RESERVOIR QUALITIES OF LOKOJA BASANGE FORMATION IN THE SOUTHERN ANAMBRA BASIN

BY

Destiny IDEMUDIA

LSC1807227

DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY

(GEOLOGY AND MINING TECHNIQUE)

FACULTY OF LIFE SCIENCES

UNIVERSITY OF BENIN

BENIN-CITY

MAY, 2024

RESERVOIR QUALITIES OF LOKOJA BASANGE FORMATION IN THE SOUTHERN ANAMBRA BASIN

BY

Destiny IDEMUDIA

LSC1807227

A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, BENIN-CITY, IN PARTIAL FULFILLMENT FOR THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE DEGREE (B.Sc.) IN SCIENCE LABORATORY TECHNOLOGY (GEOLOGY AND MINING TECHNIQUES)

MAY, 2024

CERTIFICATION

This is to certify that this project work titled 'RESERVOIR QUALITIES OF THE LOKOJA BASANGE FORMATION IN THE SOUTHERN ANAMBRA BASIN' was carried out by Destiny IDEMUDIA, with matriculation number LSC1807227, of the Department of Science Laboratory Technology, Faculty of Life Sciences, University of Benin, Benin-City.

________________________ ____________________

MR. K. OJEAGA Date

(Project Supervisor)

________________________ ____________________

MRS. P. OMOZUWA Date

(Project Coordinator)

________________________ ____________________

DR. E. O. OSHOMOH Date

(Head of Department)

DEDICATION

This project work is dedicated to God, who in His divine grace and love has provided me with the strength and motivation to begin and complete this work. May His name forever be praised.

I also dedicate this work to my parents for their unwavering love, support, and encouragement throughout my pursuit of education. I would not be where I am today without them.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my appreciation to God for bringing me this far. I would also like to thank my Supervisor, Mr. K. Ojeaga, for his wisdom, guidance, patience, and support towards me in the course of this project. His expertise played a crucial role in the successful completion of this project. Additionally, I would like to acknowledge the Head of Department, Dr. E. O. Oshomoh, my well-established and knowledgeable lecturers, Mr. P. Bassey, Mrs. A. Janet, and my Course Adviser, Mr. Archibong, for their continuous support throughout this project.

Lastly, I extend my appreciation to my loving parents, Mr. Alfred Idemudia, and Mrs. Faith Idemudia, as well as my siblings, Confidence Idemudia, Prince Collins Idemudia, Shadrack Idemudia, Prosper Idemudia, Progress Idemudia, and Famous Obaho, for their infinite love, encouragement, and prayers. The completion of my project would not have been possible without them.

TABLE OF CONTENTS

TITLE PAGE i

CERTIFICATION iii

DEDICATION iv

ACKNOWLEDGEMENT v

TABLE OF CONTENTS vi

LIST OF TABLES viii

LIST OF FIGURES ix

ABSTRACT x

CHAPTER ONE 1

INTRODUCTION 1

1.1 Background of study 1

1.2 Aim and Objectives 3

1.3 Justification of the study 4

CHAPTER TWO 6

LITERATURE REVIEW 6

2.1 Evolution of the Anambra Basin 6

2.2 Stratigraphy of the Benin Flank of the Anambra Basin 6

2.3 Lokoja-Basange Formation 6

2.4 Regional Geological Framework of Anambra Basin 8

2.5 Paleoenvironments of Anambra Basin 9

2.6 Lithofacies Characteristics of the Sediments 12

2.7 Reservoir Quality of Anambra Basin 13

CHAPTER THREE 16

MATERIALS AND METHODS 16

3.1 Field Studies 16

3.2 Detailed Study 16

3.3 Laboratory Analysis....................17
3.4 Reservoir Parameters.................... 18
CHAPTER FOUR....................19
RESULTS AND INTERPRETATION.................... 19
4.1 Presentation of Results.................... 19
4.2 Particle Size Distribution Analysis....................24
4.3 The Summary of Textural Attributes of the Sediments as obtained from the Sieve Analysis are given in Table 4.11....................25
CHAPTER FIVE....................29
SUMMARY, CONCLUSION AND RECOMMENDATION....................29
5.1 Summary....................29
5.2 CONCLUSION.................... 29
5.3 RECOMMENDATIONS....................29
REFERENCES....................30
APPENDIX....................34

LIST OF TABLES

TABLES PAGES

Table 4.1. Particle size distribution for Lokoja Basange Sediments (L9) — 19

Table 4.2. Particle size distribution for Lokoja Basange Sediments (L10) — 20

Table 4.3. Particle size distribution for Lokoja Basange Sediments (L11) — 20

Table 4.4. Particle size distribution for Lokoja Basange Sediments (L12) — 21

Table 4.5. Particle size distribution for Lokoja Basange Sediments (L13) — 21

Table 4.6. Particle size distribution for Lokoja Basange Sediments (L14) — 22

Table 4.7. Particle size distribution for Lokoja Basange Sediments (L15) — 22

Table 4.8. Particle size distribution for Lokoja Basange Sediments (L16) — 23

Table 4.9. Particle size distribution for Lokoja Basange Sediments (L17) — 23

Table 4.10. Particle size distribution for Lokoja Basange Sediments (L18) — 24

Table 4.11. Textural interpretation of sediments from each location — 25

Table 4.12. Results of porosity parameters for Lokoja Sandstone reservoirs — 27

LIST OF FIGURES

Fig. 2.1. Photograph of Bawa Hill section of the Lokoja Basange Formation outcropping a road cut along the Auchi-Igarra road. Note the hammer resting on the thorough crossbed..................7

ABSTRACT

This study was conducted to investigate the reservoir quality of outcropping sediments in the Lokoja Basange Formation, which is located in the Anambra Basin and specifically determine sieve analysis and characterize the reservoir qualities of the sediments by inferring the porosity of the Lokoja Basange Formation. A total of fourteen (10) samples were collected and analyzed for the study. Freshly obtained samples for sieve analysis were systematically retrieved from different layers on each outcrop in the study area. The reservoir porosity and permeability of the sandstone units of the Lokoja Formations were estimated from sieve analysis. The predictive tools for the determination of reservoir quality of the outcropping sediments in Lokoja Basange which are porosity and textural characteristics and textural parameters of the sediments. The result showed that the mean size of sediments in all ten locations from the area of study ranges from 2.94 - 4.03mm. The highest mean was observed at L9, while the lowest mean was observed in L14. The results from Table 4.11 also showed that at locations L9, L10, L11, L12, and L13, the sediments exhibit coarse characteristics, as indicated by their relatively higher grain sizes, which exceed 2mm. The result showed that the porosity values across all locations are consistent (0.255), indicating that regardless of the variations in grain size distribution, the overall volume of void space within the sediment remains the same. It is recommended that further studies be carried out on this basin so as to determine the provenance of the sediments.

CHAPTER ONE

INTRODUCTION

1.1 Background of study

The Anambra Basin developed as a result of the differential subsidence of the fault block in the southern Benue Trough, which preceded the Santonian tectonic pulse. According to Edegbai *et al*. (2019), it was a deltaic complex full of lithostratigraphic units similar to those of the Cenozoic Niger Delta. According to Edegbai *et al*. (2019), the Anambra Basin is located between the Niger Delta Basin and the Benue Trough to the south. Thick sedimentary deposits are a defining feature of the basin and are crucial to the discovery and extraction of hydrocarbons. Exploration efforts have been conducted in the Anambra Basin to evaluate its hydrocarbon reserves because it is thought to have significant oil and gas resources (Edegbai *et al*., 2019).

Sandstones are sedimentary rocks that are created when sediment is cementated by material cements. They exhibit a wide range of mineral composition variations, varying degrees of sorting and roundness, and excellent mineralogy and reservoir qualities. Rock features (such as sorting, sedimentary structures, particle size, form, lithology, porosity, texture, maturity, etc.) can be ascertained through sedimentological research (Okoro *et al*., 2020). Analyzing and interpreting the mineralogical (petrographic) aspects of rocks, such as their composition, abundance, and form, is also greatly aided by petrographic research.

The geological history of rocks, including their distances from provenance, paleoenvironmental conditions of formation and/or deformation, diagenetic processes acting on rocks, tectonic history, and the stratigraphy, is largely reconstructed through the combined use of sedimentology and petrography (Onuigbo *et al*., 2016). Geologists have a unique opportunity to directly see and evaluate rock formations through the investigation of outcropping sediments, which are exposed at the Earth's surface. This process offers vital insights into the Earth's previous environments.

In the southern sub-basin of the northwest-southeast trending, sedimentological and reservoir characterization, according to Sunny and Ezeh (2011), reveals that the Formation is composed of three major lithofacies associations: conglomeratic sandstone facies, massive sandstone facies, and clayey siltstone facies. Sandstone exhibits a high concentration of Ophiomorpha and Thalassonoides burrows, according to Sunny and Ezeh (2011). The sandstone is primarily medium grained with platykurtic to highly platykurtic properties, according to the granulometric analysis. The sandstone has a kaolinitic clay matrix and large feldspar grains, indicating its juvenile texture.

Rahman *et al*. (2019) and Sunny and Ezeh (2011) demonstrated that morphometric analysis suggests a fluvial process dominance with strong beach action influence, whereas two segments with few three segment curve types, indicating fluvial characteristics, dominated the log probability curves. One of the main goals is to reconstruct the paleodepositional environment by combining petrographic and sedimentological data to determine past conditions. According to Sunday *et al*. (2020), this entails figuring out the climate, energy regime, and water depth during the sedimentation period. Whereas the multivariate analysis reveals a shallow sea with a high influence of fluvial process, the palaeocurrent analysis indicates a unimodal and bimodal perpendicular rose diagram that typifies a fluvial process that has been affected by beach action. The features of a reservoir include quantitatively estimating permeability, which measures fluid movement through the rock, and inferring porosity, a critical component impacting fluid storage inside rocks. These reservoir characteristics are crucial in determining the southern Basin's hydrocarbon reservoir potential and add to its strategic and economic importance (Ogbe and Osokpor, 2021).

The petrographic analysis of the Filele sands shows that the sediments consist on average of 78% Quartz, 17% Feldspar, and 5% Rock Fragment, while the Mount Patti sands consist on average of 90% Quartz, 6% Feldspar, and 4% Rock Fragment, according to Okolo *et al*.'s (2021) study of outcropping sediments exposed in Lokoja and its environs. According to Okolo *et al*. (2021), the majority of the sediments are sub-arkose. Numerous researchers have examined sedimentology, stratigraphy, and sequence stratigraphic ideas in relation to the Anambra Basin and Niger Delta (Obi, 2000). In the northern Niger Delta and Anambra Basins, this author examined the depositional model of the outcrops along the Isele Azagba-Onitsha-Akwa areas.

Rebuilding sedimentary facies characteristics, diagenetic histories, and dominating controls on sequence development are made possible by the analysis and interpretation of the data sets. Additionally, the sediments of the northern Niger Delta and the reservoir qualities of the Anambra Basin can be further interpreted. The potential for the southern Anambra Basin to serve as a sedimentary archive that holds secrets about Earth's past makes it a region of great geological significance. Because of the exposed sediments in this area, which present a rare chance to examine the sedimentological and reservoir characteristics of the outcropping formations, geoscientists and researchers like me have been interested in this region. The sedimentary facies and depositional mechanism of the Cretaceous Ajali Sandstone in the Anambra Basin were documented by Ladipo (1986) and Amajor (1991). Based on process interpretation, Ladipo came to the conclusion that the sandstones were formed in a tidal shelf environment, whereas Amajor came to the conclusion that they were deposited in a fluvio-marine context.

1.2 Aim and Objectives

This study is aimed at investigating the reservoir quality of outcropping sediments in Anambra Basin.

The objectives of this study include:

i. To determine the particle size distribution of sediments in the Lokoja formations by carrying out sieve analysis.

ii. To determine the porosity of the sediments, thereby characterizing the reservoir qualities of the Lokoja Formation.

1.3 Justification of the study

There are various reasons to investigate the sedimentological characteristics and reservoir attributes of the outcropping sediments in the southern Anambra Basin. A geological window providing insights into Earth's past is the Anambra Basin. This study advances our knowledge of the region's geological evolution, depositional processes, and historical environmental conditions by closely examining the sedimentary strata. Determining the sedimentary rocks' identity and characteristics is essential to determining how valuable the basin could be as a storehouse for natural resources, especially hydrocarbons. Understanding lithofacies and reservoir properties provides valuable information for resource exploration and exploitation. The data generated from this study can contribute to strategic resource management, aiding in the sustainable exploitation of geological resources. By understanding the sedimentology and reservoir properties, policy makers and industry stakeholders can make informed decisions for long-term resource utilization. An in-depth analysis of the sediments helps in understanding the environmental conditions that prevailed during their formation. This knowledge is not only essential for geological interpretations but also for assessing the impact of human activities on the geological setting, contributing to environmentally responsible resource management. The study adds to the body of scientific knowledge in sedimentology, petrography, and geological history. The findings may serve as a reference for future research endeavors in similar geological settings, contributing to the broader scientific community's understanding of sedimentary basins. The research has educational value by providing a hands-on opportunity for geoscientists, students, and researchers to engage in fieldwork, sample collection, and laboratory analyses. The project contributes to skill development and fosters collaboration between academia and industry.

CHAPTER TWO

LITERATURE REVIEW

2.1 Evolution of the Anambra Basin

The tectonic processes that accompanied the separation of the African and South American plates in the Early Cretaceous are associated with the creation of the Anambra Basin (Murat, 1972). According to Nwajide (2013), the southern Benue Trough area constituted a longitudinally fractured crust whose eastern sector declined preferentially to form the Abakaliki sub-basin, suggesting a megatectonic context. The eastern part of the Abakaliki sub-basin, which had previously sunk, became a depocenter during the Santonian period, whereas the western sector remained a platform (Nwajide, 2013). The depobelt shifted to the west and northwest of the sub-basin, resulting in the development of the Anambra Basin, as a result of the flexural inversion of the Abakaliki sub-basin caused by the Santonian folding and uplift in the Abakaliki area (Nwajide, 2013).

2.2 Stratigraphy of the Benin Flank of the Anambra Basin

The oldest sedimentary unit on the Benin side of the Anambra Basin is the Lokoja-Basange Formation, which is the subject of the current study. This sedimentary series, which is hardly noted in the Anambra Basin stratigraphy, is a continental deposit that is immediately non-conformably deposited on the Igarra Schist Belt's basement complex. The Mamu Formation in that area of the Anambra Basin conformably overlays the Lokoja-Basange Formation, with the Ajali Formation capping the sequence.

2.3 Lokoja-Basange Formation

The oldest sedimentary unit on the Benin Flank of the Anambra Basin is the Lokoja-Basange Formation. It protrudes in a road-cut alongside the Auchi-Igarra road and is positioned non-conformably on the basement complex. There are siltstones, mudstones, claystones, and sandy horizons in the massively bedded formation (Fig. 2.1).

Figure 2.1 Photograph of Bawa Hill section of the Lokoja-Basange Formation outcropping in a road cut along the Auch-Igarra road. Note the hammer resting on the through crossbed

The basal units are substantially consolidated and ferruginized as seen at the contact with the basement complex. While the higher units show signs of iron oxide cement and are somewhat cemented, the middle units are friable and poorly sorted. The sandstones, which range in grain size from fine to coarse, have an angular to sub-angular texture and are typically poorly sorted. They have basal conglomerates and regular grading. In the intermediate units of the formation, mud chips and kaolinite beds with restricted lateral continuity are also typical. Large-scale trough cross-beddings and lag deposits, which suggest the presence of channels that have been shown to stack, predominate in sedimentary structures.

2.4 Regional Geological Framework of Anambra Basin

An appropriate geo-reactor for a variety of complicated chemical reactions that resulted in the production and occurrence of commercially viable hydrocarbon deposits is the Anambra Basin, a Cretaceous basin with a total sediment thickness of roughly 9 km (Whiteman, 1982). The roughly triangular-shaped Basin, which is situated in south central Nigeria and extends northward in the Benue River, has an area of around 40,000 square kilometers (Olubayo, 2010). The Niger Delta hinge line borders the basin on the south. It stretches north-east to Lafia, north-west into the Niger Valley, and northward to the Jos Massif. The Abakaliki Anticlinorium and Ibadan Massif, respectively, define the basin's eastern and western boundaries. The Anambra Basin's structural evolution has been documented by Ojoh (1992) and Obi *et al*. (2001). Most people agree that the Abakaliki-Benue Basin's Santonian tectonics, which folded the Abakaliki Anticlinorium as a result of a N–S compression between the African and Eurasia plates, is the source of the basin (Obi *et al*., 1995). The Anambra Basin was a platform with very little sediment cover before the tectonic event. The Anticlinorium folded laterally, shifting the depositional axis into the Anambra Platform, where sediments primarily shed from the Abakaliki Anticlinorium started to collect (Murat, 1972). The Anambra Basin-fill comprises over 2500 m of sediments that accumulated during the Campanian–Maastrichtian Period.

The rocks are sedimentary Cretaceous to Tertiary sediments, roughly 6,000 meters thick. It was first investigated in the early 1960s, when numerous unsuccessful exploratory wells were drilled. The cyclic pattern of the shales and sandstone facies, which can be traced back to the underlying Niger Delta, is the result of short intervals of transgression and extended periods of regression, which led to the formation of Neogene stratigraphic units. Quartz grains can be found in cobbles, pebbles, and granules with grain diameters ranging from subangular to subrounded. The paleocurrent trend of the sediments indicates a fluvial depositional environment, and the sediments are texturally young (Ojo and Akande, 2020; Ocheli *et al*., 2018; Obaje *et al*., 2011; Akande *et al*., 2006). Petters (1986) identified microfossils in the shale units that indicate shallow marine habitats, which are represented in the overlying Patti Formation in the Kotonkarfi, Ahoko, and Abaji localities. The enormous ironstone layers with oolitic characteristics make up the Agbaja Formation. As per Obaje *et al*. (2011) and Rahman *et al*. (2019), they create a continuous shield that protects the Campaniane Maastrichtian deposits in the Basin.

The granulometric analysis revealed a mixture of poorly to moderately sorted, positively skewed mesokurtic to platykurtic coarse-grained conglomerate and sandstone facies suggestive of strong to moderate energy of deposition, according to Alege *et al*. (2022)'s field associations and sedimentological studies of the Nataco-Banda outcrops of the Lokoja Formation. The fluvial environment is dominant in the pebble morphometric analysis, whereas the linear discriminate analysis reveals a shallow, agitated marine environment that is heavily impacted by the fluvial deposition (fluvial-deltaic) (Alege *et al*., 2022).

2.5 Paleoenvironments of Anambra Basin

Situated in Eastern Nigeria, the Anambra Basin is a sedimentary basin with a multimillion-year geological history. Over time, the Anambra Basin's paleoenvironments have changed, leaving behind sedimentary rocks that preserve past climatic conditions and landscapes (Aigbadon *et al*., 2022). The Basin was distinguished by the deposition of marine sediments throughout the Cretaceous epoch. The existence of marine species in the fossil record implies that the region was once submerged under a sea or other shallow marine habitat. The Basin saw a change from marine to continental environments during the Paleogene. Sandstones, mudstones, and coal beds are examples of continental deposits that were deposited during this period (Aigbadon *et al*., 2022).

The formation of terrestrial ecosystems, such as rivers and swamps, is suggested by the presence of these sediments. The Anambra Basin's paleoenvironments saw additional modifications during the Neogene epoch. This period's sedimentary deposits comprise lacustrine (associated to lakes) and fluviatile (related to rivers) sediments. These sediments suggest that river systems have developed and that lakes may have existed in the region. The Quaternary epoch, spanning to the present day, is distinguished by the recent sediments that have been deposited (Turner and Riddle 2005). Alluvial deposits, which are connected to river activity and sedimentation in floodplain areas, are among these sediments. It's possible that throughout this time, tectonic activity and climate variations caused changes in the landscape. The paleoenvironments of the Basin have been significantly shaped by tectonic processes like faulting and folding. The basin's structural evolution and sedimentary history have been influenced by tectonic activity, and it is a component of the wider West African Rift System. Anambra Basin's lithofacies' textural and statistical characteristics have been thoroughly examined, and the results have provided information about the paleoenvironments. The sandstone units of the Formation are comprised of distinct cross-strata, including as planar cross strata, trough cross strata, and herringbone cross strata, which are distinguished by the presence of sheet-like pebbles orientated between them (Aigbadon *et al* 2023). (Miall 2000; Nichols 2009) have attributed planar and trough cross-strata sandstone lithofacies to point bars and estuary channels.

The absence of organic remains, or fossils, in the planar-cross and herringbone strata outcrop exposures may be related to high energy environments that are linked to wave and little tidal processes. Okoro *et al*. (2020) report that comparable lithofacies have been identified in shoreline and subtidal habitats. The Patti Formation's shale outcrops exhibited fissility, indicating that the shale deposition took place at a time beneath the dominant wave (Aigbadon *et al*., 2023). Aigbadon *et al*. (2022) state that the mudstones' laminations, the dark grey shale that interbedded with the mud, and the fossiliferous muddy shale all point to the deposits being mudflats in an estuary environment.

The occurrence of an open to shallow marine environment was indicated by the presence of carbonaceous grey shale in the Basin. According to Aigbadon *et al*. (2023), the particle size distribution data also show the existence of fluvial in shallow maritime environments. Furthermore, because the middle estuary is composed of lagoonal silt and intertidal bay fill, the particle size distribution of the fine-grained and bioturbated sandstones and plant remains clearly shows that the sandstone units were deposited in a low-energy environment. This is thought to imply the causes of the fine sediment deposit in outcrop (Turner and Riddle 2005).

Conversely, the skewness value, when interpreted as a coarse skewness compared to a strongly fine skewness, indicates that the sandstones were deposited in a riverine environment (Turner and Riddle 2005). The Anambra Basin's highly finely skewed sediments show that the sediments were significantly winnowed. The sandstone facies' mesokurtic to leptokurtic characteristics show a continual accretion of finer sediments after the sandstone's initial characteristics were preserved throughout deposition by the depositional medium.

The presence of a predominantly mesokurtic cross-stratified sandstone suggests that sediments deposited by a unidirectional current flow are the source of the Anambra Basin Formation's sandstones. The Formation's leptokurtic nature suggests that unstable currents are in charge in the prevailing low-energy environment (Aigbadon *et al*., 2022). At outcrops, the texture of the Lokoja sandstone ranges from fine to medium sandstones, with generally fair sorting capabilities (Aigbadon *et al* 2023). The combination of unstable current linked to tidal and fluvial processes that were common during deposition is assumed to account for the fine and medium to coarse sandstone facies, which exhibit a marginal marine setting (Aigbadon *et al* 2023). However, the poor sorting properties of the sandstone have demonstrated that it was deposited under varying degrees of turbulent flow and current velocities. The arithmetic average of the skewness and kurtosis of the sandstone of the Lokoja Formation indicates that it is strongly coarse skewed and mesokurtic. The Patti Formation's extremely coarse skewed sandstone has travelled less distance and shows less sifting. Mesokurtic patterns are common in Patti sandstone from the Patti Formation, suggesting that the sandstone was produced in a low-energy environment by a unidirectional flow. The skewness of the formation and the depositional environment may account for the apparent predominance of fine sandstone in the basin (Aigbadon *et al* 2023).

2.6 Lithofacies Characteristics of the Sediments

A unique rock unit with particular lithologic properties, such as composition, texture, and sedimentary formations, is referred to as a lithofacies. Different lithofacies are found in sedimentary basins like Lokoja, which represent the environmental circumstances and geological history during deposition (Omali *et al*., 2011). In sedimentary basins, lithofacies are often categorized according to their mineralogy, sedimentary structures, and other characteristics. Certain depositional habitats, such as those that are deltaic, marine, lacustrine, or fluvial, are linked to particular lithofacies. Sediment types are influenced by the climate during the time of deposition. For instance, the kind and size of sediments can vary depending on the climate (Uzoegbu *et al*., 2013). Basin form is influenced by tectonic activity, which includes subsidence and elevation and influences the kinds of sediments deposited.

The lithofacies of the sediments are influenced by the characteristics of the parent rocks, such as their mineral makeup and organic content. The initial lithofacies are altered by post-depositional processes like diagenesis, which are changes in sediment characteristics brought on by cementation, compaction, etc.

Geometry, lithology, sedimentary structures, palaeocurrent pattern, and fossils are characteristics that identify and set apart sedimentary facies (Ojo and Akande, 2009; Vakarelov and Bhattacharya, 2009; Omali *et al*., 2011; Obaje *et al*., 2011; Uzoegbu *et al*., 2013). A depositional environment produces sedimentary facies.

A facies sequence is considered to be a collection of related facies, either genetically or environmentally. The Anambra Basin's facies was composed of brownish silty sandstone at the base, grey shale, bituminous coal, and grey shale, with whitish grey silty sandstone on top. The petrographic examinations revealed that the grains are sub-rounded and fairly sorted, with a parallel lamination structure. The grains are fine. Lack of glauconite and the presence of coal seams may indicate that the environment is not entirely marine (Odebode, 1987). According to Uzoegbu and Uchebo (2014), the sample's probability plot tends to show just one sand population curve, which could indicate deposition in a riverine environment.

2.7 Reservoir Quality of Anambra Basin

In evaluating the Anambra Basin's reservoir quality or any geological formation, geoscientists and petroleum engineers take into account a number of crucial elements, including: The percentage of pores or open areas in a rock is called its porosity. Since higher porosity makes it possible to store fluids like oil and gas, it usually denotes a higher quality reservoir. Rock permeability is a measure of how well fluids can pass through it. The qualities of a reservoir are dependent on the kind of rock and the minerals that make up that rock (Likkason *et al*., 2013). For instance, because of their high porosity and permeability, sandstones are frequently chosen rocks for reservoirs. The physical and chemical alterations that a rock experiences after it is first formed are known as diagenesis. Permeability and porosity may be impacted by the diagenetic processes.

Reservoir quality is also influenced by the characteristics of the fluids (water, gas, and oil) inside the reservoir. For example, fluid flow can be affected by the salinity of water and the viscosity of oil. Reservoir quality may be impacted by the basin's structural features, such as folds and faults. Permeability may be improved by well-connected fractures (Okolo *et al*., 2020).

Several authigenic minerals, including carbonates, quartz, chlorites, and clay minerals, have been observed during cementation in the sandstones of the Anambra Basin based on investigations conducted using thin section, SEM, and XRD techniques. During diagenesis, these authigenic minerals, quartz and calcite, precipitate when they come into direct contact with an alkaline fluid.

The overgrowth of calcite and quartz, which fills pore spaces, has caused the reservoirs' pore throats to become heavily blocked. This lowers the reservoirs' porosity and permeability, which has an immediate impact on their quality and heterogeneity. Aigbadon *et al*. (2023) state that the primary authigenic/diagenetic phase in the siliciclastic succession is quartz cement, as demonstrated by the thin section, SEM, and other methods. Every sandstone unit in the sandstones contains quartz cement. This quartz reduces the intergranular pore diameters and appears as overgrowths and quartz grains. In certain sandstone samples, clay mineral or cement was also found between the quartz grains and quartz overgrowth (Likkason *et al*., 2013).

In the pore throat of the impacted reservoirs, the presence of authigenic minerals such as kaolinite, illite, and chlorite was also demonstrated by SEM, thin section, and XRD analyses. Silica is a byproduct of pressure dissolution altering the clay mineral. The result of this multi-source silica precipitation was a high quartz content, which naturally led to a decrease in the sandstones' porosity and permeability. The Anambra Basin Formation's sandstone porosity varies from 8.42 to 19.45%, and its permeability values range from 5 to 91 milliseconds. The large range of permeability values indicates the quality of the reservoir, from poor to good (Okoro *et al*., 2020).

The Patti Formation's sandstones have a porosity of 9.38–15.42% and a permeability range of 6.75–97.56 md, according to Okoro *et al*. (2020). This indicates that, based on the computed permeability, the reservoirs have poor-good characteristics. However, outcrop exposures of the Patti Formation at the Abaji road portion and the Lokoja sandstone at Robinson Road, which both showed moderate to coarse textures embedded with herringbone, planar, or trough cross-strata, as reported by Aigbadon *et al*. (2023), are suggestive of lithofacies with good reservoir properties. The Patti sandstone outcrop at the Ahoko part differs significantly from those at the Abaji road section due to the fact that the former are primarily fine-textured, bioturbated sandstones that are rather well-sorted and usually contain less clay debris.

Davis and Dalrymple (2011) state that the poor reservoir potentials found in the Ahoko section are likely related to the severe bioturbation that has impacted the sandstones in this outcrop. In the Lokoja and Patti sandstones, the range of quartz values is 49–67% and 43–68%, respectively. The Patti sandstone at Ahoko has a slightly higher clay content than the Lokoja Formation, but both formations are primarily composed of quartz minerals, according to Okolo *et al*.'s (2020) mineral analysis, which also shows low-to-moderate amounts of kaolinites and illite minerals.

The clay mineral of Lokoja sandstones ranges from 23 to 25%, while Patti sandstone ranges from 25 to 30% within the Abaji area and 36.8–48% in the Ahoko area, respectively. The high porosity and permeability values of sandstone reservoir facies of the Lokoja and Patti formations in the Lokoja and Abaji outcrop sections, respectively, singled out the sandstones to be good reservoirs. This means that the sandstone facies could provide a good prospect for hydrocarbon search in the basin.

CHAPTER THREE

MATERIALS AND METHODS

This is a work flow was designed for this research, illustrating the flows of tasks to complete the study.

3.1 Field Studies

A field investigation was undertaken in the study areas to examine and describe exposed rock units, log their vertical sections and identify reservoir qualities of the sediments by determining the porosity in the southern Anambra Basin. Ten (10) samples were collected at different outcrops within the area of study, which were further analyzed in the laboratory, with the aim of determining their grain size, the particle size distribution, and the reservoir parameters of each sample. The outcropping rocks in the study area were photographed, while sandstones and pebbles were taken for laboratory analysis.

3.2 Detailed Study

This is the stage at which field mapping operations were accomplished. At this stage, detailed observations were made. The mapping was usually started from well exposed and uncomplicated area/horizon. The detailed mapping lasted for about one week and this involved the use of the following geologic equipment:

GPS – used in taking the coordinates and the elevations of the locations/stations.

Compass/clinometer – used for taking routine dip and strike and other structural measurements and for measuring paleocurrent directions.

Field note – used in recording observations in the field.

Pen, pencil and eraser – used for writing field observations in the field.

Geologic hammer – used for breaking rock for the collection of samples.

Hand Auger – used for drilling and collecting subsurface samples

Spade – used in scraping off the surface samples before using the Hand Auger

Pen knife – used in scraping the surface of the outcrops for fresh surfaces to reveal.

Measuring Tape – used for measuring the thickness of beds and sedimentary structures.

Camera – used for taking picture of geologic features in the field during the detailed mapping.

Hand lens – used for magnifying features that are not macroscopic.

Topographic and geologic maps – show both observations (relief, outcrop/drainage features) and the geologist's interpretation of those observations. The symbols which represent rock types and structural measurements made at individual exposures are as a matter of direct observation. The way geological boundaries and structures are inferred through unexposed ground is entirely a matter of interpretation.

3.3 Laboratory Analysis

Freshly obtained samples for sieve analysis were systematically retrieved from different layers on each outcrop in the study area. The samples collected were subjected to disaggregation to enhance a loose aggregate. Disaggregation was achieved by inserting the sample inside a mortar and with a rubber-padded pestle; little force was applied to avoid crushing the grains. A 50g mass of the sample was weighed as a portion of the total disaggregated samples and subsequently subjected to sieve analyses (Pettijohn, 1975). A shaker shook the portions for 15m in with the samples already poured on to the top of a well-arranged set of sieves with a mesh diameter of 0.54 φ apart.

Mean $(\bar{x}) = \Sigma x/n$ …………………………………………… (1)

3.4 Reservoir Parameters

The reservoir porosity of the sandstone units of the Lokoja Formations were estimated from sieve analysis and equation (2) (Okoro *et al*., 2020), respectively.

The porosity (φ) = 0:255 (1 + 0:83)μ …………………………………………… (2)

The values of the coefficient of uniformity (μ), which is the ratio of d60 to d10 in the sandstone units of the formations within the southern Anambra Basin, are estimated from the grain size distribution curve (mm) that is plotted against the cumulative weight in percentage (%). The d10 represents grain size at the 10th percentile; d60 represents grain size at the 60th percentile.

CHAPTER FOUR

RESULTS AND INTERPRETATION

4.1 Presentation of Results

The results of sieve analysis of soil samples obtained from Lokoja Basange sandstone is presented in Tables 4.1 - 4.10. The results of the estimated textural and statistical indices are presented in Table 4.11, while the results for the porosity of the Lokoja Basange Sandstones are displayed in Table 4.12.

Table 4.1: Particle size distribution for Lokoja Basange Sediments (LOCATION: L9)

SEIVE NO.					
APPROX IMPERIAL EQUIV (phi)	**BRITISH STANDARD SIEVE SIZES (mm)**	**RETAINED IN gm**	**% Retained**	**Cumm weight %**	**% passing**
2	4	0	0	0	100
-1.5	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.3	1.5	1.5	98.5
0.75	0.6	2.9	14.5	16	84
1.75	0.3	5.1	24.5	41.5	58.5
2.75	0.15	2.5	12.5	54	46
3.75	0.075	0.5	2.5	56.5	43.5
4	0.063	0.1	0.5	57	43
5	0.03			69	31
7	0.008			77	23.25
8	0.004			81	19.38
9	0.002			84	15.5

Table 4.2: Particle size distribution for Lokoja Basange Sediments (L10)

APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% Retained	Cumm weight %	% passing
2	4	0	0	0	100
-1.5	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0	0	0	100
0.75	0.6	3	15	15	85
1.75	0.3	5.4	27	42	58
2.75	0.15	2.6	13	55	45
3.75	0.075	0.4	2	57	43
4	0.063	0.2	1	58	42
5	0.03			69	31
7	0.008			81	19.38
8	0.004			84	15.5
9	0.002			89	11.63

Table 4.3 Particle size distribution for Lokoja Basange Sediments (L11)

APPROX IMPERAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% Retained	Cumm weight %	% passing
2	4	0	0	0	100
-1.5	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.2	1	1	99
0.75	0.6	2.5	12.5	13.5	86.5
1.75	0.3	5.1	25.5	39	61
2.75	0.15	2.4	12	51	49
3.75	0.075	0.4	2	53	47
4	0.063	0.2	1	54	46
5	0.03			69	31
7	0.008			81	19.35
8	0.004			85	15.5
9	0.002			89	11.63

Table 4: Particle size distribution for Lokoja Basange Sediments (L12)

APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% Retained	Cumm weight %	% passing
2	4	0	0	0	100
-1.5	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.4	2	2	98
0.75	0.6	2.8	14	16	84
1.75	0.3	5.1	25.5	42.5	58.5
2.75	0.17	2.4	12	53.5	46.5
3.75	0.075	0.4	2	55.5	44.5
4	0.063	0.1	0.5	56	44
5	0.03			69	31
7	0.008			71	23.25
8	0.004			81	19.38
9	0.002			85	15.5

Table 4.5: Particle size distribution for Lokoja Basange Sediments (L13)

APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% Retained	Cumm weight %	% passing
2	4	0	0	0	100
-1.5	2.36	0	0	0	100
-0.75	1.7	0.1	0.5	0.5	99.5
-0.25	1.18	0.2	1	1.5	98.5
0.75	0.6	2.9	14.5	16	84
1.75	0.3	5.1	25.5	41.5	58.5
2.75	0.17	2.2	11	52.5	47.5
3.75	0.075	0.3	1.5	54	46
4	0.063	0.1	0.5	54.5	45.5
5	0.03			69	31
7	0.008			77	23.25
8	0.004			81	19.38
9	0.002			85	15.5

Table 4.6: Particle size distribution for Lokoja Basange Sediments (L14)

APPROX IMPERAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% Retained	Cumm weight %	% passing
2	4	0	0	0	100
-1.5	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.4	2	2	98
0.75	0.6	3.1	15.5	17.5	82.5
1.75	0.3	5.4	27	44.5	55.5
2.75	0.17	2.4	12	56.5	43.5
3.75	0.075	0.3	1.5	58	42
4	0.063	0.1	0.5	58.5	41.5
5	0.03			73	27.13
7	0.008			89	11.63
8	0.004			92	7.75
9	0.002			97	3.89

Table 4.7: Particle size distribution for Lokoja Basange Sediments (L15)

APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% Retained	Cumm weight %	% passing
2	4	0	0	0	100
-1.5	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.3	1.5	1.5	98.5
0.75	0.6	2.9	14.5	16	84
1.75	0.3	5.6	28	44	56
2.75	0.17	2.5	12.5	56.5	43.5
3.75	0.075	0.5	2.5	59	41
4	0.063	0.1	0.5	59.5	40.5
5	0.03			76.75	23.25
7	0.008			84.5	15.5
8	0.004			88.37	11.63
9	0.002			92.25	7.75

Table 4.8 Particle size distribution for Lokoja Basange Sediments (L16)

APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% Retained	Cumm weight %	% passing
2	4	0	0	0	100
-1.5	2.36	0	0	0	100
-0.75	1.7	0.1	0.5	0.5	99.5
-0.25	1.18	0.3	1.5	2	98
0.75	0.6	3.2	16	18	82
1.75	0.3	5.6	28	46	54
2.75	0.17	2.2	11	57	43
3.75	0.075	0.3	1.5	58.5	41.5
4	0.063	0.1	0.5	59	41
5	0.03			72.87	27.13
7	0.008			80.92	19.38
8	0.004			84.5	15.5
9	0.002			88.37	11.63

Table 4.9: Particle size distribution for Lokoja Basange Sediments (L17)

APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% Retained	Cumm weight %	% passing
2	4	0	0	0	100
-1.5	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.3	1.5	1.5	98.5
0.75	0.6	3.1	15.5	17	83
1.75	0.3	5.1	25.5	42.5	57.5
2.75	0.17	2.1	10.5	53	47
3.75	0.075	0.2	1	54	46
4	0.063	0.1	0.5	54.5	45.5
5	0.03			72.87	27.13
7	0.008			80.62	19.38
8	0.004			84.5	15.5
9	0.002			92.25	7.75

Table 4.10: Particle size distribution for Lokoja Basange Sediments (L18)

APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% Retained	Cumm weight %	% passing
2	4	0	0	0	100
-1.5	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.3	1.5	11.5	98.5
0.75	0.6	3.2	16	17.5	82.5
1.75	0.3	5.5	27.5	45	55
2.75	0.17	2.3	11.5	56.5	43.5
3.75	0.075	0.3	1.5	58	42
4	0.063	0.1	0.5	58.5	41.5
5	0.03			76.75	23.25
7	0.008			88.37	11.63
8	0.004			92.25	7.75
9	0.002			96.11	3.89

4.2 Particle Size Distribution Analysis

As shown in Table 4.1 - 4.10 and also graphically presented in the Figures, the Lokoja Sandstone falls predominantly range from fine to coarse sand, silt and gravel. The phi mean showed that the sediments exhibit coarse characteristics, as indicated by their relatively higher grain sizes, which typically exceed 2mm. This suggests the presence of larger particles within these sediment samples, contributing to their coarse texture (Aigbadon *et al*., 2022). The Lokoja Sandstone facies' medium to coarse-grained sandstone and moderately to poorly-sorted texture point to variations in deposition energy that may be related to interactions between shallow marine environments and tidal and fluvial channels (Okolo *et al*., 2020). The poor sorting qualities of the sandstone further suggest that they were deposited by turbulent flow at a wide range of current velocities, which could lead to the deposition of sediments with different sand sizes throughout the basin (Okolo *et al*., 2020).

Table 4.11: Textural Interpretation of the Sediments

Location	Mean Size (mm)	Standard deviation (mm)	Skewness	Kurtosis
L9	4.033333	3.504545	0.598323	0.802944
L10	4	3.413636	0.629268	0.745156
L11	3.616667	3.124242	0.517991	0.802596
L12	3.983333	3.467045	0.555448	0.749415
L13	3.983333	3.451894	0.563452	0.734612
L14	2.94	2.622727	0.517857	0.85003
L15	3.35	2.971591	0.520817	0.989994
L16	3.56667	3.304545	0.588964	0.846113
L17	3.716667	3.214015	0.534576	0.815265
L18	2.95	2.65303	0.523256	0.965641

4.3 The Summary of Textural Attributes of the Sediments as obtained from the Sieve Analysis are given in Table 4.11

From the result shown in Table 4.11, it was observed that the mean size of sediments in all ten locations from the area of study ranges from 2.94 - 4.03mm. The highest mean was observed at L9, while the lowest mean was observed in L14. The results from Table 4.11 also showed that at locations L9, L10, L11, L12, and L13, the sediments exhibit coarse characteristics, as indicated by their relatively higher grain sizes, which exceed 2mm. The inclusive standard deviation of 2.6 - 3.5mm shows moderately sorted to poorly sorted with an average of 3.17mm. The 2.6 - 3.5mm standard deviation range indicates that the energy of the transportation medium fluctuated randomly during the sandstone deposition phases, resulting in moderate to poorly sorted sandstone (Okoro *et al*., 2020). On average, the sandstone is poorly sorted .

Furthermore, a moderate degree of diversity in grain sizes around the mean is indicated by the standard deviations associated with these locations, which may indicate a mixed composition of sediment particles. Conversely, sediments at locations L14, L15, and L18 display medium characteristics, with mean grain sizes falling within the range of 0.063 mm to 2 mm. This suggests a more moderate grain size distribution, with particles ranging from fine to medium sizes. The standard deviations at these locations also indicate a degree of variability in grain sizes, albeit to a lesser extent compared to the coarse sediments.

The skewness values across all locations indicate a relatively symmetrical distribution of grain sizes, with no significant bias towards either larger or smaller particles. However, the kurtosis values suggest varying degrees of peakedness or flatness in the grain size distribution curves. Locations L14, L15, and L18 exhibit relatively higher kurtosis values (Leptokurtic), indicating sharper peaks in their distribution curves, whereas locations L9, L10, L11, L12, and L13 show lower kurtosis values (Platykurtic), suggesting a flatter distribution. The average kurtosis value from the location of study suggests that the Lokoja sandstone is Mesokurtic in nature, which means that they have the same kurtosis as that of the normal distribution. (Folk, 1974).

Table 4.12 : Results of Porosity parameters for Lokoja Sandstone Reservoirs.

Location	D10	D60	Porosity (%)
L9	0.008	0.31	0.255
L10	0.0018	0.32	0.255
L11	0.0018	0.3	0.255
L12	0.0008	0.3	0.255
L13	0.0008	0.31	0.255
L14	0.007	0.34	0.255
L15	0.003	0.4	0.255
L16	0.0018	0.35	0.255
L7	0.0024	0.33	0.255
L18	0.006	0.35	0.255

Porosity is a crucial parameter in understanding the physical properties of sedimentary materials, as it denotes the volume of void space within the material. The result showed that the porosity values across all locations are consistent (0.255), indicating that regardless of the variations in grain size distribution (as indicated by D10 and D60 values), the overall volume of void space within the sediment remains the same. Porosity refers to the percentage of open spaces (pores) within the rock. Higher porosity generally indicates a better reservoir quality as it allows for the storage of fluids like oil and gas. The result showed that the clay porosity (0.255) has good qualities. This result is similar to Okolo *et al*., (2020) who indicated that the Lokoja sandstones ranges from 23 to 25%. According to Okolo *et al*., (2020) the high porosity values of sandstone reservoir facies of the Lokoja outcrop sections, singled out the sandstones to be good reservoirs. This means that the sandstone facies could provide a good prospect for hydrocarbon search in the basin. Aigbadon *et al* (2023) however, determined from his study that the outcrop exposures of Lokoja sandstone, which both displayed moderate to coarse textures embedded with herringbone, planar, or trough cross-strata is suggestive of lithofacies with good reservoir qualities. In geological contexts, porosity influences fluid flow and storage within sedimentary rocks, affecting groundwater movement and oil/gas reservoir capacity.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

This study was conducted to investigate the reservoir quality of outcropping sediments in the Lokoja Basange Formation and specifically carry out sieve analysis to characterize the reservoir qualities by inferring the porosity of the Lokoja sandstone sediments

A total of fourteen (10) samples were collected and analyzed for the study. Freshly obtained samples for sieve analysis were systematically retrieved from different layers on each outcrop in the study area. The reservoir porosity of the sandstone units of the Lokoja Formations were estimated from sieve analysis.

5.2 CONCLUSION

The predictive tools for the determination of reservoir quality of the outcropping sediments in Lokoja Basange Formation are porosity, textural characteristics and textural parameters of the sediments. The textural characteristics such as grain size of the sediments ranges from fine to pebbly coarse sandstones. The size of sediments in all ten locations from the area of study ranges from 2.94 - 4.03mm. The results showed that at locations L9, L10, L11, L12, and L13, the sediments exhibit coarse characteristics, as indicated by their relatively higher grain sizes, which exceed 2mm. The result showed that the porosity values across all locations are consistent (0.255), indicating that regardless of the variations in grain size distribution, the overall volume of void space within the sediment remains the same.

5.3 RECOMMENDATIONS

It is recommended that further studies be carried out on this basin so as to determine the provenance of the sediments.

REFERENCES

Aigbadon, G. O., Akakuru O. C, Akudo E. O, Onyekuru S. O., Musa K. O., Obasi I. A, Ocheli A, Sanni Z. A., Ahmed J B., Aminu M. B., Lamja R, and Esharive O, (2023). Facies, textural and geochemical evaluation of the post-Santonian sandstones in the Bida basin, Nigeria: Implications for control on hydrocarbon sandstone reservoir characteristics and paleoenvironments, *Unconventional Resources*, **3**(2**)** 192-211

Aigbadon, G. O., Christopher S. D, Akudo E. O., and Akakuru O. C., (2022). Sedimentary facies and textural characteristics of Cretaceous sandstones in the southern Bida Basin, Nigeria: Implication for reservoir potential and depositional environment. *Energy Geoscience **3** 323-341*

Aigbadon, G.O., Ocheli, A., Akakuru, C.O., Akudo E.O., Christopher S.D., and Esharive O. (2022). Paleoenvironments and hydrocarbon reservoir potentials from the selected sedimentary basins in Nigeria using sedimentary facies and textural analyses. *Journal of Sedimentary Environments,* **7**, 3-4.

Akande, S.O., Ojo, O.J., Adekeye, O.A., and Ladipo, K.O. (2006). In: A Geological Field Guide to the Southern Bida Basin. Nigeria Association of Petroleum Explorationists (NAPE), 24th Annual Conference and Exhibition, Abuja, p. 21-

Alege, T. S; Omada, J. I; Uchendu, K (2022). Field and Sedimentological Studies of Nataco-Banda Sediments of Lokoja Formation, Southern Bida Basin, Nigeria: Implication for Depositional Environment. *Journal of Applied Science Environment Management,* 26 (**11)** 1835-1842

Benkhelil, J., (1989). The origin and evolution of the cretaceous Benue Trough (Nigeria). *Journal of African Earth Sciences.* **8**, 251-282.

Davis, A.R., and Dalrymple R.W. (2011). Principles of Tidal Sedimentology Springer, New York Heidelberg

Dim, P.I.C., Mode, W.A., and Okwara, C.I., (2018). Signatures of key petroleum system elements: outcrop examples from the Anambra Basin, Southeastern Nigeria. *Journal of Petroleum Exploration Production Technology*, **9**, 1615-1631.

Edegbai, A.J., Schwark, I., and Oboh-Ikuenobe, F.E., (2019). Maastrichtian geological evolution of Nigeria and its stratigraphy and paleographic implications. *Journal of African Earth Science*, **50**, 823-837.

Folk, R.L., (1974). Petrology of Sedimentary Rocks. *American Journal of Analytical Chemistry*, 6 (**6**), 170-175.

Likkason, O.K., Singh, G.P., and Samaila, N.K. (2013). A study of the middle Benue Trough (Nigeria) based on geological application and analyses of spectra of aeromagnetic data

Energy Sources, *Part A Recovery, Utilization, and Environmental Effects,* 35 **(8)**, 706-716

Miall, A.D. (2000). Principles of Sedimentary Basin Analysis, vol. 3, Springer, Berlin, 616

Murat, R.C. (1972). Stratigraphy and paleogeography of the Cretceous and Lower Tertiary in Southern Nigeria, In: Dessauvagie, T.F.J. and Whiteman A.J. (Eds). *African Geology,* . **261**-266.

Nichols, G. (2009). Sedimentology and Stratigraphy. Wiley- Blackwell Publication Hoboken, **419.**

Nwajide, C.S. (2013). Geology of Nigeria's Sedimentary Basins. CSS Bookshops Limited, 265.

Obaje, N.G., (2009). Geology and Mineral Resources of Nigeria. *Open Journal of Forestry*, **7**, 34-37.

Obaje, N.G., Moumouni, A., Goki, N.G., and Chaanda, M.S., (2011). Stratigraphy, paleogeography and hydrocarbon resource potentials of the Bida Basin in north-Central Nigeria. *Journal of Mining and Geology*, 47 (**2**), 97-114.

Obaje, N.G., Musa, M.K., Odoma AN, Hamza H (2011). The Bida Basin in north-central Nigeria: Sedimentology and petroleum geology. *Journal of Petroleum and Gas Exploration Resources*, 1(**1**): 001- 013.

Obi, G.C., Okogbue, C.O. and Nwajide, C.S. (2001). Evolution of the Enugu cuesta: A tectonically driven erosion process: *Global Journal of Pure and Applied Science*, **7**: 321- 330.

Ocheli, A., Okoro, A.U., Ogbe, O.B., and Aigbadon, G.O., (2018). Granulometric and pebble Morphometric applications to Benin Flank sediments in Western Anambra Basin, Nigeria: Proxies for Paleoenvironmental Reconstruction. *Environmental Monitoring and Assessment*, 190 (**5**), 1-17.

Odebode, M.O. (1987). Palynological dating of Lamja Swdstone (Benue Basin, Nigeria) and its geological significance. *Journal of African Earth Sciences*, 6(**4**), 421-426.

Ogbe, O.B., Osokpor, J., (2021). Depositional facies, sequence stratigraphy, and reservoir potential of Eocene Nanka formation of the Ameki Group in Agwu- Awka and Umunya, southeast Nigeria. Heliyon **7**, 05846.

Ojo, O.J., Akande, S.O. (2009). Sedimentology and depositional environments of the Maastrichtian Patti Formation, Southeastern Bida Basin, Nigeria. *Cretaceous Research*, **30**: 1415–1425

Ojo, O.J., Akande, S.O., (2020). A revised stratigraphy of the Bida Basin, Nigeria. *Journal of African Earth Sciences*, **151**, 67-81.

Ojoh, K.A. 1992. Cretaceous Geodynamic Evolution of the Southern part of the Benue Trough (Nigeria) in the equatorial domain of the South Atlantic: Stratigraphy, Basin Analysis and Paleo-Oceanography. *Bulletin Centre for Research*, *Exploration Production, Elfaquitaine*, **14**: 419-442.

Okolo, C.G., Emedo, C.O., Obumselu, C.A., Madukwe, C.F., and Ulasi, N.A., (2020). Lithofacies, particle size analysis, and paleodepositional environment of the EzeAku Group (Cenomaniane-Turonian) in the Itigidi-Ediba area, Afikpo Synclinorium, southeastern Nigeria. Journal of Sedimentary Environments, **5**, 375-398.

Okoro, A.U., Igwe, E.O., and Umo, I.A. (2020). Sedimentary facies, paleoenvironments, and reservoir potential of the Afikpo Sandstone on Macgregor Hill area in the Afikpo Sub basin, southeastern Nigeria. SN Applied Sciences (**2**), 1862.

Olubayo, L.B., (2010). The main oil source Formations of the Anambra Basin, Southeastern Nigerian AAPG convention and exhibition, Calgary, Alberta, Canada, 21.

Omali, A.O., Imasuen, O.I., Okiotor, M.E., (2011). Sedimentological characteristics of Lokoja Sandstone exposed at Mount Patti, Bida Basin, Nigeria. *Advances in Applied Science Research,* 2(**2**): 227-245.

Omoniyi, B., (2023). Lithofacies Analysis of Multistorey Braidplain Sandstone, Lokoja-Basange Formation, Benin Flank of Anambra Basin, Nigeria. *Journal of Geography, Environment and Earth Science*, **4**, 1-20.

Onuigbo, E.N., Okoro, A.U., Obiadi, I.I., and Okoyeh, E.I., (2016). Sedimentary facies characterization and depositional settings of the Ajali Sandstone, Anambra Basin, Southeastern Nigeria. *Library Archives of Applied Science Research*. 8 (**10**), 10-25.

Petters, S.W., (1986). Terminal Cretaceous regressions in Nigeria basins. Geologic de I' Atlantic Sud, Actes Colloqnes Angers, El'f Aquitaine, **16**, 166-173.

Pettijohn, F.J., (1975). Sedimentary Rocks, Third edition. Harper and Row, New York. 628.

Rahman, M.A.O., Fadiya, S.L., Adekola, S.A., Coker, S.J., Bale, R.B., Olawoki, O.A., Omada, I.J., Obaje, N.G., Akinsanpe, O.T., Ojo, G.A., and Akande, W.G., 2019. A revised stratigraphy of the Bida Basin, Nigeria. *Journal of African Earth Sciences*, **15**, 67-81.

Sunday, E.O., Stephen, A.B., and David, I.M.M., (2020). Diagenesis and reservoir quality in high- resolution sandstone sequence: an example from Middle Jurassic Ravenscar Sandstone, Yorkshire coast, UK. *Marine and Petroleum Geology*. **118**, 104-426.

Sunny C. Ezeh and Mode, A.W., (2011). Sedimentological and reservoir characterization of the upper cretaceous Lokoja formation in the Bida Basin, Nigeria. Sedimentology. Vol. 32. pp. 41-57.

Turner S., Riddle B., (2005). Estuarine Sedimentation and Vegetation Management Issues and Monitoring Priorities. Environment Waikato Internal Series 2001-2005.

Uzoegbu, M.U. and Uchebo, U.A., (2014). The Lamja sandstone in Northeast Nigeria: Sedimentology and reservoir quality. *International Journal Geology and Mining* (**1**),016-029.

Uzoegbu, M.U., Uchebo, U.A., and Okafor, I., (2013). Lithostratigraphy of the Maastrictian Nsukka Formation in the Anambra Basin, SE Nigeria. International Organization of Scientific Research (IOSR): Journal of Environmental Science, Toxicology and Food Technology, 5(**5**): 96-102.

Valkarelov, B.K., Bhattacharya, J.P., (2009). Local tectonic control on parasequence architecture; second frontier sandstone, Powder River Basin, Wyoming, American Association of Petroleum Geologists Bulletin, 93(**3**): 295-327.

APPENDIX

GRAIN SIZE ANALYSIS BY DRYAND WET-SIEVING

JOB:**ACADEMICTHESIS** SITE**:..**

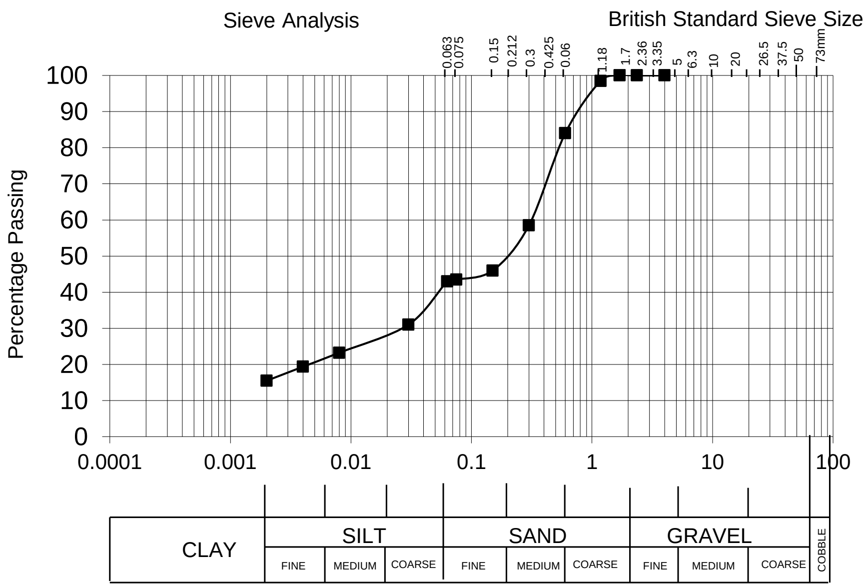
LOCATION**:.. L9** DATE**: …2024……**

DEPTH**:.. 0-15cm** TESTED BY:……**WET AND DRY SIEVE**………

WEIGHT OF DRY MATERIAL AND CONTAINER IN GRAMMS:……

WEIGHT OF CONTAINER IN GRAMMS..

SIEVE NO.					
APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% retained	Cumm wt %	% passing
-2	4	0	0	0	100
-1.25	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.3	1.5	1.5	98.5
0.75	0.6	2.9	14.5	16	84
1.75	0.3	5.1	25.5	41.5	58.5
2.75	0.15	2.5	12.5	54	46
3.75	0.075	0.5	2.5	56.5	43.5
4	0.063	0.1	0.5	57	43
5	0.03			69	31
7	0.008			77	23.25
8	0.004			81	19.38
9	0.002			84	15.5

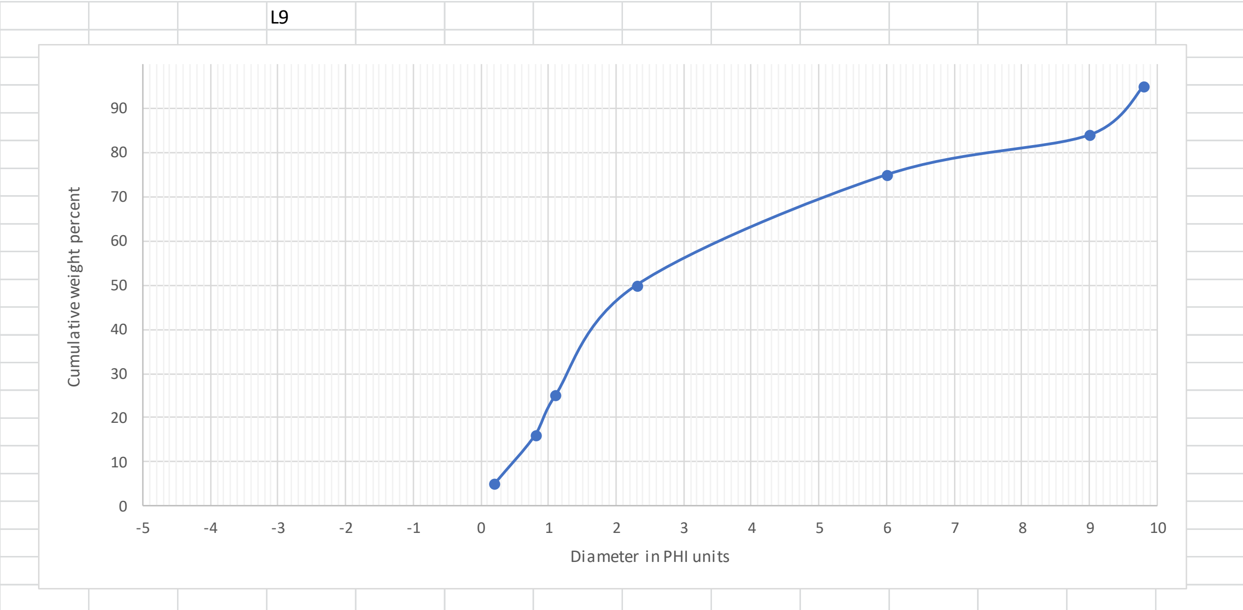


D10= 0.008

D60= 0.31

Porosity= 0.255

	L9								
phi									
5	0.2	MEAN	4.033333	SD	3.504545	SKEWNESS	0.598323	KURTOSIS	0.802944
16	0.8								
25	1.1								
50	2.3								
75	6								
84	9								
95	9.8								



GRAIN SIZE ANALYSIS BY DRYAND WET-SIEVING

JOB:**ACADEMICTHESIS** SITE:**..**

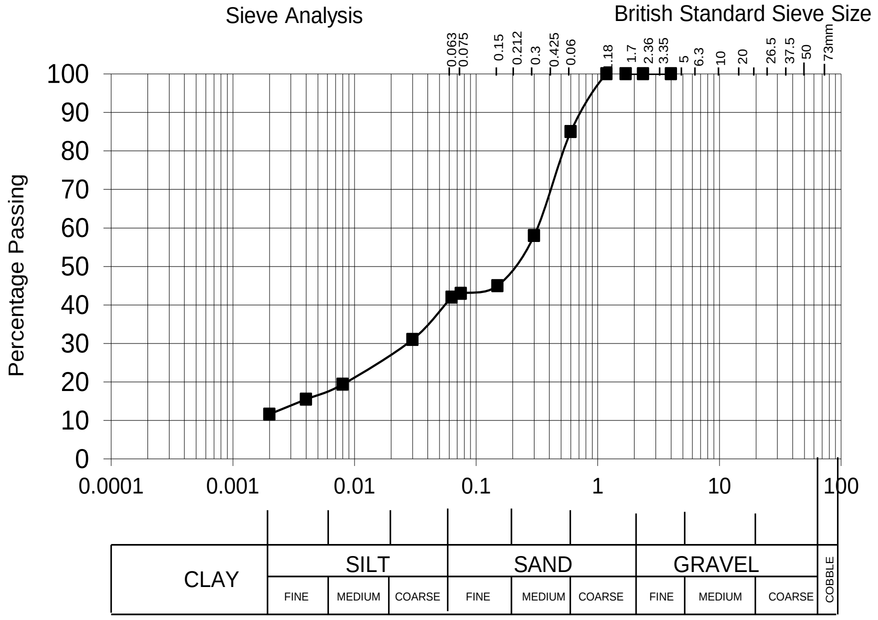
LOCATION:**.. L 10** DATE:**: …2024……**

DEPTH:**.. 0.15 cm** TESTED BY:……**WET AND DRY SIEVE**………

WEIGHT OF DRY MATERIAL AND CONTAINER IN GRAMMS:……

WEIGHT OF CONTAINER IN GRAMMS...

SIEVE NO.					
APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% retained	Cumm wt %	% passing
-2	4	0	0	0	100
-1.25	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0	0	0	100
0.75	0.6	3	15	15	85
1.75	0.3	5.4	27	42	58
2.75	0.15	2.6	13	55	45
3.75	0.075	0.4	2	57	43
4	0.063	0.2	1	58	42
5	0.03			69	31
7	0.008			81	19.38
8	0.004			84	15.5
9	0.002			89	11.63



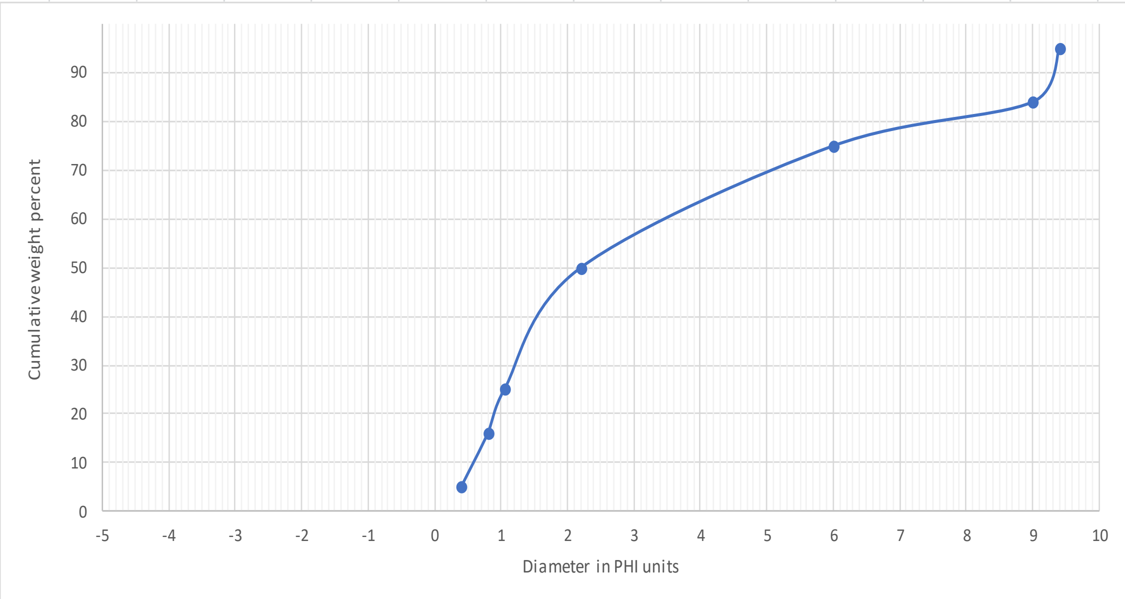
D10=.0018

D60= 0.32

Porosity = 0.255

	L10								
phi									
5	0.4	MEAN	4	SD	3.413636	SKEWNESS	0.629268	KURTOSIS	0.745156
16	0.8								
25	1.05								
50	2.2								
75	6								
84	9								
95	9.4								

L10



GRAIN SIZE ANALYSIS BY DRYAND WET-SIEVING

JOB:**ACADEMICTHESIS** SITE**:..**

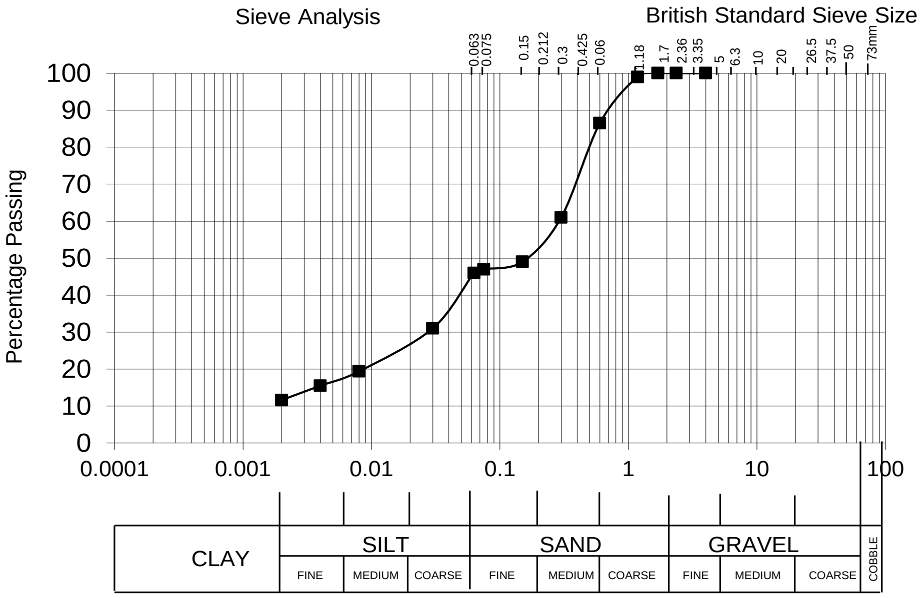
LOCATION**:.. L 11** DATE**: …2024……**

DEPTH**:.. 0.15 cm** TESTED BY:……**WET AND DRY SIEVE**………

WEIGHT OF DRY MATERIAL AND CONTAINER IN GRAMMS:……

WEIGHT OF CONTAINER IN GRAMMS...

SIEVE NO.					
APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% retained	Cumm wt %	% passing
-2	4	0	0	0	100
-1.25	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.2	1	1	99
0.75	0.6	2.5	12.5	13.5	86.5
1.75	0.3	5.1	25.5	39	61
2.75	0.15	2.4	12	51	49
3.75	0.075	0.4	2	53	47
4	0.063	0.2	1	54	46
5	0.03			69	31
7	0.008			81	19.38
8	0.004			85	15.5
9	0.002			89	11.63



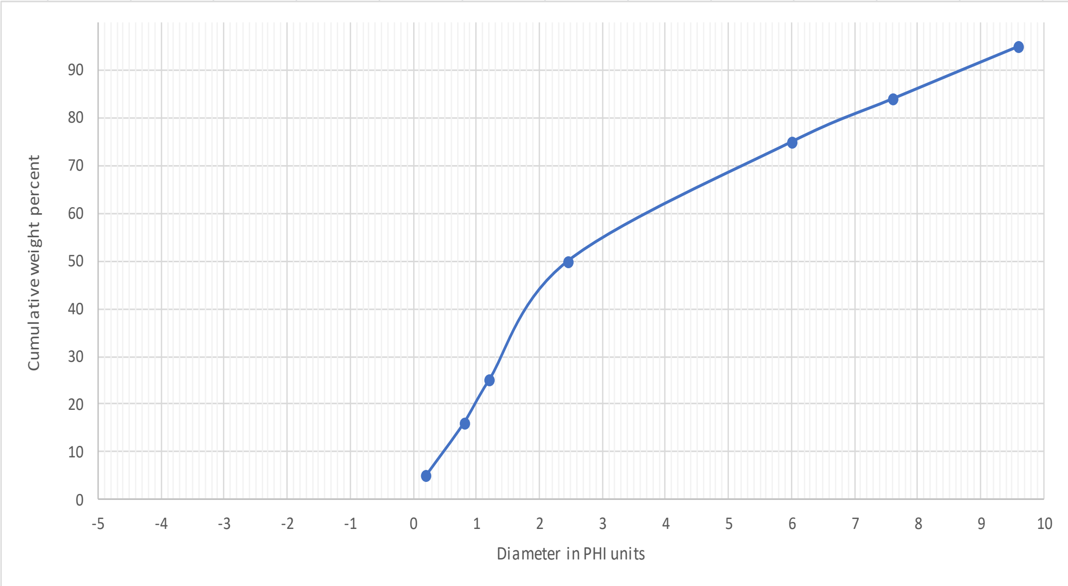
D10= 0.0018

D60= 0.3

Porosity = 0.255

	L11								
phi									
5	0.2	MEAN	3.616667	SD	3.124242	SKEWNESS	0.517991	KURTOSIS	0.802596
16	0.8								
25	1.2								
50	2.45								
75	6								
84	7.6								
95	9.6								

L11



GRAIN SIZE ANALYSIS BY DRYAND WET-SIEVING

JOB:**ACADEMICTHESIS** SITE:**..**

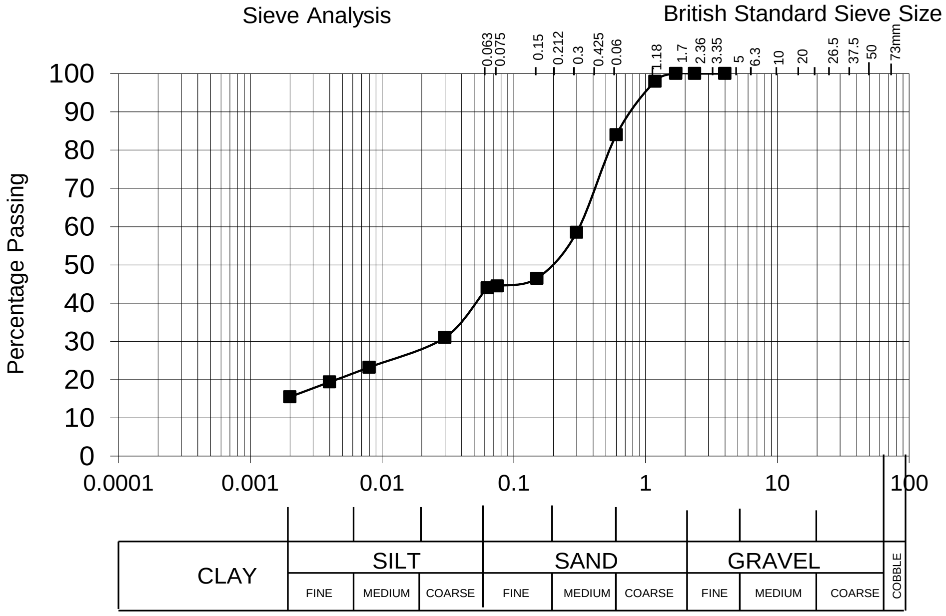
LOCATION**:.. L 12** DATE**: …2024……**

DEPTH**:.. 0.15 cm** TESTED BY:……**WET AND DRY SIEVE**………

WEIGHT OF DRY MATERIAL AND CONTAINER IN GRAMMS:……

WEIGHT OF CONTAINER IN GRAMMS...

SIEVE NO.					
APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% retained	Cumm wt %	% passing
-2	4	0	0	0	100
-1.25	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.4	2	2	98
0.75	0.6	2.8	14	16	84
1.75	0.3	5.1	25.5	41.5	58.5
2.75	0.15	2.4	12	53.5	46.5
3.75	0.075	0.4	2	55.5	44.5
4	0.063	0.1	0.5	56	44
5	0.03			69	31
7	0.008			77	23.25
8	0.004			81	19.38
9	0.002			85	15.5



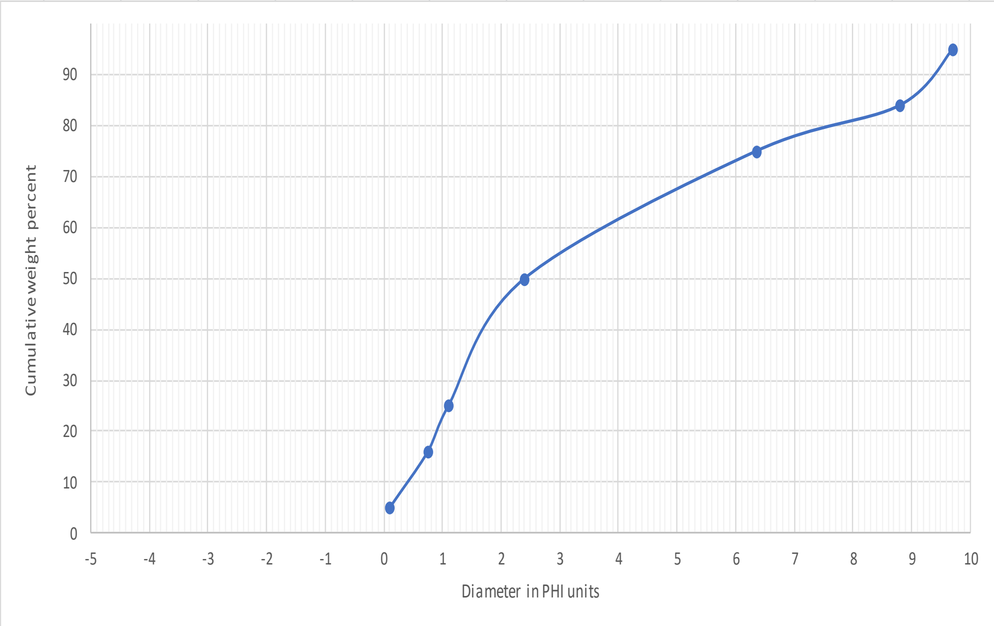
D10= 0.0008

D60= 0.3

Porosity =0.255

	L12								
phi									
5	0.1	MEAN	3.983333	SD	3.467045	SKEWNESS	0.555448	KURTOSIS	0.749415
16	0.75								
25	1.1								
50	2.4								
75	6.35								
84	8.8								
95	9.7								

L12



GRAIN SIZE ANALYSIS BY DRYAND WET-SIEVING

JOB:**ACADEMICTHESIS** SITE**:..**

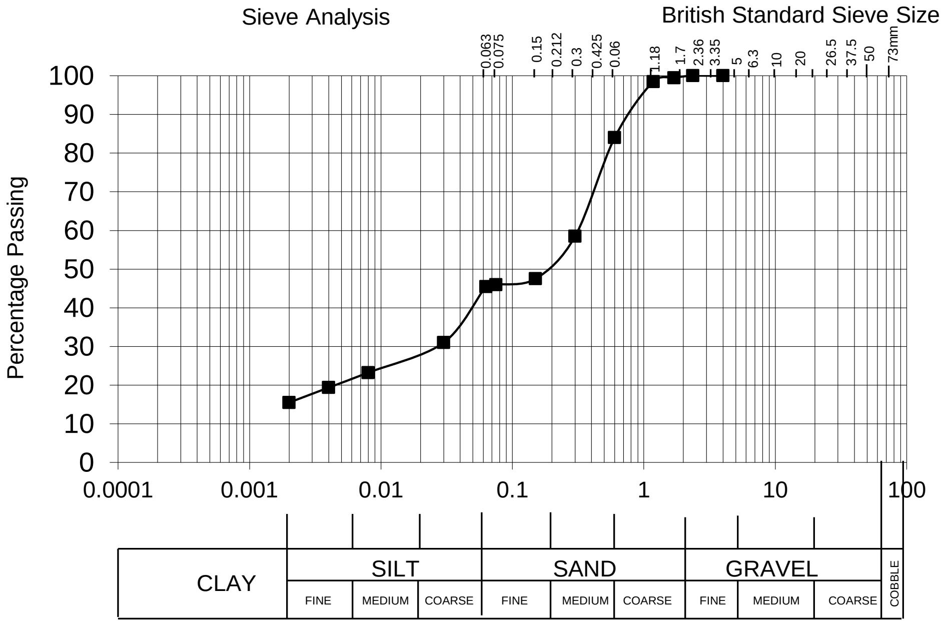
LOCATION**:.. L 13** DATE**: …2024……**

DEPTH**:.. 0.15 cm** TESTED BY:……**WET AND DRY SIEVE**………

WEIGHT OF DRY MATERIAL AND CONTAINER IN GRAMMS:……

WEIGHT OF CONTAINER IN GRAMMS...

SIEVE NO.					
APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% retained	Cumm wt %	% passing
-2	4	0	0	0	100
-1.25	2.36	0	0	0	100
-0.75	1.7	0.1	0.5	0.5	99.5
-0.25	1.18	0.2	1	1.5	98.5
0.75	0.6	2.9	14.5	16	84
1.75	0.3	5.1	25.5	41.5	58.5
2.75	0.15	2.2	11	52.5	47.5
3.75	0.075	0.3	1.5	54	46
4	0.063	0.1	0.5	54.5	45.5
5	0.03			69	31
7	0.008			77	23.25
8	0.004			81	19.38
9	0.002			85	15.5

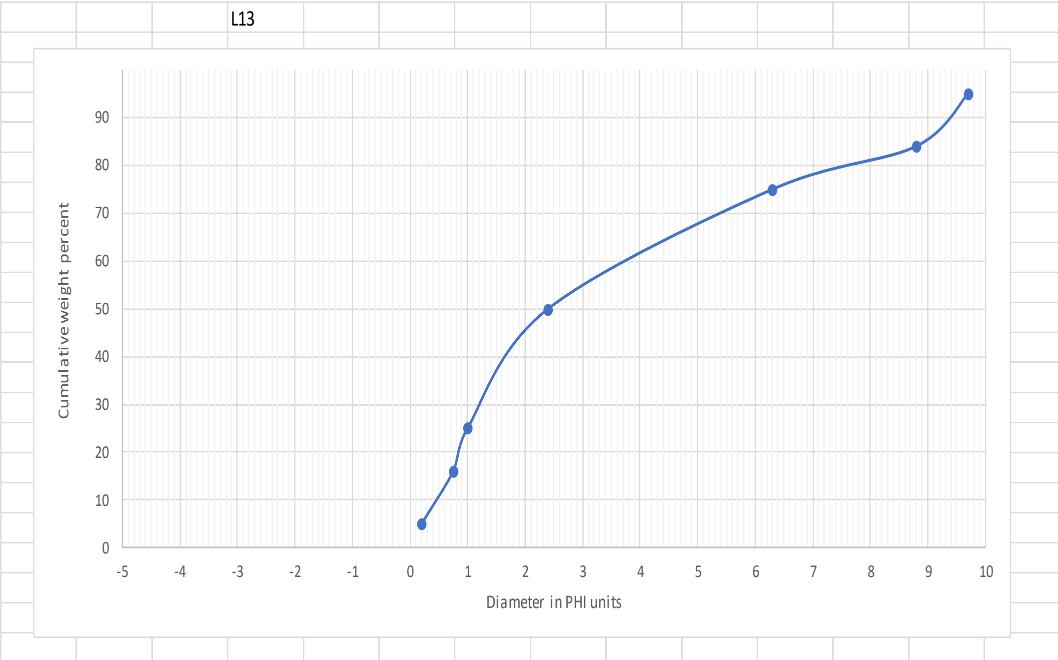


D10= 0.0008

D60= 0.31

Porosity = .255

	L13								
phi									
5	0.2	MEAN	3.983333	SD	3.451894	SKEWNESS	0.563452	KURTOSIS	0.734612
16	0.75								
25	1								
50	2.4								
75	6.3								
84	8.8								
95	9.7								



GRAIN SIZE ANALYSIS BY DRYAND WET-SIEVING

JOB:**ACADEMICTHESIS** SITE:**..**

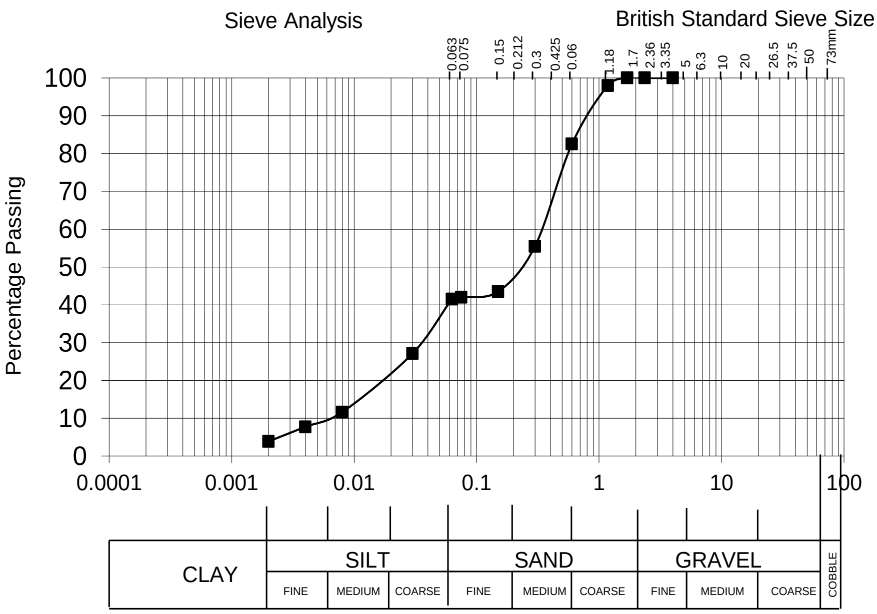
LOCATION:**.. L 14** DATE**: …2024……**

DEPTH:**.. 0.15 cm** TESTED BY:……**WET AND DRY SIEVE**………

WEIGHT OF DRY MATERIAL AND CONTAINER IN GRAMMS:……

WEIGHT OF CONTAINER IN GRAMMS...

SIEVE NO.					
APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% retained	Cumm wt %	% passing
-2	4	0	0	0	100
-1.25	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.4	2	2	98
0.75	0.6	3.1	15.5	17.5	82.5
1.75	0.3	5.4	27	44.5	55.5
2.75	0.15	2.4	12	56.5	43.5
3.75	0.075	0.3	1.5	58	42
4	0.063	0.1	0.5	58.5	41.5
5	0.03			73	27.13
7	0.008			89	11.63
8	0.004			92	7.75
9	0.002			97	3.89

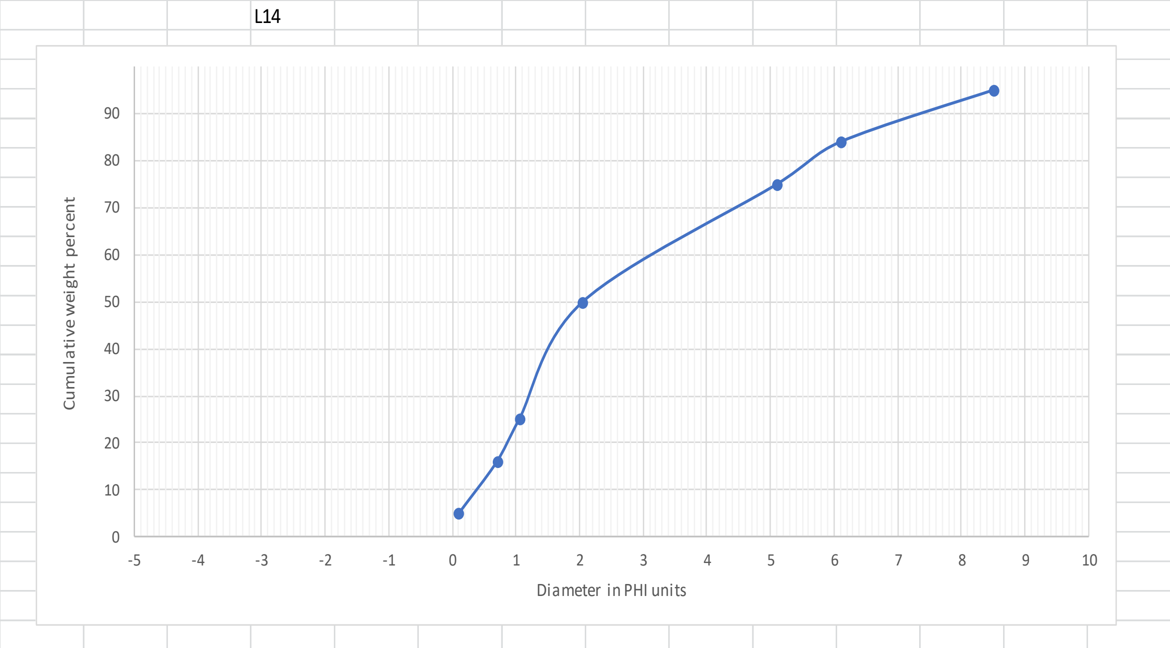


D10= 0.007

D60= 0.34

Porosity= 0.255

	L14								
phi									
5	0.1	MEAN	2.95	SD	2.622727	SKEWNESS	0.517857	KURTOSIS	0.85003
16	0.7								
25	1.05								
50	2.05								
75	5.1								
84	6.1								
95	8.5								



GRAIN SIZE ANALYSIS BY DRYAND WET-SIEVING

JOB:**ACADEMICTHESIS** SITE**:..**

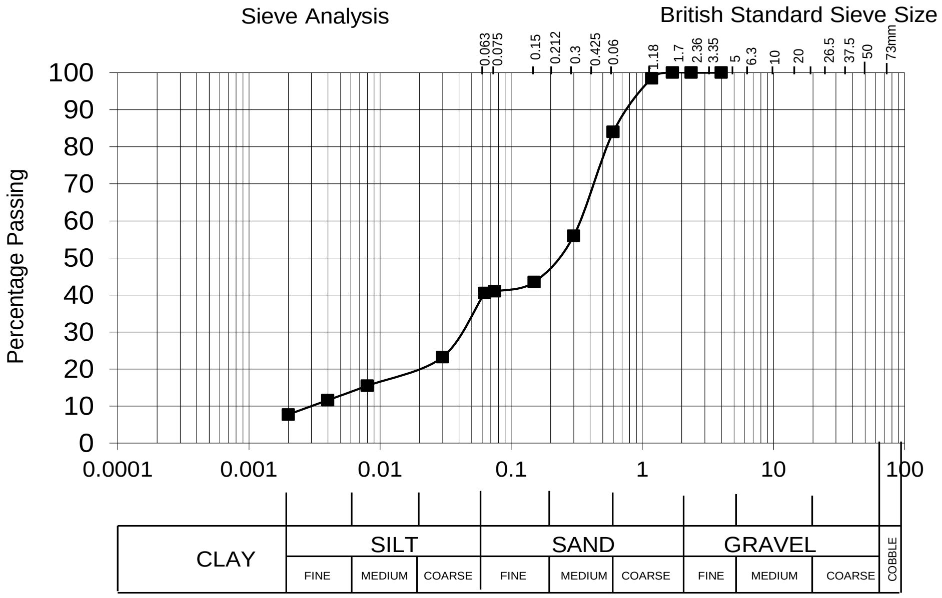
LOCATION**:.. L 15** DATE**: …2024……**

DEPTH**:.. 0.15 cm** TESTED BY:……**WET AND DRY SIEVE**………

WEIGHT OF DRY MATERIAL AND CONTAINER IN GRAMMS:……

WEIGHT OF CONTAINER IN GRAMMS...

SIEVE NO.					
APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% retained	Cumm wt %	% passing
-2	4	0	0	0	100
-1.25	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.3	1.5	1.5	98.5
0.75	0.6	2.9	14.5	16	84
1.75	0.3	5.6	28	44	56
2.75	0.15	2.5	12.5	56.5	43.5
3.75	0.075	0.5	2.5	59	41
4	0.063	0.1	0.5	59.5	40.5
5	0.03			76.75	23.25
7	0.008			84.5	15.5
8	0.004			88.37	11.63
9	0.002			92.25	7.75

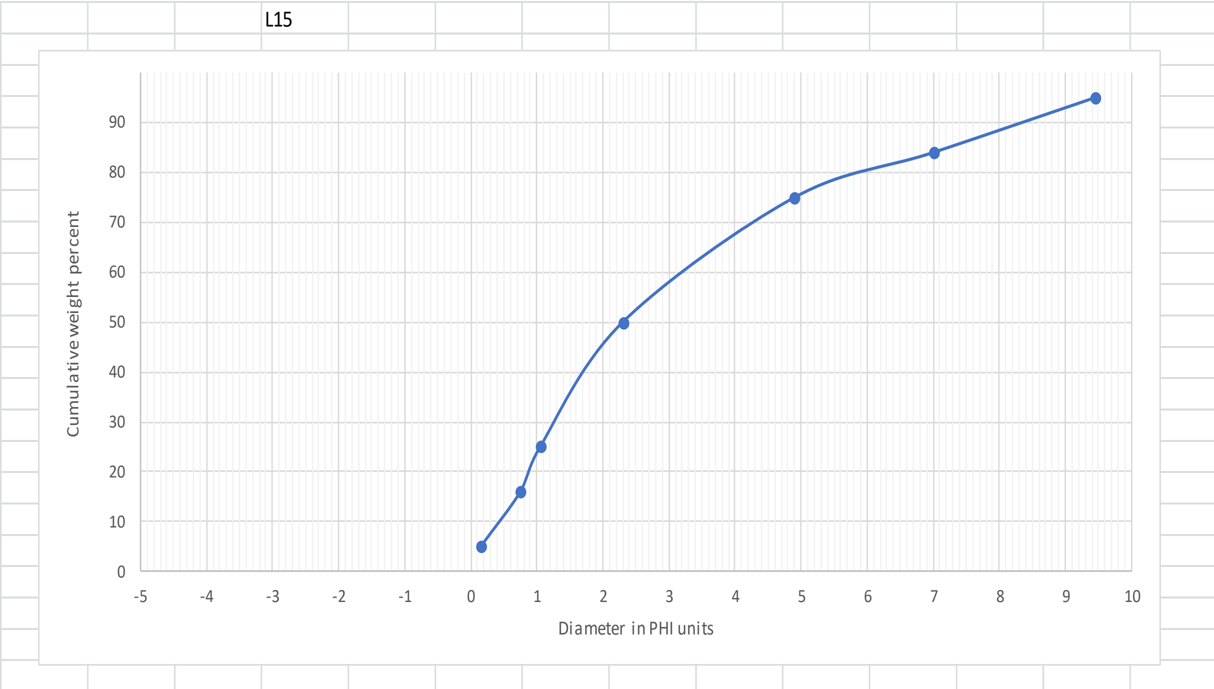


D10= 0.003

D60= 0.34

Porosity= 0.255

	L15								
phi									
5	0.15	MEAN	3.35	SD	2.971591	SKEWNESS	0.520817	KURTOSIS	0.989994
16	0.75								
25	1.05								
50	2.3								
75	4.9								
84	7								
95	9.45								



GRAIN SIZE ANALYSIS BY DRYAND WET-SIEVING

JOB:**ACADEMICTHESIS** SITE:**..**

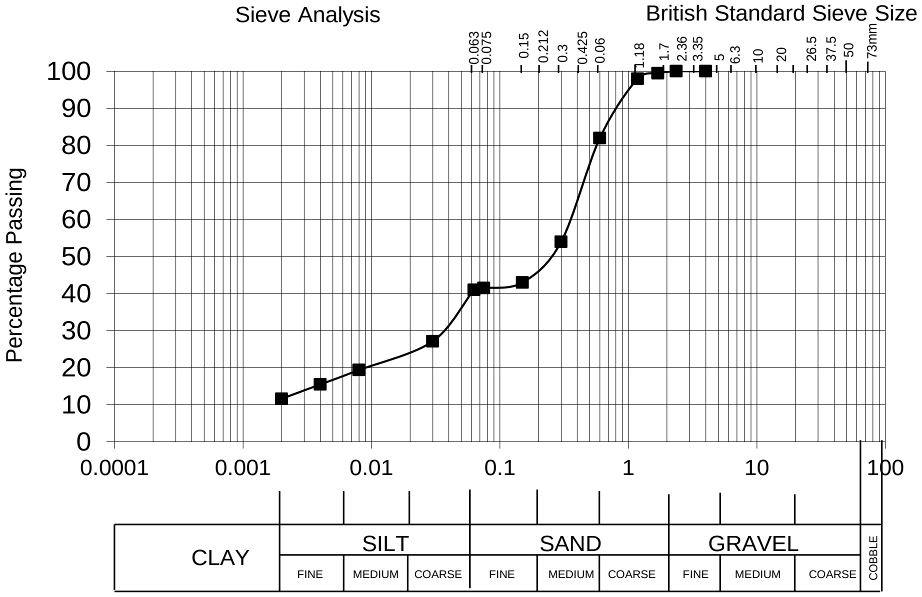
LOCATION:**.. L 16** DATE: **…2024……**

DEPTH:**.. 0.15 cm** TESTED BY:……**WET AND DRY SIEVE**………

WEIGHT OF DRY MATERIAL AND CONTAINER IN GRAMMS:……

WEIGHT OF CONTAINER IN GRAMMS...

SIEVE NO.					
APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% retained	Cumm wt %	% passing
-2	4	0	0	0	100
-1.25	2.36	0	0	0	100
-0.75	1.7	0.1	0.5	0.5	99.5
-0.25	1.18	0.3	1.5	2	98
0.75	0.6	3.2	16	18	82
1.75	0.3	5.6	28	46	54
2.75	0.15	2.2	11	57	43
3.75	0.075	0.3	1.5	58.5	41.5
4	0.063	0.1	0.5	59	41
5	0.03			72.87	27.13
7	0.008			80.62	19.38
8	0.004			84.5	15.5
9	0.002			88.37	11.63



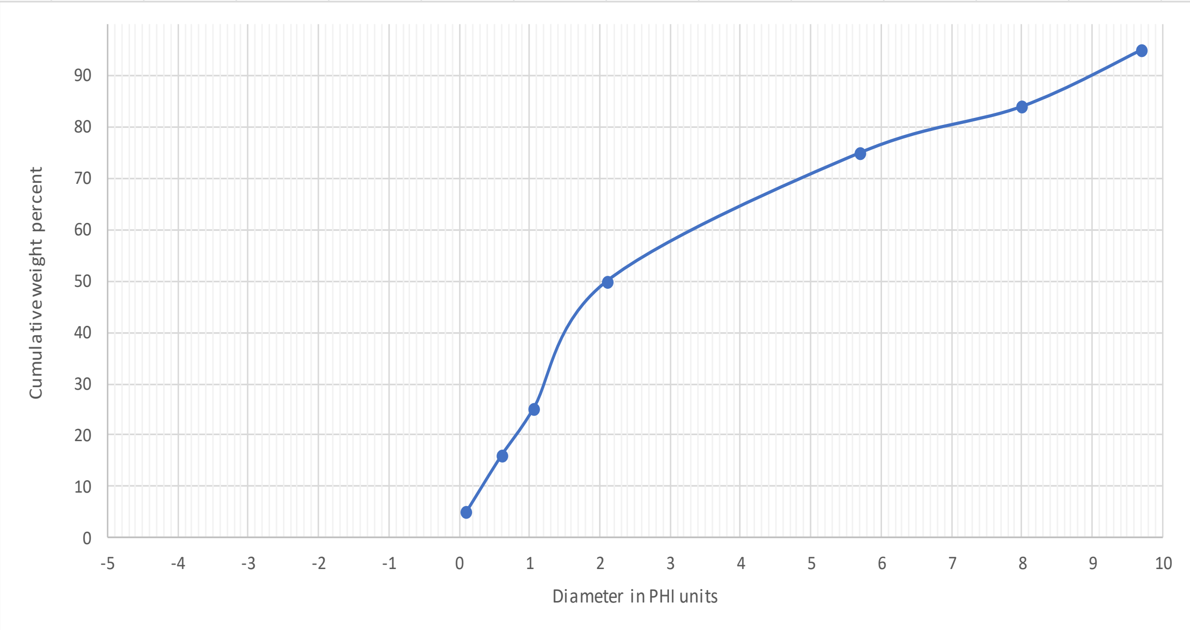
D10= 0.0018

D60= 0.35

Porosity = 0.255

	L16								
phi									
5	0.1	MEAN	3.566667	SD	3.304545	SKEWNESS	0.588964	KURTOSIS	0.846113
16	0.6								
25	1.05								
50	2.1								
75	5.7								
84	8								
95	9.7								

L16



GRAIN SIZE ANALYSIS BY DRYAND WET-SIEVING

JOB:**ACADEMICTHESIS** SITE:**..**

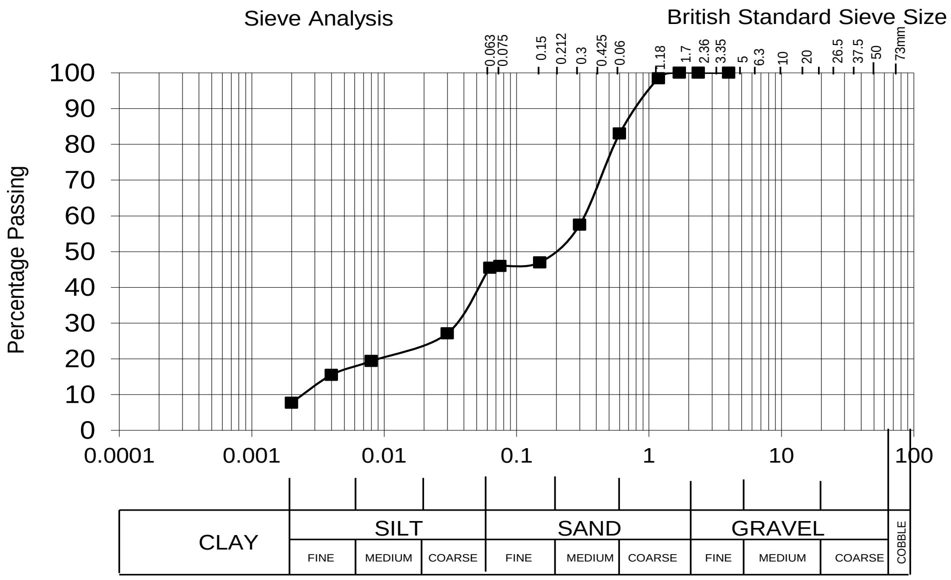
LOCATION:**.. L 17** DATE**: …2024……**

DEPTH:**.. 0.15 cm** TESTED BY:……**WET AND DRY SIEVE**………

WEIGHT OF DRY MATERIAL AND CONTAINER IN GRAMMS:……

WEIGHT OF CONTAINER IN GRAMMS...

SIEVE NO.					
APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% retained	Cumm wt %	% passing
-2	4	0	0	0	100
-1.25	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.3	1.5	1.5	98.5
0.75	0.6	3.1	15.5	17	83
1.75	0.3	5.1	25.5	42.5	57.5
2.75	0.15	2.1	10.5	53	47
3.75	0.075	0.2	1	54	46
4	0.063	0.1	0.5	54.5	45.5
5	0.03			72.87	27.13
7	0.008			80.62	19.38
8	0.004			84.5	15.5
9	0.002			92.25	7.75



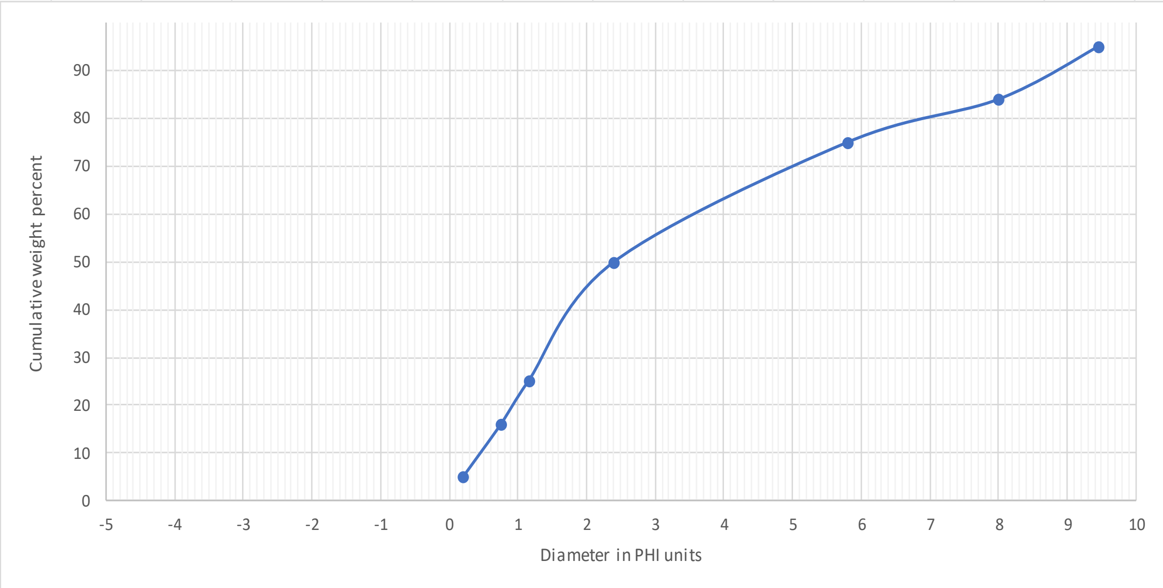
D10= 0.0024

D60= 0.33

Porosity= 0.255

	L17								
phi									
5	0.2	MEAN	3.716667	SD	3.214015	SKEWNESS	0.534576	KURTOSIS	0.815265
16	0.75								
25	1.15								
50	2.4								
75	5.8								
84	8								
95	9.45								

L17



GRAIN SIZE ANALYSIS BY DRYAND WET-SIEVING

JOB:**ACADEMICTHESIS** SITE**:..**

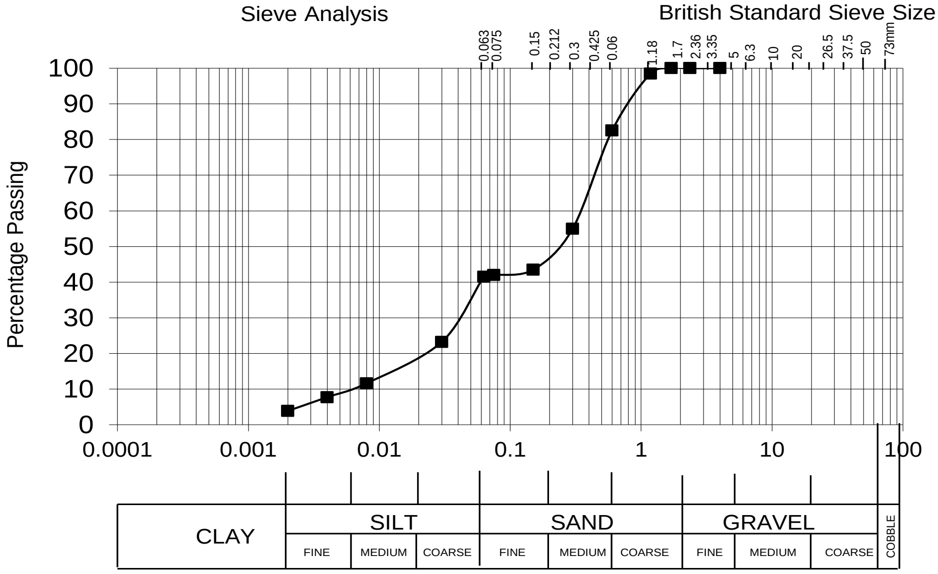
LOCATION**:.. L 18** DATE**: …2024……**

DEPTH**:.. 0.15 cm** TESTED BY:……**WET AND DRY SIEVE**………

WEIGHT OF DRY MATERIAL AND CONTAINER IN GRAMMS:……

WEIGHT OF CONTAINER IN GRAMMS...

SIEVE NO.					
APPROX IMPERIAL EQUIV (phi)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	% retained	Cumm wt %	% passing
-2	4	0	0	0	100
-1.25	2.36	0	0	0	100
-0.75	1.7	0	0	0	100
-0.25	1.18	0.3	1.5	1.5	98.5
0.75	0.6	3.2	16	17.5	82.5
1.75	0.3	5.5	27.5	45	55
2.75	0.15	2.3	11.5	56.5	43.5
3.75	0.075	0.3	1.5	58	42
4	0.063	0.1	0.5	58.5	41.5
5	0.03			76.75	23.25
7	0.008			88.37	11.63
8	0.004			92.25	7.75
9	0.002			96.11	3.89



D10 = 0.006

D60 =0.35

Porosity = 0.255

	L18								
phi									
5	0.1	MEAN	2.95	SD	2.65303	SKEWNESS	0.523256	KURTOSIS	0.965641
16	0.7								
25	1.05								
50	2.05								
75	4.7								
84	6.1								
95	8.7								

L18