GEOTECHNICAL INVESTIGATION OF THE SHALE-CLAY MEMBER OF THE PATTI FORMATION, SOUTHERN BIDA BASIN

BY

ADEYEMI OPEYEMI D.

GLY/14/2249

A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF GEOLOGY,

FACULTY OF SCIENCE,

FEDERAL UNIVERSITY OYE-EKITI

IN

Partial Fulfilment of the Requirements for the Award of Bachelor of Science (B.Sc.) Degree in Geology

February, 2019

CERTIFICATION

This is to certify that the research project on the Geotechnical Investigation Of The Shale-Clay Member Of The Patti Formation, Southern Bida Basin was carried out by ADEYEMI OPEYEMI D. with matriculation number GLY/14/2249 under the supervision of PROF. O.J. OJO.

The work has been approved as meeting the required standard for the award of Bachelor of Science (B.Sc.) Degree of the Department of Geology, Faculty of Science, Federal University Oye-Ekiti, Ekiti State, Nigeria.

Signature.............................. Date 18/02/2019

Project Supervisor

Signature.............................. Date..............................

PROF. O.J. OJO

Head of Department

Signature Prof. S.A. Opeloye Date 28/02/19

(Name of External Examiner)

External Examiner

DEDICATION

This report is dedicated to the Lord Almighty who kept me in his abiding mercies throughout the period of the research.

ACKNOWLEDGEMENT

My thanks go to the Almighty God for the good health, knowledge and intensive memory, given to me throughout the period of my research, all glory and adoration is unto Him. I will also thank my parents Pst. (Dr.) & L/Evang. T.O Adeyemi for the support financially and spiritually.

My gratitude also goes to my supervisor Prof. O.J. Ojo and assistant supervisor Mrs. Ndukwe for her encouragement and advice. I must not fail to acknowledge my colleagues who helped during the field mapping, big thanks to you guys.

To everyone not mentioned, I remember you.

Table of Contents

Title page i

Certification/approved page ii

Dedication iii

Acknowledgements iv

Table of contents v

List of Figures viii

List of Tables ix

List of Plates x

Abstract xi

Chapter One

1.0 Introduction

1.1 General statement 1

1.2 Location of the study area 1

1.3 Physiography 3

1.4 Climate 3

1.5 Vegetation 4

1.6 Occupation of the inhabitants of the Study Area 4

1.7 Aim and Objectives of the Study 4

1.8 Previous work done 5

Chapter Two

2.0 Regional Geology/Tectonic setting 6

2.1 Tectonic Evolution 6

2.2 Stratigraphic framework 6

Chapter Three

3.0 Materials and Methods **12**

3.1 Materials 12

3.2 Methods 13

3.3 Field mapping 13

3.4 Sample Collection 13

3.5 Laboratory processing of the Samples 14

3.5.1 Geotechnical Analysis 14

3.5.1.1 Atterberg Limit 14

3.5.1.2 Permeability 17

3.5.1.3 Grain size analysis 19

3.5.1.4 Compaction Test 20

Chapter Four

4.0 Results and Discussions **23**

4.1 Lithology Description of the study area 23

4.2 Lithology description of Ahoko 23

4.3 Lithology description of Geheku 26

4.4 Results and Discussions 29

4.4.1 Compaction Analysis 29

4.4.2 Atterberg Limit 33

4.4.3 Grain Size Analysis 36

4.4.4 Permeability 44

Chapter Five

5.0 Conclusions 47

References 48
Appendices 52

LIST OF FIGURES

Figure 1.1: Map of Nigeria showing the Sedimentary Basins in Nigeria, 2

Figure 2.1: Stratigraphic successions in the Mid-Niger Basin 11

Figure 4.1: Field photograph of Ahoko section showing the lithology of Patti Formation 24

Figure 4.2: Lithological log of Patti Formation at Ahoko 25

Figure 4.3: Field photograph of Geheku 1 section showing the lithology of Patti Formation 27

Figure 4.4: Lithological log of Geheku 1 28

Figure 4.5: Compaction Plot of AK1E 31

Figure 4.6: Compaction Plot of GH1E 32

Figure 4.7: Chart for plasticity of the shale in Ahoko and Geheku 35

Figure 4.8: Grain size curve for GH1A 39

Figure 4.9: Grain size curve for GH1C 39

Figure 4.10: Grain size curve for GH1E 40

Figure 4.11: Grain size curve for AK1E 40

Figure 4.12: Grain size curve for AK1L 41

Figure 4.13: Grain size curve for AK1P 41

Figure 4.14: Grain size curve for AK1S 42

Figure 4.15: Grain size curve for AK1U 42

Figure 4.16: Grain size curve for AK1A 43

LIST OF TABLES

Table 4.1: Compaction analysis result 30

Table 4.2: Atterberg Limit analysis result 34

Table 4.3: Grain size analysis result 37

Table 4.4: Cumulative frequency table of the grain size analysis 38

Table 4.5: Permeability analysis result 45

LIST OF PLATES

Plate I: Global Positioning System 52

Plate II: Compass Clinometer 52

Plate III: Field notebook 52

Plate IV: Geological Hammer 52

ABSTRACT

The area of study forms part of the Bida Basin or more appropriately, the Lokoja sub-basins or part of the southern Bida Basin. The objective of the study is to determine the permeability and compaction strength of the shale-clay member of Patti Formation and also to determine its particle grain size. The analysis done on the shale-clay samples are: Atterberg limit, grain size analysis, compaction test and permeability.

The shale in the study area is intercalated with ironstone and claystone. The shales are dark to gray in color at the base followed by light colored shale and siltstone at the top. The compaction test reveals that it has a high value of optimum moisture content which are AK1E to be 13.60 and GH1E to be 16.18 which makes the soils to have high dry densities which are 1.80 and 1.79 respectively. The engineering analysis of the shale samples show that it is not reliable for road or pavement construction due to high plasticity index which ranges from 31-46. The two (2) sampled shale is impermeable i.e. it has a low value of 5.16×10^{-6} and 3.43×10^{-6}.

The samples are fine grained making the grain size analysis to have high value of passing than retained and it's a dark to gray color and can be used in industries to make cement, bricks, etc.

CHAPTER ONE

1.0 INTRODUCTION

1.1 GENERAL STATEMENT

The northwest southeastern trending Bida Basin forms one of the major inland sedimentary basins in Nigeria. It is a shallow, linear depression with sedimentary fill of about 3,000m thick (Udensi and Osazuwa, 2004). Geological developments in the basin in terms of basin evolution and structural features have been discussed by many authors. King (1950) and Kennedy (1965) described the Bida Basin as a rift bounded tensional structure produced by faulting associated with Benue Trough system and break-up of the Gondwana.Landsat imageries analysis by Kogbe et al. (1981) indicates that the southern Bida Basin is controlled by NW-SE trending faults which support a rift model. The existence of a deep seated central positive anomaly flanked by negative anomalies typical of rift structure was confirmed by the geophysical study Ojo and Ajakaiye (1989) that proposed Bida Basin as post-Satonian shallow cratonic sag whilst Braide (1992) suggest the idea of pull-apart origin for Bida Basin.

1.2 LOCATION OF THE STUDY AREA

The Bida Basin, located at central Nigeria, is one of the hinterland sedimentary basins in Nigeria, having a sedimentary fill of about 4km (Ojo, 1984; Udensi & Osasuwa, 2004). It is a Northwest-Southeast trending intracratonic structural depression adjacent and contiguous with Sokoto and Anambra Basins in the Northwest and Southeast respectively (Figure 1). The Bida Basin is subdivided into the northern and southern sub-basins ,to accommodate the fast and wide facies changes across its long and large areal extent (Jones, 1955; Braide, 1992 a&b).

King, 1950; Kennedy, 1965; Kogbe *et al.*, 1981, 1983; Ojo & Ajakaiye, 1989, showed robust arguments, supported by geophysical data and landsat images, in favor of rift origin associated with drifting apart of South America and Africa plates. The authors agreed that Bida Basin is part of the tectonic evolution of the Benue Trough which began in the early Jurassic to early Cretaceous with the opening of Gulf of Guinea about a triple junction. The main dissenting position on the origin is that of Braide (1992) which advanced a wrench fault tectonics for its evolution and, thus, suggested a pull-apart origin for the Bida Basin.

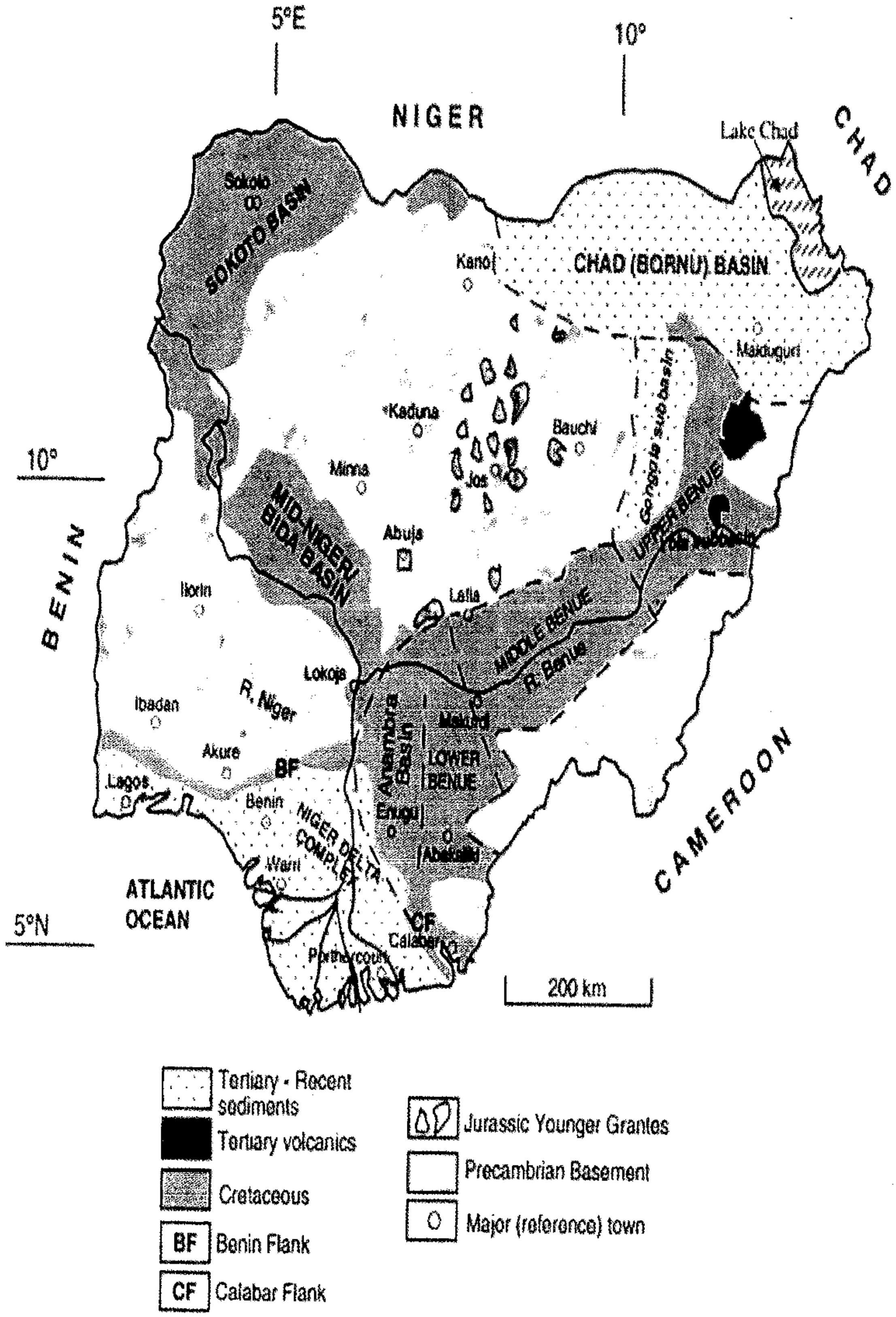

Figure 1.1: Map of Nigeria showing the Sedimentary Basins in Nigeria, (Obaje et al, 2004)

The sedimentary succession in the Bida Basin, central Nigeria, has the potential to include an active petroleum system with the generation, migration and accumulation of hydrocarbons in 256+commercial quantities. Hydrocarbon seepages have been reported in the basin around Pategi/Muregi on the River Niger in Niger State and around Ahoko near Lokoja in Kogi State. Field sedimentological evaluation in four localities, namely, Lokoja, Agbaja, Ahoko, and Abaji, indicates braided – fluvial depositional facies for the Lokoja Formation; fluvial - flood plain–marine (shelf) facies for the Patti Formation and marginal marine–fluvial channels for the Agbaja Formation. Geochemical investigations show that potential source rocks in the Bida Basin are gas-prone. Potential reservoir units occur in the fluvial sandstones of the Lokoja Formation and in the shelf and flood plain sandstones of the Patti Formation. The shales and claystones of the Patti and Agbaja Formations may provide regional seals. Different trap configurations are possible in the basin, ranging from traps within uplifted blocks, traps in drapes and/or compacted structures over deep horsts to stratigraphic traps along flanks of uplifted blocks. Cross-sections indicate that the area around Bida, and to the south of Bida around Pategi, Muregi, Baro, Agbaja, Ahoko, Abaji, Gada Biyu, are particularly prospective.

1.3 PHYSIOGRAPHY

Lokoja lies about 7.8023° N of the equator and 6.7333° E of the meridian. It is about 165km SW of Abuja as the crow flies and 390km NE of Lagos by same measure. Residential district are varying density and the city has various suburbs such as Felele, Adankolo, Otokiti and Ganaja. The town is situated in the tropical wet and dry savanna climate zone of Nigeria and temperature remains hot all year round. The various sedimentary rock groups extend along the banks of River Niger and Benue and southeast wards through Enugu and Anambra state to join the Udi plateau.

1.4 CLIMATE

The type of climate in Lokoja is that of the tropical hinterland of Nigeria (Iweana, 2012). The area is characterized by two distinct seasons namely; the rainy season and the dry season. The rainy season last for seven months from April to October. The dry season last for five months from November to March. Average annual precipitation from 2001 – 2010 for the area range between 1000 mm -1500 mm. Daily temperatures in the area vary with the seasons. Minimum average temperatures of about $25^{O}C$ -$27^{O}C$ are recorded mainly during the rainy season while maximum temperatures of about 35oC are experienced during the dry season. Relative humidity in the area ranges from 55% to 65% during the dry season and from 70% to 80% during the rainy season (Iloeje, 1980). Measured evapo-transpiration within the area range from 914 mm to 954 mm.

1.5 VEGETATION

The vegetation of the study area is classified as Guinea savanna of Nigeria. It is characterized by the presence of tall grasses and scattered short deciduous trees. Arrival of rainfall in the area marks the beginning of the growth of grasses in the area. Examples of trees in the study area include Afezilia Africana, Uapacatogoenesis, Daniella oliveri (locust bean), Buttryospenum paradoxim, (sheabutter), Montes kerstingi and Isoberlina dalzieli .The dominant grasses include Elephant grass (Axonopus Comprssors), Pine grass (L. Penisefum SPP), species of Devil bean stems with delicate, offensive, adhesive hairs that produce unpleasant irritation when in contact with the skin are also common.

1.6 OCCUPATION OF THE INHABITANTS

Fishing and farming are the main occupation of the people in the state and crops produced include cassava, yam, rice, maize, guinea corn, beans and soya beans etc.

1.7 AIMS AND OBJECTIVES OF THE STUDY

The aim of this research was to expand the knowledge of the geotechnical characteristics of the shale-clay member of the Patti Formation of the basin, which include; Atterberg limit, compaction, permeability and grain size analysis.

The objectives are as follows:

1) To determine the particle grain size.
2) To assess the permeability of the shale.
3) To determine if it will be suitable for engineering purposes or not.

1.8 PREVIOUS WORK DONE

The Bida Basin has potential source rocks composed of carbonaceous shales, intercalated with sandstones and clay. Interpretation of geochemical data by Obaje et al. (2004) indicates that organic matter in these source rocks is in the early-mature stage of gas generation and may have reached peak stages in the deeper portions of the basin. Further geochemical investigations (Obaje, 2009) suggest that kerogen in the Patti Formation is dominated by Type III material (vitrinites) with some Type II (liptinites) and Type IV (inertinites). Vitrinite reflectance and fluorescent properties of investigated macerals suggest immature to marginally mature kerogens with Ro values varying mostly from 0.42 to 0.63%. T0C values range from 0.17 to as high as 3.8% (mean = 2.3%). Rock Eval data for the shale support the microscopic evidence for the prevalence of land derived humic kerogen derived from terrestrial organic matter. The results indicate that the shales are gas prone with minor oil generation potential.

Worked was done in the basin to know the Sedimentological and Paleodepositional Studies of Outcropping Sediments in Parts of Southern Middle Niger Basin. The field and laboratory analysis of siliciclastics sediment samples from outcrops of the Lokoja Formation enabled the discrimination of various subfacies formed in continental paleodepositional settings of dominantly fluvial systems during the Late Cretaceous out-building of sedimentary sequences in the Southern Middle Niger Basin and signaled as lowstand systems tract architecture.

Previous studies on the geology of the Bida Basin were reported in Adeleye (1973) and the micropaleontological studies of Jan du Chene et al. (1979) which documented the palynomorph-foraminiferal associations including the interpretation of the paleoenvironments of the Lokoja and Patti Formations. Akande et al. (2005) interpreted the paleoenvironments of the sedimentary successions in the southern Bida Basin as ranging from continental to marginal marine and marsh environments for the Cretaceous lithofacies. Whereas the origin of the oolitic ironstones in the Bida Basin has been a principal subject of several workers (e.g.Adeleye,1973; Ladipo et al., 1994; Abimbola, 1997), only few investigations have been made on the hydrocarbon prospectivity of the basin.

CHAPTER TWO

2.0 REGIONAL SETTINGS

2.1 TECTONIC EVOLUTION

The Upper Cretaceous Bida basin of central Nigeria is sandwiched between the Precambrian schist belts of the Northern Nigerian massif and the West African craton. Of interest is the southern part of the basin, which developed in continental settings, because the facies architecture of the sedimentary fill suggests a close relation between sedimentation dynamics and basin margin tectonics. This relationship is significant to an understanding of the basin's origin, which has been controversial. A simple sag and rift origin has been suggested, and consequently dominated the negative thinking on the hydrocarbon prospects of the basin which were considered poor. This detailed study of the facies indicates rapid basin-wide changes from various alluvial fan facies through flood-basin and deltaic facies to lacustrine facies. Paleogeographic reconstruction suggests lacustrine environments were widespread and elongate. Lacustrine environments occurred at the basin's axis and close to the margins. This suggests the depocenter must have migrated during the basin's depositional history and subsided rapidly to accommodate the 3.5-km-thick sedimentary fill. Although distinguishing pull-apart basins from rift basins, based solely on sedimentologic grounds, may be difficult, the temporal migration of the depocenter, as well as the basin architecture of upward coarsening cyclicity, show a strong tectonic and structural overprint that suggests a tectonic framework for the Southern Bida basin similar in origin to a pull-apart basin (Braide S.P 1992a).

2.2 STRATIGRAPHIC FRAMEWORK

The stratigraphic framework in this basin has been along the geographic subdivision of the basin into North and South Bida basins as shown in Figure 2. Adeleye (1974) and Adeleye and Dessauvagie (1972) established four stratigraphic horizons in the Northern Bida Basin and these include; the basal Campanian - Maastrichtian Bida Formation (conglomerate, sandstone), Sakpe Ironstone, Enagi Formation (sandstone, siltstone, claystone) and Batati Ironstone. Their lateral equivalents in the Southern Bida Basin are Lokoja Formation (conglomerate, sandstone), Patti Formation (sandstone, shale, claystone) and Agbaja

Formation (ironstone). Stratigraphic nomenclatures in the present study area is not well defined, however, the present investigated sediments, which were referred to as depositional unit I in Ojo & Akande (2011), have characteristics best comparable to type section of Bida Formation and are hereby held as Bida Formation.

Jones, (1955, 1958); Adeleye (1971, 1973, 1974, 1989); Braide (1992a and 1992); Ladipo et al. (1994) and Abimbola et al, (1999) also investigated on the stratigraphy and sedimentation of the Upper Cretaceous sequences of the Bida Basin which reveals that the Bida Basin has four recognizable mappable stratigraphic units with each of the units having a lateral equivalent. The units include the Bida Sandstone (with the Doko and Jima members) overlain by the Sakpe Ironstone, followed by the Enagi Siltstone which in turn is overlain by the Batati Ironstone. The respective lateral equivalents of these units to the south (Lokoja sub basin) are the Lokoja Formation (lateral equivalent to Bida sandstone), the Patti Formation (lateral equivalent of the Sakpe Ironstone and the Enagi Siltstone) and the Agbaja Formation (lateral equivalent of the Batati Ironstone). The correlation of the stratigraphic successions across the northern and central portions of the basin into the Lokoja area to the south is largely based on the lithologic and depositional characteristics and has been extended into the Anambra Basin to the south. The lateral equivalents represent continuous depositional phases from the south to the north and northwest, controlled by the major sea level rises and falls of the uppermost Cretaceous (Akande et al, 2006).

The sedimentary fill of the Benue Trough consists of three unconformity-bounded depositional sequences (Petters, 1978) and the Bida and Anambra regions were platforms until the Santonian. Pre-Santonian rocks are recorded in parts of the older Benue Trough and in the southern Anambra Basin. Collapse of the Mid-Niger and Anambra platforms led to the initiation of Upper Cretaceous deposition commencing with the fully-marine shales of the Campanian Nkporo and Enugu Formations, which may have lateral equivalents in the Lokoja Formation of the Bida Basin. Overlying the Nkporo Formation in the Anambra Basin is the Mamu Formation consisting of shales, siltstones, sandstones and coals of fluvio-deltaic to fluvio-estuarine origin (Nwajide and Reijers, 1996) whose lateral equivalents in the Bida Basin are the conglomerates, cross-bedded and poorly sorted sandstones and claystones of the Lokoja and Bida formations and part of the Patti Formation. The Mamu Formation is overalin by sandstones of the Lower Maastrichtian Ajalli Formation, laterally equivalent to the Patti, Ṣakpe and Enagi Formations of the Bida Basin. The Ajalli sandstones are well sorted quartz arenites (Nwajide, 1990) that are commonly interbedded with siltstones and claystones and are similar to the lithologies of the Patti and Enagi Formations. The Patti and Enagi Formations are overlain by the Upper Maastrichtian Agbaja and Batati Formations (lateral equivalents). These consist of oolitic, pisolitic and concretionary ironstones deposited within a continental to shallow marine setting (Ladipo et al., 1994) The nature of the sedimentary succession in the Bida Basin suggests that full-marine conditions were not established here, compared to the marine sedimentation which was established for the Campanian Nkporo Formation in the adjacent Anambra Basin during that transgressive cycle. A comparison of sedimentary thicknesses in the two Basins indicate that the Anambra Basin fill reaches up to 8km compared with an average of 3.4 km of sediment in the Bida Basin (Akande and Erdtmann, 1998).

Bida Basin is divided into two categories, southern and northern. The northern part is divided into Bida Sandstone, Sakpe Ironstone, Enagi Siltstone and Batati Irônstone, while the southern part is divided into: Lokoja Sandstone, Patti Formation and Agbaja Ironstone. The study area is in Southern Bida Basin.

SOUTHERN BIDA BASIN

The Lokoja Formation

Lithologic units in this formation range from conglomerates, coarse to fine grained sandstones, siltstones and claystones in the Lokoja area. Subangular to subrounded cobbles, pebbles and granule sized quartz grains in the units are frequently distributed in a clay matrix. Both grain supported and matrix supported conglomerates form recognizable beds at the base of distinct cycles at outcrop. The sandstone units are frequently cross-stratified, generally poorly sorted and composed mainly of quartz plus feldspar and are thus texturally and mineralogically immature. The general characteristics of this sequence especially the fining upward character, compositional and textural immaturity and unidirectional paleocurrent trends, suggest a fluvial depositional environment dominated by braided streams with sands deposited as channel bars consequent to fluctuating flow velocity. The fine grained sandstones, siltstones and clays represent flood plain over bank deposits. However, Petters (1986) reported on the occurrence of some diversity arenaceous foraminifera from clayey interval of the Lokoja Formation indicating some shallow marine influence.

These foraminiferal microfossils identified by Petters (1986) are however more common in the overlying Patti Formation where shallow marine depositional conditions are known to have prevailed more.

The Patti Formation

Outcrops of the Patti Formation occur between Koton-Karfi and Abaji. This formation consists of sandstones, siltstones, claystones and shales interbedded with bioturbated ironstones. Argillaceous units predominate in the central parts of the basin. The siltstones of the Patti Formation are commonly parallel stratified with occasional soft sedimentary structures (e.g. slumps), and other structures such as wave ripples, convolute laminations, load structures. Trace fossils (especially Thallasanoides) are frequently preserved. Interbedded claystones are generally massive and kaolinitic, whereas the interbedded grey shales are frequently carbonaceous. The subsidiary sandstone units of the Patti Formation are more texturally and mineralogically mature compared with the Lokoja Sandstones. The predominance of argillaceous rocks, especially siltstones, shales and claystones in the Patti Formation requires suspension and settling of finer sediments in a quiet low energy environment probably in a restricted body of water (Braide, 1992b). The abundance of woody and plant materials comprising mostly land-derived organic matter, suggests prevailing fresh water conditions. However, biostratigraphic and paleoecologic studies by Petters (1986) have revealed the occurrence of arenaceous foraminifera in the shales of the Patti Formation with an assemblage of Ammobaculites, Milliamina, Trochamina and Textularia which are essentially cosmopolitan marsh species similar to those reported in the Lower Maastrichtian marginal marine Mamu Formation (the lateral equivalent) in the adjacent Anambra Basin (Gebhardt, 1998). Shales of the Mamu Formation on the south side of the Anambra Basin are commonly interbedded with chamositic carbonates and overlain by bioturbated siltstones, sandstones and coal units in coarsening upward cycles towards the north side of the basin (Akande et al., 1992). This sequence is overlain by herringbone crossbedded mature sandstones of the Ajali Formation (Middle Maastrichtian) in the northern fringes of the basin hence providing strong evidence for shallow marine, deltaic to intertidal depositional environments for the Maastrichtian sediments of the Anambra Basin. The Patti Formation therefore appears to have been deposited in marginal shallow marine to brackish water condition identical to the depositional environments of similar lithologic units of the Mamu and Ajali Formations in the Anambra Basin (Ladipo, 1988; Adeniran, 1991; Nwajide and

Reijers, 1996). The more marine influences in the adjacent Anambra Basin is probably related to the nearness of that basin to the Cretaceous Atlantic Ocean prior to the growth of the Niger Delta.

The Agbaja Formation

This formation forms a persistent cap for the Campanian – Maastrichtian sediments in the Southern Bida Basin as a lateral equivalent of the Batati Formation on the northern side of the basin. It consists of sandstones and claystones interbedded with oolitic, concretionary and massive ironstone beds in this region. The sandstones and claystones are interpreted as abandoned channel sands and overbank deposits influenced by marine reworking to form the massive concretionary and oolitic ironstones observed (Ladipo et al., 1994). Minor marine influences were also reported to have inundated the initial continental environment of the upper parts of the Lokoja Sandstone and the Patti Formation (Braide, 1992; Olaniyan and Olobaniyi, 1996). The marine inundations appear to have continued throughout the period of deposition of the Agbaja ironstones in the southern Bida Basin (Ladipo et al., 1994).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 MATERIALS

1. **Geographical Positioning System (GPS)**: This is satellite navigation system used to determine the ground position of an object. The GPS is a sophisticated technology which is basically used in determining the exact position of any sampling point on the map. Modern GPS can enable the geologist to lock down the navigation patterns adopted in a particular area; this will allow the geologist to know the exact distance from one sampling point to another. (check Plate I)

2. **Compass/Clinometer**: The compass was used in the field for accurately determining the bearing from any feature and also used in measuring the trend of geologic features like faults, joints, intrusions, foliations etc. The clinometer on the other hand was used in measuring the amount and direction of inclination on necessary geologic features observed. (check Plate II)

3. **Field notebook:** The field notebook was used to record all form of observations made while in the field. The observations which might be geological or non-geological will retain all the elements of truth in them due to adequate recording of such information on the field note. (check Plate III)

4. **Paper tape and marker pen**: Both were used together to label any rock samples collected. The paper tape and marker pen was used to tie every sample to the location of collection.

5. **Sample bag:** The sample bag is normally used in the field to store any collected rock sample. This also allows the sample to be perfect condition before it is being taken to the laboratory for analysis.

6. **Hammer and Chisel:** These were used to break samples in to a moderate size to get the fresh face of the bed. (check Plate IV)

3.2 METHODS

The methods employed in this study include field mapping, sample collection and laboratory analysis. The laboratory analysis that is geotechnical analysis included: AtterberA limit, permeability, grain size and California Bearing Ratio (CBR) analysis.

3.3 FIELD MAPPING

The field mapping was done by navigating through a system of grid patterns which is basically known as traversing. Here, movement around various outcrops is done by automobile or foot and so as to examine as many outcrops as possible. Navigation is being done from one location to another with the aid of the geographical positioning system GPS device and the compass/clinometer. The compass/clinometer is essentially used to measure all observed geologic structure, be it ductile or brittle. The GPS is used essentially to know the exact position on the field map. During traversing, every grid on the map is being walked across with the aim of studying every outcrop that falls within such grid. When walking across the grids, necessary geologic information is collected in any outcrop encountered; such information may include description of the outcrop, description of the lithology, and measurement of the thickness of each bed in the particular outcrop. Finally, a very good representative sample is collected from the outcrop.

3.4 SAMPLE COLLECTION

The sections were logged, described and correlated with special attention paid to the sedimentary structures. Systematic logging technique was adopted and this involved measuring the thickness of the beds using measuring tape, location of different lithofacies boundaries along section with the aid of Global Positioning System and sample were collected for laboratory analysis. Lithologic log were drawn with the use of Corel Photo-paint (X5) software. The paleoenvironment interpretation was attempted based on integration of facies association, sedimentary structures, textures and petrography. Eleven (11) sections were logged within the study area. The lithofacies encountered in the study locations comprises of conglomeratic carbonaceous shale and ironstone.

3.5 LABORATORY PROCESSING OF THE SAMPLES

3.5.1 GEOTECHNICAL ANALYSIS

3.5.1.1 ATTERBERG LIMIT

The analyzed sample is shale, which is a fine grained soil. There are nine (9) samples. Atterberg limit is done to measure the water content of the sample..

Atterberg limit are a basic measure of the critical water contents of a fine-grained soil e.g. shale: its shrinkage limit, plastic limit and liquid limit. Depending on the water content, a soil may appear in one of the four states: solid, semi-solid, plastic and liquid. In each state, the consistency and behavior of the soil is different and consequently so are its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behavior. Atterberg limit is used to distinguish between different cohesive soils. Consistency is the term used to describe the ability of the soil to resist rupture and deformation. It is commonly describe as soft, stiff or firm, and hard.

Water content greatly affects the engineering behavior of fine-grained soils. In the order of increasing moisture content, a dry soil will exist into four distinct states: from solid state, to semisolid state, to plastic state, and to liquid state. The water contents at the boundary of these states are known as Atterberg limits. Between the solid and semisolid states is shrinkage limit, between semisolid and plastic states is plastic limit, and between plastic and liquid states is liquid limit. The instruments used are, Liquid limit device, Porcelain (evaporating) dish, Flat grooving tool with gage, Eight moisture cans, Balance, Spatula, Wash bottle filled with distilled water, Drying oven set at 105°C.

- **Plastic Limit, PL**

Plastic limit is the water content in which the soil will pass from plastic state to semi-solid state. Soil can no longer behave as plastic; any change in shape will cause the soil to show visible cracks. Plastic Limit is the soil water content at the boundary between the semi-solid state and plastic (flexible) state. It is determined as the gravimetric water content at which a soil sample can be rolled by hand into a thread of 3.2 mm diameter without breaking.

Test procedure:

(1) Weigh the remaining empty moisture cans with their lids and record the respective weights and can numbers on the data sheet.

(2) Take the remaining 1/4 of the original soil sample and add distilled water until the soil is at a consistency where it can be rolled without sticking to the hands.

(3) Form the soil into an ellipsoidal mass. Roll the mass between the palm or the fingers and the glass plate. Use sufficient pressure to roll the mass into a thread of uniform diameter by using about 90 strokes per minute. (A stroke is one complete motion of the hand forward and back to the starting position.) The thread shall be deformed so that its diameter reaches 3.2 mm (1/8 in.), taking no more than two minutes.

(4) When the diameter of the thread reaches the correct diameter, break the thread into several pieces. Knead and reform the pieces into ellipsoidal masses and re-roll them. Continue this alternate rolling, gathering together, kneading and re-rolling until the thread crumbles under the pressure required for rolling and can no longer be rolled into a 3.2 mm diameter thread.

(5) Gather the portions of the crumbled thread together and place the soil into a moisture can, then cover it. If the can does not contain at least 6 grams of soil, add soil to the can from the next trial (see step). Immediately weigh the moisture can containing the soil, record its mass, remove the lid, and place the can into the oven. Leave the moisture can in the oven for at least 16 hours.

(6) Repeat steps three, four, and five at least two more times. Determine the water content from each trial by using the same method used in the first laboratory. Remember to use the same balance for all weighing.

- **Liquid Limit, LL**

Liquid limit is the water content of soil in which soil grains are separated by water just enough for the soil mass to loss shear strength. A little higher than this water content will tend the soil to flow like viscous fluid while a little lower will cause the soil to behave as plastic. Liquid Limit is the soil water content where the soil changes from a plastic to a viscous (liquid) state. Liquid limit is determined using the Casagrande cup. This involves finding the soil water content that corresponds to the number of drops (25) needed to bring together a 13 mm section of a groove cut into the soil sample:

Test procedure

(1) Take roughly 3/4 of the soil and place it into the porcelain dish. Assume that the soil was previously passed through a No. 40 sieve, air-dried, and then pulverized. Thoroughly mix the soil with a small amount of distilled water until it appears as a smooth uniform paste. Cover the dish with cellophane to prevent moisture from escaping.

(2) Weigh four of the empty moisture cans with their lids and record the respective weights and can numbers on the data sheet.

(3) Adjust the liquid limit apparatus by checking the height of drop of the cup. The point on the cup that comes in contact with the base should rise to a height of 10 mm. The block on the end of the grooving tool is 10 mm high and should be used as a gage. Practice using the cup and determine the correct rate to rotate the crank so that the cup drops approximately two times per second.

(4) Place a portion of the previously mixed soil into the cup of the liquid limit apparatus at the point where the cup rests on the base. Squeeze the soil down to eliminate air pockets and spread it into the cup to a depth of about 10 mm at its deepest point. The soil pat should form an approximately horizontal surface.

(5) Use the grooving tool carefully cut a clean straight groove down the center of the cup. The tool should remain perpendicular to the surface of the cup as groove is being made. Use extreme care to prevent sliding the soil relative to the surface of the cup.

(6) Make sure that the base of the apparatus below the cup and the underside of the cup is clean of soil. Turn the crank of the apparatus at a rate of approximately two drops per second and count the number of drops, N, it takes to make the two halves of the soil pat come into contact at the bottom of the groove along a distance of 13 mm (1/2 in.). If the number of drops exceeds 50, then go directly to step eight and do not record the number of drops, otherwise, record the number of drops on the data sheet.

(7) Take a sample, using the spatula, from edge to edge of the soil pat. The sample should include the soil on both sides of where the groove came into contact. Place the soil into a moisture can cover it. Immediately weigh the moisture can containing the soil, record its mass, remove the lid, and place the can into the oven. Leave the moisture can in the oven for at least 16 hours. Place the soil remaining in the cup into the porcelain dish. Clean and dry the cup on the apparatus and the grooving tool.

(8) Remix the entire soil specimen in the porcelain dish. Add a small amount of distilled water to increase the water content so that the number of drops required to close the groove decrease.

(9) Repeat steps six, seven, and eight for at least two additional trials producing successively lower numbers of drops to close the groove. One of the trials shall be for a closure requiring 25 to 35 drops, one for closure between 20 and 30 drops, and one trial for a closure requiring 15 to 25 drops. Determine the water content from each trial by using the same method used in the first laboratory. Remember to use the same balance for all weighing.

- **Shrinkage Limit, SL**

Shrinkage limit is the water content in which the soil no longer changes in volume regardless of further drying. It is the lowest water content possible for the soil to be completely saturated. Any lower than the shrinkage limit will cause the water to be partially saturated. This is the point in which soil will pass from semi-solid to solid state.

3.5.1.2 PERMEABILITY

In this analysis, two (2) shale samples were analyzed. This test was done to determine if the sample is permeable or not.

Permeability is a measure of how a material can transmit water or other fluid. Materials like gravel have high permeability, but in case of shale, it transmits water poorly and always has low value of permeability. This is usually determined by the size of the pore spaces and their degree of interconnection. Permeability is measured in unit of velocity, such as centimeters per second. Shale has low permeability; this makes it a good trap for petroleum. Instruments include Permeameter, Tamper, Balance, Scoop, 1000 mL Graduated cylinders, Watch (or Stopwatch), Thermometer, Filter paper.

Test Procedure:

(1) Measure the initial mass of the pan along with the dry soil (M1).

(2) Remove the cap and upper chamber of the permeameter by unscrewing the knurled cap nuts and lifting them off the tie rods. Measure the inside diameter of upper and lower chambers. Calculate the average inside diameter of the permeameter (D).

(3) Place one porous stone on the inner support ring in the base of the chamber then place a filter paper on top of the porous stone.

(4) Mix the soil with a sufficient quantity of distilled water to prevent the segregation of particle sizes during placement into the permeameter. Enough water should be added so that the mixture may flow freely.

(5) Using a scoop, pour the prepared soil into the lower chamber using a circular motion to fill it to a depth of 1.5 cm. A uniform layer should be formed.

(6) Use the tamping device to compact the layer of soil. Use approximately ten rams of the tamper per layer and provide uniform coverage of the soil surface. Repeat the compaction procedure until the soil is within 2 cm. of the top of the lower chamber section.

(7) Replace the upper chamber section, and don't forget the rubber gasket that goes between the chamber sections. Be careful not to disturb the soil that has already been compacted. Continue the placement operation until the level of the soil is about 2 cm. below the rim of the upper chamber. Level the top surface of the soil and place a filter paper and then the upper porous stone on it.

(8) Place the compression spring on the porous stone and replace the chamber cap and its sealing gasket. Secure the cap firmly with the cap nuts.

(9) Measure the sample length at four locations around the circumference of the permeameter and compute the average length. Record it as the sample length.

(10) Keep the pan with remaining soil in the drying oven.

(11) Adjust the level of the funnel to allow the constant water level in it to remain a few inches above the top of the soil.

(12) Connect the flexible tube from the tail of the funnel to the bottom outlet of the permeameter and keep the valves on the top of the permeameter open.

(13) Place tubing from the top outlet to the sink to collect any water that may come out.

(14) Open the bottom valve and allow the water to flow into the permeameter.

(15) As soon as the water begins to flow out of the top control (deairing) valve, close the control valve, letting water flow out of the outlet for some time.

(16) Close the bottom outlet valve and disconnect the tubing at the bottom. Connect the funnel tubing to the top side port.

(17) Open the bottom outlet valve and raise the funnel to a convenient height to get a reasonable steady flow of water.

(18) Allow adequate time for the flow pattern to stabilize.

(19) Measure the time it takes to fill a volume of 750 - 1000 mL using the graduated cylinder, and then measure the temperature of the water. Repeat this process three times and compute the average time, average volume, and average temperature. Record the values as t, Q, and T, respectively.

(20) Measure the vertical distance between the funnel head level and the chamber outflow level, and record the distance as h.

(21) Repeat step 17 and 18 with different vertical distances.

(22) Remove the pan from the drying oven and measure the final mass of the pan along with the dry soil (M2).

3.5.1.3 GRAIN SIZE ANALYSIS

This test is performed to determine the percentage of different grain sizes contained within a soil. Nine (9) shale samples were analyzed. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. The distribution of different grain sizes affects the engineering properties of soil. Grain size analysis provides the grain size distribution, and it is required in classifying the soil.

The test procedure is as follows:

(1) Write down the weight of each sieve as well as the bottom pan to be used in the analysis.

(2) Record the weight of the given dry soil sample.

(3) Make sure that all the sieves are clean and assemble them in the ascending order of sieve numbers. Carefully pour the soil sample into the top sieve and place the cap over it.

(4) Place the sieve stack in the mechanical shaker and shake for 10 minutes.

(5) Remove the stack from the shaker and carefully weigh and record the weight of each sieve with its retained soil. In addition, remember to weigh and record the weight of the bottom pan with its retained fine soil.

Data analysis

(1) Obtain the mass of soil retained on each sieve by subtracting the weight of the empty sieve from the mass of the sieve + retained soil and record this mass as the weight retained on the data sheet. The sum of these retained masses should be approximately equals the initial mass of the soil sample. A loss of more than two percent is unsatisfactory.

(2) Calculate the percent retained on each sieve by dividing the weight retained on each sieve by the original sample mass. (3) Calculate the percent passing (or percent finer) by starting with 100 percent and subtracting the percent retained on each sieve as a cumulative procedure.

3.5.1.4 COMPACTION TEST

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort. Two (2) shale samples were analyzed. The compactive effort is the amount of mechanical energy that is applied to the soil mass. Several different methods are used to compact soil in the field, and some examples include tamping, kneading, vibration, and static load compaction. The test is also known as the Proctor test.

Test Procedure:

(1) Depending on the type of mold you are using obtain a sufficient quantity of air-dried soil in large mixing pan. For the 4-inch mold take approximately 10 lbs, and for the 6-inch mold take roughly 15 lbs. Pulverize the soil and run it through the # 4 sieve.

(2) Determine the weight of the soil sample as well as the weight of the compaction mold with its base (without the collar) by using the balance and record the weights.

(3) Compute the amount of initial water to add by the following method:

(a) Assume water content for the first test to be 8 percent.

(b) Compute water to add from the following equation:

$Water\ to\ add\ (in\ ml) = (Soil\ mass\ in\ grams) * 8100$

Where "water to add" and the "soil mass" are in grams. Remember that a gram of water is equal to approximately one milliliter of water.

(4) Measure out the water, add it to the soil, and then mix it thoroughly into the soil using the trowel until the soil gets a uniform color.

(5) Assemble the compaction mold to the base, place some soil in the mold and compact the soil in the number of equal layers specified by the type of compaction method employed. The number of drops of the rammer per layer is also dependent upon the type of mold used. The drops should be applied at a uniform rate not exceeding around 1.5 seconds per drop, and the rammer should provide uniform coverage of the specimen surface. Try to avoid rebound of the rammer from the top of the guide sleeve.

(6) The soil should completely fill the cylinder and the last compacted layer must extend slightly above the collar joint. If the soil is below the collar joint at the completion of the drops, the test point must be repeated. (Note: For the last layer, watch carefully, and add more soil after about 10 drops if it appears that the soil will be compacted below the collar joint.)

(7) Carefully remove the collar and trim off the compacted soil so that it is completely even with the top of the mold using the trowel. Replace small bits of soil that may fall out during the trimming process.

(8) Weigh the compacted soil while it's in the mold and to the base, and record the mass. Determine the wet mass of the soil by subtracting the weight of the mold and base.

(9) Remove the soil from the mold using a mechanical extruder and take soil moisture content samples from the top and bottom of the specimen. Fill the moisture cans with soil and determine the water content.

(10) Place the soil specimen in the large tray and break up the soil until it appears visually as if it will pass through the # 4 sieve, add 2 percent more water based on the original sample mass, and re-mix as in
step 4. Repeat steps 5 through 9 until, based on wet mass, a peak value is reached followed by two slightly lesser compacted soil masses.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 LITHOLOGY DESCRIPTION OF THE STUDY AREA

The facies that are widely distributed in the study area include: sandstone facies, ironstone, claystone and shale. It lies about 7.8023° N of the equator and 6.7333° E of the meridian. The study area is in the Southern part of the Bida Basin. Bida Basin is part of the tectonic evolution of the Benue Trough which began in the early Jurassic to early Cretaceous with the opening of Gulf of Guinea about a triple junction. At the outcrop section at Ahoko and Geheku, along Lokoja - Abuja expressway (Fig.4.1 and 4.3) within the interval 5.5-8.0 m at the upper section contains abundant woody fragments and plant remains. Silty shales and siltstones become more pronounced towards the upper part of the section where they are interbedded with ironstones. The ironstones have an average thickness of 0.2 m and are mainly concretional, although some of the beds are massive and contain vertical and horizontal burrows (40) (Adebayo, et al 2015).

Ahoko lies within the Lokoja Sub-basin of the Bida Basin in the North Central part of Nigeria. Local stratigraphy of the sediments and the field relationship show that the lithologic succession consists of dark grey shales at the base, followed by light grey shales and siltstones that are intercalated at intervals by grey to brownish, highly indurated ironstone concretion (Adebayo, et al 2015).

4.2 LITHOLOGY DESCRIPTION OF AHOKO

Ahoko has the elevation of 85m at the base with the latitude of 8°18'14.9'' and the longitude of 6°51'29.8''. It falls within the Patti Formation which consists of shale, claystone and ironstone. This area is composed of shale and ironstone with an intercalation of claystone. The shale is carbonaceous and most color is grayish. The ironstone is of two types: laminated and concretional. At AK1P, there is an intercalation of shale and ferroginized ironstone. It is brown in color. Overlying this layer is a claystone layer (AK1Q). After this bed is massive ironstone, about 2.24m. Ahoko covers a large. Mining has been done on the site which makes the beds to be obvious.

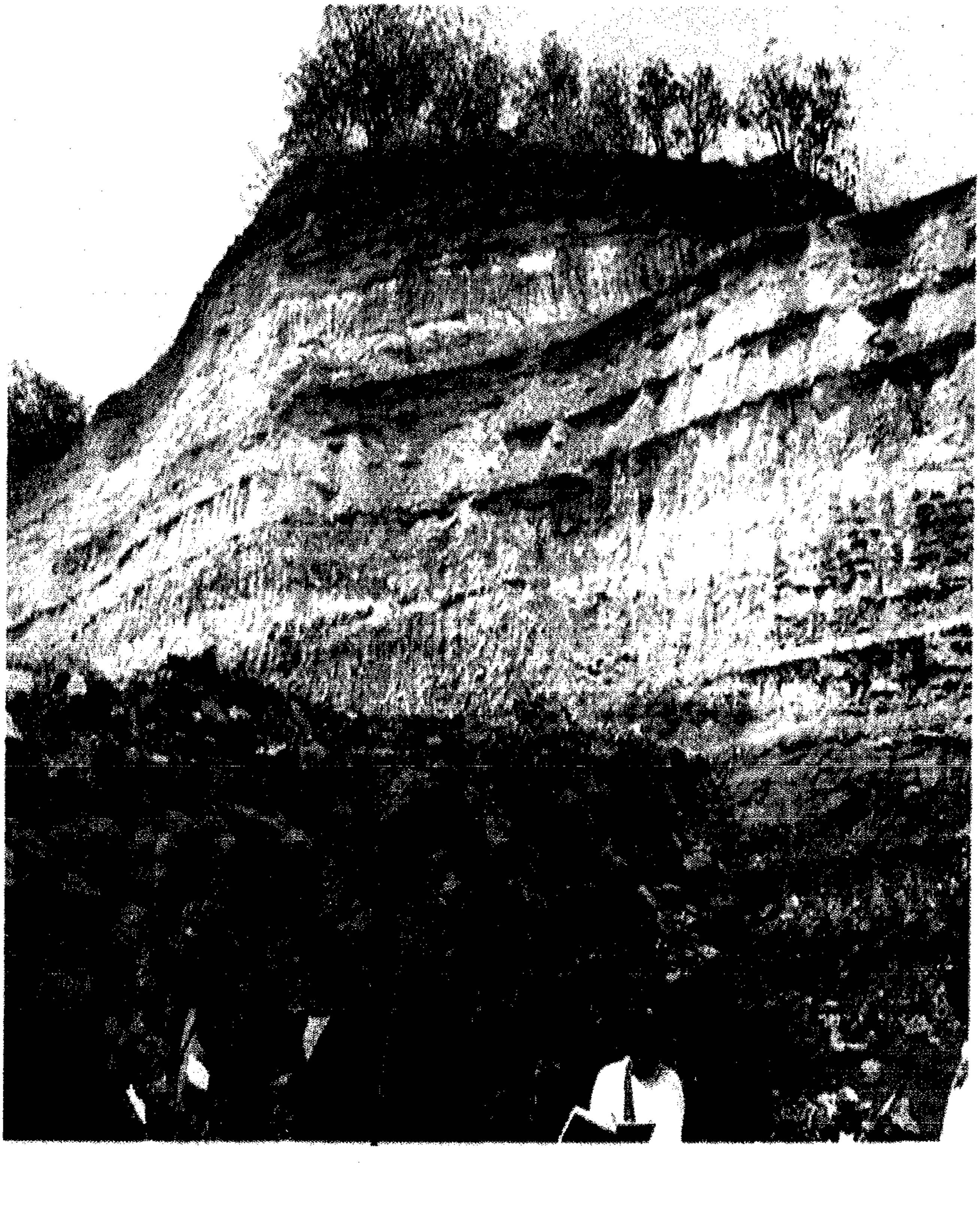

Figure 4.1: Field photograph of Ahoko section showing the lithology of Patti Formation

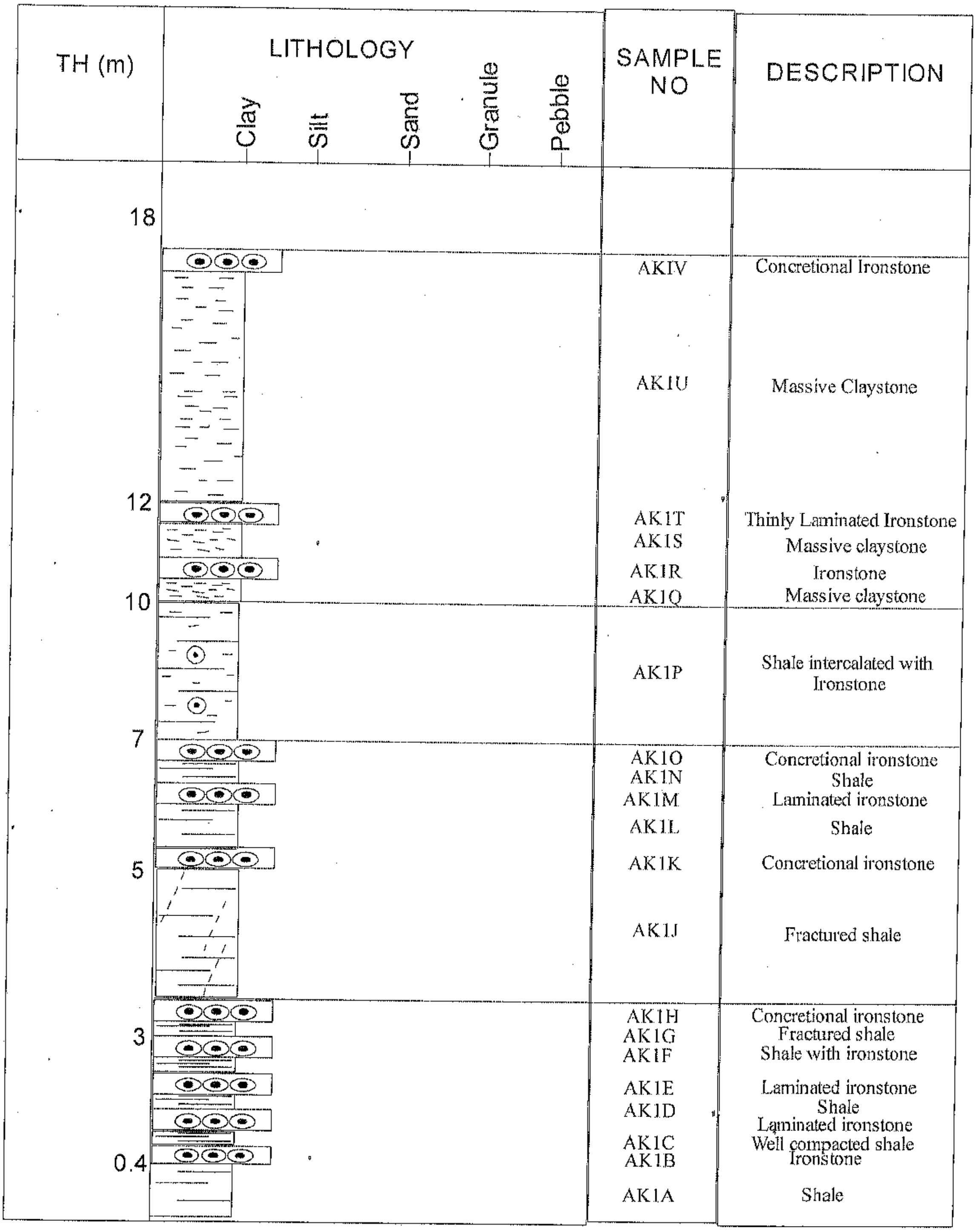

Figure 4.2: Lithological log of Patti Formation at Ahoko

4.3 LITHOLOGY DESCRIPTION OF GEHEKU 1

Geheku 1 is located on latitude $8^{o}18'51''$ and the longitude $6^{o}32'34''$. It has the elevation of 98m at the base. It falls within the Patti Formation which consists of shale, claystone and ironstone. Geheku 1 is composed of shale and concretional ironstone. The oldest bed is shale preceded by concretional ironstone. At GH1E, there is intercalation of shale, claystone and ironstone which is grayish in color. The youngest bed is a milky intercalation of claystone and ironstone.

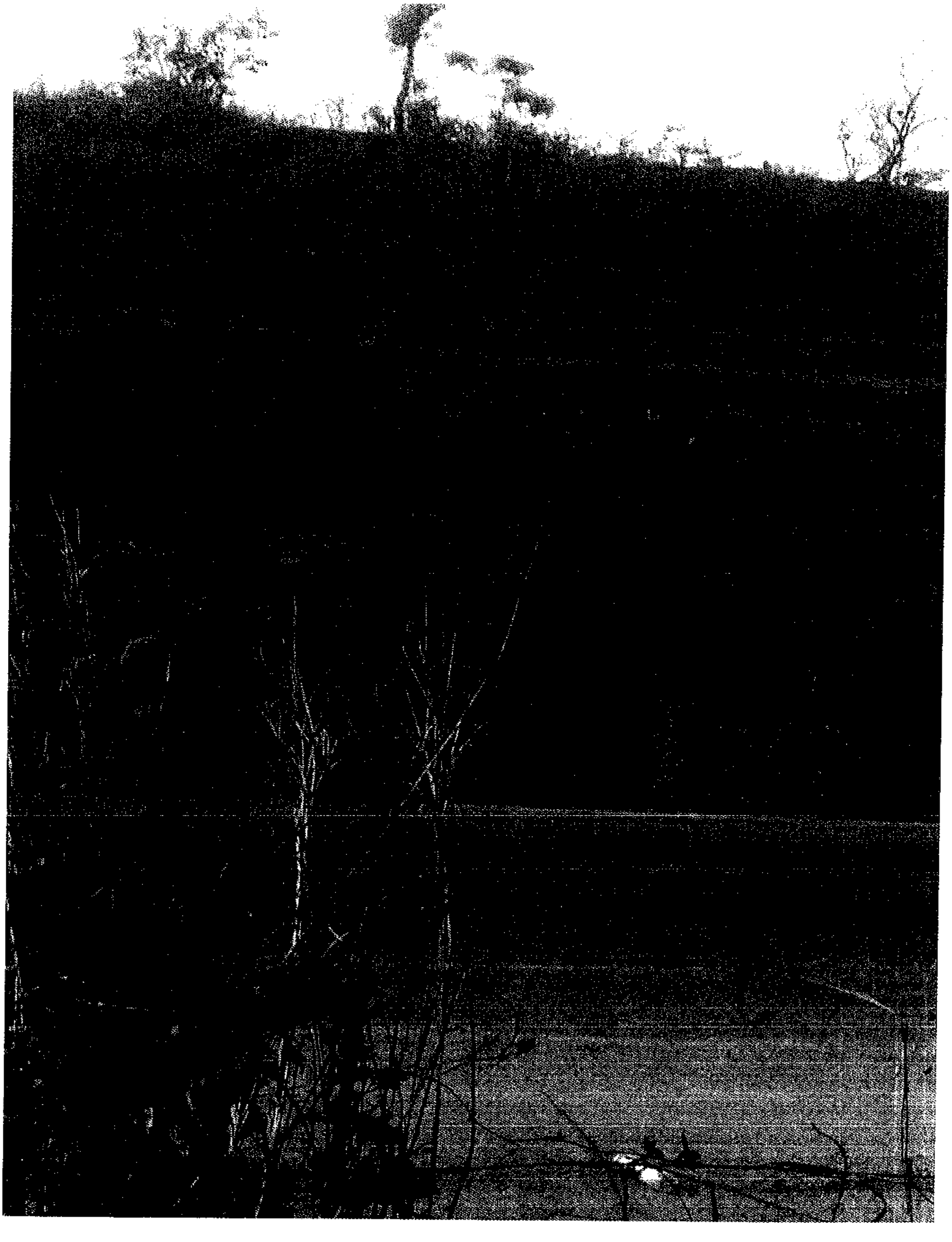

Figure 4.3: Field photograph of Geheku 1 section showing the lithology of Patti Formation

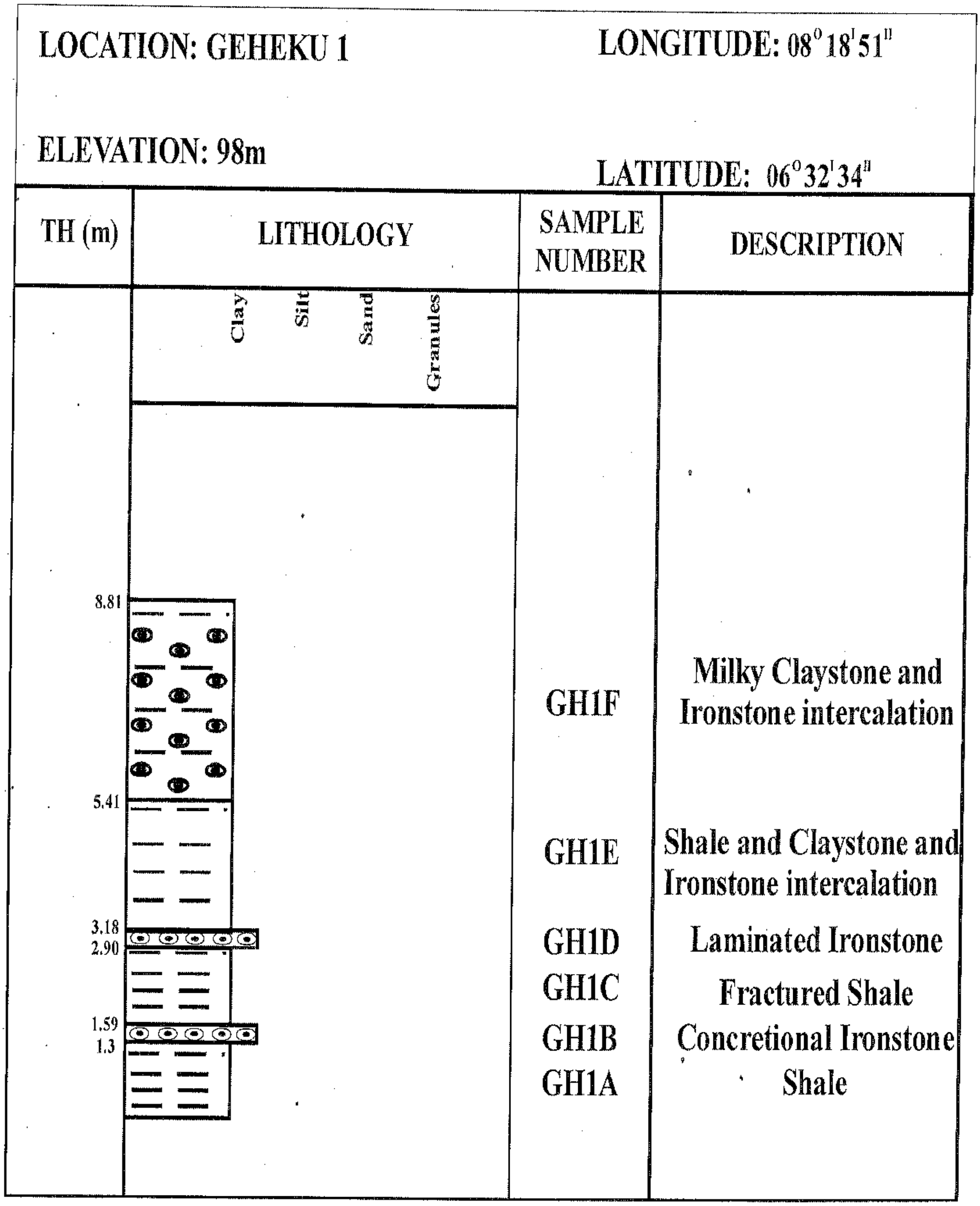

Figure 4.4: Lithological log of Patti Formation at Geheku 1

4.4: RESULTS AND DISCUSSION

4.4.1 COMPACTION ANALYSIS

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil for a specified compactive effort. Two (2) shale samples were analyzed which are GH1E and AH1E. The compactive effort is the amount of mechanical energy that is applied to the soil mass. The analysis is to determine if the soil is well compacted or not. The table and plots below shows the result:

Table 4.1: Compaction analysis result

	Sample	Optimum Moisture Content (O.M.C)	Maximum Dry Density
.No.	No	%	(M.D.D)
			mg/m^3
1	**GH1E**	16.18	1.79
2	**AK1E**	13.60	1.80

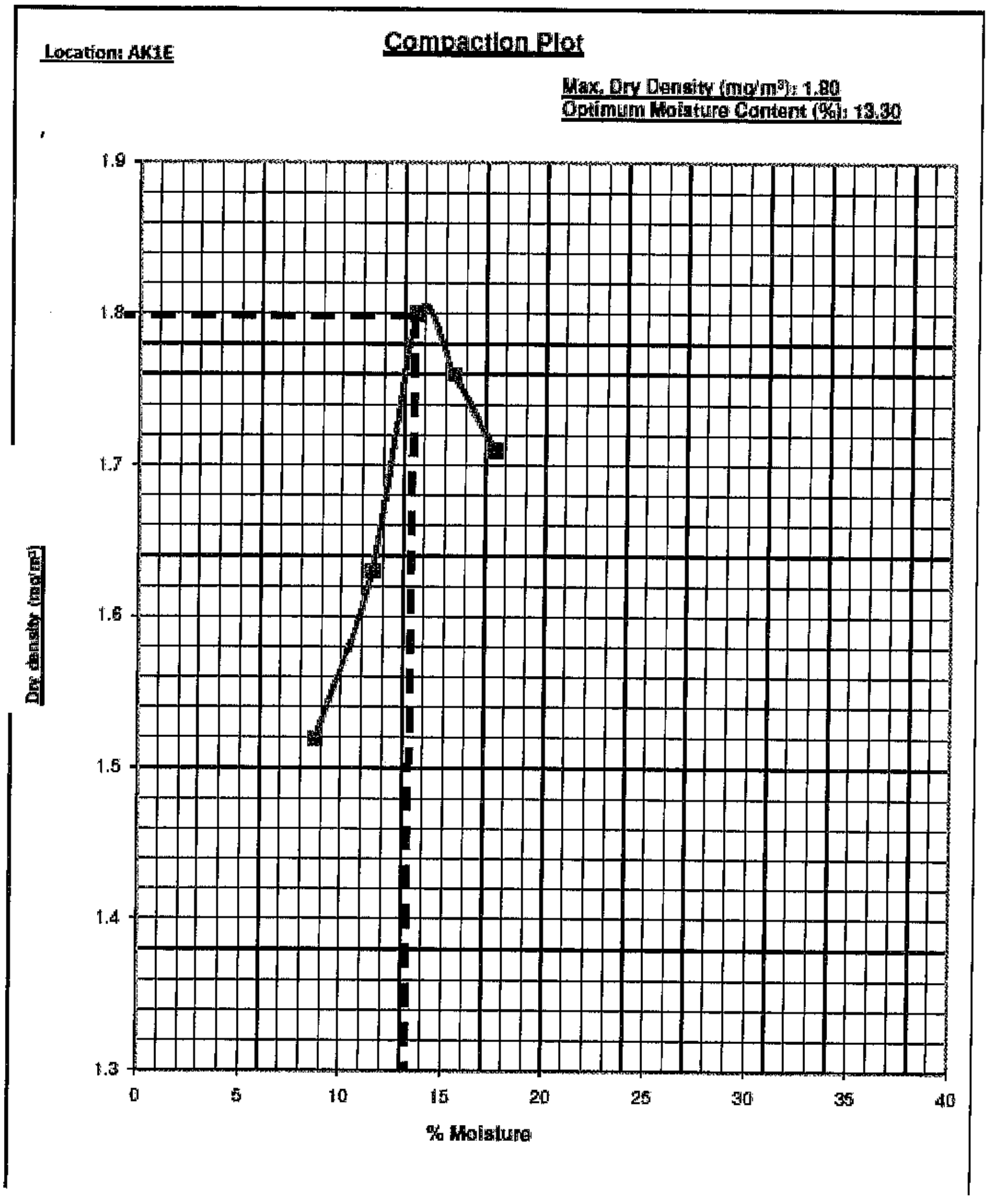

Figure 4.5: Compaction Plot of AK1E

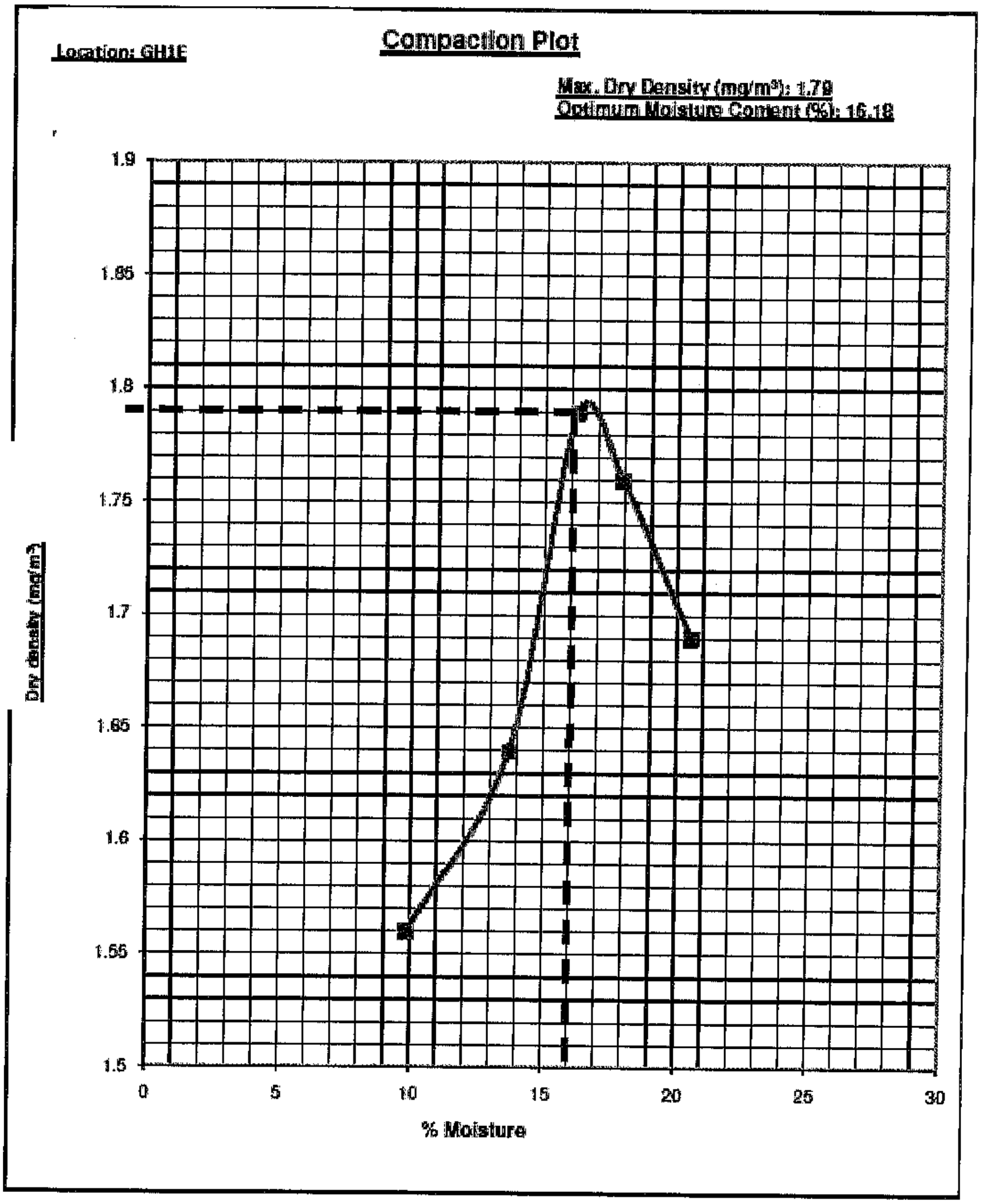

Figure 4.6: Compaction Plot of GH1E

Compaction test of a soil is use to determine the compaction of the soil so as to develop the engineering properties of the samples. It is used to determine the maximum dry density and optimum moisture density content. High density improves the shear strength and elastic modulus as the permeability is decreased. To achieve the high densities, the material is compacted at optimum moisture density. After the analysis, the optimum moisture density content for AK1E and GH1E are high at 13.60% and 16.18%respectively, this making the shale to be good for engineering purposes. The densities are high because the samples are cohesive soil. Shale has high compaction value making it impermeable.

4.4.2 ATTERBERG LIMIT

Atterberg limit are a basic measure of the critical water contents of a fine-grained soil e.g. shale: its shrinkage limit, plastic limit and liquid limit. The numbers of samples analyzed are 9. The table and chart below shows the result:

Table 4.2: Atterberg Limit analysis result

No.	Sample No	Liquid Limit	Plastic Limit	Plastic Index
1	**GH1A**	63	27	36
2	**GH1C**	60	26	34
3	**GH1E**	72	32	40
4	**AK1E**	55	25	30
5	**AK1L**	66	28	38
6	**AK1P**	70	26	46
7	**AK1S**	67	23	44
8	**AK1U**	60	29	31
9	**AK1A**	65	25	40

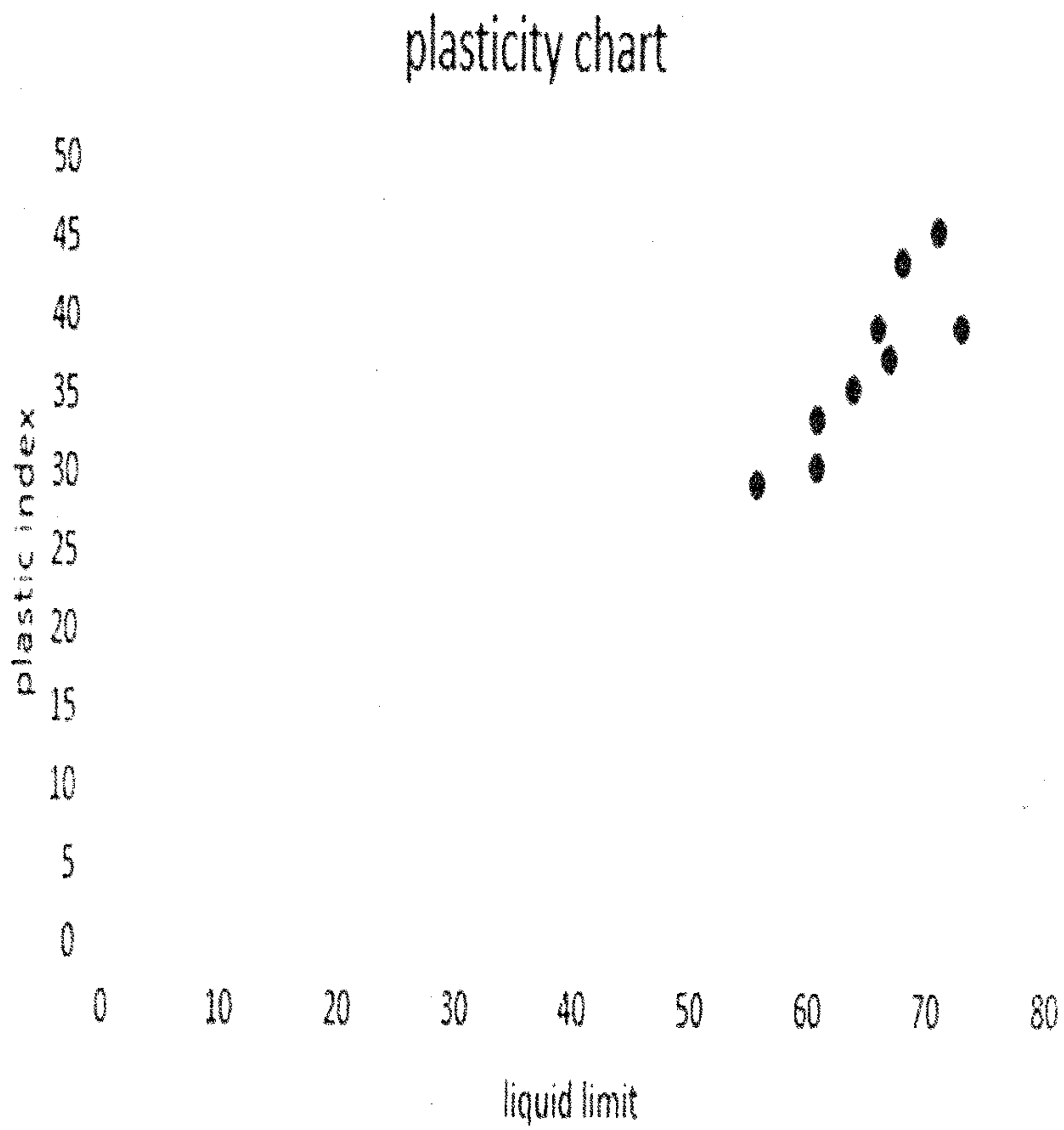

Figure 4.7: Chart for plasticity of the shale in Ahoko and Geheku

The Atterberg limits test consists of liquid limit, plastic limit and a value frequently used in conjunction with these limits is the plasticity index. The engineering properties of soil vary with the amount of water present. The results of the Atterberg tests are used to differentiate between various states of the soil at different moisture contents. Low plasticity index indicates a granular soil with little or no cohesion. The Atterberg limits in the construction of pavements are very vital in that it indicates the shrinkage of the material. A material having high plasticity index is not suitable in pavement construction since it will suffer excessive shrinkage in dry conditions and excessive expansion in wet conditions. The effect of constructing on such material would be cracks on the pavement, settlement of the pavement and rutting of the road surface. The above chart shows that the analyzed shale samples have higher value of plastic index than plastic limit varying from 31-46, this makes it not too good for pavement or any engineering structure.

4.4.3 GRAIN SIZE ANALYSIS

Grain size analysis was done using different sizes of sieve, ranging from 3.35mm to 63mic. The table below shows the result gotten from the analysis.

Table 4.3; Grain size analysis result

		Dry Sieving (% Passing)								
Sample no	U WGT KN/m3	3.35mm	2.00mm	1.18mm	600mic	425mic	300mic	212mic	150mic	63mic
GH1A	10.40	100	100	98	92	90	88	86	83	80
GHIC	7.40	100	98	96	90	86	83	82	80	78
GHIE	11.00	100	100	99	96	93	90	88	85	82
AK1E	7.30	100	100	99	95	93	90	87	85	83
AKIL	6.20	100	100	91	89	87	85	83	80	78
AKIP	6.90	100	100	100	98	90	87	84	82	80
AK1S	8.70	100	99	98	98	96	93	90	88	85
AK1U	5.30	100	100	98	96	94	92	90	87	84
AK1A	15.10	100	97	95	90	89	87	86	85	82

The initial size for each sample is 100g. Shale is a fine grained soil which leads to high percentage of passing.

The table below is the calculation of the cummulative frequency of the samples.

CUMULATIVE FREQUENCY TABLE

Table 4.4: Cumulative frequency table of the grain size analysis

sieve size(mm)	GH1A	GH1C	GH1E	AK1E	AK1L	AK1P	AK1S	AK1U	AK1A
3.35	0	0	0	0	0	0	0	0	0
2	0	2	0	0	0	0	1	0	3
1.18	2	6	1	1	9	0	3	2	8
0.6	10	16	5	6	20	2	5	6	18
0.425	20	30	12	13	33	12	9	12	29
0.3	32	47	22	23	48	25	16	20	42
0.212	46	65	34	36	65	41	26	30	56
0.15	63	85	49	51	85	59	38	43	71
0.063	83	107	67	68	107	79	53	59	89
Sum	256	358	190	198	367	218	151	172	316

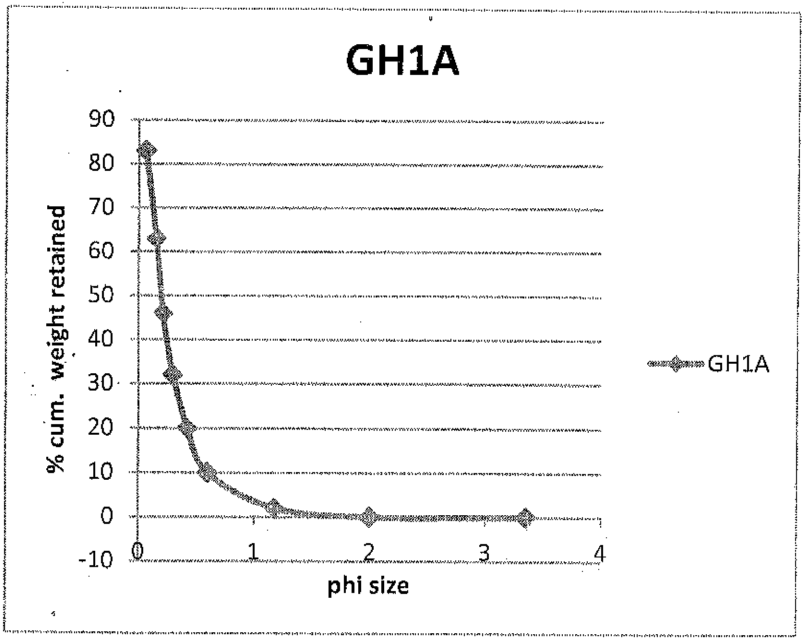

Figure 4.8: Grain size curve for GH1A

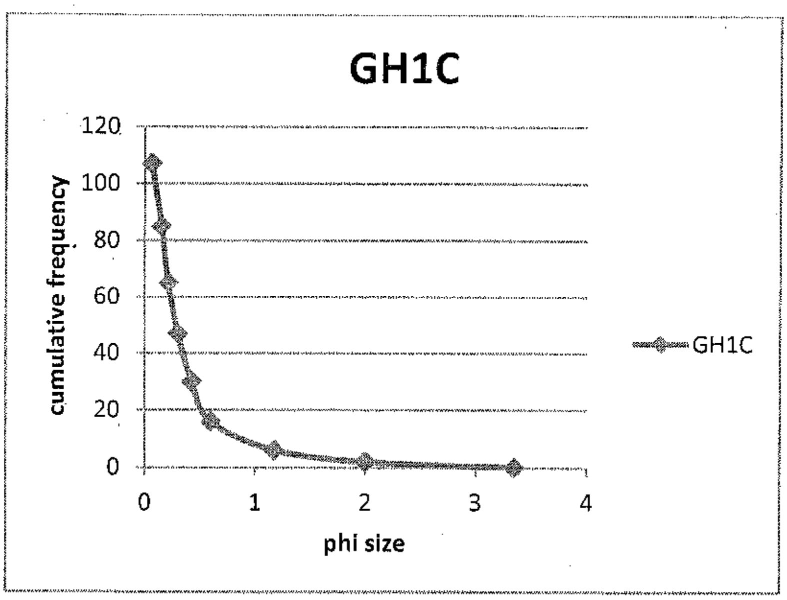

Figure 4.9: Grain size curve for GH1C

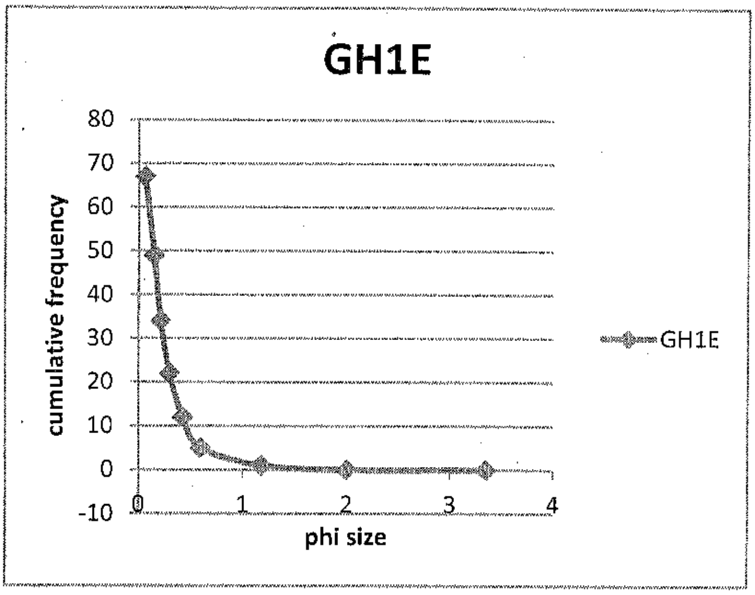

Figure 4.10: Grain size curve for GH1E

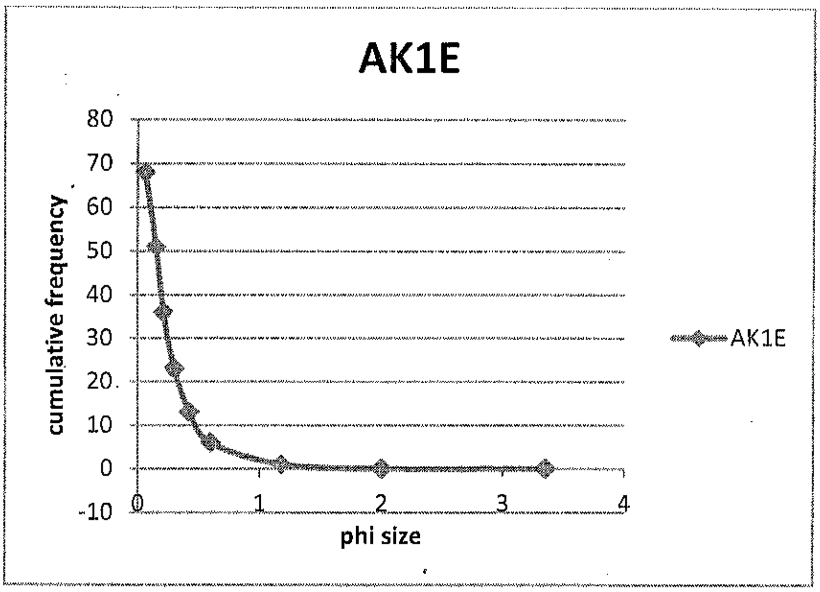

Figure 4.11: Grain size curve for AK1E

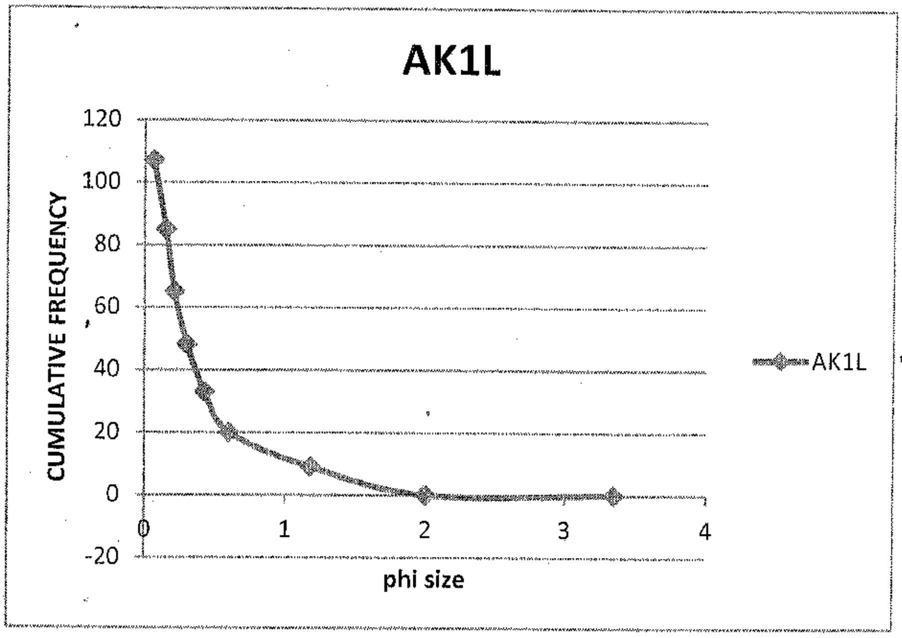

Figure 4.12: Grain size curve for AK1L

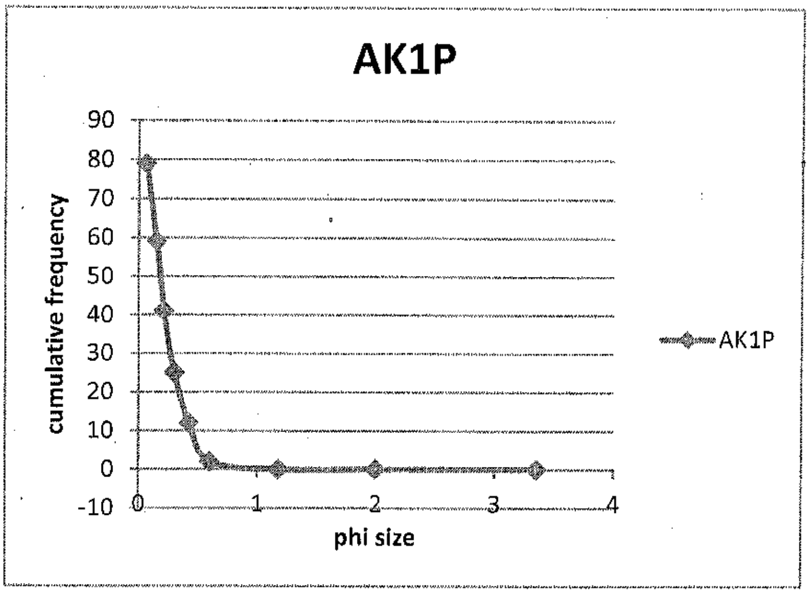

Figure 4.13: Grain size curve for AK1P

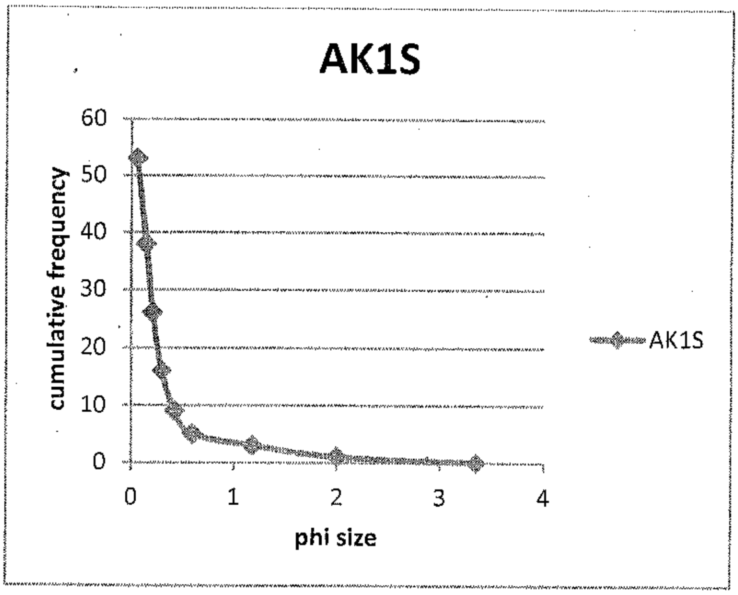

Figure 4.14: Grain size curve for AK1S

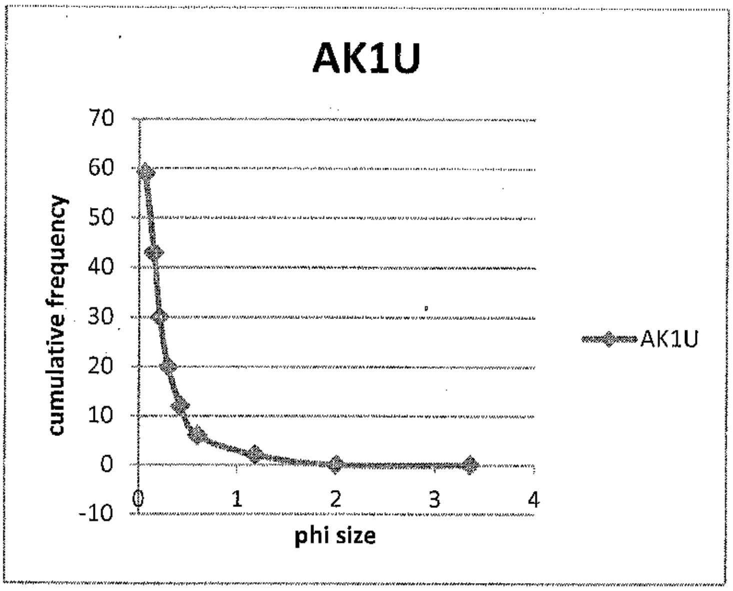

Figure 4.15: Grain size curve for AK1U

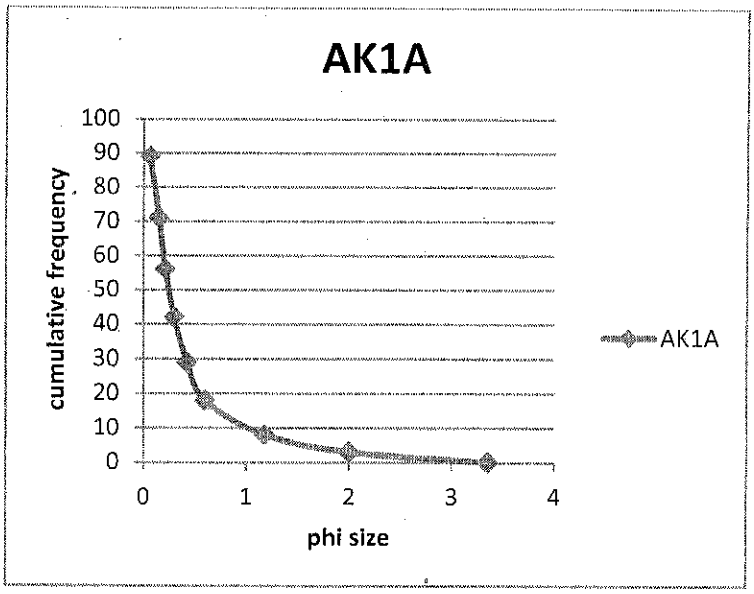

Figure 4.16: Grain size curve for AK1A