-
	9t- 12	-	-	10.44	2.40	-	1.98	77.50	5.58	2.10	-
	12- 15	-	-	2.50	1.82	-	1.75	82.38	6.56	4.98	-
	15 -18	-	-	3.29	0.93	-	1.04	36.5	-	1.45	56.43
	18- 33	-	-	2.35	1.5	-	2.61	91.41	-	2.05	-
KUET campus	*0-3*	-	-	3.38	-	2.06	2.37	82.17	9.42	-	-
	6 - 12	-	-	1.85-	1.26		1.56	92.10	1.32	0.73	1.17
	12 -21	-	4.24	10.51	2.02		1.99	8430	4.12	-	3.33
	21 -33	-		3.47	3.25		4.79	75.50	9.20	3.80	-

Table 4.8: Approximate Mineral Content (%) in the collected soil sample (after Clay separation)

Sample no	*Depth (ft)*	*Chlorite-Vermi culite*	*Vermi culite*	*Illite*	*Chlorite - Surpentine*	*Kaoli nite*	*Chlo rite*	*Quartz*	*Albite*	*Montomori llonite*	*K Feldspar*
Fultala	*0-4.5*	-	-	17.11	-	10.24	8.48	43.81	10.19	10.16	-
	4.5 -6.5	7.65	-		8.84	-	-	72.04	6.66	4.82	-
	6.5-16.5	-	-	5.39	-	3.01	28.29	47.90	10.19	5.22	-
	16.5-23	-	-	11.97	-	8.07	18.53	48.21	8.53	4.49	-
	23-33	10.02	-	16.98	-	7.76	-	52.93	6.87	5.33	-
Raj bandh	*0-6*	-	-	17.64	-	8.51	18.33	50.46	5.06	-	-
	6 -9	-	-	12.58	-	6.16	8.52	67.05	5.68	-	-
	9-18	4.69		14.74	8.16	-	-	49.09	16.66	6.67	-
	18 -21	-	-	12.67	-	6.71	8.31	63.13	5.53	3.65	-
	21 -33	-	2.26	10.74	-	6.08	7.51	60.87	7.33	2.64	2.58
Samanta sena	*0-3*	-	-	8.05	-	8.91	7.07	64.78	6.75	4.43	-
	0-3	-	-	11.61	-	5.99	-	69.22	7.05	3.75	2.39
	9t- 12	-	-	14.94	-	8.42	11.07	54.09	6.51	4.96	-
	12- 15	-	-	14.55	-	13.02	9.73	54.65	5.04	3.01	-
	15 -18	-	8.74	11.65	-	9.07	11.04	51.31	5.14	3.05	-
	18- 33	-	-	-	-	10.71	11.18	54.81	9.60	7.18	6.52
KUET campus	*0-3*	-	-	12.70	-	8.12	11.85	58.39	8.93	-	-
	6 - 12	-	-	7.51	-	7.03	11.11	64.94	4.77	4.63	-
	12 -21	8.97	-	10.33	11.04	-	-	55.98	12.06	3.29	3.32
	21 -33	-	4.90	13.11	9.44	-	13.14	49.76	8.42	1.23	-

Table 4.9: Approximate mineral content (%) in the collected Khulna soil sample (after Glycolation)

Sample no	*Depth (ft)*	*Chlorite-Vermi culite*	*Vermi culite*	*Illite*	*Chlorite - Surpentine*	*Kaoli nite*	*Chlo rite*	*Quartz*	*Albite*	*Montomori llonite*	*K Feldspar*
Fultala	*0-4.5*	6.80	3.18	11.43	17.13	-	4.78	50.72	5.89	8.02	
	4.5 -6.5	6.73	-	11.97	7.78	-	-	63.41	5.86	4.24	
	6.5-16.5	5.09	-	9.10	5.22	-	-	76.58	-	4.02	
	16.5-23	-	7.87	13.61	8.75	-	-	52.64	10.07	7.04	
	23-33	6.62	-	-	12.54	-	-	74.79	-	5.90	
Raj bandh	*0-6*		16.4	11.52	6.51	-	-	53.7	-	-	
	6 -9	3.45	-	9.92	6.20	-	-	67.62	12.80	-	
	9-18	-	-	-	21.62	-	-	69.68	-	8.50	
	18 -21	3.24	-	4.27	11.30	-	-	78.28	-	2.90	
	21 -33	-	-	2.30	6.96	-	9.32	81.42	-	-	-
Samanta sena	*0-3*	4.87	-	4.59	6.01	-	-	77.89	-	6.64	
	0-3	7.71	-	-	6.33	-	-	79.20	-	2.37	4.36
	9t- 12	-	9.53	6.07	15.14	-	15.23	47.80	-	6.23	
	12- 15		-	-	8.95	-	26.38	59.93	-	4.75	
	15 -18	8.68	-	6.65	8.96	-	-	68.96	-	6.74	
	18- 33	-	-	6.82	-	10.84	7.44	62.60	6.85	5.84	
KUET campus	*0-3*		10.80	14.69	-	7.83	8.97	47.47	10.25	-	
	6 - 12	8.17	-	3.92	6.36	-	-	75.38	-	6.17	
	12 -21	6.40	-	4.84	13.17	-	-	70.45	5.13	-	
	21 -33	-	-	6.05	10.77	-	5.80	73.92	-	3.46	

Table 4.16 : Approximate mineral content (%) in the soil sample (after heat treatment at 350^0 C)

Sample no	*Depth (ft)*	*Chlorite-Vermi culite*	*Vermi culite*	*Illite*	*Chlorite - Surpentine*	*Kaoli nite*	*Chlo rite*	*Quartz*	*Albite*	*Montomori llonite*	*K Feldspar*
Fultala	*0-4.5*	8.99	-	20.50	8.04	-	-	48.22	6.05	8.19	-
	4.5 -6.5	2.51	-	13.90	6.91	-	-	72.53	-	4.15	-
	6.5-16.5	-	5.29	-	5.85	-	4.48	75.06	-	4.78	4.54
	16.5-23	2.76	-	18.33	9.36	-	-	58.19	5.53	5.82	-
	23-33	3.54	-	23.12	11.10	-	-	43.30	9.43	9.57	-
Raj bandh	*0-6*	5.17	-	17.89	-	6.08	-	57.42	9.20	-	4.23
	6 -9	3.55	-	17.03	-	6.25	-	59.31	6.04	4.20	3.62
	9-18	4.22	-	16.72	-	9.86	-	60.22	8.98	-	-
	18 -21	-	2.49	-	10.07	-	-	68.17	16.11	3.16	-
	21 -33	2.15		11.96	9.46	-	-	65.88	7.07	--	3.47
Samanta sena	*0-3*			12.55	-	5.18	6.68	57.63	11.47	6.49	-
	0-3			8.00	-	8.41	9.04	63.27	7.66	3.61	-
	9t- 12		15.69	-	6.19	-	9.82	53.87	9.74	4.70	-
	12- 15	4.39	-	12.69	-	8.09	-	57.25	7.31	4.19	6.13
	15 -18	4.64	-	4.72	-	7.36	-	71.04	6.15	6.08	-
	18- 33	-	-	24.41	-	8.14	9.33	17.67	29.61	6.56	4.22
KUET campus	*0-3*	-	1.27	7.90	-	4.19	-	75.24	4.92	2.59	3.88
	6 - 12	-	-	7.95	-	4.44	5.63	71.68	7.08	3.27	-
	12 -21	2.81	-	8.05	5.66	-	-	76.28	7.20	-	-
	21 -33	3.69	-	14.06		6.87	-	58.34	13.88	3.05	-

Table 4.21: Approximate mineral content (%) in the soil sample (after heat treatment at 550 ^{0} C)

Sample no	***Depth (ft)***	***Chlorite-Vermi culite***	***Vermi culite***	***Illite***	***Chlorite - Surpentine***	***Kaoli nite***	***Chlo rite***	***Quartz***	***Albite***	***Montomori llonite***	***K Feldspar***
Fultala	*0-4.5*	4.77	-	21.95	-	2.53	-	45.43	20.29	4.80	-
	4.5 -6.5	-	2.48	16.95	-	3.10	3.89	54.00	9.71	4.27	5.60
	6.5-16.5	3.67	-	10.98	-	3.08	3.89	71.08	4.95	2.91	3.32
	16.5-23	-	2.64	16.71	-	4.80	4.86	54.45	13.58	2.91	-
	23-33	-	3.81	22.20	-	4.62	5.97	54.28	6.21	2.90	-
Raj bandh	*0-6*	4.09	-	16.17	-	3.07	-	59.08	14.21	3.38	-
	6 -9		2.96	16.36	-	1.16	3.62	62.38	13.52	-	-
	9-18		-	32.98	-	6.83	14.43	27.77	18.00	-	-
	18 -21		-	13.54	-	4.41	5.59	60.77	7.16	4.04	4.48
	21 -33		1.96	16.13	-	3.72	4.01	64.25	7.59	2.34	-
Samanta sena	*0-3*			35.84		13.44	15..35	64.25	20.93	14.41	
	0-3			3.25		9.14	18.40	14.63	25.57	28.99	
	9t- 12	7.56		16.43		2.80		54.26	16.02	2.93	
	12- 15	6.18		10.56	2.70	-		63.57	9.39	3.94	
	15 -18			12.85		4.70	6.63	63.57	6.85	5.70	
	18- 33			15.83		3.47	2.51	48.55	10.50	2.33	
KUET campus	*0-3*		1.81	6.37		1.65	1.44	74.72	6.61	3.07	
	6 - 12		3.01	8.99		1.63	3.31	68.97	8.90	5.20	
	12 -21		2.89	-		12.54	3.68	66.11	8.63	3.57	
	21 -33		1.80	11.69		2.20	4.27	62.71	13.21	4.32	

CHAPTER FIVE

INVESTIGATION ON LEACHATE TRANSPORTATION

5.1 General

In case of compacted soil layers to be chosen as landfill liner, hydraulic conductivity is the most variable parameter. Although accurate measurement of hydraulic conductivity of fine-grained clay/soil is not an easy task, it is often required to satisfy the acceptable requirements of various methods which regulate the design, construction, and operation of compacted clay liners. Results are sensitive to the experimental apparatus and testing procedure used for the measurement, thickness of the specimen and time period conducting the experiment. As the flow volumes being measured are very small, any minute leakage of permeant during the test will significantly affect the results obtained. The quantification of a significant transport of permeant through the reconstitute soil specimen placed in the fabricated apparatus has been tested for chemical properties.

5.2 Interactions of clay liner with Waste

Waste placed in a unit can interact with compacted clay liner materials, thereby influencing soil properties such as hydraulic conductivity and permeability. Two ways that waste materials can influence the hydraulic conductivity of the liner materials are through dissolution of soil minerals and changes in clay structure. Soil minerals can be dissolved, or reduced to liquid form, as a result of interaction with acids and bases.

It can be mentioned that aluminum and iron in the soil can be dissolved by acids, and silica can be dissolved by bases. While some plugging of soil pores by dissolved minerals can lower hydraulic conductivity in the short term, the creation of piping and channels over time can lead to an increased hydraulic conductivity in the long term.

The interaction of waste and clay materials can also cause the creation of positive ions, or cations. The presence of cations such as sodium, potassium, calcium, and magnesium can change the clay structure, thereby influencing the hydraulic conductivity of the liner.

Depending on the cation type and the clay mineral, an increased presence of such cations can cause the clay minerals to form clusters and increase the permeability of the clay.

Therefore, before selecting a compacted clay liner material, it is important to develop a good understanding of the composition of the waste that will be placed on the Soil liner.

5.3 Characteristics of Collected Leachate Sample

Leachate samples were collected from the ultimate disposal site of MSW at Rajbandh, Dumuria, Khulna. of KCC in order to determine the concentration of the elements those were leached from the bottom of the reconstitute liner sample and to quantify the amount of leachate transported though the soil sample.

Leachate samples were tested in the Environmental laboratory of KUET. Some important properties of collected leachate shown in Table 5.1.

Table 5.1: Characteristics of the collected Leachate sample

Parameter	*Concentration (mg/l)*
Chlorite (Cl^-)	68.5
pH	8.52
Hardness	824.14
Chemical Oxygen Demand (COD)	9600
Dissolve Oxygen (DO_1)	87.6
Dissolve Oxygen (O_5)	21.5
Total Dissolve Solids (TDS)	2960
Iron (Fe)	1.1
NO_3 –N (Nitrate-N)	2.0
Phosphate (PO_4)	742

5.4 Experimental Setup for Hydraulic Conductivity

The experimental setup fabricated in the laboratory in order to model the influence of Khulna Soil sample on chemical properties of leachate is detailed in Figure 5.1. Eight representative samples from four different sites were selected on the basis of percentage of clay content. Reconstitute soil samples were prepared in the laboratory for determination of hydraulic conductivity. Fabricated laboratory apparatus consists of a PVC column with diameter of 20.3 cm (8 inch) and height of 80 cm (30 inch).

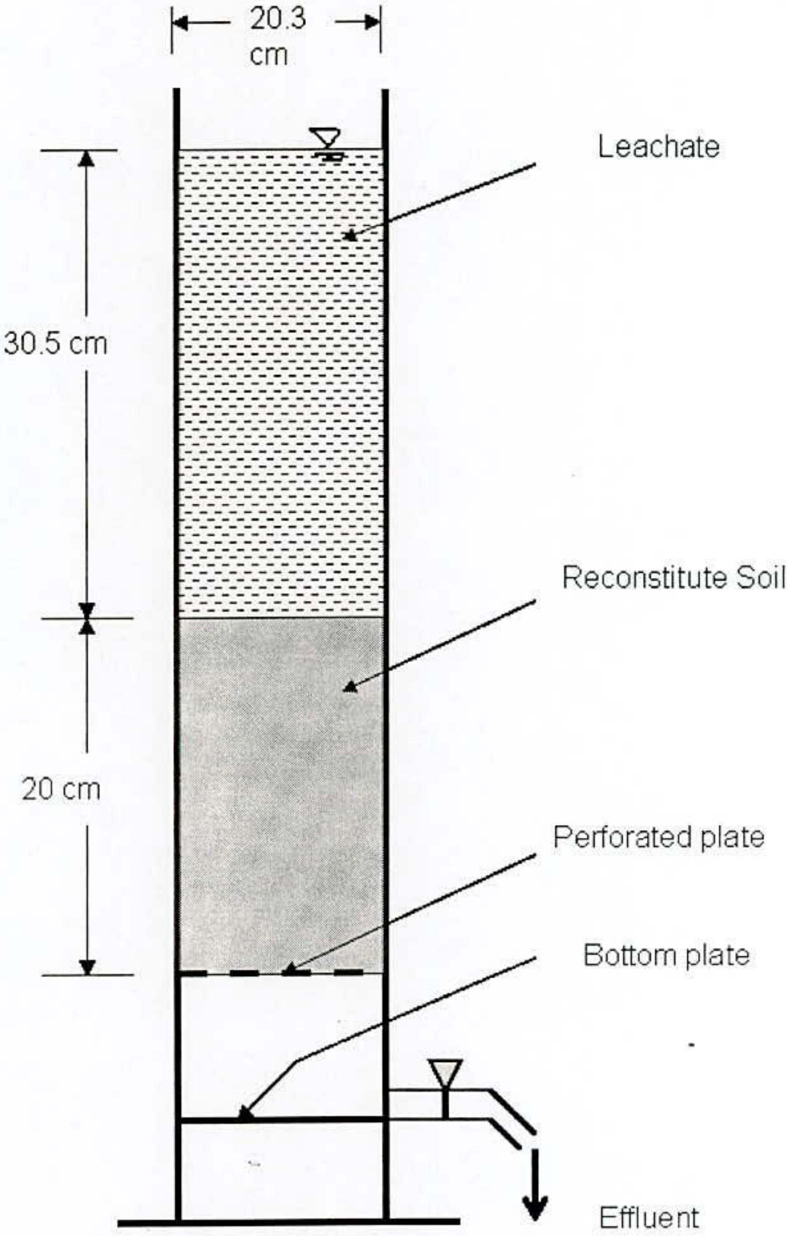


Fig 5.1: Schematic diagram of the experimental set up for Hydraulic Conductivity

The soil/ clay was made slurry in order to place in all (8 nos.) the moulds of PVC column. A weight of 30 kg was placed on the top of each of the specimen to make compacted upto required level. The weight continued for seven day till the water stopped draining out. The compacted specimens were supposed to be at the optimum moisture content. The reconstitute liner soils, reached to 18-20 cm in heights. The quantity of leachate placed on the top of the each liner specimen at a rate of 2 litres/mould.

A number of laboratory investigation were done to find the variation in concentration and quantity of the leachate and the physical properties of soil samples having the leachate passed through the soil liner specimen.

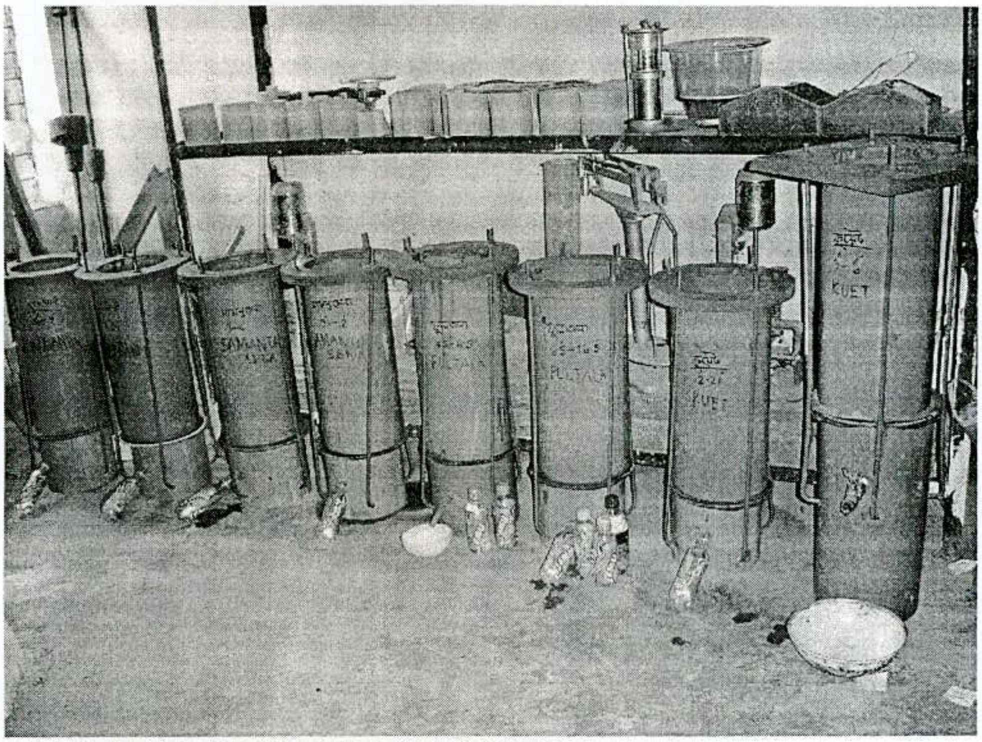


Fig 5.2 Photograph of the Experimental set up

Table 5.2 : Physical properties of the liner specimen samples

Exp. Set up no	*Location of Soil sample*	*Depth*	*Soil properties*						
			Sand	*silt*	*clay*	*W_L (%)*	*W_p (%)*	*PI (%)*	*Activity*
1	Fultala	4.5-6.5	1.8	63.1	35.1	28.20	26.70	1.5	0.04
2		6.5-16.5	3.8	67.63	28.57	28.20	26.70	1.5	0.04
3	Raj bandh	6—9	0.5	57.15	42.35	54.43	29.29	25.14	0.59
4		9—12	0.2	61.27	38.53	88.23	31.46	56.77	1.47
5	Samanta sena	3—6	3.93	56.91	39.16	43	20	23	0.58
6		9-12	4.2	65.46	30.34	36.10	24.13	11.97	0.52
7	KUET campus	3-6	1.2	74.55	74.55	55	29	26	1.07
8		12-21	0.5	51.43	48.07	72	44	28	0.58

5.5 Characteristics of Effluent

The collected leachate were placed in each of the testing mould having same design. Total eight test set up were prepared in which two were used for each site. The Leachate sample above the reconstitute soil specimen as in fig. 5.1 and were allowed to percolate through the soil specimen under gravity. Chemical analysis of the effluent leachate was carried out to examine the concentration of the chemicals leaching out of the soil specimens, with the purpose of establishing chemical compatibility. The chemical analysis also served as a means to determine the influence of dissolved and other solid elements present in the soils, on the final result of the coefficient of hydraulic conductivity.

Liquid/solid ratio is an important factor in case of leaching. But as the same leachate was placed over the soil specimen the liquid /solid ration of the leachate was constant and have little influence on result variation.

The effluent leachate were monitored and collected from each of the outlets at 7 days interval from a period of one month as given in the Tables 5.3 to 5.8. Altogether 28 samples of the Leachate were tested for their chemical properties. Test result are summerised below: (COD could not be measured due to interrupted electricity supply)

Table 5.3: Quantity of effluent collected after Leaching through liner soil

Experiment no	**Location**	***Depth (ft)***	**Quality of percolated effluent (ml)**			
			After 7 days	**After 14 days**	**After 21 days**	**After 28 days**
1	*Fultala*	*4.5-6.5*	470	570	390	---
2	*Fultala*	*6.5-16.5*	1000	670	3	-----
3	*Rajbandh*	*6-9*	85	114	123	168
4	*Rajbandh*	*9-12*	600	78	74	90
5	*Samanta Sena*	*3-6*	230	270	270	350
6	*Smanta Sena*	*9-12*	70	110	164	210
7	*KUET*	*3-6*	33	55	29	83
8	*KUET*	*12-21*	102	132	140	200

Table 5.4(a): Characteristics of effluent percolated through the reconstitute soil for the elapsed of 7 days

Exp. no	**Location**	***Depth (ft)***	***Measured value of different parameter***						
			pH	*Cl^- mg/l*	*Hardness mg/l*	*Fe mg/l*	*NO_3 mg/l*	*SO_4 mg/l*	*TDS mg/l*
1	*Fultala*	*4.5-6.5*	6.75	1000	963.4	1.4	3	380	476
2		*6.5-16.5*	7.49	1200	1666.8	2	0	640	375
3	*Raj bandh*	*6-9*	6.58	1510	3889.2	1	1	1060	369
4		*9-12*	6.81	2220	2778.21	3.1	0	1080	194.5
5	*Samanta Sena*	*3-6*	7.73	1050	1666.8	1.2	0	720	155
6		*9-12*	7.21	1800	2129.8	15.1	2	580	329
7	*KUET*	*3-6*	6.83	1450	1574.2	9.5	8	300	364
8		*12-21*	6.74	2350	2963.2	0	3	1280	218

Table 5.4 (b) Effluent collected after 14 days

Exp. No.	**Location**	***Depth (ft)***	***Measured value of different parameter***						
			pH	*Cl^- mg/l*	*Hardness mg/l*	*Fe mg/l*	*NO_3 mg/l*	*SO_4 mg/l*	*TDS mg/l*
1	*Fultala*	*4.5-6.5*	7.17	850	1203	17.7	7	250	100.3
2	*Fultala*	*6.5-16.5*	7.3	1250	1074	0.3	4	300	102.4
3	*Rajbandh*	*6-9*	6.71	1550	2315	3	0	460	953
4	*Rajbandh*	*9-12*	7.3	2000	3241	3	4	940	91.6
5	*Samanta Sena*	*3-6*	7.11	1050	1111.2	0	0	220	167.7
6	*Smanta Sena*	*9-12*	7.34	1150	2315	1.3	3	310	177.9
7	*KUET*	*3-6*	7.28	1800	2315	4.3	0	230	149.9
8	*KUET*	*12-21*	7.17	1350	2963	1.2	0	1200	125.4

5.4 (c) Effluent collected after 21 days

	Location	***Depth (ft)***	***Measured value of different parameter***						
			pH	*Cl^- mg/l*	*Hardness mg/l*	*Fe mg/l*	*NO_3 mg/l*	*SO_4 mg/l*	*TDS mg/l*
1	*Fultala*	*4.5-6.5*	7.69	1150	3333.6	0.03	1	24	365
3	*Rajbandh*	*6-9*	7.37	1600	2963.2	0.54	11	60	488
4	*Rajbandh*	*9-12*	7.54	1600	1481.6	1.30	9	122	231
5	*Samanta Sena*	*3-6*	7.59	1150	3055.8	0.41	11	26	126.3
6	*Smanta Sena*	*9-12*	7.66	1000	1666.8	0.76	1	22	491
7	*KUET*	*3-6*	7.19	2800	333.6	0.18	21	26	485
8	*KUET*	*12-21*	7.16	1850	2685.4	1.34	2	1080	386

5.4 (d) Effluent collected after 28 days

Exp no	**Location**	***Depth (ft)***	***Measured value of different parameter***						
			pH	*Cl^- mg/l*	*Hardness mg/l*	*Fe mg/l*	*NO_3 mg/l*	*SO_4 mg/l*	*TDS mg/l*
3	*Raj bandh*	*6-9*	7.61	2700	1800	0.63	0.1	394	2.44
4	*Raj bandh*	*9-12*	7.68	1550	2800	0.15	0.7	640	3.46
5	*Samanta Sena*	*3-6*	7.74	1200	1000	0.41	0	53	1632
6	*Smanta Sena*	*9-12*	7.58	1400	1100	0.98	0	204	1786
7	*KUET*	*3-6*	7.47	2250	4100	0.49	0.2	69	3.09
8	*KUET*	*12-21*	7.12	1550	2000	0.25	0.1	282	3.05

5.6 Soil properties after leachate percolation

Table 5.5 : Physical properties of the soil samples

Exp. Setup No.	*Location of Soil sample*	*Depth (ft)*	*Soil properties*					
			Sand (%)	***Silt (%)***	*Clay (%)*	*Liquid Limit (%)*	*Plastic Limit (%)*	*Plasticity Index (%)*
1	Fultala	4.5-6.5	2.5	67.0	30.5	37.68	25.64	12.04
2		6.5-16.5	2.6	65.0	32.4	25.72	23.20	2.52
3	Raj bandh	6—9	0.5	44.69	54.71	43.62	32.4	11.22
4		9—12	0.8	60.31	38.89	76.50	40.65	35.85
5	Samanta sena	3—6	1.8	57.56	40.44	31.12	23.88	7.24
6		9--12	1.2	58.12	40.68	29.64	26.34	3.3
7	KUET campus	3-6	2.0	49.31	48.69	42.18	31.93	10.25
8		12-21	1.5	49.65	48.85	51.82	27.52	24.3

Table 5.6: Physical properties of the soil samples (contd.)

Exp. Set up no	*Location of Soil sample*	*Depth*	*Soil properties*			
			Hydraulic conductivity (cm/sec)	**Moisture content (%)**	*Shrinkage Limit (%)*	*Activity* **(PI /% clay fraction)**
1	Fultala	4.5-6.5	$2.35*10^{-6}$	23.99	22.80	0.39
2		6.5-16.5	$2.218*10^{-6}$	27.12	18.23	0.08
3	Rajbandh	6—9	$3.77*10^{-11}$	39.70	23.22	0.21
4		9—12	$7.34*10^{-11}$	60.64	43.39	0.92
5	Samanta sena	3—6	$9.96*10^{-11}$	32.60	21.80	0.18
6		9--12	$4.34*10^{-11}$	31.02	24.25	0.08
7	KUET campus	3-6	$3.07*10^{-11}$	37.26	2.0	0.21
8		12-21	$1.20*10^{-6}$	42.16	1.5	0.50

5.7 Remarks

The experiments were done under worst case scenario. The thickness of the specimen for is a vital criteria to consider. Because the retardation and attenuation depends of thickness of the liner. The quality and quantity of the leachate passing through the leachate is a time dependent factor as well. Possible side effects during the laboratory tests were ignored.

CHAPTER SIX

RESULTS AND DISCUSSIONS

6.1 General

The use of local clayey soil as liner material to hold back landfill leachate is being considered for its economy and easy availability. The research is focused on Khulna, a divisional town of Bangladesh where all industrial waste and domestic wastes are dumped in disposal sites without liner. The research work was aimed to investigate the potentialities of selected Khulna soil collected from four different site within Khulna Municipal area to get benefit from the natural soil of this area.

The reactions at leachate – clay liner – groundwater interfaces are critical. Physical and chemical characteristics of landfill clay liner materials contributes significantly to the leachate isolation performance. The application of clayey materials or clay minerals in the construction of landfill liner requires an understanding of the properties of the clay liners since the incorporation of chemicals such as metal species into the clay liner materials may change the morphology or even the structure of the clays.

Design Objectives for Compacted Soil Liner is to maintain low hydraulic conductivity to minimize leakage ($K \leq 10^{-7}$ cm/sec), adequate shear strength to maintain liner stability, minimal shrinkage potential to minimize desiccation cracking. These criteria are quite complex to investigate because the performance of the liner material is influenced by many variables, as clay content, liquid limit, plasticity Index, activity, amount of fines, properties of the fines, gradings, compaction level, water content, mineralogy etc.

6.2 Index Properties of Investigated Soils

The work concentrated a lot on the parameter related to soil composition and structure using particle size analysis curve and Atterberg's Limits. The conditions those are necessary to meet the required low hydraulic conductivity are % fines greater or equal to 30%, % Clay greater or equal to 15%, Liquid limit greater or equal to 20%, Plasticity Index greater or equal to 7% and activity ratio greater or equal to 0.3. Laboratory analyses show that the collected soils exhibits adequate geotechnical properties for building impervious base liner for sanitary landfill. Soil from highly Organic content layers have been excluded from the test samples.

6.2.1 Fultala Soil

Specific gravity of the Fultala site soil upto 10 meter depth is found in the range of 2.68 to 2.73. The particle size analysis shows that the selected soils of Fultala contains 29-35% clay (<0.002 mm) 63-75% fines (< 0.075) and 1.8% sand. Moreover, the results of Atterberg limits reveal that the value of liquid limit (LL), Plastic Limit and Plasticity Index are 28.20-34.20%, 23-28.5% and 5.5-6.5% respectively.

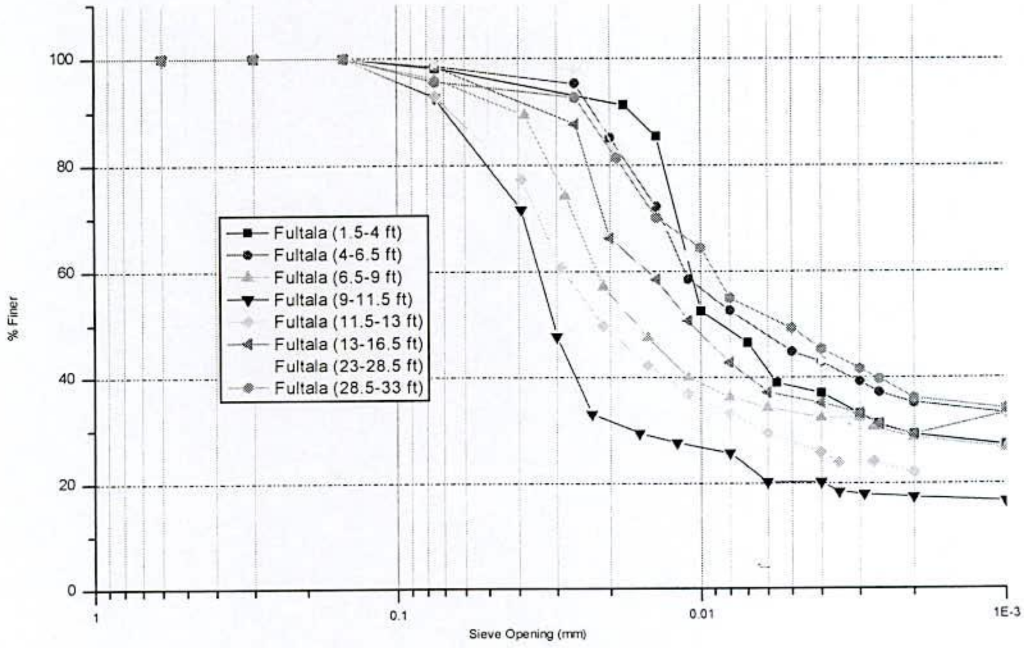


Fig 6.1 : Grain size analysis (Curves of Fultala sub-soil)

The reconstitute soil samples of Fultala within depth of 4.5 to 6.5 ft and 6.5 to 6.5 ft shows 30.5% and 32.4% of clay , 67.0% and 65.0 % of silt, 2.5% and 2.6% of sand. The samples have the LL of 37.68 % and PL of 25.72 % with PI of 12.04% and 2.52%.

6.1.2 Rajbandh Soil

Rajbandh soil is having Specific gravity in the range of 2.15 to 2.73. From grain size analysis we get about 42-44% of clay , 57-61% of silts and 0.2-0.5 % sand. Portion of sand in this samples are comparatively very less. The calculated value of Liquid limit plastic limit and the plasticity index are 54.43%, 29.29% and 25.14% respectively.

The layer of soil from 6-9 ft in Rajbandh has got much higher Plasticity Index value of 56.77% with the liquid limit value of 88.23% and Plastic limit of 31.46%.

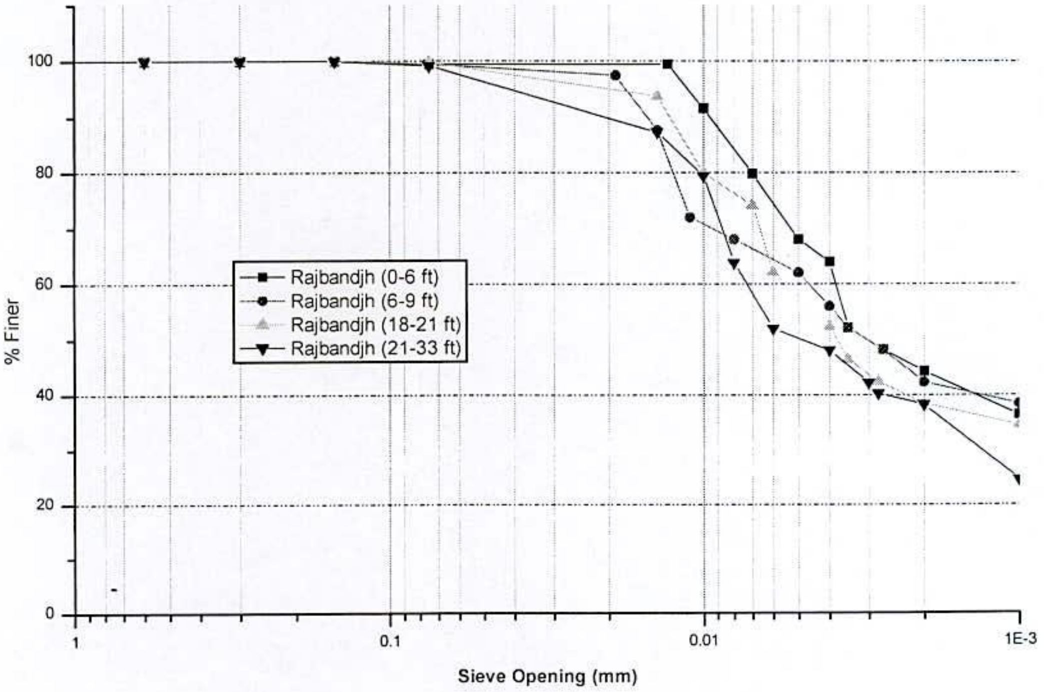


Fig 6.2 : Grain Size analysis (Curves of Rajbandh sub-soil)

The liner samples with reconstitute soil of Rajbandh, taken from a depth of 6—9 ft and 9—12 ft found to have clay content of 54.71% and 38.89 % of clay respectively with negligible quantity of fine sand. The samples have LL values of 43.62 % and 76.50 % with PI values of 11.22 % and 35.85 %.

6.2.3 Samanta sena Soil

In Samanta sena selected soils are having Specific gravity within the range of 2.72 to 2.74. the grain size analysis came up with a figure of clay contained about 30-39% , fines are about 56-65% with a sand contained of about 4%. Liquid limit in the layer 3-6 is found to be 43%, the PL 20% and PI figured out as 23 %, whereas in the layer 9-12, Liquid limit and Plastic limit comes to the values of 36.10% and 24.13% respectively and the plasticity index found out to be 11.97%.

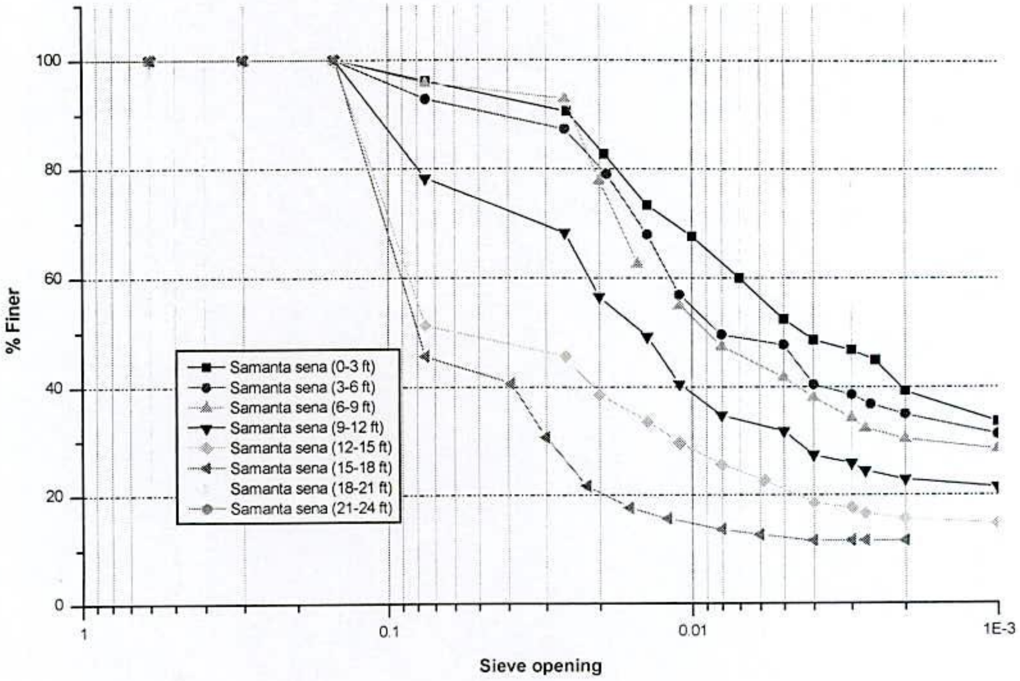


Fig 6.3: Grain size analysis (curves of Samanta sena sub-soil)

The moulded sample prepared from the soil collected from 3-6 ft and 9-12 ft depth of Samantasena bore hole have shown (after leachate passing) about 40% clay content, with LL 31.12% and 29.64%, again the PI comes to 7.24% and 3.3%.

6.2.4 KUET Campus Backyard Soil

Specific gravity has been found to be in the range of 2.69 to 2.74 in KUET campus backyard site with clay contained in the range of about 48% to 52 %, silt has been about 65% to 74% and sand contained ranging from 0.4 to 1.2%. Portion of Sand in these sample are less which is comparable to Rajbandh. Liquid limit value in the layer 3-6 ft is 55%, the plastic limit value is 29% following the plasticity index of 26%.

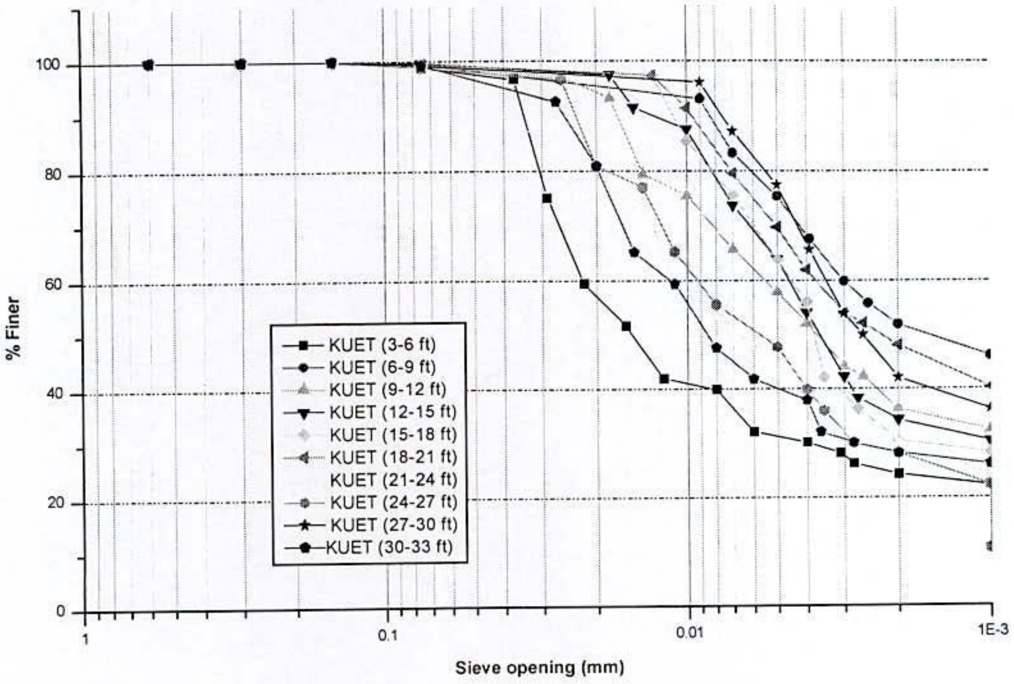


Fig 6.4: Grain size analysis (curves of KUET campus sub-soil)

A similar layer very much like Rajbandh exists in the KUET campus backyard also. The soil collected from a depth of 6 to 9 ft has shown Liquid Limit (LL) value of 80% and the Plastic Limit (PL) value of 29% and consequently the plasticity index (PI = LL – PL) comes to 51 %. Again in the soil sample from the layer of 18 to 21 we get LL of 79%, PL of 45% and PI of 34%.

The reconstitute liner specimens prepared from the KUET soil of 3 to 6 ft and 12 to 21ft depth are found having clay content of 48.69% and 48.85 %, LL of 42.18% and 51.82% and PI 10.25% and 24.3% as well.

All the above data show that majority of the samples from four sites are having high clay content. Clays have low hydraulic conductivity because of the particles' small size, compact soil fabric (i.e. configuration of clay plates). It is learnt that the dispersed particles create more tortuous paths and lower k. Flocculate particles creates large channel of flow.

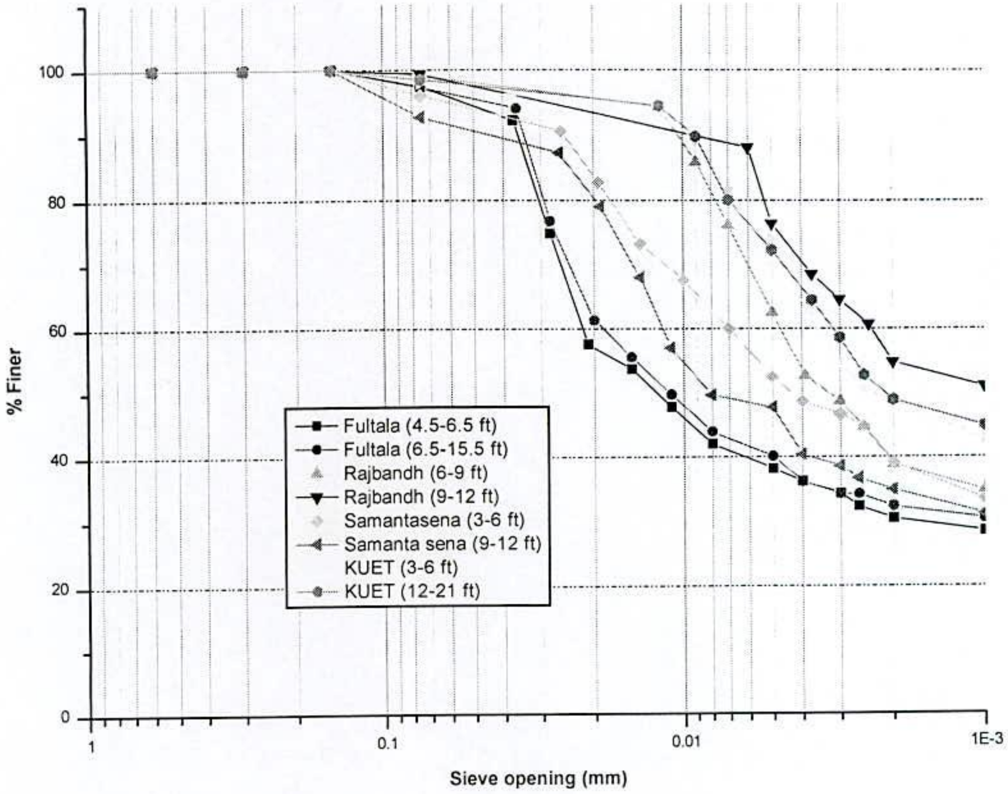


Fig 6.5: Grain size analysis of liner specimen after leachate percolation

Benson et al (1992) related hydraulic conductivity to clay content (<0.002) and suggested that the soils must have at least 10-20% of clay in order to be capable of being compacted to a hydraulic conductivity of ≤ 1×10^{-7} cm/s. Large sodium molecules between clay particles cause clay to swell and plates to disperse. As such high sodium clays have lowest K. Also double layer holds water which reduces K.

The Rajbandh and KUET campus backyard soil can be classified as clay with high plasticity with traces of organic. The soils from 4.5 to 6.5 ft depth of Fultala bore hole and 3 to 6 ft depth of Samanta sena borehole reveal high clay content and inorganic with PI value of 12.04% and 7.24%. According to the USCS, inorganic clay with high plasticity is typical material for landfill liner (Oweis and Khera 1998).

6.3 Hydraulic Conductivity

Both the subsoil of Rajbandh and KUET campus backyard comprising predominantly fine grain soils. They are expected to have desirable characteristics to minimize hydraulic conductivity. The containment potentiality of a liner material depends greatly on the value its hydraulic conductivity. It is the principal indicator. The Hydraulic conductivity performance of soil liners is greatly influenced by the particle size distribution because the relative proportions of large and small particle sizes affect the size of voids which facilitate percolation. Liner soil should have at least 30% fines (Daniel 1993b; Benson et al. 1994) and 15% clay (Benson et al. 1994) to achieve hydraulic conductivity value of $1x10^{-7}$ cm/s. Thus, the soil of Rajbandh and KUET campus backyard can be used for liner to achieve a hydraulic conductivity of $1x10^{-7}$ cm/s, as it possesses suitable amount of clay and fine fractions.

Samanta sena soil have fulfilled the requirement of clay contain and fines. Moreover, the soil contains adequate amount of sand, which may offer notable protection from volumetric shrinkage and impart adequate strength as well.

After reconstitute the soils, hydraulic conductivity of the compacted specimens have increased to a much higher values. Eight reconstitute specimens of Samanta sena, Rajbandh, and KUET have significantly low hydraulic conductivity (Table 5.6).

6.4 Plasticity Index

The plasticity index is one of the most important criterion for selection of soil for liner construction. It is one of the key property in achieving low hydraulic conductivity. If the soil has extremely low plasticity it will contain insufficient clay to develop low hydraulic conductivity. Daniel (1990) recommended that the soil needs to have plasticity Index (PI) of ≥ 10% . But Albrecht and Cartwright in 1989 noted that some soil with PI as low as 7% have been used successfully to build soil liners with extremely low in situ Hydraulic conductivity. It was observed Bension et al. (1992) compiled a database from CQA (Construction Quality Assurance), which shows that soil with PI as low as approximately 10% can be compacted to achieve a hydraulic conductivity $\leq 1x10^{-7}$ cm/s.

It is reported that the soil having very high plasticity becomes sticky when wet and then becomes difficult to work with in the field. Also high plasticity soil forms hard lumps when they are dry and are difficult to break down during compaction. The hard lumps, if not properly compacted, create zones of higher hydraulic conductivity. Moreover, high plasticity soil tends to be more susceptible to desiccation cracking. For plasticity index value greater than 35, excessive shrinkage can be expected (Daniel 1991).

Fultala soil has lower Plasticity Index than 7% (reconstitute soil of Fultala from 4.5 to 6.5 ft depth shows greater PI as of 12.04%), although having higher liquid limit than required.

Rajbandh soils have wide range of Plasticity index values, mostly within range of 8.77 to 25.14. There are exceptions in soil sample from 9 to 12 ft depth with PI value 56.77%, sample from 15 to18 ft depth with PI value of 42.39%, and sample from 21 to 24 ft depth having PI value of 66.40%.

Samanta sena soils from 0-15 ft depth got the value of PI above 7% but below 35% .

Almost all the layer of KUET campus soil samples are having the PI within range of 21 to 34 except in one layer (6-9 ft) which shows PI value of 51

Thus, the all the soils except Fultala have suitable plasticity property to minimize hydraulic conductivity and shrinkage susceptibility as well.

6.4.1 Liquid Limit

Liquid limit is correlated with various engineering properties. Benson et al. (1994) recommended that the liquid limit of the liner material be at least 20%. Soils with high liquid limit generally have low hydraulic conductivity. However, soils with very high liquid limit have poor volume stability and high shrink-swell potentials. As long as it does not create any working problem, soils with high liquid limit generally preferred because of their low hydraulic conductivity. All the collected samples have shown much higher value of liquid limit than 20% and appears to be promising for use as base liner to construct Sanitary landfill.

6.5 Clay Content and Activity

Activity is an index of the surface activity of the clay fraction. Soils with higher activity are likely to consist of smaller particles having larger specific surface area and thicker electrical double layers. Therefore, hydraulic conductivity should decrease with increasing activity. However, soils with high activity are more readily affected by pollutant if they used in containment structures (Oweis and Khera 1998).

A high activity (>1) indicates that expandable mineral such as montomorilllonite is present in the soil sample. Lambe and whitman (1969) report that the activities of Kaolinite, Illite and montomorilllonite are 0.38, 0.9, 7.2 respectively. Activities for naturally occurring clay liner materials, contains a mix of minerals, is frequently in the range of $0.5 \leq A \geq 1$.

Activity in Fultala soil is found within the range of 0.04 to 0.19, Rajbandh in the range of 0.7 to 1.73, Samanta sena in the range of 0.10 to 0.55 and that of KUET campus in the range of 0.11 to 1.07 (Table 3.14).

The reconstitute soils have the range of Activity within 0.08 to 0.92 (Table 5.6)

Inactive clayey soils are the most desirable materials for compacted soil liners (Rowe et al. 1995). In order to achieve a hydraulic conductivity = 1×10^{-7} cm/s for soil liners, soils with an activity of 0.3 or greater may be specified (Benson et al. 1994; Rowe et al. 1995). This criteria is fulfilled at Fultala at 4.5-6.5ft depth, at Rajbandh at 9-12 ft depth and at KUET campus at 12 -21 ft depth.

Table 6.1 : Index properties of reconstitute soil

Location	*Depth (ft)*	*% Clay*	*% Fines*	*Liquid Limit (%)*	*Plasticity Index (%)*
Fultala	4.5-6.5	30.5	97.5	37.68	12.04
	6.5-16.5	32.4	97.4	25.72	2.52
Rajbandh	6—9	54.71	99.5	43.62	11.22
	9—12	38.89	99.2	76.50	35.85
Samanta sena	3—6	40.44	98.2	31.12	7.24
	9--12	40.68	98.2	29.64	3.3
KUET campus	3-6	48.69	98	42.18	10.25
	12-21	48.85	98.5	51.82	24.3

Thus, the comparison between the index properties of selected Khulna soil and the index properties as recommended by various researchers for a good liner material shows that Khulna sub-soil specially Rajbandh and KUET campus backyard soil have greater suitable properties to use as base liner material.

6.6 Compaction Properties

In the construction of soil liners, compaction is done to achieve a soil layer of improved engineering properties. Compaction of soils results a homogeneous mass that is free of large, continuous inter-clods voids; increases their density and strength, and reduced their hydraulic conductivity. Hydraulic conductivity is the key design parameter when evaluating the acceptability of a liner material. When the soil is compacted close to its maximum dry density, low hydraulic conductivity is achieved. Thus, compaction test is performed to determine the maximum dry density and corresponding optimum water content for a soil under a specific compactive effort.

The compaction curves for the Khulna soil collected from four different locations are shown in Figure 6.2 The compaction curves clearly illustrate that the dry density is the function of compaction water content and compactive effort. For each compactive effort, at the dry side of optimum water content the dry density increases with the increasing water content. This is due to the development of large water film around the particles, which tend to lubricate the particles and make them easier to be moved about and reoriented into a denser configuration (Holtz and Kovacs 1981). Whereas, at the wet side of optimum water content water starts to replace soil particles in the compaction mold and since the unit weight of water is much less than the unit weight of soil the dry density decreases with the increasing water content.

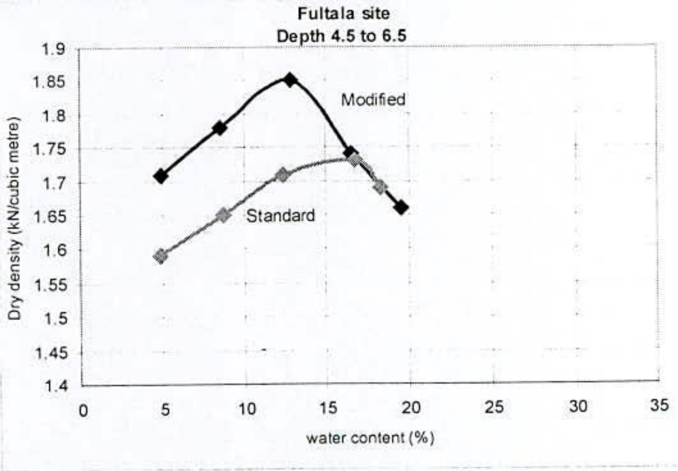


Fig 6.6 (a): Compaction curve of specimen sample (Fultala site)

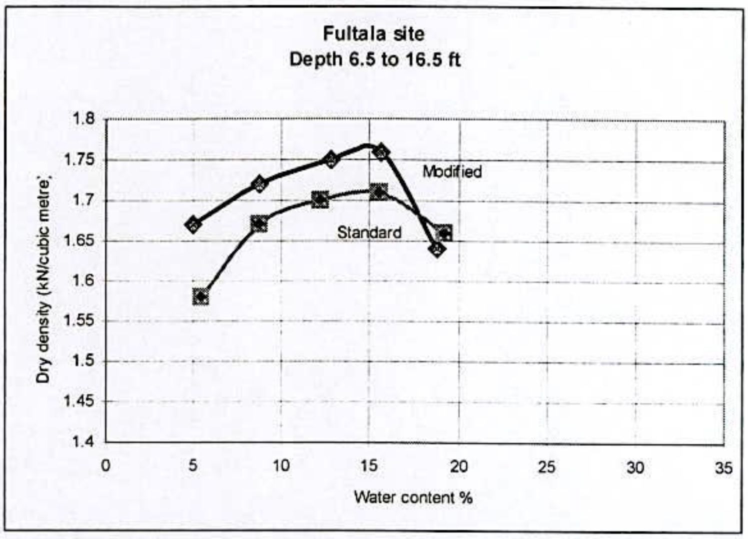


Fig 6.6 (b): Compaction curve of specimen sample (Fultala site)

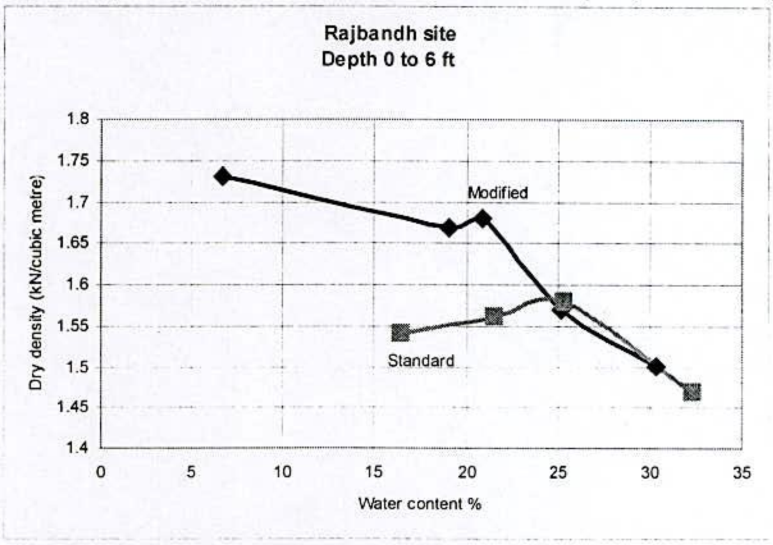


Fig 6.6 (c): Compaction curve of specimen sample (Samanta sena site)

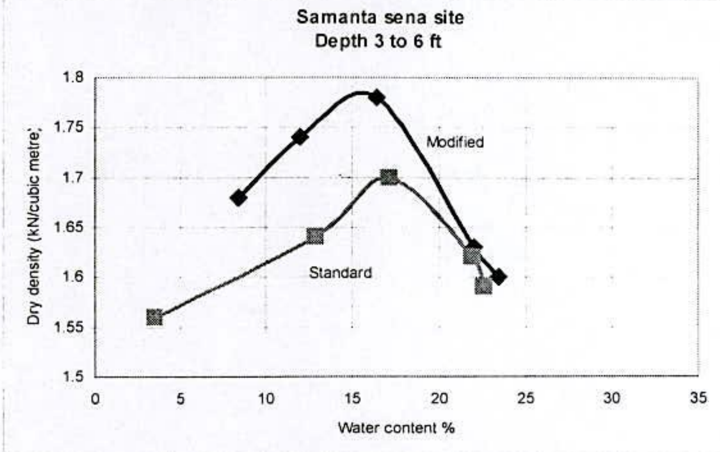


Fig 6.6 (d): Compaction curve of specimen sample (Samanta sena site)

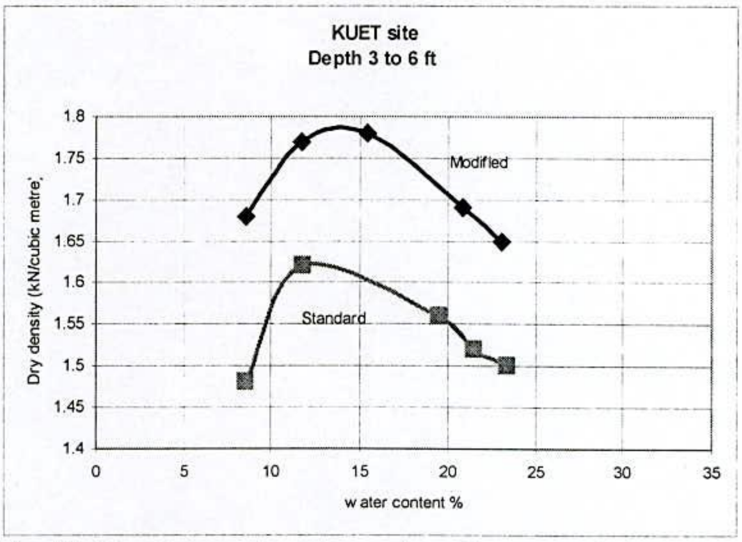


Fig 6.7 (e): Compaction curve of specimen sample (KUET site)

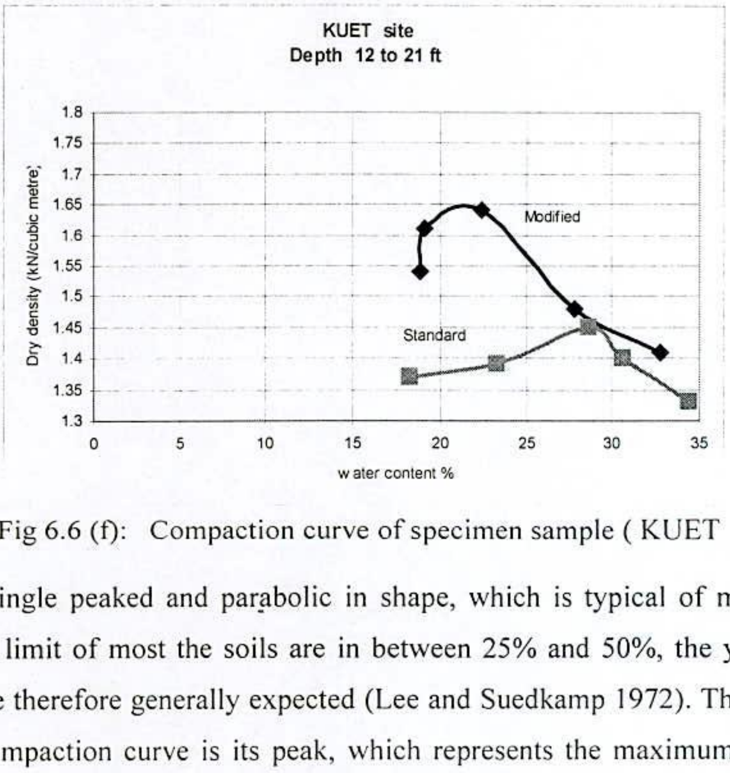


Fig 6.6 (f): Compaction curve of specimen sample (KUET site)

The curves are single peaked and parabolic in shape, which is typical of most clayey soils. Since the liquid limit of most the soils are in between 25% and 50%, the yielding of single peaked curves are therefore generally expected (Lee and Suedkamp 1972). The most important feature on the compaction curve is its peak, which represents the maximum dry density and corresponding optimum water content for a given compactive effort.

The maximum dry density and the optimum water content obtained from this test are given in Table 6.1. An increase in compactive effort increases the maximum dry density but decreases the optimum water content. Because higher compactive effort yields a more parallel orientation to the clay particles, which gives a more dispersed structure; the particles become closer and a higher unit weight of compaction results (Das 1998).

Table 6.2. Maximum dry density and corresponding optimum water content

Location	**Sample no.**	**Depth**	**Compactive Effort**	**Optimum Water Content W_{opt} (%)**	**Max. Dry Density γ_d (kN/m^3)**
Fultala	1	4.5-6.5	Modified Proctor	12.84	1.85
			Standard Proctor	16.74	1.73
	2	6.5-16.5	Modified Proctor	12.83	1.75
			Standard Proctor	15.54	1.71
Rajbandh	1	6-9	Modified Proctor	20.82	1.68
			Standard Proctor	25.32	1.58
	2	9-12	Modified Proctor	29.04	1.39
			Standard Proctor	26.08	1.38
Samanta sena	1	3-6	Modified Proctor	16.44	1.78
			Standard Proctor	17.20	1.70
	2	9-12	Modified Proctor	14.48	1.81
			Standard Proctor	17.33	1.72
KUET campus	1	3-6	Modified Proctor	15.47	1.78
			Standard Proctor	19.50	1.56
	2	12-21	Modified Proctor	22.41	1.64
			Standard Proctor	28.69	1.45

Generally the lowest hydraulic conductivity of clayey soil is achieved when the soil is compacted at water content slightly higher than the optimum water content (Mitchell et al. 1965; U.S. Environmental Protection Agency 1989; Daniel and Benson 1990).

The hydraulic conductivity also changes with the change of compaction water content. Soils compacted at dry of optimum water content tend to have relatively high hydraulic conductivity whereas soils compacted at wet of optimum water content tend to have lower hydraulic conductivity. Increasing water content generally results in an increased ability to break down clay aggregates and to eliminate inter-aggregate pores (Mitchell et al. 1965; Benson and Daniel 1990; Garcia-Bengochea et al. 1979). In addition, the clay particles are more uniformly dispersed and the macropores become constricted and tortuous (Barden 1974).

Again the hydraulic conductivity decreases with the increasing compactive effort. Because increasing compactive effort decreases the frequency of large pores and can eliminate the large pore mode (Acar and Oliveri 1989). These changes in pore size yield lower hydraulic conductivity.

Moreover, increasing water content result in reorientation of clay particles and reduction in the size of interparticle pores (Lambe 1954; Acar and Oliveri 1989). Great attention is generally focused on ensuring that low hydraulic conductivity is achieved as the hydraulic conductivity is the key parameter affecting the performance of most soil liners. Therefore, it is usually preferred to compact the soil ***wet of optimum***.

Table 6.3 : Hydraulic Conductivity of reconstitute soil samples

Location of Soil sample	*Depth*	*Hydraulic conductivity (cm/sec)*	
		Before reconstitute	*After reconstitute*
Fultala	4.5-6.5	4.07*10-5	2.35*10-6
	6.5-16.5	11.3*10-5	2.218*10-6
Rajbandh	6—9	0.4*10-5	3.77*10-11
	9—12	0.7*10-5	7.34*10-11
Samanta sena	3—6	0.08*10-5	9.96*10-11
	9--12	0.03*10-5	4.34*10-11
KUET campus	3-6	0.12*10-5	3.07*10-11
	12-21	0.50*10-5	1.20*10-6

6.7 Volumetric Shrinkage

Compacted soil liners are subjected to frequent desiccation due to evaporative water losses. Desiccation leads to the development of shrinkage cracks. Cracks provide pathways for leachate migration and ultimately increases the potential for soil and groundwater contamination. Thus, the soil liner significantly losses its effectiveness as an impermeable barrier. Literature suggested that cracking do not likely to occur in soil liners when compacted cylinders of the same soil undergo less than about 4% volumetric shrinkage strain upon drying (Daniel and Wu 1993; Tay et al. 2001).

Soil shrinks simply due to water loss, which is independent of the pressure if water and soil particles are considered incompressible. Much information is not available on the relationship between overburden pressure and volumetric shrinkage of compacted soil. In a recent study Briaud et al. (2003) reported that vertical pressure does not influence the volumetric shrinkage.

However, in this study shrinkage limits of the soil specimen are calculated. The specimens were allowed to dry at approximately at room temperature at 35 ^{0} C and the specimen were kept open to the atmosphere. In the field usually the rate of dry would be slower. The results are shown in Table 5.6. The cylindrical specimens began to shrink into smaller cylinders.

Volume change occurs as the water surrounding the individual soil particles of the specimens is removed, the soil particles move closer together. The drying tests were conducted for a period of about 1 month to get the possible maximum volume change.

During drying the sides of the specimens were, which does not replicate the field condition. Drying from the top surface only requires much longer times, and was not practical. Again, the laboratory drying conditions did not replicate the field conditions precisely, but the relative effects of soil type on volumetric shrinkage are required to be preserved.

6.8 Leachate percolation

Table 5.3 shows the Quantity of leachate percolated through the reconstitute soil specimens with time. The specimen made of Rajbandh soil (experiment no 3), Samanta sena soil (experiment no 6) and KUET soil (experiment no 7) showed better leachate retaining capabilities. pH value decreases (raw leachate pH value 8.52) after leachate percolated for seven days and came to a range of 6.5 to 7.7 and remain more or less within this range for the 14th day , 21st day and 28th days results. Iron has got the decreasing tendency. TDS reduced considerably even after 7th day. The quantity of effluent collected after 14th day in the experiment no 1, 3, 5, 6, 7, 8 is found to be larger than those after 7th day . Again exp. set up no 3, 6 and 8 showed an increasing tendency in effluent quantity throughout the experiment upto 28th day. It might have happened due to waste and soil interaction and consequent change in soil structure which might lead to higher porosity.

Since the migration of leachate is often a slow process and the dangerous effects of heavy metal will typically become evident after a long period of time, the prediction of the fate of heavy metal in the leachate is challenging. Compacted soil liner thickness is expected to be 2-3 ft (600mm - 900mm). These experimental test is done under worst case scenario. About 200 mm thickness of soil specimen could not reproduce the field conditions as well, it gives an indication of the changes in concentration of chemical and metal within a short period (Table 5.4(a) to %.4(d) as well as the changes in physical properties (Table 5.5) of the tested soil.

6.9 Mineral composition

The significant finding from the mineral identification is the presence of Vermiculite and Montomorillonite in most of the samples in varying percentage. These are desirable mineral in case of clay liner due to their swelling capability. They can contribute to the imperviousness of the liner system. Moreover, because of their high surface charge and specific surface areas, Vermiculite and Smectite (Montomorillonite) can profoundly influence the interfacial chemistry of clay liner materials.

Table 6.4: Mineral composition of liner specimen

Location	*Depth (ft)*	*Mineral content of the tested specimen*
Fultala	4.5--6.5	Chlorite –Vermiculite, Illite, Kaolinite, Chlorite-Surpentine, Chlorite, Quarts, Albite, Montorillonite (10.16%)
	6.5—16.5	Illite, Kaolinite, Chlorite, Quarts, Albite, K-feldspar, Montorillonite (5.22%)
Rajbandh	6—9	Illite, Kaolinite, Chlorite, Quarts, Albite,
	9—12	Chlorite –Vermiculite, Illite, Chlorite-Surpentine, Quarts, Montorillonite (6.67%)
Samanta sena	3—6	Illite, Kaolinite, Chlorite-Surpentine, Chlorite, Quarts, Montorillonite (4.43%)
	9--12	Illite, Chlorite-Surpentine, Chlorite, Quarts, Albite, K-feldspar, Montorillonite (4.96%)
KUET campus	3-6	Illite, Chlorite-Surpentine, Kaolinite, Chlorite, Quarts, Albite, K-feldspar, Montorillonite (3.75%)
	12-21	Vermiculite, Illite, Kaolinite, Chlorite-Surpentine, Chlorite, Quarts, Albite, K-feldspar, Montorillonite (3.05%)

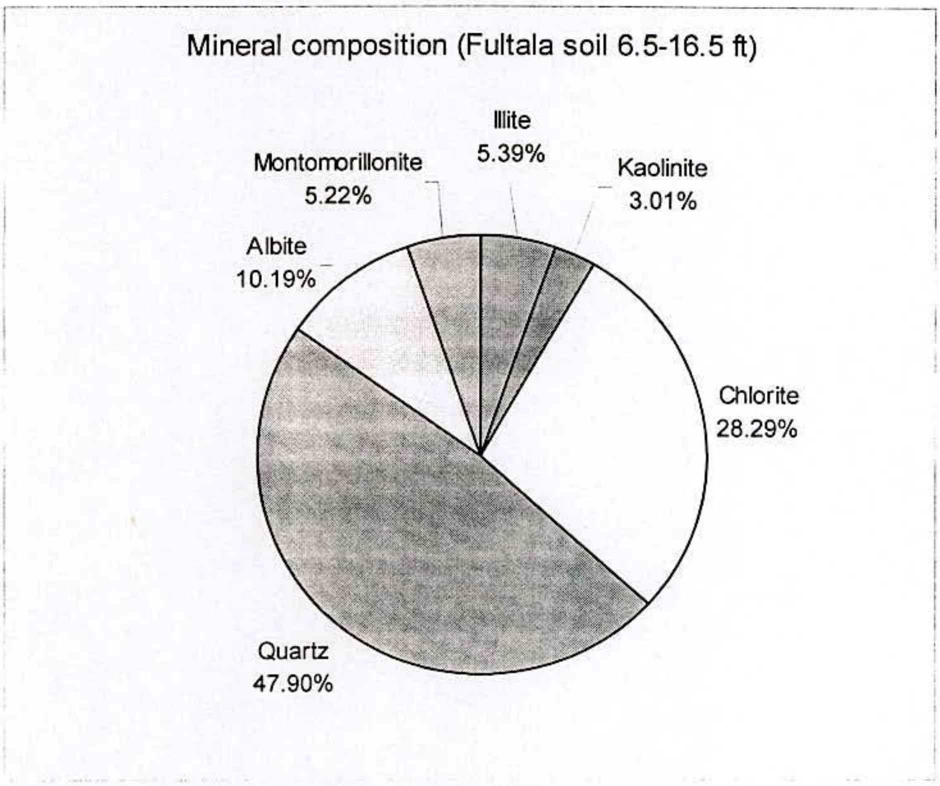


Fig 6.7 (a) : Pie charts showing mineral composition of selected Fultala soil sample

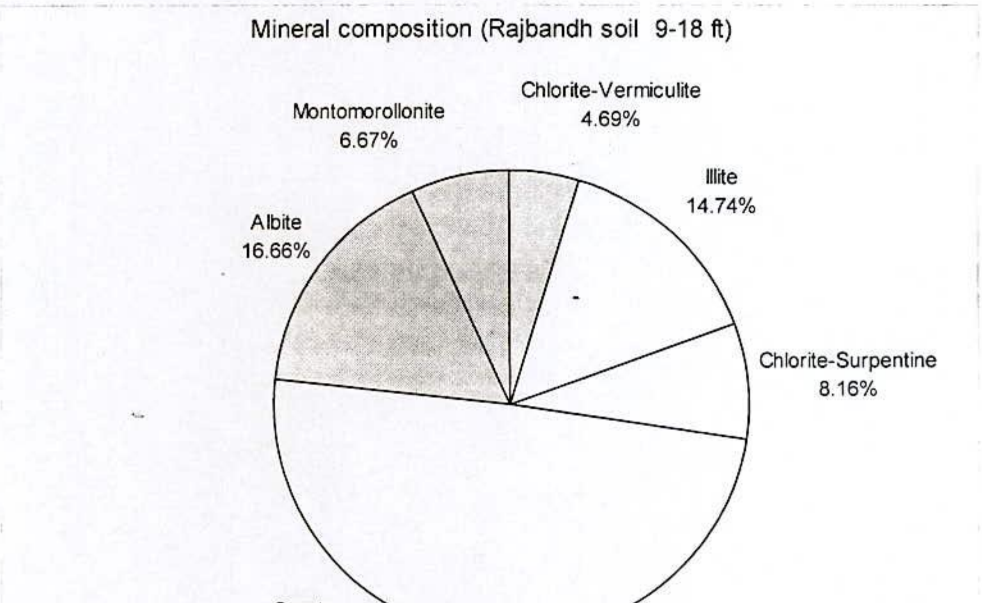


Fig 6.7 (b) : Pie charts showing mineral composition of selected Rajbandh soil sample

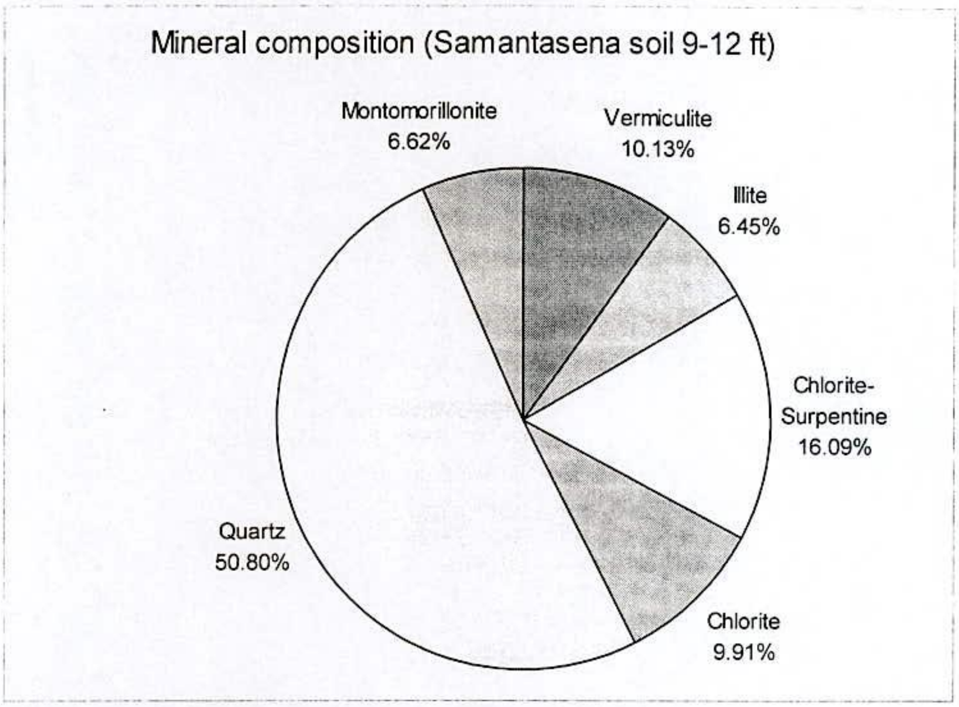


Fig 6.7 (c) : Pie charts showing mineral composition of selected Saman sena soil sample

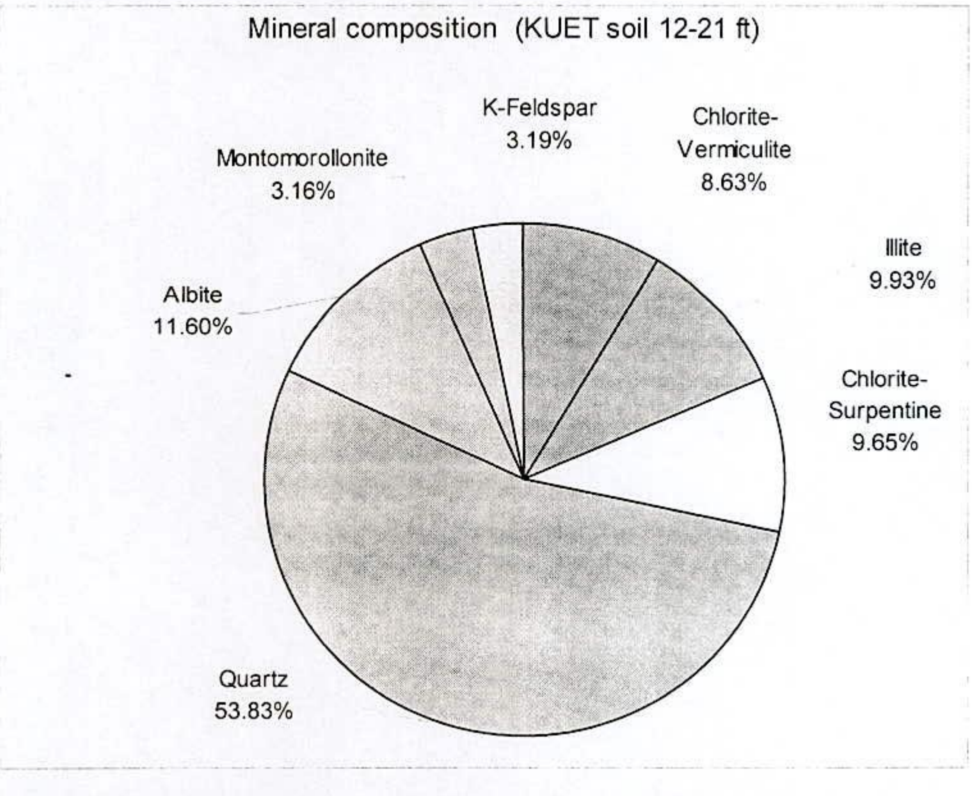


Fig 6.7 (d) : Pie charts showing mineral composition of selected KUET soil sample

Landfill clay liner is subjected to structural change, due to seasonal fluctuation in groundwater table. It is found in the recent researches that the cyclic redox and pH changes have a significant influence of the structure change of clay liner. In particular the smectite-dominated clayey soil showed irreversible structural change.. In contrast, clay liner with kaolinite remained almost intact after exposure to cyclic redox potential and pH changes (Zhou, 2003).

So kaolinite soil is suitable material to construct landfill liner in the costal areas which is subject to cyclic redox potential and coupled pH changes in groundwater. It is learnt that although the smaller pores in the Smectite (Montomorillonite) clays are effective with respect to diffusion of metal species, these small pores were not effective for advection.

Competition will be dominant in landfill system. It is believed that the behavior of heavy metal adsorption with the presence of other metal(s) will be changed in the multiple-element system of clay liner.

6.9 Limitations

It must be noted that this is only a limited study effort with Khulna soil collected from four representative sites. Physical properties of soils were examined, Compacted clay liners specimen were tested for permeability, Mineral composition of the soils were identified. Chemical properties of the soil could not be taken care of. However, as it can be seen from the discussion in this chapter that it is possible to see the potentiality of Khulna soil to be selected as base liner material.

CHAPTER SEVEN

CONCLUSION

7.1 General

The research led to assess whether the sub-soil selected in Khulna could be compacted as a potential hydraulic barrier in waste containment facilities. Linear correlation are considered in between the index properties in order to allow the selection, in the waste landfill preliminary design stage, of the soils that can be used in the construction of compacted soil layers as base liner material. Laboratory tests were performed on natural fine-grained Khulna soils covering a wide range of mineralogical, chemical and physical properties and the laboratory-measured values of the hydraulic conductivity were obtained in hydrogeochemical performance tests carried out on soil specimens permeated directly.

7.2 Conclusion

Based on the experimental study, the following conclusions can be drawn:

(1) The Khulna soil is inorganic clay with high plasticity. Generally, this type of soil possesses desirable characteristics to minimize hydraulic conductivity, and frequently used for the construction of compacted soil liners.

(2) The index properties (liquid limit, plastic limit, % clay content, % fines, activity etc.) of the soil satisfy the basic requirements as a liner material.

(3) It is mostly inactive (activity <0.75) clayey soil. Thus, the soil would be less affected by waste chemicals and also less susceptible to shrinkage.

(4) The soil has hydraulic conductivity of less than 1×10^{-7} cm/s, when it is compacted and reconstituted.

(5) Selected Khulna soil has contain Montomorollonite (upto 10.16%), due to this mineral swelling capability and high surface area indicate the soils are moderately expansive. Eventually it is a desirable mineral for clay liner material.

(6) The leachate percolation tests results depict that the selected soils has the potential to reduce the leachate percolation rate and retard the concentration of contaminants.

(7) The overall findings suggest that the Khulna soil can potentially be utilized as compacted soil liner material for isolating waste materials in landfills. Its future use as natural isolation barrier will enhance the waste management programs in Khulna area.

3.0 Recommendation for Future Study

(1) Although the Khulna soil meets almost all the basic requirements as a good Liner material, it would be hard to work with due to its high plasticity. The soil should properly blend and homogenize to achieve a mixer of relatively small clods with reasonably uniform moisture distribution. Blending the soil on site with a pulverizing mixer would be helpful in reducing clod size and producing more uniform moisture content. Therefore, during liner construction soil preparation should be focused on.

(2) A critical step in designing of a compacted soil liner is determination of the range of acceptable water content and a minimum dry density of the soil. Water content and dry density values can greatly affect a soil's ability to restrict the transmission of flow. Even small variations in water content and dry density may results a tremendous change to the hydraulic conductivity (Mitchell et al. 1965).

The physical properties (such as hydraulic conductivity, strength, and shrinkage potential) controlling the performance of soil liners are greatly influenced by water content. If the soil is too dry at the time of compaction, suitably low hydraulic conductivity may become unachievable. If the soil is too wet, problems with construction equipment operating on soft, weak soils and potential slope instability caused by low strength of the soil may arise. In addition, very wet soil may crack due to desiccation shrinkage. Thus, it is very important to specify the range of water contents within which the compacted soil will exhibit hydraulic conductivity = 1×10^{-7} cm/s, volumetric shrinkage = 4% and unconfined compressive strength = 200 kPa. As such a detailed study on Khulna soil is needed in this perspective.

(3) Advection and diffusive transport of contaminant into Khulna selected soil including the migration profile may be of greater interest in future study.

(4) As Khulna is situated on the coastal zone great attention should be given to the changing water table and pH value. It should be so modeled as to reflect the consequence of cyclic redox potential change caused by the fluctuation of the groundwater table and the structural changes of the clay liners under different experimental conditions are to be studied.

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ANNEXURE

DETAILED MINERAL CALCULATION

Soil 1: fultala 0 -4.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
20.9022	916.64	0.1181	**4.25**	16.66		
22.11	116.89	0.2362	**4.02**	2.12		
22.9957	109.98	0.2362	**3.87**	2		
24.3482	197.2	0.1181	**3.66**	3.58		
25.2075	188.22	0.1181	**3.53**	1	Chlorite (100%)	22.228782
25.507	194	0.1574	**3.49**	3.53		
26.6794	5502.84	0.1181	**3.34**	100	Quartz (100%)	649.885404
27.9873	352.09	0.3149	**3.19**	6.4	Albite (100%)	110.873141
29.4561	485.33	0.1181	**3.03**	8.82	Montomorollonite (100%)	57.317473
						840.3048

Soil 2: fultala 4.5 ft-6.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1099	153.46	0.1574	**14.47**	2.26		
8.9499	491.11	0.0984	**9.88**	7.25		
10.5924	68.45	0.1574	**8.35**	1.01		
12.6017	159.57	0.0984	**7.02**	2.35	Chlorite-Surpentine (100%)	15.701688
17.872	247.31	0.1181	**4.96**	3.65		
18.8698	72.57	0.1181	**4.70**	1.07		
19.9143	103.52	0.2362	**4.46**	1.53	Illite(100%)	24.451424
20.9242	1208.27	0.0787	**4.25**	17.83		
22.0685	239.32	0.1181	**4.03**	3.53		
22.9685	42.84	0.3936	**3.87**	0.63		
25.2537	53.24	0.2362	**3.66**	0.79		
26.6914	148.1	0.1574	**3.53**	2.18	Chlorite (100%)	23.31094
24.3488	6778.08	0.1181	**3.34**	100	Quartz (100%)	800.491248
27.9473	700.49	0.059	**3.19**	10.33	Albite (100%)	41.32891
29.5643	207.39	0.059	**3.02**	3.06	Montomorollonite (100%)	12.23601
						917.52022

Soil 3: fultala -6.5 ft-16.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.0884	50.34	0.4723	**14.52**	0.64		
8.9327	249.31	0.1378	**9.90**	3.17	Illite(100%)	34.354918
12.5036	56.66	0.3149	**7.08**	0.72	Kaolinite (100%)	17.842234
17.8601	144.58	0.0984	**4.97**	1.84		
19.8458	56.66	0.2362	**4.47**	0.72		
20.9065	1145.93	0.1181	**4.25**	14.59		
22.0769	50.41	0.2362	**4.03**	0.64		
23.0635	50.15	0.2362	**3.86**	0.64		
23.5752	100.32	0.1574	**3.77**	1.28		
25.6947	233.27	0.0984	**3.47**	2.97	Chlorite (100%)	22.953768
26.6771	7856.8	0.1181	**3.34**	100.00	Quartz (100%)	927.88808
27.5044	942.45	0.1378	**3.24**	12.00	Fieldspar	129.86961
27.967	288.75	0.1968	**3.19**	3.68	Albite (100%)	56.826
28.3091	163.82	0.0787	**3.15**	2.09		
29.5041	145.93	0.0787	**3.03**	1.86	Montomorollonite (100%)	11.484691
						1201.219301

Soil 4: fultala 16.5 ft -23 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spaci ing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1134	173.96	0.1574	**14.46**	2.40		
8.9351	514.27	0.059	**9.90**	7.10	Illite(100%)	30.34193
12.5647	189.79	0.0984	**7.05**	2.62	Kaolinite (100%)	18.675336
17.8469	261.86	0.0984	**4.97**	3.61		
18.7201	55.38	0.4723	**4.74**	0.76		
19.852	103.85	0.2362	**4.47**	1.43		
20.9133	1064.74	0.1181	**4.25**	14.69		
22.0629	119.73	0.1574	**4.03**	1.60		
22.9127	75.9	0.3936	**3.88**	1.05		
23.6217	268.09	0.0984	**3.77**	3.70		
25.2087	235.6	0.1181	**3.53**	3.25	Chlorite (100%)	27.82436
25.6474	205.66	0.2362	**3.47**	2.84		
26.6748	7247.1	0.1181	**3.34**	100.00	Quartz (100%)	855.88251
26.9087	997.74	0.059	**3.31**	13.77		
27.5429	234.98	0.1181	**3.24**	3.24	K-fieldspar	27.751138
27.815	808.49	0.059	**3.21**	11.16	Albite (100%)	47.70091
27.9813	740.15	0.0984	**3.19**	10.21		
29.4921	227.37	0.1574	**3.03**	3.14	Montomorollonite (100%)	35.788038
						1043.964222

Soil 5: fultala 23 ft- 33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spaci ing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1467	85.47	0.2362	**14.38**	0.92		
8.9339	437.03	0.0787	**9.90**	4.71	Illite(100%)	34.394261
12.4758	55.71	0.2362	**7.10**	0.6	Kaolinite ((100%)	13.158702
17.8529	216.82	0.1378	**4.97**	2.33		
19.9258	60.84	0.4723	**4.46**	0.66		
20.9243	1512.29	0.1181	**4.25**	16.29		
22.0634	106.37	0.1968	**4.03**	1.15		
23.8313	207.33	0.059	**3.73**	2.23		
24.3371	103.59	0.2362	**3.66**	1.12		
24.644	295.94	0.0787	**3.61**	3.19		
25.5664	154.57	0.1574	**3.48**	1.66	Chlorite (100%)	24.329318
26.6767	9285.92	0.1378	**3.34**	100	Quartz (100%)	1279.599776
27.5176	199.12	0.1181	**3.24**	2.14	K-fieldspar	
27.9592	574.43	0.0984	**3.19**	6.19	Albite (100%)	56.523912
29.4822	139.95	0.1574	**3.03**	1.51	Montomorollonite (100%)	22.02813
						1430.034099

Soil 6: Rajbandh 0-6 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1051	103.84	0.3149	**14.48**	3.14		
8.9284	203.09	0.0984	**9.90**	6.15	Illite (100%)	19.984056
12.5433	119.72	0.1181	**7.06**	3.62	Kaolinite (100%)	14.138932
17.8264	80.06	0.2362	**4.98**	2.42		
19.889	275.09	0.1574	**4.46**	8.32		
20.9177	566.67	0.0984	**4.25**	17.15		
22.0832	134.06	0.1181	**4.03**	4.06		
22.9604	108.49	0.2362	**3.87**	3.28		
23.762	83.12	0.4723	**3.74**	2.52		
25.5662	154.41	0.2362	**3.48**	4.67	Chlorite (100%)	36.471642
26.679	3304.59	0.1181	**3.34**	100	Quartz (100%)	390.272079
27.9546	283.44	0.2362	**3.19**	8.58	Albite (100%)	66.948528
						527.815237

Soil 7: Rajbandh 6 ft--9 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1616	51.37	0.4723	**14.34**	1.63		
8.918	182.78	0.1181	**9.92**	5.8	Illite (100%)	21.586318
12.5077	66.69	0.2362	**7.08**	2.12	Kaolinite (100%)	15.752178
17.8293	43.55	0.4723	**4.97**	1.38		
19.863	204.52	0.1968	**4.47**	6.49		
20.9078	555.65	0.0984	**4.25**	17.62		
22.0299	60.97	0.4723	**4.03**	1.93		
22.941	78.73	0.3149	**3.88**	2.5		
25.5558	156.76	0.1574	**3.49**	4.97	Chlorite (100%)	24.674024
26.6952	3152.96	0.1378	**3.34**	100	Quartz (100%)	434.477888
27.978	336.46	0.1574	**3.19**	10.67	Albite (100%)	52.958804
						549.449212

Soil 8: Rajbandh 9 ft-18 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2752	77.94	0.551	**14.09**	3.27	Chlorite-Vermiculite (100%)	42.94494
9.0073	288.73	0.0984	**9.82**	12.11		
12.6337	139.78	0.1574	**7.01**	5.86	Chlorite-Surpentine (100%)	22.001372
17.9063	139.52	0.1181	**4.95**	5.85		
19.8829	114.23	0.3149	**4.47**	4.79	Illite (100%)	35.971027
20.969	329.33	0.0984	**4.24**	13.81		
22.108	62.71	0.1181	**4.02**	2.63		
25.2645	121.24	0.2362	**3.53**	5.08		
26.7431	2384.41	0.0984	**3.33**	100	Quartz (100%)	234.625944
28.081	155.03	0.1574	**3.18**	6.5		
						335.543283

Soil 9: Rajbandh 18 ft-21 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.162	42.01	0.4723	**14.34**	1.19		
8.9179	166.96	0.1378	**9.92**	4.73	Illite (100%)	23.007088
12.5702	134.22	0.1574	**7.04**	3.8	Chlorite-Surpentine (100%)	21.126228
17.8489	77.83	0.1181	**4.97**	2.21		
19.8582	126.47	0.2362	**4.47**	3.58		
20.9661	556.31	0.1574	**4.24**	15.77		
22.1001	80.9	0.1181	**4.02**	2.29		
22.9638	84.37	0.2362	**3.87**	2.39		
23.6014	82.49	0.1181	**3.77**	2.34		
24.322	58.96	0.2362	**3.66**	1.67		
25.5502	133.66	0.1181	**3.49**	3.79	Chlorite (100%)	15.785246
26.6919	3528.42	0.1378	**3.34**	100	Quartz (100%)	486.216276
27.9456	369.6	0.2362	**3.19**	10.47	Albite (100%)	87.29952
29.5016	55.85	0.1181	**3.03**	1.58	Montomorollonite (100%)	6.595885
						640.030243

Soil 10: Rajbandh 21 ft- 33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2501	96.49	0.2362	**14.14**	1.9	Vermiculite (100%)	22.790938
8.9868	485.68	0.0787	**9.84**	9.59		
12.6309	271.29	0.1181	**7.01**	5.35	Chlorite-Surpentine (100%)	32.039349
17.9263	193.79	0.1378	**4.95**	3.83		
18.909	103.42	0.1181	**4.69**	2.04	Illite (100%)	12.213902
19.9293	212.31	0.1968	**4.46**	4.19		
20.9756	757.88	0.0984	**4.24**	14.96		
22.1282	142.54	0.1574	**4.02**	2.81		
22.9892	105.85	0.1968	**3.87**	2.09		
23.8742	85.12	0.6298	**3.73**	1.68		
25.2658	227.94	0.1378	**3.53**	4.5	Chlorite (100%)	24.57245
25.605	197.32	0.1181	**3.48**	3.89		
26.7315	5066.53	0.1378	**3.33**	100	Quartz (100%)	698.167834
28.0128	470.08	0.1181	**3.19**	9.28	Albite (100%)	55.516448
						845.300921

Soil 11: Samanta sena 0-3 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.998	148.44	0.3149	**14.74**	2.74		
8.9436	375.01	0.0787	**9.89**	6.91		
12.619	154.22	0.0787	**7.01**	2.84	Chlorite-Surpentine (100%)	12.137114
17.8735	224.99	0.059	**4.96**	4.15		
19.882	156.37	0.1574	**4.47**	2.88	Illite (100%)	24.612638
20.927	993.54	0.0984	**4.25**	18.31		
22.0205	353.96	0.0984	**4.04**	6.52		
23.05	89.72	0.2362	**3.86**	1.65		
24.0284	97.98	0.6298	**3.70**	1.81		
25.251	187.22	0.1181	**3.53**	3.45	Chlorite (100%)	22.110682
25.5989	226.92	0.1574	**3.48**	4.18		
26.7027	5426.17	0.1181	**3.34**	100	Quartz (100%)	640.830677
28.00	373.5	0.2755	**3.19**	6.88	Albite (100%)	102.89925
29.5283	521.85	0.1181	**3.03**	9.62	Montomorollonite (100%)	61.630485
						864.220846

Soil 12: Samanta sena 3 ft- 9 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.0128	204.45	0.1181	**14.70**	2.68		
8.952	605.48	0.0787	**9.88**	7.94		
12.5728	202.35	0.059	**7.04**	2.65	Chlorite-Surpentine (100%)	11.93865
17.8698	304.8	0.0984	**4.96**	4		
18.8792	87.17	0.1181	**4.70**	1.14		
19.8898	105.46	0.3149	**4.46**	1.38	Illite (100%)	33.209354
20.9336	1310.35	0.0984	**4.24**	17.18		
22.114	181.52	0.0787	**4.02**	2.38		
23.7146	34.53	0.2362	**3.75**	0.45		
25.2309	140.71	0.1181	**3.53**	1.84	Chlorite(100%)	16.617851
25.5463	123.05	0.1574	**3.49**	1.61		
26.1464	154.76	0.0787	**3.41**	2.03		
26.6907	7628.7	0.1181	**3.34**	100	Quartz (100%)	900.94947
26.9215	815.53	0.059	**3.31**	10.69		
28.1061	486.74	0.0787	**3.17**	6.38		
29.5301	80.48	0.1181	**3.02**	1.05	Montomorollonite (100%)	9.504688
						972.220013

Soil 13: Samanta sena 9 ft-12 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.0951	181.72	0.1574	**14.50**	2.97		
8.9589	932.06	0.0787	**9.87**	15.24		
12.5928	227.41	0.0984	**7.03**	3.72	Chlorite-Surpentine (100%)	22.377144
17.8721	402.36	0.0984	**4.96**	6.58		
18.8708	80.47	0.1181	**4.70**	1.32		
19.9483	108.16	0.1574	**4.45**	1.77		
20.9287	1523.2	0.0984	**4.24**	24.9		
24.3088	62.76	0.2362	**3.66**	1.03		
25.2482	156	0.1181	**3.53**	2.55	Chlorite(100%)	18.4236
26.7011	6117.17	0.1181	**3.34**	100	Quartz (100%)	722.437777
26.9061	1330.08	0.0787	**3.31**	21.74	Illite (100%)	97.30786
27.5199	168.95	0.1181	**3.24**	2.76		
27.9836	440.33	0.1181	**3.19**	7.2	Albite (100%)	52.002973
29.5319	199.28	0.0984	**3.02**	3.26	Montomorollonite (100%)	19.609152
						932.158506

Soil 14: Samanta sena 12 ft-15 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1518	83.32	0.3149	**14.37**	1.34		
8.9474	270.53	0.1378	**9.88**	4.33		
12.5719	120.98	0.1574	**7.04**	1.94	Chlorite-Surpentine (100%)	19.042252
17.8373	154.5	0.1574	**4.97**	2.48		
19.8482	110.63	0.2362	**4.47**	1.77	Illite (100%)	26.130806
20.9338	1133.08	0.1181	**4.24**	18.16		
22.1338	180.9	0.0984	**4.02**	2.9		
23.0225	79.48	0.2362	**3.86**	1.27		
23.8958	849.91	0.0984	**3.72**	13.62		
24.3568	163.9	0.1574	**3.65**	2.63		
25.2167	154.66	0.1181	**3.53**	2.48	Chlorite (100%)	18.265346
25.6605	163.26	0.2362	**3.47**	2.62		
26.6915	6240.61	0.1378	**3.34**	100	Quartz (100%)	859.956058
28.0127	434.8	0.1574	**3.19**	6.97	Albite (100%)	68.43752
29.4755	293.62	0.1771	**3.03**	4.71	Montomorollonite (100%)	52.000102
						1043.832084

Soil 15 Samanta sena 15 ft-18 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.0877	165.29	0.1574	14.52	1.95		
8.9688	597.99	0.1574	9.86	7.06		
12.609	244.98	0.0787	7.02	2.89	Chlorite-Surpentine (100%)	19.279926
13.7842	91.2	0.1181	6.42	1.08		
17.8832	299.85	0.0984	4.96	3.54		
18.8711	88.29	0.2362	4.70	1.04		
19.9331	151.04	0.1968	4.45	1.78		
20.9417	1368.92	0.0984	4.24	16.16		
22.114	85.97	0.2362	4.02	1.02		
23.0662	134.68	0.2362	3.86	1.59		
24.338	213.09	0.1181	3.66	2.52		
25.2545	273.02	0.0787	3.53	3.22	Chlorite (100%)	21.486674
25.6756	208	0.2362	3.47	2.46		
26.7113	6452.59	0.1181	3.34	76.19	Quartz (100%)	762.050879
26.9289	1154.32	0.059	3.31	13.63	Illite (100%)	68.10488
27.6303	8469.09	0.1378	3.23	100	K feldspar (100%)	1167.040602
28.0458	490.61	0.1574	3.18	5.79		
29.5163	381.15	0.0787	3.03	4.5	Montomorollonite (100%)	29.996505
						2067.959466

Soil 16 Samanta sena 18 ft-33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1552	49.21	0.4723	14.36	0.69		
8.9236	366.01	0.059	9.91	5.15	Illite (100%)	21.59459
9.587	73.63	0.551	9.23	1.04		
12.5722	92.42	0.1574	7.04	1.3	Chlorite-Surpentine (100%)	14.546908
17.8128	180.61	0.059	4.98	2.54		
19.8896	74.21	0.3149	4.46	1.04		
20.9043	1672.24	0.0984	4.25	23.52		
22.101	203.52	0.0984	4.02	2.86		
23.2048	158.1	0.0787	3.83	2.22		
25.1965	142	0.1181	3.53	2	Chlorite (100%)	23.95742857
25.5368	626.3	0.0984	3.49	8.81		
26.6681	7110.01	0.1181	3.34	100	Quartz (100%)	839.692181
28.0898	898.8	0.059	3.18	12.64		
29.4409	119.57	0.1574	3.03	1.68	Montomorollonite (100%)	18.820318
						918.6114256

Soil 17 KUET Campus 0-3 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2046	26.17	0.6298	14.25	0.52		
8.9327	155.76	0.1574	9.90	3.09	Illite (100%)	24.516624
12.5577	31.58	0.4723	7.05	0.63	Kaolinite (100%)	14.915234
17.8654	104.94	0.1181	4.97	2.08		
19.9097	113.81	0.2755	4.46	2.26		
20.913	1763.54	0.1181	4.25	34.98		
22.1115	92.11	0.1968	4.02	1.83		
25.581	68.39	0.3149	3.48	1.36	Chlorite (100%)	21.536011
26.6885	5041.21	0.1181	3.34	100	Quartz (100%)	595.366901
27.9068	346.83	0.1574	3.20	6.88	Albite (100%)	68.2388025
						724.5735725

Soil 18 KUET Campus 6 ft - 12 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.0661	261.97	0.1574	**14.57**	2.67		
8.9705	571.8	0.0787	**9.86**	5.82		
12.5998	235.33	0.0787	**7.03**	2.4	Chlorite-Surpentine (100%)	18.520471
17.874	284.94	0.0787	**4.96**	2.9		
19.8585	86.34	0.3149	**4.47**	0.88	Illite (100%)	27.188466
20.9374	1368.38	0.0984	**4.24**	13.94		
22.1207	114.32	0.1574	**4.02**	1.16		
23.0318	55.76	0.2362	**3.86**	0.57		
23.6197	72.58	0.1574	**3.77**	0.74		
24.3041	43.2	0.2362	**3.66**	0.44		
25.2299	136.23	0.1181	**3.53**	1.39	Chlorite (100%)	22.98394714
25.6958	108.93	0.1968	**3.47**	1.11		
26.7049	9817.23	0.1378	**3.34**	100	Quartz (100%)	1352.814294
27.5946	292.51	0.059	**3.23**	2.98	K-feldspar (100%)	17.25809
27.8166	262.58	0.059	**3.21**	2.67	Albite (100%)	19.365275
28.0584	415.8	0.059	**3.18**	4.24		
29.473	68.16	0.1574	**3.03**	0.69	Montomorollonite (100%)	10.728384
						1468.858927

Soil 19 KUET Campus 12 ft-21 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2291	79.18	0.4723	**14.19**	1.47	Vermiculite (100%)	37.396714
8.9739	343.55	0.1378	**9.85**	6.37		
12.5761	150.66	0.1181	**7.04**	2.79	Chlorite-Surpentine (100%)	17.792946
17.8677	191.98	0.1181	**4.96**	3.56		
19.917	136.93	0.2362	**4.46**	2.54		
20.9452	800.53	0.1378	**4.24**	14.83		
22.0891	198.8	0.1181	**4.02**	3.68		
22.9651	75.76	0.2362	**3.87**	1.4		
23.6287	122.8	0.1181	**3.77**	2.28		
24.3796	145.03	0.1574	**3.65**	2.69		
25.2156	148.42	0.1181	**3.53**	2.75	Chlorite- (100%)	17.528402
25.5629	207	0.1181	**3.48**	3.84		
26.7031	5396.5	0.1378	**3.34**	100	Quartz (100%)	743.6377
27.5674	298.96	0.0984	**3.24**	5.54	K-feldspar (100%)	29.417664
28.0089	307.63	0.1181	**3.19**	5.7	Albite (100%)	36.331103
						882.104529

Soil 20 KUET Campus -21 ft-33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1085	193.23	0.1968	**14.47**	3.28		
8.9454	718.76	0.0984	**9.89**	12.2		
12.5935	253.34	0.1181	**7.03**	4.3	Chlorite-Surpentine (100%)	29.919454
17.8518	337.14	0.1181	**4.97**	5.72		
18.8766	120.35	0.1181	**4.70**	2.04		
19.8433	162.59	0.1968	**4.47**	2.76	Illite (100%)	31.997712
20.917	1538.34	0.0984	**4.25**	26.11		
22.0669	178.1	0.1181	**4.03**	3.02		
23.0291	134.22	0.1968	**3.86**	2.28		
23.5999	160.03	0.1181	**3.77**	2.72		
24.3025	173.43	0.1574	**3.66**	2.94		
25.2395	320.46	0.1378	**3.53**	5.44	Chlorite (100%)	44.159388
26.6856	5891.97	0.1181	**3.34**	100	Quartz (100%)	695.841657
27.9943	615.08	0.1378	**3.19**	10.44	Albite (100%)	84.758024
29.4945	253.97	0.1378	**3.03**	4.31	Montomorollonite (100%)	34.997066
						921.673301

Clay 1 Fultala 0-4.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.114	540.2	0.4723	**14.46**	19.22		
8.8918	784.06	0.1378	**9.95**	27.89	Illite (100%)	108.043468
12.5207	656.71	0.0984	**7.07**	23.36	Kaolinite (100%)	64.620264
17.7922	773.37	0.1378	**4.99**	27.51		
18.8087	253.59	0.1574	**4.72**	9.02		
20.8858	439.73	0.1181	**4.25**	15.64		
25.1302	680.46	0.0787	**3.54**	24.21	Chlorite (100%)	53.552202
26.6377	2810.91	0.0984	**3.35**	100	Quartz (100%)	276.593544
27.8418	233.47	0.2755	**3.20**	8.31	Albite (100%)	64.320985
29.4607	325.97	0.1968	**3.03**	11.6	Montomirollonite (100%)	64.150896
						631.281359

Clay 2 Fultala 4.5 ft-6.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.179	95.51	0.7872	**17.06**	2.74		
6.3073	131.97	0.2755	**14.01**	3.79	Chlorite -Vermiculite(100%)	36.357735
8.9381	547.74	0.1181	**9.89**	15.73		
12.5669	427.18	0.0984	**7.04**	12.27	Chlorite- Surpentine (100%)	42.034512
17.8526	321.1	0.1181	**4.97**	9.22		
18.8578	173.11	0.1181	**4.71**	4.97		
19.9413	45.99	0.4723	**4.45**	1.32		
20.9264	553.18	0.0984	**4.25**	15.89		
25.2554	405.96	0.1378	**3.53**	11.66		
26.6917	3481.12	0.0984	**3.34**	100	Quartz (100%)	342.542208
27.9874	201.19	0.1574	**3.19**	5.78	Albite (100%)	31.667306
29.5194	145.6	0.1574	**3.03**	4.18	Montomirollonite (100%)	22.91744
						475.519201

Clay 3 Fultala -6.5 ft-16.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2078	230.06	0.2362	**14.24**	6.14		
8.8903	491.94	0.1181	**9.95**	13.13	Illite (100%)	58.098114
12.5493	412.06	0.0787	**7.05**	11	Kaolinite (100%)	32.429122
17.7819	393.82	0.1181	**4.99**	10.51		
18.8127	216.21	0.1574	**4.72**	5.77		
19.8439	106.47	0.2755	**4.47**	2.84		
20.8862	526.72	0.0984	**4.25**	14.06		
22.0703	123.26	0.1574	**4.03**	3.29		
23.6612	129.9	0.3149	**3.76**	3.47		
25.2107	516.43	0.1771	**3.53**	13.79	Chlorite (100%)	304.8658433
26.675	3746.21	0.1378	**3.34**	100	Quartz (100%)	516.227738
27.9614	372.06	0.2362	**3.19**	9.93	Albite (100%)	109.850715
29.438	407.91	0.1378	**3.03**	10.89	Montomirollonite (100%)	56.209998
						1077.68153

Clay 4 Fultala 16.5 ft-23 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2143	302.49	0.2755	**14.22**	8.22		
8.8701	652.62	0.1378	**9.97**	17.74	Illite (100%)	89.931036
12.5118	615.58	0.0984	**7.07**	16.73	Kaolinite (100%)	60.573072
17.7946	516.96	0.1574	**4.98**	14.05		
18.7806	268.92	0.1574	**4.73**	7.31		
19.7278	71.46	0.4723	**4.50**	1.94	Montomirollonite (100%)	33.750558
20.8657	598.43	0.0984	**4.26**	16.26		
21.9978	62	0.2362	**4.04**	1.69		
25.1509	706.8	0.1378	**3.54**	19.21	Chlorite (100%)	139.1386286
26.6276	3679.36	0.0984	**3.35**	100	Quartz (100%)	362.049024
26.8416	1322.96	0.0787	**3.32**	35.96		
27.9016	333.39	0.1574	**3.20**	9.06	Albite (100%)	65.5944825
29.4493	316.51	0.0787	**3.03**	8.6		
						751.0368011

Clay 5 Fultala 23 ft-33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2473	366.42	0.1968	**14.15**	11.48	Chlorite -Vermiculite(100%)	72.111456
8.9206	683.04	0.1771	**9.91**	21.4	Illite (100%)	120.966384
12.5424	702.41	0.0787	**7.06**	22	Kaolinite (100%)	55.279667
17.8318	574.54	0.1378	**4.97**	18		
18.8221	305.29	0.1574	**4.71**	9.56		
19.8819	93.03	0.3149	**4.47**	2.91		
20.9033	475.35	0.0984	**4.25**	14.89		
25.1986	731.65	0.0984	**3.53**	22.92		
26.6667	3192.44	0.1181	**3.34**	100	Quartz (100%)	377.027164
26.8795	1336.36	0.0984	**3.32**	41.86		
27.9485	311.11	0.1574	**3.19**	9.75	Albite (100%)	48.968714
29.4661	321.4	0.1181	**3.03**	10.07	Montomirollonite (100%)	37.95734
						712.310725

Clay 6 Rajbandh 0-6 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.25	369.74	0.2755	**14.14178**	10.3	Chlorite +Vermi(100%)	101.86337
8.8982	836.19	0.1181	**9.94**	23.29	Illite (100%)	98.754039
12.5413	605.18	0.0787	**7.06**	16.86	Kaolinite (100%)	47.627666
17.8438	547.99	0.1574	**4.97**	15.26		
18.8409	227.84	0.1181	**4.71**	6.35		
19.8514	96.6	0.3149	**4.47**	2.69		
20.901	593.2	0.1181	**4.25**	16.52		
25.1753	608.27	0.1181	**3.54**	16.94	Chlorite (100%)	102.6238386
26.6672	3589.85	0.0787	**3.34**	100	Quartz (100%)	282.521195
26.8785	1452.22	0.0787	**3.32**	40.45		
27.9651	299.69	0.1181	**3.19**	8.35	Albite (100%)	28.3147112
						559.8414498

Clay 7 Rajbandh -6 ft -9 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2109	184.12	0.1574	**14.23**	4.47		
8.8835	773.25	0.1181	**9.95**	18.76	Illite (100%)	91.320825
11.6172	113.88	0.0984	**7.62**	2.76		
12.5157	454.27	0.0984	**7.07**	11.02	Kaolinite (100%)	44.700168
17.7771	445.48	0.0984	**4.99**	10.81		
18.8097	179.67	0.1574	**4.72**	4.36		
19.8804	88.18	0.2755	**4.47**	2.14		
20.8704	761.04	0.1181	**4.26**	18.47		
22.0362	95.32	0.1574	**4.03**	2.31		
23.5852	86.74	0.2362	**3.77**	2.1		
25.1548	448.95	0.1378	**3.54**	10.89	Chlorite (100%)	61.86531
26.6328	4120.7	0.1181	**3.35**	100	Quartz (100%)	486.65467
27.97	299.36	0.1378	**3.19**	7.26	Albite (100%)	41.251808
						725.792781

Clay 8 Rajbandh -9 ft-18 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	min.identification	Height* FWHM
6.2765	158.76	0.1574	**14.08**	3.19	Chlorite -Vermiculite(100%)	24.988824
8.8942	664.36	0.1181	**9.94**	13.36	Illite (100%)	78.460916
11.6528	4972.09	0.0787	**7.59**	100		
12.5724	441.35	0.0984	**7.04**	8.88	Chlorite- Surpentine (100%)	43.42884
17.8173	457.41	0.1574	**4.98**	9.2		
18.863	213.05	0.1968	**4.70**	4.28		
19.779	112.8	0.3149	**4.49**	2.27	Montomirollonite (100%)	35.52072
20.9131	509	0.0984	**4.25**	10.24		
23.4054	176.58	0.2362	**3.80**	3.55		
25.235	498.89	0.1574	**3.53**	10.03		
26.6735	2656.34	0.0984	**3.34**	53.42	Quartz (100%)	261.383856
26.8871	1455.87	0.0787	**3.32**	29.28		
27.9851	375.49	0.2362	**3.19**	7.55	Albite (100%)	88.690738
29.1508	290.38	0.1181	**3.06**	5.84		
						532.473894

Clay 9 Rajbandh -18 ft-21 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2076	257.19	0.1968	**14.24**	5.23		
8.8661	985.76	0.1181	**9.97**	20.06	Illite (100%)	116.418256
11.572	277.09	0.059	**7.65**	5.64		
12.51	783.3	0.0787	**7.08**	15.94	Kaolinite (100%)	61.64571
17.7732	553.71	0.1181	**4.99**	11.27		
18.7891	285.83	0.1771	**4.72**	5.82		
19.7848	106.54	0.3149	**4.49**	2.17	Montomirollonite (100%)	33.549446
20.858	878.32	0.0984	**4.26**	17.88		
22.0388	102.25	0.1181	**4.03**	2.08		
25.1836	646.86	0.1181	**3.54**	13.17	Chlorite (100%)	76.394166
26.6291	4913.06	0.1181	**3.35**	100	Quartz (100%)	580.232386
26.841	1577.24	0.0787	**3.32**	32.1		
27.908	516.35	0.0787	**3.20**	10.51	Albite (100%)	50.79593125
29.4549	163.77	0.1574	**3.03**	3.33		
						919.0358953

Clay 10 Rajbandh 21 ft-33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2475	197.08	0.1181	**14.15**	3.7	Vermi(100%)	23.275148
8.8906	938.25	0.1181	**9.95**	17.64	Illite (100%)	110.807325
11.5919	92.43	0.1574	**7.63**	1.74		-
12.5318	637.46	0.0984	**7.06**	11.98	Kaolinite (100%)	62.726064
17.8237	516.3	0.1181	**4.98**	9.71		
18.8461	252.19	0.1181	**4.71**	4.74		
19.8379	115.57	0.2362	**4.48**	2.17	Montomirollonite (100%)	27.297634
20.8749	845.16	0.1181	**4.26**	15.89		
22.0578	123.69	0.1181	**4.03**	2.33		
23.6206	104.85	0.2362	**3.77**	1.97		
25.1685	601.25	0.0984	**3.54**	11.3	Chlorite (100%)	77.53
26.6584	5319.7	0.1181	**3.34**	100	Quartz (100%)	628.25657
26.8645	1600.22	0.059	**3.32**	30.08		
27.5043	225.11	0.1181	**3.24**	4.23	K Feldspar	26.585491
27.9662	480.41	0.1574	**3.19**	9.03	Albite (100%)	75.616534
						1032.094766

Clay 11 Samanta sena 0-3 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1276	233.65	0.4723	**14.42**	6.95		
8.8909	417.94	0.0984	**9.95**	12.43	Illite (100%)	41.125296
12.5284	330.31	0.1378	**7.07**	9.82	Kaolinite (100%)	45.516718
17.7913	397.46	0.1378	**4.99**	11.82		
18.8269	195.05	0.059	**4.71**	5.8		
19.826	95.79	0.2362	**4.48**	2.85	Montomirollonite (100%)	22.625598
20.8851	681.7	0.1181	**4.25**	20.28		
25.1898	305.65	0.1181	**3.54**	9.09	Chlorite (100%)	36.097265
26.6572	3362.15	0.0984	**3.34**	100	Quartz (100%)	330.83556
27.954	292	0.1181	**3.19**	8.69	Albite (100%)	34.4852
29.4707	212.17	0.1574	**3.03**	6.31		
						510.685637

Clay 12 Samanta sena 3 ft- 9 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2187	315.91	0.2362	**14.21**	7.64		
8.8724	495.17	0.1378	**9.97**	11.97	Illite (100%)	68.234426
12.5043	447.14	0.0787	**7.08**	10.81	Kaolinite (100%)	35.189918
17.7692	413	0.1574	**4.99**	9.99		
18.8109	165.98	0.1574	**4.72**	4.01		
19.7575	55.97	0.3936	**4.49**	1.35	Montomirollonite (100%)	22.029792
20.8674	654.82	0.0984	**4.26**	15.84		
25.1807	403.92	0.1181	**3.54**	9.77		
26.6376	4135.11	0.0984	**3.35**	100	Quartz (100%)	406.894824
27.4591	89.17	0.1574	**3.25**	2.16	K Feldspar	14.035358
27.9299	263.13	0.1574	**3.19**	6.36	Albite (100%)	41.416662
						587.80098

Clay 13 Samanta sena 9 ft- 12 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2169	448.24	0.2362	**14.22**	15.4		
8.8763	670.01	0.1181	**9.96**	23.02	Illite (100%)	79.128181
12.5195	566.65	0.0787	**7.07**	19.47	Kaolinite (100%)	44.595355
17.7669	521.06	0.0787	**4.99**	17.9		
18.7707	202.34	0.1574	**4.73**	6.95		
19.7912	55.65	0.4723	**4.49**	1.91	Montomirollonite (100%)	26.283495
20.8512	464.06	0.0984	**4.26**	15.95		
25.1602	496.4	0.1181	**3.54**	17.06	Chlorite (100%)	58.62484
26.6288	2910.34	0.0984	**3.35**	100	Quartz (100%)	286.377456
26.8353	1139.3	0.059	**3.32**	39.15		
27.9339	175.09	0.1968	**3.19**	6.02	Albite (100%)	34.457712
29.4661	199.84	0.1574	**3.03**	6.87		
						529.467039

Clay 14 Samanta sena 12 ft- 15 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.203	355.42	0.1968	**14.25**	11.26		
8.9233	720.39	0.1378	**9.91**	22.82	Illite (100%)	99.269742
12.5499	644.65	0.1378	**7.05**	20.42	Kaolinite (100%)	88.83277
17.8081	560.4	0.1574	**4.98**	17.75		
18.841	260.1	0.1574	**4.71**	8.24		
19.8123	65.28	0.3149	**4.48**	2.07	Montomirollonite (100%)	20.556672
20.9122	331.64	0.1181	**4.25**	10.5		
25.1986	590.75	0.0787	**3.53**	18.71	Chlorite (100%)	66.41717857
26.6792	3157.11	0.1181	**3.34**	100	Quartz (100%)	372.854691
27.9821	199.48	0.1378	**3.19**	6.32	Albite (100%)	34.36043
29.5069	167.59	0.1574	**3.03**	5.31		
						682.2914836

Clay 15 Samanta sena 15 ft -18 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2261	326.78	0.1574	**14.20**	10.65	Vermi(100%)	51.435172
8.8756	696.67	0.0984	**9.96**	22.7	Illite (100%)	68.552328
12.533	542.82	0.0984	**7.06**	17.68	Kaolinite (100%)	53.413488
17.7952	513.83	0.1181	**4.98**	16.74		
18.7739	209.07	0.1968	**4.73**	6.81		
19.8079	76.07	0.2362	**4.48**	2.48	Montomirollonite (100%)	17.967734
20.8744	454.22	0.1181	**4.26**	14.8		
25.1769	471.54	0.1378	**3.54**	15.36	Chlorite (100%)	64.978212
26.6394	3069.47	0.0984	**3.35**	100	Quartz (100%)	302.035848
27.9106	219.77	0.1378	**3.20**	7.16	Albite (100%)	30.284306
29.4611	162.96	0.1574	**3.03**	5.31		588.667088

Clay 16 Samanta sena 18 ft- 33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.097	223.95	0.1968	**14.50**	6.54		
8.7521	719.85	0.0984	**10.10**	21.01		
12.3754	557.73	0.1181	**7.15**	16.28	Kaolinite (100%)	65.867913
17.6668	413.74	0.1181	**5.02**	12.08		
18.6849	233.17	0.1181	**4.75**	6.81		
19.7148	93.57	0.4723	**4.50**	2.73	Montomirollonite (100%)	44.193111
20.7574	603.66	0.0984	**4.28**	17.62		
21.9286	106.96	0.2362	**4.05**	3.12		
23.4641	139.8	0.1181	**3.79**	4.08		
25.0529	582.02	0.1181	**3.55**	16.99	Chlorite (100%)	68.736562
26.5291	3426.33	0.0984	**3.36**	100	Quartz (100%)	337.150872
26.732	1291.83	0.059	**3.33**	37.7		
27.3746	254.78	0.1574	**3.26**	7.44	K Feldspar	40.102372
27.8305	375.01	0.1574	**3.21**	10.94	Albite (100%)	59.026574
29.3465	325.9	0.059	**3.04**	9.51		
						615.077404

Clay 17 KUET CAMPUS 0-3 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1885	395.45	0.2755	**14.28**	11.36		
8.8459	908.71	0.0984	**10.00**	26.11	Illite (100%)	89.417064
12.5241	581.04	0.0984	**7.07**	16.7	Kaolinite (100%)	57.174336
17.7856	514.58	0.1574	**4.99**	14.79		
18.7892	276.86	0.0787	**4.72**	7.96		
20.8545	599.85	0.0984	**4.26**	17.24		
25.1566	494.24	0.1181	**3.54**	14.2	Chlorite (100%)	83.38534857
26.6293	3479.86	0.1181	**3.35**	100	Quartz (100%)	410.971466
26.8271	1526.95	0.0984	**3.32**	43.88		
27.9256	319.53	0.1574	**3.20**	9.18	Albite (100%)	62.8675275
						703.8157421

Clay 18 KUET CAMPUS 6 ft - 12 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1501	263.9	0.3936	**14.37**	5.87		
8.8725	650.03	0.0787	**9.97**	14.45	Illite (100%)	51.157361
12.5217	487.28	0.0984	**7.07**	10.83	Kaolinite (100%)	47.948352
17.7731	438.16	0.0787	**4.99**	9.74		
18.8072	181.41	0.0984	**4.72**	4.03		
19.8142	100.31	0.3149	**4.48**	2.23	Montomirollonite (100%)	31.587619
20.8735	738.65	0.1378	**4.26**	16.42		
25.1373	448.98	0.1181	**3.54**	9.98	Chlorite (100%)	75.74934
26.6411	4498.36	0.0984	**3.35**	100	Quartz (100%)	442.638624
27.9654	330.42	0.0787	**3.19**	7.35	Albite (100%)	32.5050675
29.4298	247.9	0.1181	**3.04**	5.51		
						681.5863635

Clay 19 KUET CAMPUS 12 ft -21 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2674	258.95	0.1181	**14.10**	5.91	Chlorite -Vermiculite(100%)	30.581995
8.9263	807.59	0.0984	**9.91**	18.44	Illite (100%)	79.466856
11.5815	318.08	0.059	**7.64**	7.26		
12.5681	719.64	0.1181	**7.04**	16.44	Chlorite- Surpentine (100%)	84.989484
17.8355	493.35	0.1181	**4.97**	11.27		
18.8866	214.45	0.1378	**4.70**	4.9		
19.8395	107.22	0.2362	**4.48**	2.45	Montomirollonite (100%)	25.325364
20.9123	740.93	0.1181	**4.25**	16.92		
22.0702	79.62	0.1181	**4.03**	1.82		
25.2097	637.06	0.1181	**3.53**	14.55		
26.6793	4378.39	0.0984	**3.34**	100	Quartz (100%)	430.833576
26.8881	1521.34	0.059	**3.32**	34.75		
27.5303	216.49	0.1181	**3.24**	4.94	K Feldspar	25.567469
27.9931	393.11	0.2362	**3.19**	8.98	Albite (100%)	92.852582
						769.617326

Clay 20 KUET CAMPUS 21 ft -33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2393	232.57	0.1574	**14.17**	6.15	Vermiculite (100%)	36.606518
8.9045	710.68	0.1378	**9.93**	18.81	Illite (100%)	97.931704
11.5917	67.43	0.2362	**7.63**	1.78		
12.5558	597.62	0.1181	**7.05**	15.82	Chlorite- Surpentine (100%)	70.578922
17.8058	454.35	0.1181	**4.98**	12.02		
18.8705	187.48	0.1378	**4.70**	4.96		
20.906	548.79	0.0984	**4.25**	14.52		
25.1973	647.13	0.1181	**3.53**	17.13	Chlorite (100%)	98.198
26.6653	3778.76	0.0984	**3.34**	100	Quartz (100%)	371.829984
27.9505	319.83	0.1968	**3.19**	8.46	Albite (100%)	62.942544
29.0908	77.71	0.1181	**3.07**	2.06	Montomirollonite (100%)	9.177551
29.51	131.78	0.1574	**3.03**	3.49		
						747.265223

Gly 1 Fultala 0-4.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.1299	200.87	0.6298	**17.23**	7.16		
6.2767	234.94	0.1574	**14.08**	8.38	Chlorite-Vermiculite (100%)	36.979556
8.9296	790.02	0.0787	**9.90**	28.17	Illite (100%)	62.174574
12.5726	526.09	0.1771	**7.04**	18.76	Chlorite- Surpentine (100%)	93.170539
17.8452	446.13	0.1378	**4.97**	15.91		
18.8649	206.31	0.1968	**4.70**	7.36		
20.9125	445.07	0.0787	**4.25**	15.87		
25.2124	497.1	0.0787	**3.53**	17.73		
26.6949	2804.17	0.0984	**3.34**	100	Quartz (100%)	275.930328
26.9023	1363.33	0.0984	**3.31**	48.62		
27.9617	135.73	0.2362	**3.19**	4.84	Albite (100%)	32.059426
29.4947	277.67	0.1574	**3.03**	9.9	Montomorollonite (100%)	43.705258
						544.019681

Gly 2 Fultala 4.5 ft-6.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.179	95.51	0.7872	**17.06**	2.74		
6.3073	131.97	0.2755	**14.01**	3.79	Chlorite-Vermiculite (100%)	36.357735
8.9381	547.74	0.1181	**9.89**	15.73	Illite (100%)	64.688094
12.5669	427.18	0.0984	**7.04**	12.27	Chlorite- Surpentine (100%)	42.034512
17.8526	321.1	0.1181	**4.97**	9.22		
18.8578	173.11	0.1181	**4.71**	4.97		
19.9413	45.99	0.4723	**4.45**	1.32		
20.9264	553.18	0.0984	**4.25**	15.89		
25.2554	405.96	0.1378	**3.53**	11.66		
26.6917	3481.12	0.0984	**3.34**	100	Quartz (100%)	342.542208
27.9874	201.19	0.1574	**3.19**	5.78	Albite (100%)	31.667306
29.5194	145.6	0.1574	**3.03**	4.18	Montomorollonite (100%)	22.91744
						540.207295

Gly 3 Fultala 6.5 ft- 16.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.1798	84.44	0.7872	**17.06**	2.38		
6.3231	117.79	0.2362	**13.98**	3.32	Chlorite-Vermiculite (100%)	27.821998
8.9951	326.77	0.0984	**9.83**	9.21		
12.6489	316.16	0.1574	**7.00**	8.91	Chlorite- Surpentine (100%)	49.763584
17.884	324.78	0.0984	**4.96**	9.16		
18.9448	119.14	0.2362	**4.68**	3.36		
19.9232	60.43	0.4723	**4.46**	1.7	Illite (100%)	28.541089
21.0016	417.44	0.0984	**4.23**	11.77		
25.2902	395.28	0.1574	**3.52**	11.14		
26.761	3547.1	0.1181	**3.33**	100	Quartz (100%)	418.91251
28.0856	312.72	0.1181	**3.18**	8.82		
29.6121	279.21	0.0787	**3.02**	7.87	Montomorollonite (100%)	21.973827
						547.013008

Gly 4 Fultala 16.5 ft-23 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.1131	136.28	0.6298	**17.28**	5.11		
6.2509	142.48	0.2755	**14.14**	5.34	Vermiculite (100%)	39.25324
8.9567	492.4	0.1378	**9.87**	18.46	Illite (100%)	67.85272
12.5885	443.52	0.0984	**7.03**	16.63	Chlorite- Surpentine (100%)	43.642368
17.8571	409.42	0.1574	**4.97**	15.35		
18.8868	216.44	0.1181	**4.70**	8.12		
19.9366	73.64	0.4723	**4.45**	2.76		
20.9495	460.64	0.0984	**4.24**	17.27		
25.2618	533.21	0.0984	**3.53**	19.99		
26.7064	2666.86	0.0984	**3.34**	100	Quartz (100%)	262.419024
26.9459	1078.27	0.059	**3.31**	40.43		
27.9763	255.18	0.1968	**3.19**	9.57	Albite (100%)	50.219424
29.54	223	0.1574	**3.02**	8.36	Montomorollonite (100%)	35.1002
						498.486976

Gly 5 Fultala 23 ft-33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.2374	97.21	0.6298	**16.87**	3.18		
6.3088	101.66	0.3149	**14.01**	3.32	Chlorite-Vermiculite (100%)	32.012734
8.9867	497.12	0.0984	**9.84**	16.24		
12.6316	519.14	0.1181	**7.01**	16.96	Chlorite- Surpentine (100%)	61.310434
17.8774	422.24	0.0787	**4.96**	13.8		
18.8976	176.39	0.1968	**4.70**	5.76		
19.9985	69.08	0.3149	**4.44**	2.26		
20.9835	469.06	0.1181	**4.23**	15.33		
25.2954	576.44	0.1574	**3.52**	18.83		
26.7464	3060.59	0.1181	**3.33**	100	Quartz (100%)	361.455679
28.0409	217.65	0.2755	**3.18**	7.11		
29.5549	241.56	0.1181	**3.02**	7.89	Montomorollonite (100%)	28.528236
						483.307083

Gly 6 Rajbandh 0-6 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.25	369.74	0.2755	**14.14**	10.3	Vermiculite (100%)	101.86337
5.042	78.07	0.9446	**17.53**	2.3		73.744922
6.3569	140.58	0.1968	**13.90**	4.15		
8.9723	727.08	0.0984	**9.86**	21.46	Illite (100%)	71.544672
12.6336	513.29	0.0787	**7.01**	15.15	Chlorite- Surpentine (100%)	40.395923
17.8895	454.78	0.1181	**4.96**	13.42		
18.9145	189.38	0.1181	**4.69**	5.59		
19.9053	69.97	0.2362	**4.46**	2.06		
20.9751	575.88	0.0787	**4.24**	16.99		
25.283	441.56	0.1574	**3.52**	13.03		
26.7508	3388.63	0.0984	**3.33**	100	Quartz (100%)	333.441192
26.963	1382.35	0.059	**3.31**	40.79		
28.0702	183.61	0.2755	**3.18**	5.42		
						620.990079

Gly 7 Rajbandh -6 ft -9 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2819	120.85	0.1574	**14.07**	3.19	Chlorite-Vermiculite (100%)	19.02179
8.9114	694.64	0.0787	**9.92**	18.34	Illite (100%)	54.668168
11.637	95.23	0.0787	**7.60**	2.51		
12.5539	434.33	0.0787	**7.05**	11.47	Kaolinite (100%)	34.181771
17.8173	387.55	0.1181	**4.98**	10.23		
18.8246	168.21	0.1181	**4.71**	4.44		
19.8541	116.91	0.2362	**4.47**	3.09		
20.9016	721.01	0.0984	**4.25**	19.04		
25.1943	439.75	0.0787	**3.53**	11.61		
26.6807	3786.66	0.0984	**3.34**	100	Quartz (100%)	372.607344
27.9754	298.55	0.2362	**3.19**	7.88	Albite (100%)	70.51751
						550.996583

Gly 8 Rajbandh -9 ft-18 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	min.identification	Height* FWHM
6.3704	68.86	0.3936	**13.87**	3.05		
9.0043	403.03	0.0787	**9.82**	17.87		
11.7453	513.19	0.0787	**7.53**	22.75		
12.6467	302.69	0.2755	**7.00**	13.42	Chlorite- Surpentine (100%)	83.391095
17.9478	267.33	0.1181	**4.94**	11.85		
18.9218	216.22	0.1181	**4.69**	9.59		
20.9749	486.11	0.1181	**4.24**	21.55		
23.6057	232.92	0.6298	**3.77**	10.33		
25.3062	532.67	0.1574	**3.52**	23.62		
26.7769	2255.36	0.1181	**3.33**	100	Quartz (100%)	266.358016
26.997	1055.59	0.0787	**3.30**	46.8		
28.0196	290.51	0.2362	**3.18**	12.88		
29.2436	206.51	0.1574	**3.05**	9.16	Montomorollonite (100%)	32.504674
						382.253785

Gly 9 Rajbandh -18 ft-21 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.337	141.86	0.1574	**13.95**	3.11	Chlorite-Vermiculite (100%)	22.328764
8.9922	828.37	0.1574	**9.83**	18.15		
12.6313	658.95	0.1181	**7.01**	14.43	Chlorite- Surpentine (100%)	77.821995
17.9097	449.27	0.1378	**4.95**	9.84		
18.9106	208.07	0.1574	**4.69**	4.56		
19.9338	62.34	0.4723	**4.45**	1.37	Illite (100%)	29.443182
20.9806	808.66	0.0787	**4.23**	17.71		
22.1626	90.86	0.1181	**4.01**	1.99		
25.273	603.5	0.1574	**3.52**	13.22		
26.7497	4565.12	0.1181	**3.33**	100	Quartz (100%)	539.140672
28.0504	417.69	0.1378	**3.18**	9.15		
29.5774	127.1	0.1574	**3.02**	2.78	Montomorollonite (100%)	20.00554
						688.740153

Gly 10 Rajbandh 21 ft-33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.3586	141.2	0.1181	13.90	2.91		
9.0201	745.91	0.0984	9.80	15.35		
12.6457	498.63	0.0984	7.00	10.26	Chlorite- Surpentine (100%)	49.065192
17.8986	429.74	0.1378	4.96	8.84		
18.9505	194.1	0.1378	4.68	3.99		
19.9325	68.71	0.2362	4.45	1.41	Illite (100%)	16.229302
20.9956	829.24	0.0984	4.23	17.06		
22.1677	87.57	0.1574	4.01	1.8		
25.3068	556.16	0.1181	3.52	11.44	Chlorite (100%)	65.682496
26.7684	4859.77	0.1181	3.33	100	Quartz (100%)	573.938837
28.0489	408.92	0.1378	3.18	8.41		
						704.915827

Gly 11 Samanta sena 0-3 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.3278	90.67	0.2362	13.97	2.61	Chlorite-Vermiculite (100%)	21.416254
9.0206	418.06	0.1574	9.80	12.02		
12.6346	335.58	0.0787	7.01	9.64	Chlorite- Surpentine (100%)	26.410146
17.8999	264.82	0.1574	4.96	7.61		
18.8976	100.37	0.1181	4.70	2.88		
19.9264	85.43	0.2362	4.46	2.46	Illite (100%)	20.178566
20.976	662.32	0.0787	4.24	19.04		
25.2805	311.53	0.1181	3.52	8.95		
26.7523	3479.38	0.0984	3.33	100	Quartz (100%)	342.370992
28.0439	331.44	0.1181	3.18	9.53		
29.5693	247.01	0.1181	3.02	7.1	Montomorollonite (100%)	29.171881
						439.547839

Gly 12 Samanta sena 3 ft- 9 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.1658	164.37	0.7872	17.11	4.13		
6.2784	161.32	0.2362	14.08	4.06	Chlorite-Vermiculite (100%)	38.103784
8.9935	453.25	0.1378	9.83	11.4		
12.6424	317.8	0.0984	7.00	7.99	Chlorite- Surpentine (100%)	31.27152
17.9052	404.42	0.0787	4.95	10.17		
18.9235	145.64	0.1181	4.69	3.66		
19.9381	73.23	0.4723	4.45	1.84		
20.9847	637.08	0.1181	4.23	16.02		
25.2989	436.67	0.1378	3.52	10.98		
26.7538	3977.14	0.0984	3.33	100	Quartz (100%)	391.350576
27.5784	183.59	0.1181	3.23	4.62	K feldspar	21.681979
28.0434	295.92	0.1574	3.18	7.44		
29.5794	99.33	0.1181	3.02	2.5	Montomorollonite (100%)	11.730873
						494.138732

Gly 13 Samanta sena 9 ft- 12 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spaci ing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.3817	373.08	0.3149	**16.42**	11.99		
6.2652	206.84	0.2362	**14.11**	6.65	Vermiculite (100%)	48.855608
8.9407	585.65	0.1181	**9.89**	18.82		
12.5595	563.03	0.1378	**7.05**	18.09	Kaolinite (100%)	77.585534
17.8653	400.61	0.0984	**4.97**	12.87		
18.8515	227.76	0.1574	**4.71**	7.32		
19.9021	65.89	0.4723	**4.46**	2.12	Illite (100%)	31.119847
20.9183	376.65	0.0787	**4.25**	12.1		
25.2726	495.88	0.1574	**3.52**	15.93	Chlorite (100%)	78.051512
26.7074	3112.43	0.0787	**3.34**	100	Quartz (100%)	244.948241
28.0051	216.33	0.1181	**3.19**	6.95		
29.5269	202.85	0.1574	**3.03**	6.52	Montomorollonite (100%)	31.92859
						512.489332

Gly 14 Samanta sena 12 ft- 15 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spaci ing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.2733	331.87	0.4723	**16.76**	10.79		
6.3537	203.13	0.2362	**13.91**	6.61		
9.0152	665.85	0.1181	**9.81**	21.66		
12.6622	573.96	0.0787	**6.99**	18.67	Chlorite- Surpentine (100%)	45.170652
17.95	446.94	0.1574	**4.94**	14.54		
18.9413	224.71	0.1378	**4.69**	7.31		
21.0001	413.62	0.1181	**4.23**	13.45		
25.3339	676.53	0.1378	**3.52**	22	Chlorite (100%)	133.1797629
26.7775	3074.68	0.0984	**3.33**	100	Albite (100%)	302.548512
28.0797	226	0.2362	**3.18**	7.35		
29.607	152.24	0.1574	**3.02**	4.95	Montomorollonite (100%)	23.962576
						504.8615029

Gly 15 Samanta sena 15 ft -18 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spaci ing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.1343	219.96	0.7872	**17.21**	7.03		
6.3011	164.07	0.2362	**14.03**	5.24	Chlorite-Vermiculite (100%)	38.753334
9.0012	527.84	0.0984	**9.82**	16.87		
12.6336	508.38	0.0787	**7.01**	16.25	Chlorite- Surpentine (100%)	40.009506
17.9013	392.78	0.1181	**4.96**	12.55		
18.9135	208.9	0.1574	**4.69**	6.68		
19.9151	62.9	0.4723	**4.46**	2.01	Illite (100%)	29.70767
20.9717	432.44	0.0984	**4.24**	13.82		
25.3036	551.19	0.1574	**3.52**	17.62		
26.7535	3128.91	0.0984	**3.33**	100	Quartz (100%)	307.884744
28.0517	280.23	0.1574	**3.18**	8.96		
29.5636	191.21	0.1574	**3.02**	6.11	Montomorollonite (100%)	30.096454
						446.451708

Gly 16 Samanta sena 18 ft- 33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1577	88.82	0.2362	14.35	2.92		
8.8373	414.88	0.0787	10.01	13.63	Illite(100%)	32.651056
12.4774	329.49	0.1574	7.09	10.82	Kaolinite (100%)	51.861726
17.7563	274.88	0.1181	5.00	9.03		
18.7217	122.12	0.2362	4.74	4.01		
20.8312	476.43	0.1181	4.26	15.65		
25.1519	361.62	0.0984	3.54	11.88	Chlorite (100%)	35.583408
26.6087	3043.99	0.0984	3.35	100	Quartz (100%)	299.528616
27.9116	277.7	0.1181	3.20	9.12	Albite (100%)	32.79637
29.4409	132.26	0.1968	3.03	4.35	Montomorollonite (100%)	26.028768
						478.449944

Gly 17 KUET CAMPUS 0-3 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
5.0827	183.07	0.7872	17.39	5.21		
6.2287	199.75	0.3149	14.19	5.68	Vermiculite (100%)	62.901275
8.9147	724.43	0.1181	9.92	20.62	Illite (100%)	85.555183
12.5528	463.83	0.0984	7.05	13.2	Kaolinite (100%)	45.640872
17.8834	362.7	0.1574	4.96	10.32		
18.8156	212.16	0.1378	4.72	6.04		
19.8549	73.59	0.4723	4.47	2.09		
20.9204	509.21	0.0984	4.25	14.49		
25.2656	442.37	0.1181	3.53	12.59	Chlorite (100%)	52.243897
26.6847	3513.83	0.0787	3.34	100	Quartz (100%)	276.538421
27.9907	252.81	0.2362	3.19	7.19	Albite (100%)	59.713722
						582.59337

Gly 18 KUET CAMPUS 6 ft - 12 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
4.9262	95.48	0.7872	17.94	2.25		
6.2796	143.74	0.3149	14.08	3.39	Chlorite-Vermiculite (100%)	45.263726
8.9821	524.14	0.0984	9.85	12.36		
12.6237	357.74	0.0984	7.01	8.43	Chlorite- Surpentine (100%)	35.201616
17.8882	375.55	0.0984	4.96	8.85		
18.8935	155.21	0.1181	4.70	3.66		
19.8845	91.83	0.2362	4.47	2.16	Illite (100%)	21.690246
20.9657	755.4	0.0984	4.24	17.81		
25.2583	426.86	0.1574	3.53	10.06		
26.7288	4241.98	0.0984	3.34	100	Quartz (100%)	417.410832
28.019	287.22	0.1968	3.18	6.77		
29.547	346.97	0.0984	3.02	8.18	Montomorollonite (100%)	34.141848
						553.708268

Gly 19 KUET CAMPUS 12 ft -21 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spaci ing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2975	160.79	0.2362	**14.04**	3.79	Chlorite-Vermiculite (100%)	37.978598
8.9391	731.01	0.0984	**9.89**	17.21		
11.6847	140.5	0.1181	**7.57**	3.31		
12.5889	566.92	0.1378	**7.03**	13.35	Chlorite- Surpentine (100%)	78.121576
17.8351	497.69	0.1181	**4.97**	11.72		
18.864	282.18	0.1181	**4.70**	6.64		
19.9366	91.2	0.3149	**4.45**	2.15	Illite (100%)	28.71888
20.9188	722.59	0.1181	**4.25**	17.01		
25.2436	616.81	0.1378	**3.53**	14.52		
26.6915	4247.55	0.0984	**3.34**	100	Quartz (100%)	417.95892
26.9014	1385.41	0.0787	**3.31**	32.62		
27.998	387.07	0.0787	**3.19**	9.11	Albite (100%)	30.462409
						593.240383

Gly 20 KUET CAMPUS 21 ft -33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spaci ing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.3654	145.35	0.1968	**13.89**	3.92	Chlorite (100%)	28.60488
8.977	660.71	0.1181	**9.85**	17.83		
12.6528	539.89	0.0984	**7.00**	14.57	Chlorite- Surpentine (100%)	53.125176
17.923	393.59	0.1181	**4.95**	10.62		
18.9328	195.34	0.1574	**4.69**	5.27		
19.869	94.85	0.3149	**4.47**	2.56	Illite (100%)	29.868265
20.9744	532.56	0.1181	**4.24**	14.37		
25.2911	618.88	0.1378	**3.52**	16.7		
26.7524	3705.52	0.0984	**3.33**	100	Quartz (100%)	364.623168
26.9548	1421.03	0.059	**3.31**	38.35		
28.0575	352.21	0.1574	**3.18**	9.51		
29.5831	144.49	0.1181	**3.02**	3.9	Montomorollonite (100%)	17.064269
						493.285758

(S -1) 350 Fultala 0-4.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.3038	177.19	0.3149	**14.02**	5.83	Chlorite -Vermiculite (100%)	55.797131
8.9299	1076.94	0.1181	**9.90**	35.42	Illite (100%)	127.186614
12.5816	634.07	0.0787	**7.04**	20.85	Chlorite- Surpentine (100%)	49.901309
17.8854	593.51	0.1771	**4.96**	19.52		
18.8863	293.37	0.1181	**4.70**	9.65		
19.9173	68.15	0.4723	**4.46**	2.24		
20.9187	475.28	0.0787	**4.25**	15.63		
25.2334	691.2	0.1181	**3.53**	22.73		
26.7085	3040.52	0.0984	**3.34**	100	Quartz (100%)	299.187168
26.9288	1454.24	0.0787	**3.31**	47.83		
27.9899	317.7	0.1181	**3.19**	10.45	Albite (100%)	37.52037
29.5634	368.78	0.1378	**3.02**	12.13	Montomorollonite (100%)	50.817884
					total =	620.410476

(S -2) 350 Fultala 4.5 ft-6.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2994	179.42	0.1181	**14.03**	3.46	Chlorite -Vermiculite (100%)	21.189502
8.9312	1191.91	0.0984	**9.90**	23.01	Illite (100%)	117.283944
12.5731	740.18	0.0787	**7.04**	14.29	Chlorite- Surpentine (100%)	58.252166
17.8362	654.56	0.0984	**4.97**	12.64		
18.8785	327.08	0.0984	**4.70**	6.31		
19.8929	133.54	0.3149	**4.46**	2.58		
20.9175	1012.34	0.0984	**4.25**	19.54		
22.0844	125.57	0.1181	**4.03**	2.42		
23.1689	108.35	0.3149	**3.84**	2.09		
25.2215	709.34	0.1181	**3.53**	13.69		
26.6871	5180.52	0.1181	**3.34**	100	Quartz (100%)	611.819412
26.8982	1861.41	0.059	**3.31**	35.93		
28.0481	378.91	0.1574	**3.18**	7.31		
29.4688	355.43	0.0984	**3.03**	6.86	Montomirollonite (100%)	34.974312
					total =	843.519336

(S -3) 350 Fultala 6.5 ft-16.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2322	60.18	0.4723	**14.18**	1.2	Vermiculite(100%)	41.79855
8.9859	510.86	0.0984	**9.84**	10.17		
12.6255	335.65	0.1378	**7.01**	6.68	Chlorite- Surpentine (100%)	46.25257
17.8888	370.34	0.0787	**4.96**	7.37		
18.9477	189.2	0.0984	**4.68**	3.77		
20.9749	918.51	0.1181	**4.24**	18.29		
22.122	214.65	0.1574	**4.02**	4.27		
23.6836	177.63	0.1181	**3.76**	3.54		
25.2605	450	0.0787	**3.53**	8.96	Chlorite (100%)	35.415
26.7351	5021.86	0.1181	**3.33**	100	Quartz (100%)	593.081666
27.6477	455.69	0.0787	**3.23**	9.07	K feldspar (100%)	35.862803
28.0341	412.43	0.1574	**3.18**	8.21		
29.5607	383.91	0.0984	**3.02**	7.64	Montomirollonite (100%)	37.776744
					total =	790.187333

(S-4) 350 Fultala 16.5 ft-23 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.3092	212.11	0.1181	**14.01**	3.95	Chlorite -Vermiculite (100%)	25.050191
8.947	1409.84	0.1181	**9.88**	26.24	Illite (100%)	166.502104
12.5799	864.15	0.0984	**7.04**	16.08	Chlorite- Surpentine (100%)	85.03236
17.8554	811.46	0.1181	**4.97**	15.1		
18.8877	416.17	0.0984	**4.70**	7.75		
19.9143	86.56	0.4723	**4.46**	1.61		
20.9255	855.89	0.1181	**4.25**	15.93		
23.6803	178.42	0.1181	**3.76**	3.32		
25.2264	1010.07	0.1181	**3.53**	18.8		
26.6946	5372.95	0.0984	**3.34**	100	Quartz (100%)	528.69828
26.8959	2245.34	0.0787	**3.31**	41.79		
27.9653	640.32	0.0787	**3.19**	11.92	Albite (100%)	50.393184
29.515	335.72	0.1574	**3.03**	6.25	Montomirollonite (100%)	52.842328
					total =	908.518447

(S-5) 350 Fultala 23 ft-33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2932	226.79	0.1181	**14.04**	5.45	Chlorite -Vermiculite (100%)	26.783899
8.9464	1482.02	0.1181	**9.88**	35.58	Illite (100%)	175.026562
12.5796	854.16	0.0984	**7.04**	20.51	Chlorite- Surpentine (100%)	84.049344
17.8604	814.04	0.1181	**4.97**	19.54		
18.8681	348.65	0.1181	**4.70**	8.37		
19.8666	115.3	0.2362	**4.47**	2.77		
20.9157	691.72	0.0787	**4.25**	16.61		
23.0359	97.16	0.2362	**3.86**	2.33		
23.6829	137	0.2362	**3.76**	3.29		
25.2334	839.88	0.1181	**3.53**	20.17		
26.6853	4165.02	0.0787	**3.34**	100	Quartz (100%)	327.787074
26.8958	2396.22	0.0984	**3.31**	57.53		
28.004	604.15	0.1181	**3.19**	14.51	Albite (100%)	71.350115
29.5133	365.78	0.1968	**3.03**	8.78	Montomirollonite (100%)	71.985504
					total =	756.982498

(S-6) 350 Rajbandh 0-6 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2795	141.01	0.2362	**14.08**	3.75	Chlorite -Vermiculite (100%)	33.306562
8.9117	975.44	0.1181	**9.92**	25.96	Illite (100%)	115.199464
12.5364	497.85	0.0787	**7.06**	13.25	Kaolinite (100%)	39.180795
17.7993	635.23	0.1378	**4.98**	16.91		
18.8263	246.12	0.1181	**4.71**	6.55		
19.8597	76.94	0.4723	**4.47**	2.05		
20.8922	558.25	0.0984	**4.25**	14.86		
22.0511	47.29	0.2362	**4.03**	1.26		
25.2143	524.69	0.0787	**3.53**	13.97		
26.6676	3757.02	0.0984	**3.34**	100	Quartz (100%)	369.690768
26.8563	1867.33	0.0984	**3.32**	49.7		
27.5171	230.83	0.1181	**3.24**	6.14	K feldspar (100%)	27.261023
27.9377	501.31	0.1181	**3.19**	13.34	Albite (100%)	59.204711
					total =	643.843323

(S-7) 350 Rajbandh 6 ft -9 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.254	132.4	0.1574	**14.13**	3.05	Chlorite -Vermiculite (100%)	30.64670588
8.8797	1016.94	0.0984	**9.96**	23.43	Illite (100%)	147.1572
12.5315	548.77	0.0984	**7.06**	12.64	Kaolinite (100%)	53.998968
17.7957	557.31	0.1181	**4.98**	12.84		
18.8098	222.02	0.0984	**4.72**	5.12		
19.8042	115.34	0.3149	**4.48**	2.66	Montomirollonite (100%)	36.320566
20.8775	756.04	0.1378	**4.25**	17.42		
22.0604	56.59	0.4723	**4.03**	1.3		
25.1909	472.59	0.1181	**3.54**	10.89		
26.6447	4340.34	0.1181	**3.35**	100	Quartz (100%)	512.594154
27.5114	198.92	0.1574	**3.24**	4.58	K feldspar (100%)	31.310008
27.9499	441.99	0.1181	**3.19**	10.18	Albite (100%)	52.199019
					total =	864.2266209

(S- 8) 350 Rajbandh -9 ft-18 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	min.ident-ification	Height* FWHM
6.2989	101.59	0.2362	**14.03**	3.51	Chlorite -Vermiculite (100%)	23.995558
8.9294	689.24	0.1378	**9.90**	23.79	Illite (100%)	94.977272
12.5547	355.85	0.1574	**7.05**	12.28	Kaolinite (100%)	56.01079
14.7079	79.88	0.2755	**6.02**	2.76		
17.8726	342.56	0.1771	**4.96**	11.82		
18.8877	192.07	0.1181	**4.70**	6.63		
19.8722	96.09	0.2362	**4.47**	3.32		
20.958	543.63	0.1378	**4.24**	18.76		
22.0861	43.95	0.4723	**4.02**	1.52		
25.2102	405.14	0.1771	**3.53**	13.98		
26.6948	2897.06	0.1181	**3.34**	100	Quartz (100%)	342.142786
28.0152	324.16	0.1574	**3.19**	11.19	Albite (100%)	51.022784
					total =	568.14919

(S 9) 350 Rajbandh -18 ft-21 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2804	194	0.1181	**14.07**	3.65	Chlorite -Vermiculite (100%)	22.9114
8.8904	1145.9	0.1181	**9.95**	21.55	Illite (100%)	
12.5413	785.18	0.1181	**7.06**	14.77	Kaolinite (100%)	92.729758
17.827	634.06	0.1181	**4.98**	11.93		
18.8319	320.52	0.1378	**4.71**	6.03		
19.8498	133.5	0.2362	**4.47**	2.51		
20.8915	974.99	0.0984	**4.25**	18.34		
22.0644	142.88	0.1574	**4.03**	2.69		
23.6003	132.03	0.2362	**3.77**	2.48		
25.1944	764.27	0.1378	**3.53**	14.38		
26.6623	5316.35	0.1181	**3.34**	100.00	Quartz (100%)	627.860935
26.871	1901.84	0.059	**3.32**	35.77		
27.5057	318.82	0.1181	**3.24**	6.00	K feldspar (100%)	37.652642
27.9644	538.73	0.2755	**3.19**	10.13	Albite (100%)	148.420115
29.4725	211.48	0.1378	**3.03**	3.98	Montomirollonite (100%)	29.141944
					total =	958.716794

(S 10) 350 Rajbandh 21 ft-33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.3178	156.4	0.1181	**13.99**	2.72	Chlorite -Vermiculite (100%)	18.47084
8.9468	1042.62	0.0984	**9.88**	18.16	Illite (100%)	102.593808
12.5759	588.91	0.1378	**7.04**	10.26	Chlorite- Surpentine (100%)	81.151798
17.8661	590.77	0.1574	**4.96**	10.29		
18.8904	285.88	0.0984	**4.70**	4.98		
19.8722	108.99	0.2362	**4.47**	1.9		
20.941	962.09	0.1181	**4.24**	16.76		
22.0901	138.95	0.1574	**4.02**	2.42		
23.6774	108.37	0.3149	**3.76**	1.89		
25.2273	640.67	0.1378	**3.53**	11.16		
26.7072	5741.45	0.0984	**3.34**	100	Quartz (100%)	564.95868
26.9146	1871.15	0.059	**3.31**	32.59		
27.5483	251.68	0.1181	**3.24**	4.38	K feldspar (100%)	29.723408
28.0069	513.68	0.1181	**3.19**	8.95	Albite (100%)	60.665608
					total =	857.564142

(S 11) 350 Samanta sena 0-3 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1903	64.11	0.6298	**14.28**	2.2		
8.8851	527.85	0.1181	**9.95**	18.14	Illite (100%)	62.339085
10.1513	54.11	0.1181	**8.71**	1.86		
12.5465	261.64	0.0984	**7.06**	8.99	Kaolinite (100%)	25.745376
17.8292	290.48	0.1181	**4.98**	9.98		
18.818	135.45	0.1181	**4.72**	4.65		
19.8248	68.28	0.4723	**4.48**	2.35	Montomirollonite (100%)	32.248644
20.8844	627.67	0.1181	**4.25**	21.57		
25.1895	281.13	0.1181	**3.54**	9.66	Chlorite (100%)	33.201453
26.6559	2910.04	0.0984	**3.34**	100	Quartz (100%)	286.347936
27.9756	241.28	0.2362	**3.19**	8.29	Albite (100%)	56.990336
29.4483	273.18	0.0787	**3.03**	9.39		
					total =	496.87283

(S 12) 350 Samanta sena 0-3 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1941	95.13	0.6298	**14.27**	2.5		
8.8922	480.35	0.1181	**9.94**	12.64	Illite (100%)	56.729335
12.532	336.96	0.1771	**7.06**	8.87	Kaolinite (100%)	59.675616
17.8042	464.76	0.0984	**4.98**	12.23		
18.816	166.2	0.1574	**4.72**	4.37		
19.8312	108.53	0.2362	**4.48**	2.86	Montomirollonite (100%)	25.634786
20.8646	673.22	0.1181	**4.26**	17.72		
23.5855	91.2	0.1181	**3.77**	2.4		
25.1765	465.34	0.1378	**3.54**	12.25	Chlorite (100%)	64.123852
26.6542	3799.39	0.1181	**3.34**	100	Quartz (100%)	448.707959
26.8687	1109.73	0.059	**3.32**	29.21		
27.9645	394.15	0.1378	**3.19**	10.37	Albite (100%)	54.31387
					total =	709.185418

S 13 350 Samanta sena 9 ft- 12 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2261	110.07	0.6298	**14.20**	3.71	Vermiculite(100%)	101.9442441
8.9289	539.5	0.1181	**9.90**	18.2	Illite (100%)	
12.5822	408.59	0.0984	**7.04**	13.78	Chlorite- Surpentine (100%)	40.205256
17.8233	419.33	0.1181	**4.98**	14.15		
18.8431	216.13	0.1574	**4.71**	7.29		
19.9251	72.35	0.4723	**4.46**	2.44		
20.9222	451.36	0.1181	**4.25**	15.23		
25.242	540.33	0.1181	**3.53**	18.23	Chlorite (100%)	63.812973
26.6853	2964.42	0.1181	**3.34**	100	Quartz (100%)	350.098002
27.9778	321.73	0.1968	**3.19**	10.85	Albite (100%)	63.316464
29.5092	258.44	0.1181	**3.03**	8.72	Montomirollonite (100%)	30.521764
					total =	649.8987031

S 14 350 Samanta sena 12 ft- 15 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.3258	132.04	0.2362	**13.97**	3.83	Chlorite -Vermiculite (100%)	31.187848
8.9656	762.94	0.1181	**9.86**	22.16	Illite (100%)	90.103214
12.5599	580.31	0.0984	**7.05**	16.85	Kaolinite (100%)	57.102504
17.8683	537.71	0.1378	**4.96**	15.62		
18.8867	276.25	0.1574	**4.70**	8.02		
19.8789	67.51	0.4723	**4.47**	1.96		
20.9328	457.98	0.1574	**4.24**	13.3		
25.244	580.81	0.0984	**3.53**	16.87		
26.7106	3443.27	0.1181	**3.34**	100	Quartz (100%)	406.650187
27.5423	368.73	0.1181	**3.24**	10.71	K feldspar (100%)	43.547013
28.0122	329.72	0.1574	**3.19**	9.58	Albite (100%)	51.897928
29.5329	189.17	0.1574	**3.02**	5.49	Montomirollonite (100%)	29.775358
					total =	710.264052

S 15 350 Samanta sena 15 ft -18 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2621	133.38	0.2362	**14.11**	2.72	Chlorite -Vermiculite (100%)	31.504356
8.9027	1075.96	0.1181	**9.93**	21.95	Illite (100%)	
12.5543	635.29	0.0787	**7.05**	12.96	Kaolinite (100%)	49.997323
17.8188	601.15	0.0984	**4.98**	12.26		
18.8237	303.15	0.1378	**4.71**	6.18		
19.8172	131.12	0.3149	**4.48**	2.67	Montomirollonite (100%)	41.289688
20.8921	857.89	0.0984	**4.25**	17.5		
22.0572	146.05	0.1181	**4.03**	2.98		
23.023	99.37	0.3149	**3.86**	2.03		
23.6159	134.03	0.2362	**3.77**	2.73		
25.1875	659.24	0.1574	**3.54**	13.45		
26.6588	4901.78	0.0984	**3.34**	100	Quartz (100%)	482.335152
26.8582	1805.23	0.0787	**3.32**	36.83		
27.9579	530.89	0.0787	**3.19**	10.83	Albite (100%)	41.781043
29.4653	325.85	0.0984	**3.03**	6.65	Montomirollonite (100%)	32.06364
					total =	678.971202

S 16 350 Samanta sena 18 ft- 33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1511	118.25	0.2362	**14.37**	2.93		
8.7882	1168.16	0.0984	**10.06**	28.93	Illite (100%)	114.946944
12.4432	486.73	0.0787	**7.11**	12.05	Kaolinite (100%)	38.305651
13.8026	93.77	0.1181	**6.42**	2.32		
17.7024	557.72	0.0984	**5.01**	13.81		
18.7408	191.65	0.1181	**4.74**	4.75		
19.7444	60.08	0.4723	**4.50**	1.49		
20.7864	721.4	0.0984	**4.27**	17.87		
24.1927	138.56	0.1181	**3.68**	3.43		
25.098	446.69	0.0984	**3.55**	11.06	Chlorite (100%)	43.954296
26.5658	4037.89	0.0984	**3.36**	100		
26.7642	1410.59	0.059	**3.33**	34.93	Quartz (100%)	83.22481
27.3789	168.31	0.1181	**3.26**	4.17	K feldspar (100%)	19.877411
27.8445	1182.5	0.1181	**3.20**	29.29	Albite (100%)	139.65325
29.3692	130.82	0.2362	**3.04**	3.24	Montomirollonite (100%)	30.899684
					total =	470.862046

S 17 350 KUET campus 0-3 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2682	126.81	0.1181	**14.10**	1.69	Chlorite -Vermiculite (100%)	14.976261
8.9029	946.26	0.0984	**9.93**	12.61	Illite (100%)	93.111984
12.5432	358.5	0.1378	**7.06**	4.78	Kaolinite (100%)	49.4013
17.8246	544.6	0.0787	**4.98**	7.26		
18.8146	178.22	0.1574	**4.72**	2.37		
19.8319	129.31	0.2362	**4.48**	1.72	Montomirollonite (100%)	30.543022
20.8803	1328.02	0.0984	**4.25**	17.7		
22.0516	162.02	0.0787	**4.03**	2.16		
23.6002	174.21	0.1574	**3.77**	2.32		
24.2937	104.99	0.1968	**3.66**	1.4		
25.1722	328.05	0.0984	**3.54**	4.37		
26.6582	7504.88	0.1181	**3.34**	100	Quartz (100%)	886.326328
27.5296	464.06	0.0984	**3.24**	6.18	K feldspar (100%)	45.663504
27.9136	588.44	0.0984	**3.20**	7.84	Albite (100%)	57.902496
					total =	1177.924895

S 18 350 KUET CAMPUS 6 ft - 12 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1805	96.12	0.2362	**14.30**	1.72		
8.844	745.93	0.0984	**10.00**	13.32	Illite (100%)	73.399512
12.4913	346.76	0.1181	**7.09**	6.19	Kaolinite (100%)	40.952356
17.7713	387.38	0.1181	**4.99**	6.92		
18.7772	181.81	0.1574	**4.73**	3.25		
19.7556	127.95	0.2362	**4.49**	2.28	Montomirollonite (100%)	30.22179
20.8382	1020.33	0.0984	**4.26**	18.22		
21.9793	115.54	0.2362	**4.04**	2.06		
22.9965	94.36	0.2362	**3.87**	1.68		
23.6119	135.91	0.2362	**3.77**	2.43		
25.1466	377	0.1378	**3.54**	6.73	Chlorite (100%)	51.9506
26.61	5600.77	0.1181	**3.35**	100	Quartz (100%)	661.450937
27.9102	553.74	0.1181	**3.20**	9.89	Albite (100%)	65.396694
29.4475	308.41	0.0984	**3.03**	5.51		
					total =	923.371889

S 19 350 KUET CAMPUS 12 ft -21 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2564	104.4	0.2362	**14.13**	1.84	Chlorite -Vermiculite (100%)	24.65928
8.9391	716.8	0.0984	**9.89**	12.66	Illite (100%)	70.53312
12.5684	504.24	0.0984	**7.04**	8.9	Chlorite- Surpentine (100%)	49.617216
17.8496	414.54	0.1378	**4.97**	7.32		
18.8813	267.18	0.059	**4.70**	4.72		
19.8509	135.16	0.2362	**4.47**	2.39		
20.9094	1021.64	0.0787	**4.25**	18.04		
22.0926	186.98	0.0787	**4.02**	3.3		
23.6264	116.98	0.2362	**3.77**	2.07		
25.2159	549.63	0.1181	**3.53**	9.71		
26.6871	5662.87	0.1181	**3.34**	100	Quartz (100%)	668.784947
27.987	458.15	0.1378	**3.19**	8.09	Albite (100%)	63.13307
					total =	876.727633

S 20 350 KUET CAMPUS 21 ft -33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2638	99.04	0.2362	**14.11**	1.79	Chlorite -Vermiculite (100%)	34.40183529
8.9031	753.95	0.1181	**9.93**	13.66	Illite (100%)	130.943375
12.5366	541.28	0.1181	**7.06**	9.8	Kaolinite (100%)	63.925168
17.8243	409.87	0.1378	**4.98**	7.42		
18.8229	243.6	0.0984	**4.71**	4.41		
19.8754	144.5	0.1968	**4.47**	2.62		
20.8991	1227.07	0.0984	**4.25**	22.23		
22.0516	165.7	0.1574	**4.03**	3		
23.5684	136.87	0.2362	**3.77**	2.48		
25.1826	603.4	0.1181	**3.54**	10.93		
26.6537	5520.66	0.0984	**3.34**	100	Quartz (100%)	543.232944
27.8358	550.95	0.2362	**3.21**	9.98	Albite (100%)	130.13439
29.4831	361.38	0.0787	**3.03**	6.55	Montomirollonite (100%)	28.440606
					total =	931.0783183

S 1 550 Fultala 0-4.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.3002	252.23	0.1574	**14.03**	7.88	Chlorite- Vermiculite (100%)	39.701002
8.8652	1546.7	0.1181	**9.98**	48.32	Illite (100%)	182.66527
12.4855	179.68	0.1181	**7.09**	5.61	Kaolinite (100%)	21.220208
17.7505	627.21	0.1378	**5.00**	19.59		
19.8068	84.61	0.4723	**4.48**	2.64	Montomorollonite (100%)	39.961303
20.8509	461.56	0.0984	**4.26**	14.42		
25.1136	229.53	0.1181	**3.55**	7.17		
26.6173	3200.95	0.1181	**3.35**	100	Quartz (100%)	378.032195
26.8344	1732.3	0.0984	**3.32**	54.12	Albite (100%)	170.45832
27.965	322.18	0.1574	**3.19**	10.07		
29.4584	338.57	0.1574	**3.03**	10.58		
						832.038298

S 2 550 Fultala 4.5 ft-6.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2307	185.02	0.1181	**14.19**	3.83	Vermiculite (100%)	21.850862
8.8721	1263.37	0.1181	**9.97**	26.16	Illite (100%)	149.203997
12.4891	346.28	0.0787	**7.09**	7.17	Kaolinite (100%)	27.252236
17.7985	566.88	0.1181	**4.98**	11.74		
18.7708	148.97	0.1574	**4.73**	3.08		
19.788	119.43	0.3149	**4.49**	2.47	Montomorollonite (100%)	37.608507
20.8611	715.82	0.1181	**4.26**	14.82		
22.0255	146.82	0.1574	**4.04**	3.04		
24.3366	153.78	0.1968	**3.66**	3.18		
25.104	414.56	0.0984	**3.55**	8.58	Chlorite (100%)	34.23
26.6207	4830	0.0984	**3.35**	100	Quartz(100%)	475.272
26.8237	1777.73	0.059	**3.32**	36.81		
27.4572	313.37	0.1574	**3.25**	6.49	K feldspar (100%)	49.324438
27.9067	542.75	0.1574	**3.20**	11.24	Albite (100%)	85.42885
29.4473	302.79	0.1574	**3.03**	6.27		
						880.17089

S 3 550 Fultala 6.5 ft-16.5 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2979	106.23	0.3149	**14.03**	1.94	Chlorite- Vermiculite (100%)	33.451827
8.876	847.71	0.1181	**9.96**	15.45	Illite (100%)	100.114551
12.5257	203.97	0.1378	**7.07**	3.72	Kaolinite (100%)	28.107066
17.8276	410.46	0.1181	**4.98**	7.48		
18.777	104.76	0.1181	**4.73**	1.91		
19.8227	84.29	0.3149	**4.48**	1.54	Montomorollonite (100%)	26.542921
20.8572	1018.27	0.0984	**4.26**	18.56		
22.0612	142.35	0.0984	**4.03**	2.59		
25.1376	220.31	0.1574	**3.54**	4.02		
26.6365	5486.56	0.1181	**3.35**	100	Quartz(100%)	647.962736
27.4645	307.35	0.0984	**3.25**	5.6	K feldspar (100%)	30.24324
27.9417	458.83	0.0984	**3.19**	8.36	Albite (100%)	45.148872
29.4737	300.55	0.1574	**3.03**	5.48		
						911.571213

S 4 550 Fultala 16.5 ft-23 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2251	184.41	0.1181	**14.20**	4.03	Vermiculite (100%)	21.778821
8.8635	1407.29	0.0984	**9.98**	30.79	Illite (100%)	138.477336
12.4781	402.71	0.0984	**7.09**	8.81	Kaolinite (100%)	39.626664
17.7753	614.02	0.1181	**4.99**	13.43		
18.7764	171.99	0.1574	**4.73**	3.76		
19.7662	101.75	0.2362	**4.49**	2.23	Montomorollonite (100%)	24.03335
20.8448	783.7	0.0984	**4.26**	17.15		
22.0069	190.58	0.059	**4.04**	4.17		
22.9439	93.36	0.2362	**3.88**	2.04		
23.5141	121.51	0.2362	**3.78**	2.66		
25.0898	474.27	0.0984	**3.55**	10.38	Chlorite (100%)	40.1345
26.6149	4570.9	0.0984	**3.35**	100	Quartz(100%)	449.77656
26.8132	2279.68	0.0787	**3.33**	49.87		
27.9131	474.89	0.2362	**3.20**	10.39	Albite (100%)	112.169018
29.4161	346.83	0.1181	**3.04**	7.59		825.996249

S 5 550 Fultala 23 ft-33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2183	229.97	0.1181	**14.21**	5.86	Vermiculite (100%)	27.159457
8.8403	1606.2	0.0984	**10.00**	40.9	Illite (100%)	158.05008
12.463	418.38	0.0787	**7.10**	10.65	Kaolinite (100%)	32.926506
17.7665	702.21	0.1181	**4.99**	17.88		
18.7247	172.1	0.1574	**4.74**	4.38		
19.7428	87.42	0.2362	**4.50**	2.23	Montomorollonite (100%)	20.648604
20.8364	722.85	0.1181	**4.26**	18.41		
25.1068	429.13	0.1181	**3.55**	10.93	Chlorite (100%)	42.53
26.5926	3927.18	0.0984	**3.35**	100	Quartz(100%)	386.434512
26.7907	2408.9	0.0984	**3.33**	61.34		
27.8791	449.25	0.0984	**3.20**	11.44	Albite (100%)	44.2062
29.4352	291.18	0.1181	**3.03**	7.41		
						711.955359

S 6 550 Rajbandh 0-6 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2923	136.2	0.2362	**14.05**	3.46	Chlorite- Vermiculite (100%)	32.17044
8.8648	923.26	0.1378	**9.98**	23.46	Illite (100%)	127.225228
12.5016	153.36	0.1574	**7.08**	3.9	Kaolinite (100%)	24.138864
17.7718	456.65	0.0984	**4.99**	11.6		
19.7841	112.48	0.2362	**4.49**	2.86	Montomorollonite (100%)	26.567776
20.8785	596.81	0.1181	**4.25**	15.17		
25.1575	151.43	0.1968	**3.54**	3.85		
26.6523	3935.16	0.1181	**3.34**	100	Quartz(100%)	464.742396
27.966	405.89	0.2755	**3.19**	10.31	Albite (100%)	111.822695
						786.667399

S 7 550 Rajbandh -6 ft -9 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2366	164.23	0.1574	**14.17**	3.56	Vermiculite (100%)	25.849802
8.8506	1209.81	0.1181	**9.99**	26.23	Illite (100%)	142.878561
12.4886	171.29	0.059	**7.09**	3.71	Kaolinite (100%)	10.10611
17.765	551.98	0.0984	**4.99**	11.97		
18.7749	83.32	0.2362	**4.73**	1.81		
19.7055	123.63	0.3149	**4.51**	2.68		
20.84	875.21	0.0984	**4.26**	18.98		
21.9994	141.96	0.1181	**4.04**	3.08		
23.5651	133.85	0.1181	**3.78**	2.9		
24.2207	93.86	0.2362	**3.67**	2.03		
25.1116	267.86	0.1181	**3.55**	5.81	Chlorite (100%)	31.634266
25.4247	259.96	0.1181	**3.50**	5.64		
26.6129	4612.31	0.1181	**3.35**	100	Quartz(100%)	544.713811
26.8296	1456.01	0.0787	**3.32**	31.57		
27.9217	428.36	0.2755	**3.20**	9.29	Albite (100%)	118.01318
						873.19573

S 8 550 Rajbandh -9 ft-18 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	min.identification	Height* FWHM
6.1886	86.35	0.3936	**14.28**	2.62		
8.7618	860.92	0.1181	**10.09**	26.16	Illite (100%)	101.674652
12.3886	267.45	0.0787	**7.14**	8.13	Kaolinite (100%)	21.048315
17.6781	439.44	0.1181	**5.02**	13.36		
18.6884	104.3	0.1181	**4.75**	3.17		
19.705	123.19	0.2362	**4.51**	3.74		
20.7627	538.74	0.0984	**4.28**	16.37		
23.5714	69.48	0.6298	**3.77**	2.11		
25.031	338.25	0.1378	**3.56**	10.28		
25.3587	226.06	0.1968	**3.51**	6.87	Chlorite (100%)	44.488608
26.5269	3290.39	0.1181	**3.36**	100		
26.7275	1451.28	0.059	**3.34**	44.11	Quartz(100%)	85.62552
27.8348	352.57	0.1574	**3.21**	10.72	Albite (100%)	55.494518
						308.331613

S 9 550 Rajbandh -18 ft-21 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2085	162.61	0.1574	**14.24**	3.04		
8.811	1487.13	0.0787	**10.04**	27.84	Illite (100%)	117.037131
12.4368	387.33	0.0984	**7.12**	7.25	Kaolinite (100%)	38.113272
17.7351	693.48	0.1378	**5.00**	12.98		
18.7054	173.81	0.1574	**4.74**	3.25		
19.7246	110.81	0.3149	**4.50**	2.07	Montomorollonite (100%)	34.894069
20.8042	940.36	0.0984	**4.27**	17.61		
21.9886	123.61	0.1574	**4.04**	2.31		
23.556	97.51	0.2362	**3.78**	1.83		
24.2251	105.52	0.2362	**3.67**	1.98		
25.0886	409.41	0.1181	**3.55**	7.67	Chlorite (100%)	48.351321
26.5727	5340.88	0.0984	**3.35**	100	Quartz(100%)	525.542592
26.7838	2112.39	0.0787	**3.33**	39.55		
27.4278	327.74	0.1181	**3.25**	6.14	K feldspar (100%)	38.706094
27.8841	524.1	0.1181	**3.20**	9.81	Albite (100%)	61.89621
29.4123	213.54	0.1181	**3.04**	4		864.540689

S 10 550 Rajbandh 21 ft-33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2338	180.66	0.1181	14.18	3.05	Vermiculite (100%)	21.335946
8.8447	1484.65	0.1181	10.00	25.1	Illite (100%)	175.337165
12.4553	411.15	0.0984	7.11	6.95	Kaolinite (100%)	40.45716
17.7452	700.2	0.1181	5.00	11.84		
18.7548	147.12	0.0984	4.73	2.49		
19.7448	107.53	0.2362	4.50	1.82	Montomorollonite (100%)	25.398586
20.8228	1050.22	0.0984	4.27	17.75		
22.0018	124.89	0.1181	4.04	2.11		
22.9003	52.05	0.2362	3.88	0.88		
23.5335	120.93	0.1181	3.78	2.04		
25.107	363	0.1378	3.55	6.14	Chlorite (100%)	43.62
26.5976	5915.32	0.1181	3.35	100	Quartz(100%)	698.599292
26.8084	2022.16	0.0787	3.33	34.19		
27.9056	524.03	0.1574	3.20	8.86	Albite (100%)	82.482322
						1087.230471

S 11 550 Samanta sena 0-3 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1624	85.16	0.2362	14.34	2.23		
8.7733	779.44	0.0984	10.08	20.44	Illite (100%)	76.696896
12.3814	182.67	0.1574	7.15	4.79	Kaolinite (100%)	28.752258
17.6732	353.22	0.1378	5.02	9.26		
18.653	80.69	0.2362	4.76	2.12		
19.7101	97.93	0.3149	4.50	2.57	Montomorollonite (100%)	30.838157
20.7533	688.52	0.0984	4.28	18.06		
21.9312	52.21	0.2362	4.05	1.37		
25.0249	195.15	0.1181	3.56	5.12	Chlorite (100%)	32.92459286
26.5323	3813.28	0.1181	3.36	100		
27.8371	379.32	0.1181	3.21	9.95	Albite (100%)	44.797692
29.3266	269.64	0.1574	3.05	7.07		
						214.0095959

S 12 550 Samanta sena 3 ft- 9 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.3396	6.3396	0.4723	13.94	1.53		
8.8954	8.8954	0.0787	9.94	17.95	Illite (100%)	0.70006798
12.5	12.500	0.1574	7.08	3.7	Kaolinite (100%)	1.9675
17.8122	17.8122	0.1181	4.98	8.31		
18.8043	18.8043	0.1181	4.72	2.34		
19.8131	19.8131	0.3149	4.48	2.53	Montomorollonite (100%)	6.23914519
20.8894	20.8894	0.1181	4.25	15.97		
25.1614	25.1614	0.1574	3.54	4.31	Chlorite (100%)	3.96040436
26.6587	26.6587	0.1181	3.34	100	Quartz(100%)	3.14839247
27.9614	27.9614	0.1968	3.19	8.46	Albite (100%)	5.50280352
29.4883	29.4883	0.1574	3.03	2.38		
						21.51831352

S 13 550 Samanta sena 9 ft- 12 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.3094	154.42	0.3149	**14.01**	4.35	Chlorite- Vermiculite (100%)	48.626858
8.8551	766.93	0.1378	**9.99**	21.62	Illite (100%)	105.682954
12.4492	76.28	0.2362	**7.11**	2.15	Kaolinite (100%)	18.017336
17.7577	431.89	0.1181	**4.99**	12.18		
19.7317	79.77	0.2362	**4.50**	2.25	Montomorollonite (100%)	18.841674
20.8555	501.79	0.1181	**4.26**	14.15		
25.1346	131.85	0.2362	**3.54**	3.72		
26.6364	3546.65	0.0984	**3.35**	100	Quartz(100%)	348.99036
27.9289	373.9	0.2755	**3.19**	10.54	Albite (100%)	103.00945
29.4516	232.54	0.1574	**3.03**	6.56		
						643.168632

S 14 550 Samanta sena 12 ft- 15 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.319	154.78	0.3149	**13.99**	3.65	Chlorite- Vermiculite (100%)	48.740222
8.9228	1057.4	0.0787	**9.91**	24.92	Illite (100%)	83.21738
12.5523	216.49	0.0984	**7.05**	5.1	Kaolinite (100%)	21.302616
17.8231	551.18	0.1181	**4.98**	12.99		
18.8036	101.13	0.1968	**4.72**	2.38		
19.7555	60.14	0.4723	**4.49**	1.42	Montomorollonite (100%)	28.404122
20.8972	625.96	0.0984	**4.25**	14.75		
25.1533	240.99	0.1181	**3.54**	5.68		
26.6639	4242.51	0.1181	**3.34**	100	Quartz(100%)	501.040431
26.879	1968	0.0787	**3.32**	46.39		
27.9385	470.07	0.1574	**3.19**	11.08	Albite (100%)	73.989018
29.4881	199.93	0.1574	**3.03**	4.71	Montomorollonite (100%)	31.468982
						788.162771

S 15 550 Samanta sena 15 ft -18 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2211	89.47	0.3936	**14.21**	1.67		
8.9155	864.12	0.0984	**9.92**	16.17	Illite (100%)	85.029408
12.5317	197.51	0.1574	**7.06**	3.7	Kaolinite (100%)	31.088074
17.8194	395.93	0.1378	**4.98**	7.41		
18.7809	120.94	0.1181	**4.73**	2.26		
19.8423	129.44	0.3149	**4.47**	2.42		
20.8705	834.34	0.1181	**4.26**	15.61		
22.0597	161.69	0.1181	**4.03**	3.03		
24.3633	183.31	0.1181	**3.65**	3.43		
25.1351	278.88	0.1574	**3.54**	5.22	Chlorite (100%)	43.895712
26.6686	5344.81	0.0787	**3.34**	100	Quartz(100%)	420.636547
26.8676	1704.2	0.0787	**3.32**	31.89		
27.948	575.72	0.0787	**3.19**	10.77	Albite (100%)	45.309164
29.455	227.01	0.1574	**3.03**	4.25	Montomorollonite (100%)	35.731374
						661.690279

S 16 550 Samanta sena 18 ft- 33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.1696	104.02	0.3149	14.33	2.7		
8.7759	1255.76	0.0984	10.08	32.61	Illite (100%)	123.566784
12.412	196.36	0.1378	7.13	5.1	Kaolinite (100%)	27.058408
17.676	528.51	0.0984	5.02	13.72		
18.6547	66.96	0.2362	4.76	1.74		
19.7019	55.99	0.4723	4.51	1.45		
20.7704	608.28	0.0984	4.28	15.79		
21.9376	66.46	0.2362	4.05	1.73		
25.0172	166.05	0.1181	3.56	4.31	Chlorite (100%)	19.610505
26.5486	3851.15	0.0984	3.36	100	Quartz(100%)	378.95316
26.7616	1333.66	0.0984	3.33	34.63	Quartz(100%)	131.232144
27.3747	175.67	0.1181	3.26	4.56		
27.8266	832.66	0.0984	3.21	21.62	Albite (100%)	81.933744
29.3473	153.69	0.1181	3.04	3.99	Montomorollonite (100%)	18.150789
						780.505534

S 17 550 KUET CAMPUS 0-3 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2574	76.2	0.2362	14.13	1.21	Vermiculite (100%)	17.998440
8.8552	805.56	0.0787	9.99	12.8	Illite (100%)	63.397572
12.4558	138.93	0.1181	7.11	2.21	Kaolinite (100%)	16.407633
13.8194	32.97	0.4723	6.41	0.52		
17.7707	380.04	0.0984	4.99	6.04		
18.7214	57.85	0.2362	4.74	0.92		
19.7903	110.95	0.2755	4.49	1.76	Montomorollonite (100%)	30.566725
20.8353	1597.93	0.1181	4.26	25.39		
22.0189	135.68	0.1181	4.04	2.16		
23.5633	92.23	0.2362	3.78	1.47		
24.2926	82.52	0.2362	3.66	1.31		
25.0817	120.87	0.1181	3.55	1.92	Chlorite (100%)	14.274747
26.6108	6292.67	0.1181	3.35	100	Quartz(100%)	743.164327
27.4358	273.28	0.1574	3.25	4.34	K feldspar (100%)	43.014272
27.8737	668.02	0.0984	3.20	10.62	Albite (100%)	65.733168
						994.556884

S 18 550 KUET CAMPUS 6 ft - 12 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2599	104.64	0.2362	14.12	2.18	Vermiculite (100%)	24.715968
8.8653	751.04	0.0984	9.97	15.64	Illite (100%)	73.902336
12.4835	170.52	0.0787	7.09	3.55	Kaolinite (100%)	13.419924
17.7714	337.71	0.0984	4.99	7.03		
19.7717	135.68	0.3149	4.49	2.83	Montomorollonite (100%)	42.725632
20.8428	965.13	0.0984	4.26	20.1		
21.9866	158.32	0.1181	4.04	3.3		
24.2097	128.14	0.2362	3.68	2.67		
25.114	230.34	0.1181	3.55	4.8	Chlorite (100%)	27.203154
25.4823	203.56	0.2755	3.50	4.24		
26.6179	4802.61	0.1181	3.35	100	Quartz(100%)	567.188241
27.9256	465.10	0.1574	3.20	9.68	Albite (100%)	73.20674
29.437	348.00	0.0984	3.03	7.25		
						822.361995

S 19 550 KUET CAMPUS 12 ft -21 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2371	103.53	0.2362	14.17	2.55	Vermiculite (100%)	24.453786
8.8287	769.12	0.1378	10.02	18.97	Illite (100%)	105.984736
12.4876	220.9	0.0984	7.09	5.45	Kaolinite (100%)	21.73656
17.6969	314.81	0.1574	5.01	7.77		
18.7604	112.09	0.1574	4.73	2.77		
19.7705	127.76	0.2362	4.49	3.15	Montomorollonite (100%)	30.176912
20.8298	867.45	0.1378	4.26	21.4		
22.0034	121.63	0.1181	4.04	3.00		
23.5961	108.7	0.2362	3.77	2.68		
25.1158	249.31	0.1574	3.55	6.15	Chlorite (100%)	31.09
26.5949	4053.9	0.1378	3.35	100	Quartz(100%)	558.62742
27.9286	463.2	0.1574	3.19	11.43	Albite (100%)	72.90768
						844.977094

S 20 550 KUET CAMPUS 21 ft -33 ft

Pos. [°2Th.]	Height [cts]	FWHM [°2Th.]	d-spacing[Å]	Rel.Int [%]	Mineral identification	Height* FWHM
6.2649	148.69	0.1181	14.11	2.88	Vermiculite (100%)	17.560289
8.8848	946.27	0.1181	9.95	18.32	Illite (100%)	111.754487
12.4943	271.65	0.0787	7.08	5.26	Kaolinite (100%)	21.378855
17.7995	434.21	0.1181	4.98	8.41		
18.7793	141.4	0.1181	4.73	2.74		
19.6989	122.72	0.3149	4.51	2.38		
20.8813	837.17	0.1378	4.25	16.2		
22.0526	159.01	0.1574	4.03	3.08		
24.2153	127.87	0.2362	3.68	2.48		
25.1544	339.85	0.1378	3.54	6.58	Chlorite (100%)	41.56
26.6473	5166.1	0.1181	3.35	100	Quartz(100%)	610.11641
26.863	1484.74	0.0787	3.32	28.74		
27.8255	544.23	0.2362	3.21	10.53	Albite (100%)	128.547126
29.4768	355.65	0.1181	3.03	6.88	Montomorollonite (100%)	42.002265
						972.919432