CHARACTERISING THE FRAMEWORK OF THE SAND FACIES IN THE BENIN FORMATION EXPOSED AROUND EKOSODIN/EVBUOMORE AREA, BENIN CITY IN SOUTHWESTERN, NIGERIA

BY

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(GEOLOGY AND MINING TECHNIQUES)

DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY
FACULTY OF LIFE SCIENCES
UNIVERSITY OF BENIN

NOVEMBER, 2025.

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

NOVEMBER, 2025.

CERTIFICATION

This is to certify that **Daniel MADUKA** with Matriculation Number **LSC2009917**, of the Department of Science Laboratory Technology, Faculty of Life Science, University of Benin, Benin City, participated in the 2024/2025 Academic session project work and wrote this report.

MRS JANET AILEGBO EHIMAMIOGHO **(Project Supervisor)**	**DATE**
DR. P.O ALONGE **(Project Coordinator)**	**DATE**
PROF. J.O. OSARUMWENSE **(Head of Department)**	**DATE**
EXTERNAL EXAMINER	**DATE**

DEDICATION

I dedicate this project work to the Almighty God for seeing me through school, all through my undergraduate level. Also, to my Lovely Mum, Mrs. Gladys Osahon for her love, care and support.

ACKNOWLEDGEMENTS

I wish to express my profound gratitude to God Almighty.

Special thanks goes to the Head of Department, University of Benin, **PROF. J.O. OSARUMWENSE.** My immense salute goes to my project supervisor Mrs. Janet Ailegbo Ehimamiogho. I appreciate all the members of staff of Department of Science Laboratory Technology, academic and non-academic.

I want to specially thank and express my profound gratitude to my parent; Mr. Gregory Maduka and Mrs. Gladys Osahon (Maduka) for their unending love, care and prayers throughout this work and my years of study. To my lovely aunties and uncle; Rose Osahon, Rachael Lawrence, Mr. Osamudiamen Osahon, thank you for your encouragement and immense support.

Special thanks to my family; Joy Lawrence, Emma Lawrence, Sharon Lawrence, Abigail Lawrence, Bright Lawrence, Jennifer, Eno Lawrence, Samuel Akinpelumi. I love you all.

I also want to thank my friends; Maxwell, Osayu, Thelma, Osarobo, Stanley, Denis, Favour, Daniel, Ivy, Harrietta, P.boy, Mary, Rachael, Doris. I love you all and God bless you.

To all those who have supported me and shown me love, all I can say is I’m very grateful and God bless you all abundantly

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ABSTRACT

A total of ten (10) beds exposed at the Ekosodin/Evbuomore were obtained and studied. These beds belong to the Benin Formation of the Niger Delta Basin. Sieve analyses were carried out on them, with the results plotted and the mean, standard deviation, skewness and kurtosis calculated. These calculations were used to interpret the provenance, depositional process and environment of deposition. The beds mainly contain quartz, feldspar and detrital fragments revealing their igneous and metamorphic origin. The results indicate that the grain size were fine to medium to very coarse sand; poor to very moderately well sorted. The results of the mineral assemblage based on the percentage of quartz, feldspar and lithic fragment reveal that the beds are quartz arenite, subarkose, arkose and lithic arkose. Grain sizes are mostly medium to coarse, with some fine grains in Bed 5. Grain shape is mostly angular and subrounded, with few rounded and sub angular. The values obtained from the standard deviation for the beds suggest near moderately well sorted to poorly sort. The sorting show that the maturity of the bed samples ranges from immature (BED 3, 4 and 8) to submature (BED 1, 5 and 7) to mature (BED 2, 6, 9 and 10). The Bivariant plot of inclusive skewness against inclusive standard deviation indicates that the depositional process that led to the deposition of the beds is fluvial (river systems) suggesting a low energy of transportation of the sediments as well as beach sediments. Economic importance the sands serve as the main aquifer in Benin Formation. The abundance of quartz makes it a potential for use in glass making. The sands are mined/excavated and used in construction viz; concrete making, moulding of blocks, etc. My suggestions for further studies are, thus: More detailed study should be done with morphoscopic and petrographic analysis to ascertain the minerals present in traces. Environmental studies should be done in the area under study to ascertain the presence of any heavy minerals that is a potential health hazard to the subsurface water.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The Benin Formation, the youngest lithostratigraphic unit of the Niger Delta Basin, represents a vast continental sequence of sands, gravels, and subordinate clays deposited during the Oligocene to Recent periods (Nwozor et al., 2025; Harry, Etim and Etim, 2022). It is widely referred to as the Coastal Plain Sands and underlies most of southern Nigeria, including the Benin City region where the present study area Ekosodin and Evbuomore is located. Lithologically, the formation is dominated by medium- to coarse-grained, poorly sorted sands that are generally friable and weakly cemented, interbedded with thin clay or silt horizons (Kwache et al., 2017; Adegboyega and Fajemila, 2025). The sequence attains considerable thickness, ranging between 1,800 and 2,000 m in some parts of the basin, and forms the major aquifer system across southwestern Nigeria (Harry et al., 2022; Nwozor et al., 2025).

Sedimentologically, the Benin Formation records the transition from fluvial to upper coastal plain depositional settings. Its sand facies exhibit characteristics of high-energy fluvial channel deposits, including cross-bedding, ripple marks, and variable grain sizes, all of which indicate deposition under fluctuating flow regimes (Essien and Okon, 2017). Petrographic and granulometric studies have shown that the sands are predominantly composed of quartz (over 95%), classifying them as quartz arenites and suggesting a high degree of mineralogical maturity and textural reworking (Kwache et al., 2017; Nwozor et al., 2025). This level of maturity is typical of sediments transported over long distances or subjected to multiple reworking episodes in a high-energy environment.

In the Benin City region, particularly around Ekosodin and Evbuomore, the Benin Formation is exposed along road cuts, gully walls, and sand excavation sites, providing excellent opportunities to study its sand facies architecture. The visible outcrops display multiple sand layers intercalated with minor clay seams, showing lateral and vertical variations in grain size, sorting, and sedimentary structures. Such variations are indicative of episodic depositional events influenced by changes in sediment supply, basin subsidence, and paleocurrent dynamics (Harry et al., 2022; Nwozor et al., 2025). Characterising these sand facies therefore provides crucial insight into the depositional history and paleoenvironmental evolution of the area.

Despite the regional importance of the Benin Formation, there is a scarcity of detailed facies-based studies focusing on its outcrop expressions within Benin City. Most previous works have emphasized its hydrogeological and geotechnical significance, rather than its sedimentological framework (Kwache et al., 2017; Adegboyega and Fajemila, 2025). However, understanding the facies framework at outcrop scale is essential, as it reveals the internal architecture of the formation, the connectivity of sand bodies, and their implications for groundwater potential, engineering foundations, and environmental stability.

This study, therefore, focuses on characterising the framework of the sand facies in the Benin Formation exposed around Ekosodin/Evbuomore area. By examining the lithologic composition, grain-size distribution, textural maturity, and stratigraphic relationships within these exposures, this work seeks to develop a comprehensive facies framework that reflects the depositional environment and structural development of the Benin Formation in this locality. The findings will not only bridge existing knowledge gaps but also contribute to the broader understanding of the Benin Formation as a key stratigraphic and hydrogeological unit within southwestern Nigeria.

1.2 Aim and Objectives

The aim of this work is to characterise the framework of the sand facies in the Benin Formation exposed around Ekosodin/Evbuomore area, Benin City. To achieve this aim, the following are my objectives:

- What field observations have been identified in logging of the exposure,
- What is the result of sieve analysis/grain size analysis for the sorting, skewness,
- What minerals are present,
- What are the sedimentary structures, as well as,
- What are the results on the appropriate graphs in order to make a good inference and tell a sound geologic history/provenance where necessary?

1.3 Location and Accessibility

The study area is Ekosodin/Evbuomore Ovia North East Local Government Area, Benin-City, Edo state in Nigeria, with coordinates: 6° 25' 50" latitude and 05° 38' 49.1" longitude. It is a humid tropical rural settlement and was accessed both by road and footpaths. The area was covered with loose sediments of the formation at the base due to both natural cause and man-initiated activity of quarrying the sands.

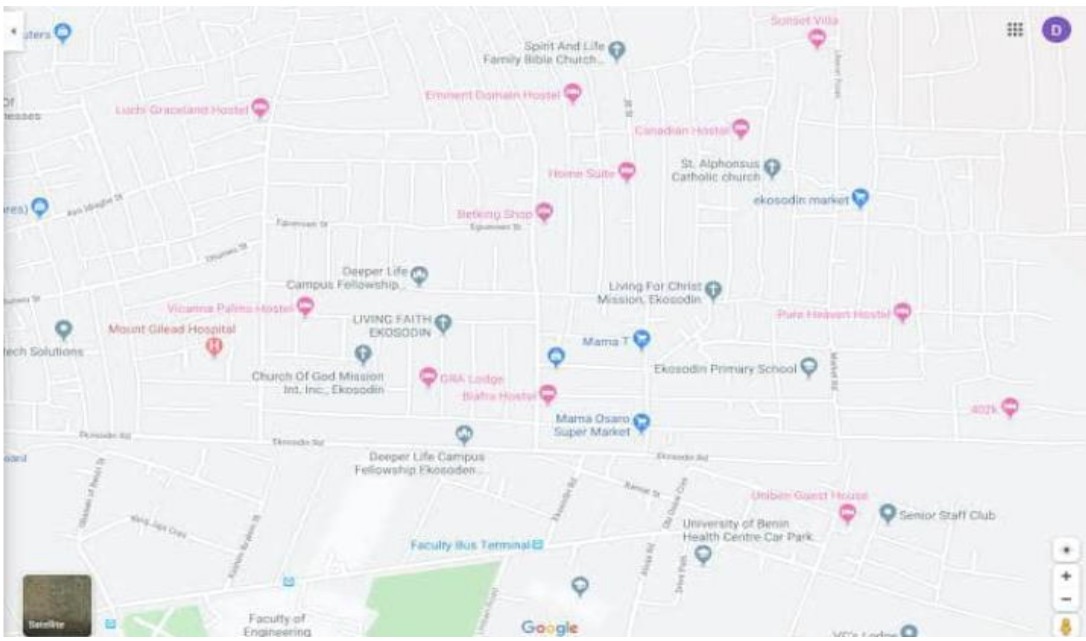


Figure 1: Topographic map of the study area with several landmarks.

1.4 Scope of Study

It entails a concise description of the stratigraphy of the Benin sands, exposed at Ekosodi Evbuomore area, both on the field and in the laboratory.

As earlier stated, it also involves sieve analysis, determination of some sedimentological properties of the sediments, plotting of graphs, logging of the outcrop of the formation, all in a bid to study the Benin formation, making inferences and adding to literature knowledge.

1.5 Climate and Vegetation

Rainfall, temperature, wind and relative humidity are the most significant climatic elements in Benin City. According to Agboola and Hodder [1979], the rainfall element strongly determines the occurrence of the wet and dry seasons in the study area. Convective and relief type of rainfall are widely experienced in the area. The area also experiences double rainfall cycles. Total annual rainfall amount recorded in the city range between 2000mm and 3000mm and this peaks between July and September. The city regularly experiences a high relative humidity of between 75% and 85%. Is stabilizes in the mornings and evenings but fluctuates in the afternoon. The city experiences a mean annual temperature of 27.50°C although some cases of temperatures between 30°C and 35°C have been recorded in November and December [Omogbai, 1985; Okhakhu, 2010]. As a result of its tropical location and observed climatic character, Benin City experiences the 'humid sub-equatorial'.

1.6 General Statement

Sedimentology encompasses the study of sediments such as sand, silt, and clay, and the processes that result in their formation (erosion and weathering), transport, deposition and diagenesis. Sedimentologists apply their understanding of modern processes to interpret geologic history through observations of sedimentary rocks and sedimentary structures. Sedimentology is closely linked to stratigraphy, the study of the physical and temporal relationships between rock layers or strata.

This work involves sieve analysis, determination of some properties of the sediments, plotting of graphs, logging of the outcrop of the formation, all in a bid to study the Benin Formation and characterising the sediments of the stratas of the exposure around Ekosodin, Evbuomore area of Benin.

CHAPTER TWO

LITERATURE REVIEW AND GEOLOGICAL SETTINGS

2.1 Regional Geology

2.1.1 Sedimentary Basins in Nigeria

The sedimentary basins in Nigeria are:

- The Sokoto (Illumeden) Basin in the North West,
- The Chad Basin in the North east,
- The Dahomey Basin in the South West,
- The Benue Trough which extends from the south to the north east joining the Chad Basin to the Niger Delta,
- The Bida (Nupe) Basin. Some workers add
- The Anambra Basin which is between the Niger Delta Basin and the Benue Trough, and
- The Niger Delta Basin in the South, consisting of the Akata, Agbada and the Benin Formations.

Sandstones, clays and limestones constitute the major rock groups in the sedimentary basins. Limestones and clays in the sedimentary basins form the main mineral components of the cement factories in Ewekoro, Sokoto, Gboko and Nkalagu. The sedimentary rocks in Nigeria range in age from the cretaceous to recent.

2.1.2 Niger Delta Basin

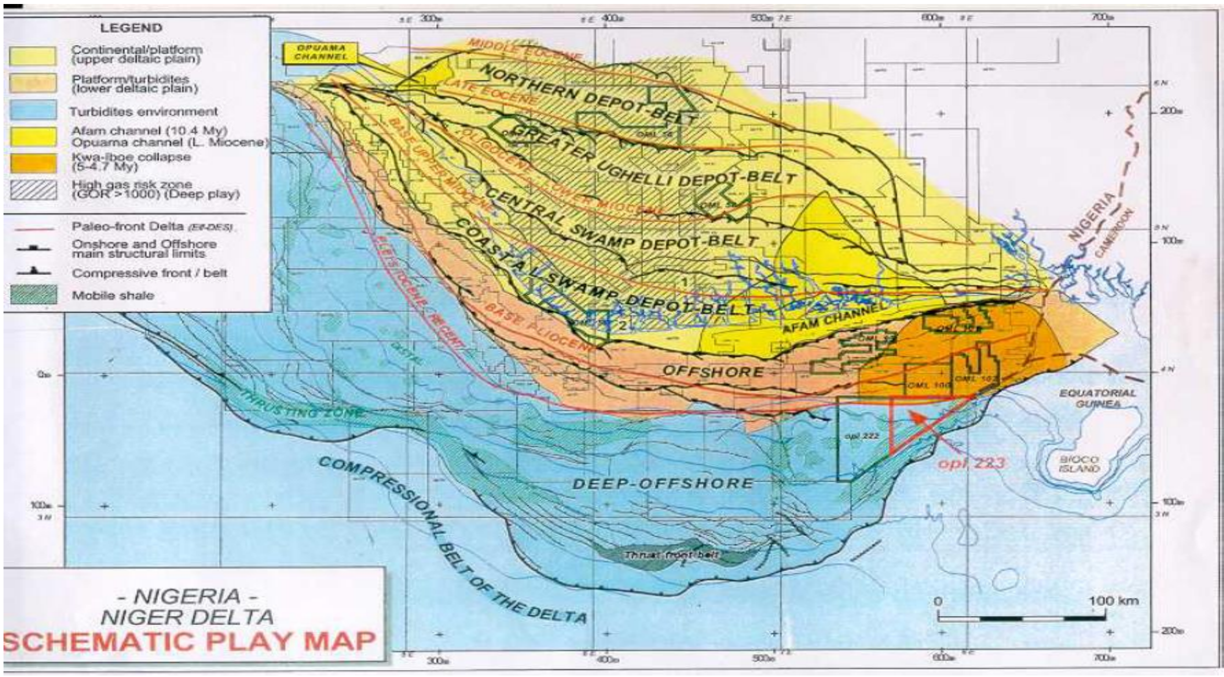


Figure 2: The map view of the different Depobelts in the Niger Delta (Doust and Omasola, 1995)

The Niger Delta basin occupies the Gulf of Guinea continental margin in equatorial West Africa, between latitudes 3° and 6° N and longitudes 5° and 8° E. It ranks among the world's most prolific petroleum-producing Tertiary deltas, comparable to the Alaska north slope, the Mississippi, the Orionoco, and the Mahakam. The Niger Delta basin occupies the coastal and oceanward part of a much larger and older tectonic feature, the Benue trough. The Benue trough is a NE-SW folded rift basin that runs diagonally across Nigeria. It formed simultaneously with the opening of the Gulf of Guinea and the equatorial Atlantic in Aptian-Albian times, when the equatorial part of Africa and South America began to separate. Sediments of the coal-bearing Mamu and the tidally influenced Ajali formations accumulated during this epoch when the Nkporo cycle tended toward an overall regression with associated progradation. The influence of basement tectonics on the structural evolution of the Niger delta was largely limited to the movements along the equatorial Atlantic oceanic fracture zones that extend beneath the delta and determined the initial locus into which the proto-Niger built its delta, (Reijers *et al*., 1997).

2.1.2.1 Depositional Setting and Stratigraphy of Niger Delta Basin

Based on the premise that both oceanic currents and tectonic activities have remained relatively constant from Eocene to recent, Weber characterized five physiographic provinces in the modern Niger Delta. They are Holomarine, Transition, Barrier Bars, Tidal coastal plain and Floodplains zones. Holomarine zone is predominantly clay deposit with depth ranging from the outer shelf to 100 feet (30.48 m). Transition zone of barrier foot or fluvio marine sedimentation consists typically of laminated clays, silts and fine sands in waters 10 to 100 feet (3.05-30.48 m). Barrier Bars which occurs along the coastal belt and consisting fine medium grained sand at depth ranging up to 30 feet (9.2m). Interfingering of these bars with barrier foot sediments swamps, beach ridges and sand splits are common. River mouth bars occurs in front of tidal channels. Tidal coastal plain includes tidal flats and swamps. It extends behind barrier bars. The sediments within this zone vary from medium to coarse clayey and peaty deposits in swam and lagoons. Floodplains consist of deposits which are predominantly medium to coarse grained point bar sands and clayey backswamps deposits.

Niger Delta started its growth during the Palaeogene (Eocene). The delta sequence consists mainly marine clays overlain paralic sediments which were finally capped by continental gravels and sands. Short and Stauble, divided the tertiary deltaic complex into three major lithofacies units based on the dominant environmental influence which continental, transitional and marine environments. The sediments from these environments in the Niger Delta are stratigraphically superimposed. The base of the stratigraphic sequence is represented by massive marine shales. The middle part of the sequence is represented by the interbedded shallow marine and fluvial sands, silts and clays which are typical of a paralic setting. This sequence is capped by a section of massive continental sands. These three depositional lithofacies are Akata, Agbada and Benin Formations respectively. They make up an overall regressive clastic sequence of about 37,000 to 39,000 feet (11278 -11887) thick.

Akata Formation

This formation which forms the base of the delta is composed of dark grey marine shale, which was deposited in the deep sea characterized by low energy condition and oxygen deficiency (Michele *et al*., 1999).

The thick shally sequence contains lenses silt and fine sand which were deposited as deep sea fans or turbidite. Its estimated thickness is about 7km in the central part of the delta (Doust and Omatsola, 1990). It is of Paleocene age.

Agbada Formation

The Agbada Formation diachroniously overlies the Akata. It represents the sedimentary overburden of the deltaic succession. This formation consists of paralicclastics of over 3.7km thick at the central part, and represent a coarsening upward regressive sequence of sandstone and shale of the delta front, distributary channel and delta plain.

The thicknesses of the sandstones and sands increase from the bottom of the formation upward while that of the shale units reduces up the formation. It is of Eocene age.

The rhythmic or paralic sequence of this formation explains its multi reservoir nature. The sandy units are coarse to fine grained and unconsolidated. The surface equivalence of the Agbada Formation is the Oguashi-Asaba and Ameki formation (Short and Stauble, 1967).

Benin Formation

It is the uppermost part of the sedimentary sequence in the basin and it is composed almost entirely of continental sands of alluvial coastal plain origin with local thin shale inter-beds considered to be of braided stream origin.

It also contains pebbly member which are believed to be deposited by braided stream as channels on natural levees. The thickness of this formation is up to 2000m (Avbovbo, 1978).

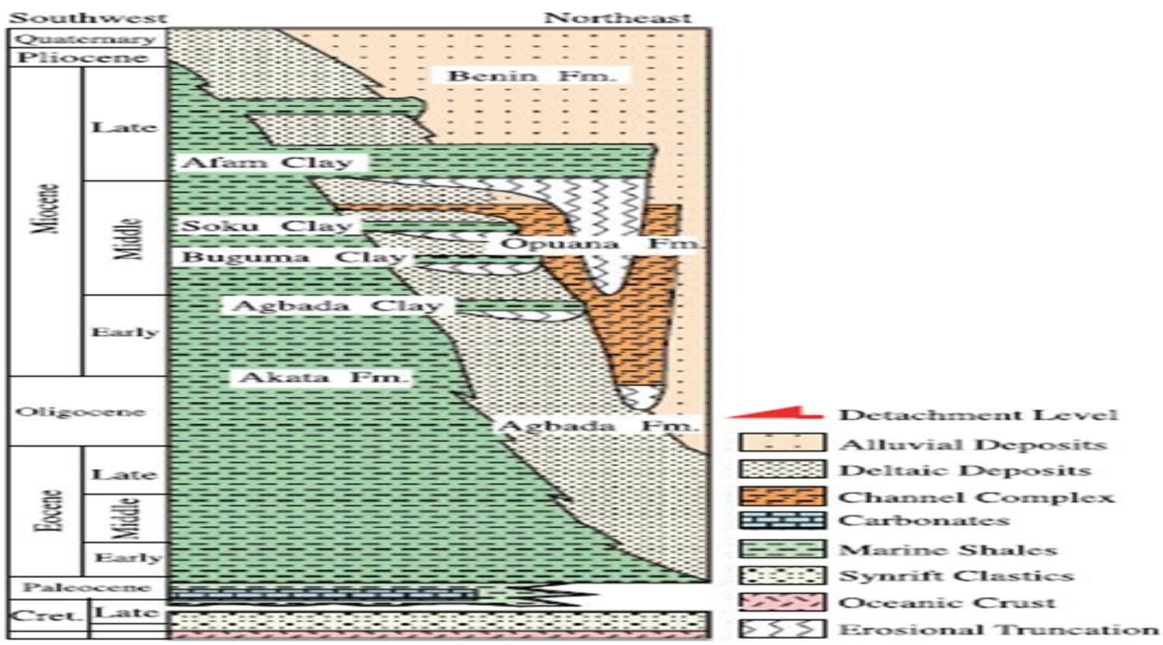


Figure 3: Schematic diagram of the regional stratigraphy of the Niger Delta and the Anambra Basin (modified from Lawrence et al., 2002)

2.2 Local Geology of the Studied Area (The Benin Formation)

2.2.1. Geology

The Benin Region is underlain by sedimentary formation of the South Sedimentary Basin. The geology is generally marked by top reddish earth, composed of ferruginized or literalized clay sand. Parkinson [1907] first used the term Benin sand to describe the reddish earth underlain by sands, sandy clays and ferruginized sandstone that mark the Paleo-Coastal Environment of Paleocene-Pleistocene Age. These sediments spread across the southern fringes of the Anambra Basin and marking the upper fancies off-flaps of the Niger Delta. Tattam [1943] used the name Coastal plain sands to describe the formation of red earth underlain by sands and clays that mark an ancient coastal plain environment now exposed in Calabar, Owerri, Onitsha and the Benin Region with the age Oligocene-Pleistocene.

However, Reyment (1965), reinstated the name Benin Formation to identify the reddish-brown-yellow generally white sands often with clayey and pebbly horizons with type-locality around Benin. This is also referenced at Calabar and other parts of South Eastern Nigeria. The sedimentary suits of the Benin Formation dip 2˚ - 8˚ south.

2.2.2 The Benin Formation

It is assigned to the Oligocene-Pleistocene period in the continent of Africa and to the Oligocene-Pleistocene recent at the sub-oceanic [Short and Stable, 1967; Whiteman, 1982]. The formation is characterized by top reddish to reddish brown lateritic massive fairly indurate clay and sand. This is often marked with reticulate muderacks. This caps the underlying more friable pinkish-yellowish white often gravelly-pebble sands clayey soils, sands and clay [Akujieze, 2004]. The sedimentary sequences are poorly bedded with discontinuous clay horizons at various depths. It is estimated to be about 800m thick under Benin City and about 1,830m near the sea shore sections of the formation. They are exposed at various erosion sites, sand quarry sites, and road cuttings. The Benin Formation covers 95% of the region.

2.2.3 Hydrogeology and Drainage

The climate and drainage experience in the study area is important because it affects the deposition of sediments. Over time, the history of sediments in Sedimentology is trace to the climatic conditions and drainage of the area, hence, the need to look at the climate and drainage of Benin.

The natural solar energy received at Ikpoba Hills during the daytime helps to stimulate regular surface evaporation which leads to increased atmospheric water contents in the study area. Consequently, evenly distributed relief rains are experienced in this part of the City. The received rain waters on the urban surface facilitate direct increase in the volume of water in Ikpoba River which is found on the valley floors. There is also intermittent moderation in the cloud cover of the area particularly during the early morning hours, and this is associated with the nature of the Hills. These hydro-geomorphic characteristics have strong climatic implications with particular reference to the processes and patterns of precipitation, temperatures, relative humidity and wind, flood occurrences, and land with atmospheric transportation in Benin City.

In the west and south of the city, the sandy coastal plain which is generally below 121.92 meters is a common geomorphic feature. It is observed that the highest contour of 121.92 meters occurs in the north-west corner of the city. This undulating terrain characteristic of the city makes the surface run-off very slow thus resulting in frequent urban inundations whenever torrential precipitation occurs (Omiunu, 1988).

Three river systems drain the Benin Region. They are the Ikpoba River, the Ogba River and Owigie-Ogbovben River systems. They are small in size being (1 - 5m) wide and (0.5 - 3.0m) deep. The major one is the Ikpoba River. It's headstream originates from the N.E outside the Benin Region and flows east to west across the northern quarter of the region and then swings south and south east. This change in direction indicates some structural control. There is a prominent artificial man-made lake referred to as the Ikpoba Lake along its course in Okhoro. The lake is about 1 km2 in area and is used mainly for municipal water supply for drinking, fishing, and recreation. The south western part of the Region is drained by the Ogba River Basin. The head of the stream originates from Oko-Ugbor environment. The three rivers constitute a dendrite drainage pattern. The drainage density can be described as lower sparse.

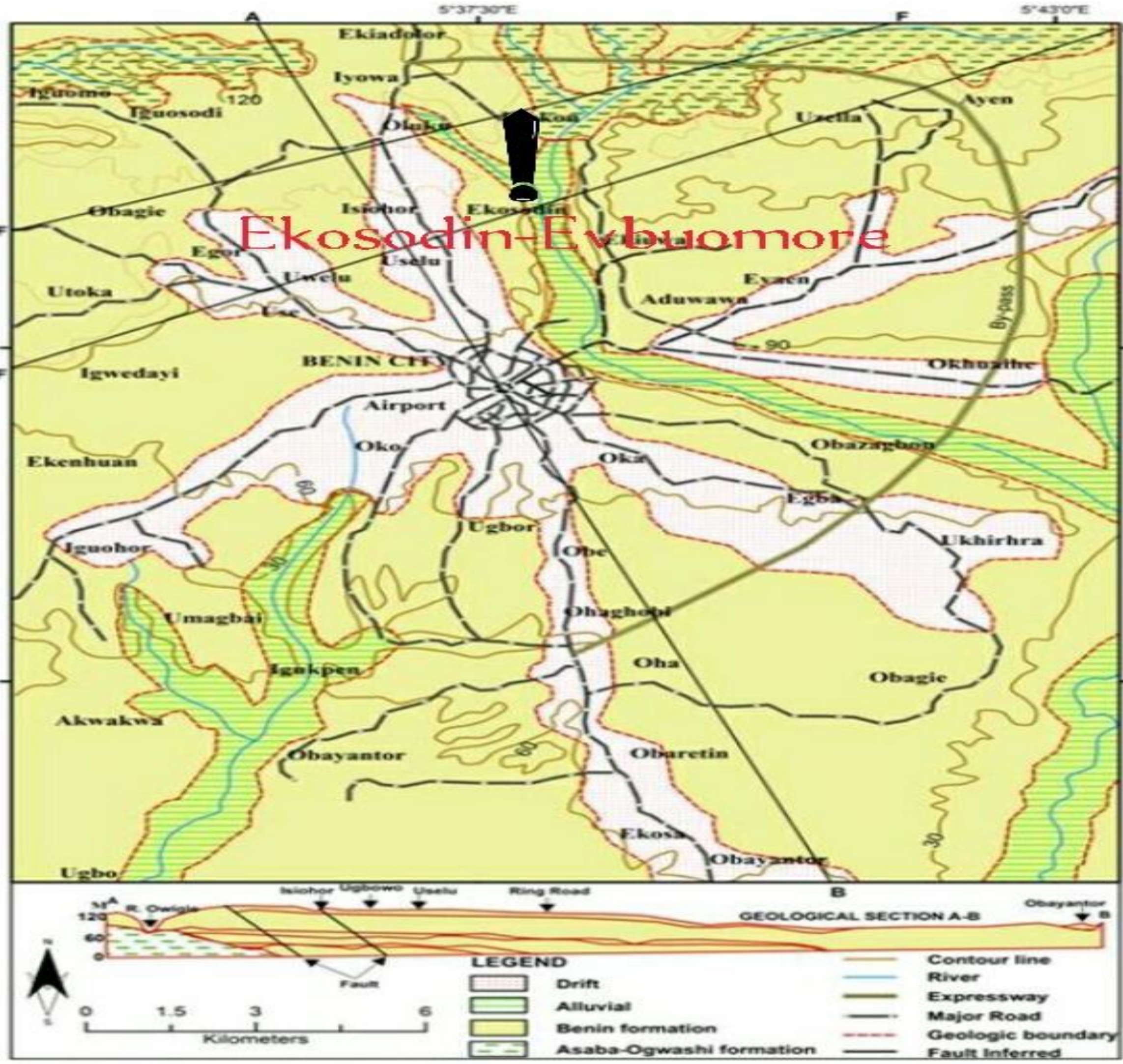


Figure 4: Geological Map of Benin City showing the quarry site and outcropping geological formations. [Modified after Akujieze, 2004]

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Materials

The materials used for the field work for collection of samples are: Compass Clinometer, Global Positioning System (GPS), camera, helmet, field note book, sample bag, measuring tape, cutlass, field boots, jacob staff, reflective jacket.

3.2 Methodology

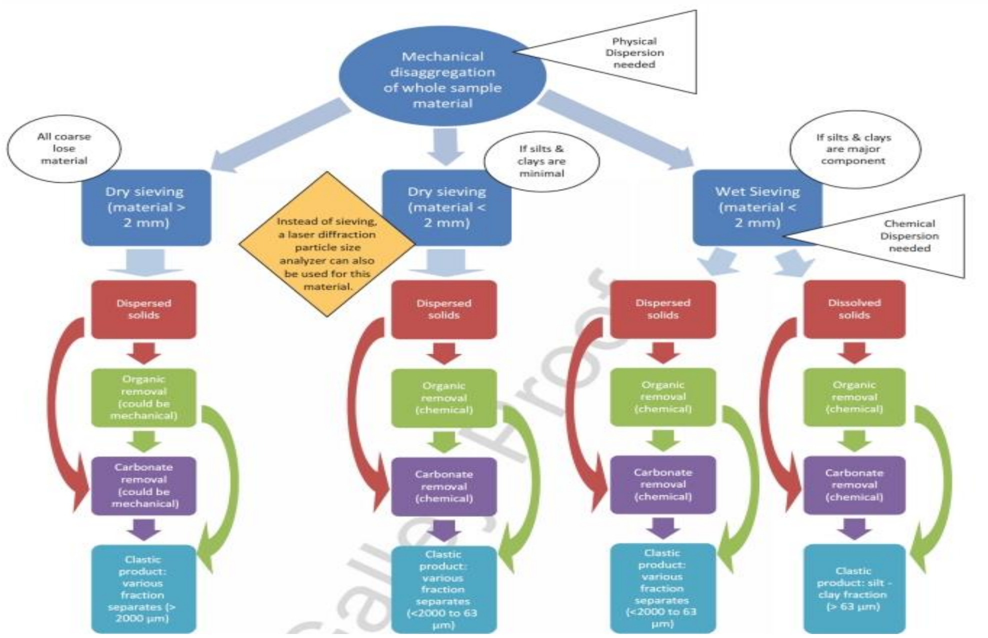


Figure 5: Work Flow of this research

The methods applied in this work is the Analytical method of include sampling for collection of samples from the locations and taking GPS coordinates.

It also involves field observations and logging of the stratas of the exposure of the Benin Formation at Ekosodin-Evbuomore area of Benin City.

Field work

Lithostratigraphic study was done on the exposure. It involved the study and organization of stratas on the basis of physical lithologic characteristics viz: rock type, color, mineral composition, grain size, texture. Based on the field data, a log is prepared.

3.3 LOGGING SEDIMENTARY SEQUENCES

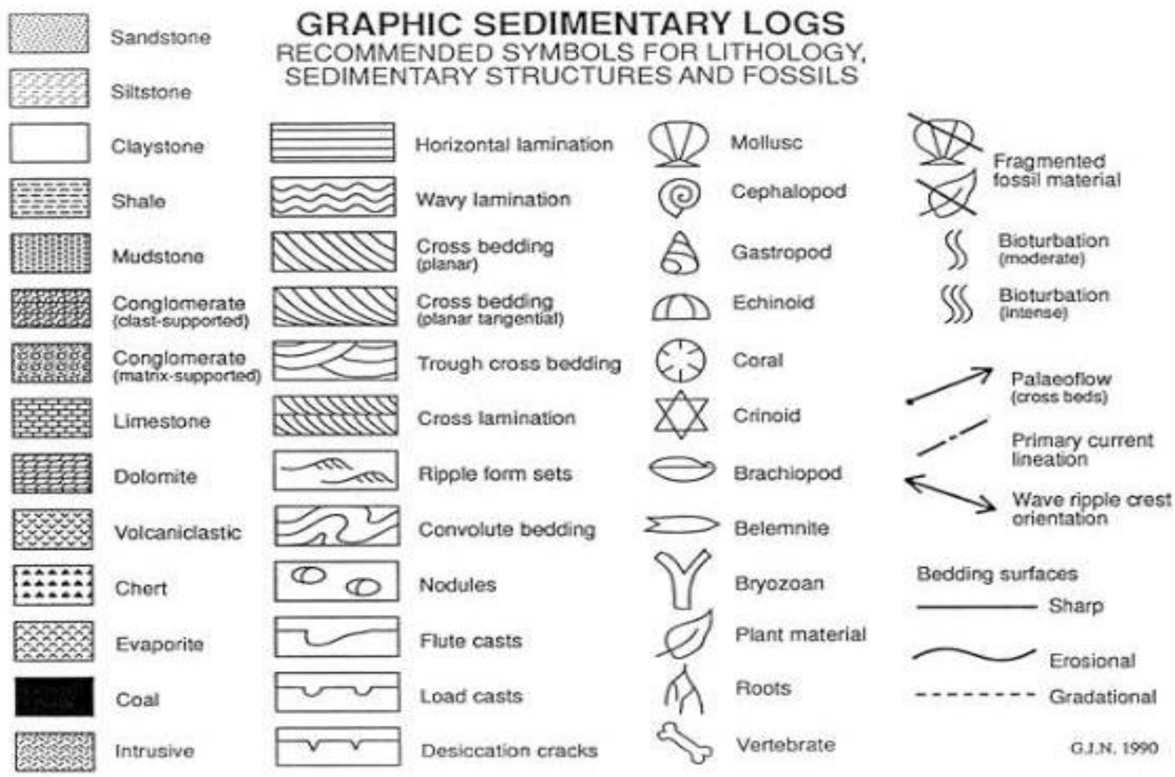


Figure 6: Symbols for sedimentary rocks

Graphic sedimentary logs are normally the most appropriate way of collecting a recording field data for sedimentary rocks. They are concise, convenient and give a visual impression of the sedimentary sequence. There is no standardised format for sedimentary logs and the most appropriate format for a log can vary depending on the type and amount of information required. The following is a set of guidelines for the collection and representation of data about a sedimentary sequence in the form of a graphic log. Recording data in the field It is normal practice to use logging sheets prepared with columns and scale already marked on, but under some circumstances a field notebook can be used. Log drawn in a field notebook may be drawn to scale or 'sketch log' may be drawn.

All the appropriate information should be shown on a sketch log, but it is not precisely drawn to scale. Use a sharp pencil, eraser and ruler; it is important that your log is neat, clear and tidy. Ideally a sedimentary log should be recorded along a continuous line perpendicular to bedding.

In practice the nature of the exposure may make it necessary to offset the log along the beds in places; if the offset is significant this should be recorded. If vegetation covers part of the sequence measure the distance obscured and record it as 'no exposure.

Start from the bottom and work upwards; this is logical because you will then be working through the sequence in the order in which things happened. Drawing the log Scale: this depends on the detail required. For precise work 1:10 (1cm on the log =10cm of rock) is used, but if the beds are relatively thick and there is a long sequence to be logged 1:50, (2cm = 1m), 1:100 (1cm = 1m) or even 1:200 (0.5cm = 1m) will be adequate. Spend time looking at the sequence before you start logging to decide on the scale.

Identification of beds: where the bedding planes are clear and the lithology changes between beds this is straightforward. However, in some cases it is appropriate to group thin beds together as a single unit. Under these circumstances record the character and range of thickness of the thin beds which make up the unit on the log.

Bed thickness: Bed contacts: measure with a tape measure perpendicular to the bedding plane. note whether the contact between beds is sharp, gradational or erosional (scoured). Care needs to be taken where contacts are gradational as beds can be difficult to define.

Lithology: this is recorded in a column on the log using appropriate ornamentation. The symbols shown are those commonly used, but other ornaments may be used in some circumstances and a key should be given.

Texture (grain size): a horizontal scale on the righthand side of the lithology column is used to show the grain size from fine on the left to coarse on the right. Changes in grain size (normal or reverse grading) are indicated by tapering the right edge.

Sedimentary structures: these can usually be indicated by symbols within the textures column, although they may also be drawn on the side to make the features clearer. Symbols used should be a simple graphical representation of the feature to make the log easy to understand If the features cannot be satisfactorily shown by symbols, make a note in the description column.

Cross bedding: tabular, planar of the angle of the forest, the shape of the crosser trough, the thickness of the set of cross strata tangential or strata and the thickness of the individual laminae should be recorded in the description column. The direction of dip of the forest should be recorded and entered in the palaeocurrent column.

Fossils: symbols for fossils found in the beds should be placed within or alongside the texture column. Use symbols which can be recognized easily. If the fossils are broken, a diagonal line may be drawn through the symbol. The size and orientation of the fossils should be noted. Trace fossils (burrows and trails etc) are important so record the shape, size, orientation and abundance of trace fossils.

Description: Any features which cannot be adequately represented in the symbols should be noted in this column. The composition of the rock should be recorded where this can be determined in the field. Record the color of the rock (fresh and weathered surfaces if different).

Make a note of the numbers of any samples collected, photographs taken or if there is additional information in the field notebook on that part of the sequence.

Presentation of the log: The log can be drawn up neatly and accurately in the same style when you return from the field. Two columns should be added to present your interpretations

.

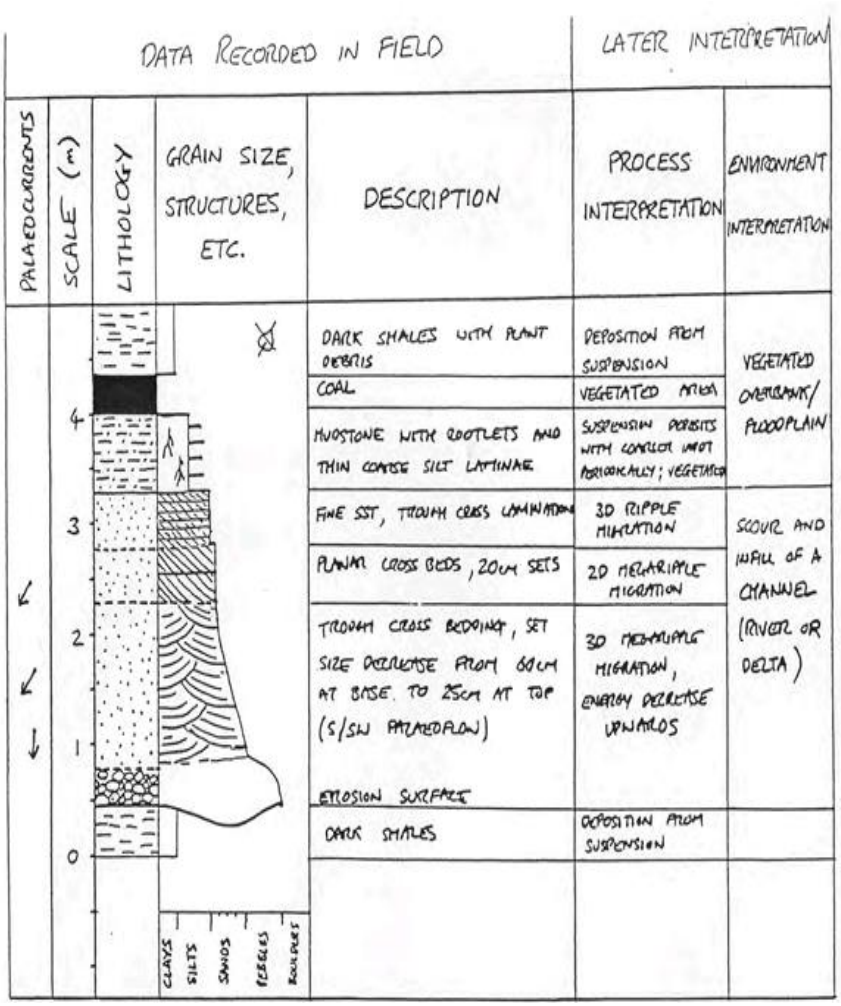


Figure 7: Schematic diagram showing an example of a sedimentary log (Zeruas et al 2009)

3.4 Laboratory Work

Grain size analysis is an analytical technique typically conducted within the earth sciences and implemented as a routine laboratory study. Other disciplines, such as archaeology and geoarchaeology, also use it regularly. It is a sedimentological analysis carried out in order to determine the size of the different particles that constitute a particular unconsolidated sedimentary deposit, sedimentary rock, archaeological locus, or soil unit. The main goal of this procedure is to determine the type of environment and energy associated with the transport mechanism at the time of deposition; this is done by inference from the sizes of the sediment particles analyzed and their distributions.

3.5 Sieve Analysis

A sieve analysis can be performed on any type of non-organic or organic granular materials including sand, crushed rock, clay, granite, feldspar, coal, soil, a wide range of manufactured powder, grain and seeds, down to a minimum size depending on the exact method.

(A) Steps to Performing a Test Sieve Analysis

Now that we have the preparation done, let's get into the reason you came to this article in the first place, how to perform a dry sieve analysis.

1. Place your sieve stack (without the sample material) in your sieve shaker.

2. Pour your representative sample into the top sieve of your sieve stack. 3. Try and pour your sample as evenly around the surface of the top sieve as possible.

4. Once the representative sample has been poured in its entirety, place the test sieve lid on. This lid is used to prevent the sample material from falling off the edges and, in addition, is not durable enough to withstand the tapping of the sieve shaker hammer (performs tapping motion).

A second, more robust lid is placed on top of the test sieve lid to soften the impact.

5. Now you can drop the hammer into place.

6. You are now ready to turn your machine on and set your timer. Once the sieve shaker has finished its cycle, it will turn itself off.

3.6 Analyzing Your Sample

Most often, you will be weighing the material retained on each sieve of the stack. This should add up to the weight of your representative sample.

The second and most common method for analysis, is to see what percentage of material passed through. An example of this is to determine the amount of material that passed through the top sieve, record it, then do the same with the material that passed the second. Continue this process until you make your way down the sieve stack.

3.7 Statistical Analysis

Important statistical parameters obtained from the analysis of the distribution of particles – which can help elucidate how uniform, symmetric or well sorted the sediment sample is – are the standard deviation, skewness and kurtosis (Folk, 1980). The standard deviation is a precise measure of the scatter of grain size values from the mean, corresponding then to a measure of spread or sorting of the sample. In combination with the mean, the standard deviation is the most useful and widely applied value in granulometric statistics.

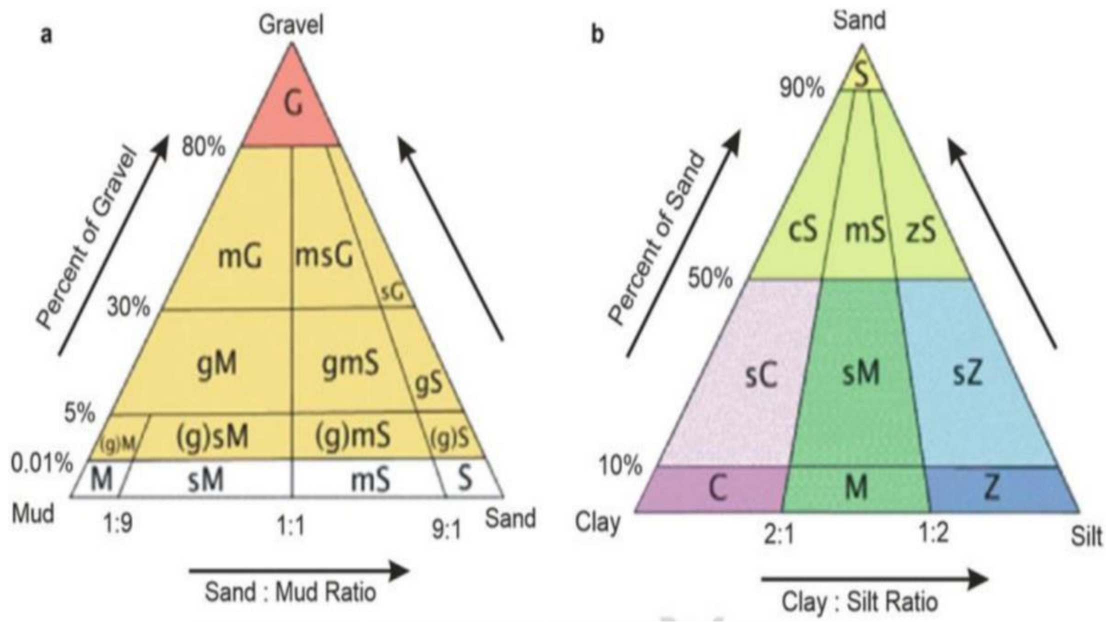


Figure 8: Classification of sedimentary rocks based on sand, clay, silt, mud and gravel (FOLK 1980).

Three limits are useful when computing standard deviations within a single sample:

1. Standard deviation (±σ) from the mean implies that 68% of the grain size values fall within this limit;

2. Standard deviations (±2σ) corresponds to 95% of the particles; and

3. Standard deviations (±3σ) to 99% (Folk, 1980).

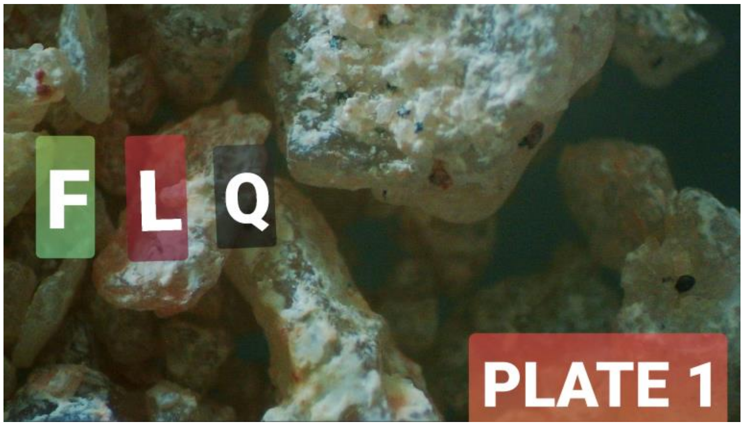
The skewness is used to establish the normality or symmetry of the distribution, hence to quantify the degree of dispersion within a sample, rather than only visualizing it on a frequency histogram. The closer the skewness value is to zero, the more symmetrical (i.e., normal or uni-modal) the distribution is. Asymmetrical and multi-modal sediment mixtures exhibit high values of skewness, to maximums of +1.00 and -1.00. The positive and negative sign of the skewness value indicates whether the asymmetrical tail extends to the left or right of the curve as follows (Folk, 1980).

The kurtosis is also a quantitative measure to describe the degree of Gaussian normality of the grain size distribution, but in terms of how acute or flat the curve is.

This is a sorting relation between the end members of the curve and its center (Folk, 1980). If the central portion of the curve is peaked, hence better sorted than its tails, the distribution curve is said to be leptokurtic with values > 1.00. The opposite, a flat-peaked curve with a large spread of grain size in the centre, is called platykurtic, with values < 1.00. Normal probability curves have a kurtosis of 1.0 (Folk, 1980).

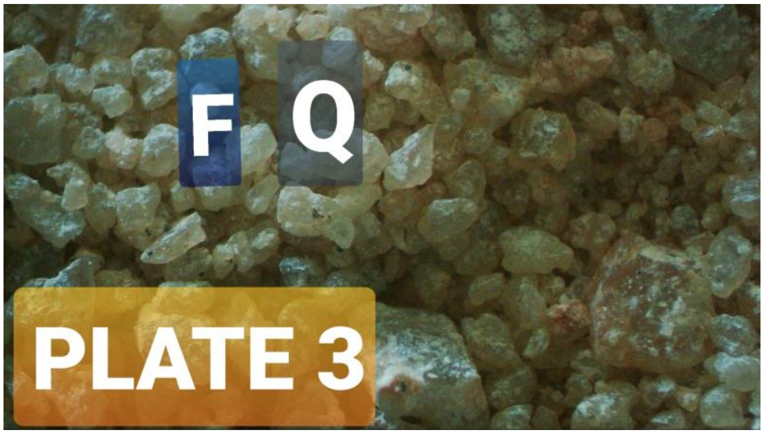
CHAPTER FOUR

PRESENTATION OF RESULTS



Photomicrograph of Bed 1

Photomicrograph of Bed 2



Photomicrograph of Bed 3

Photomicrograph of Bed 4

Photomicrograph of Bed 5

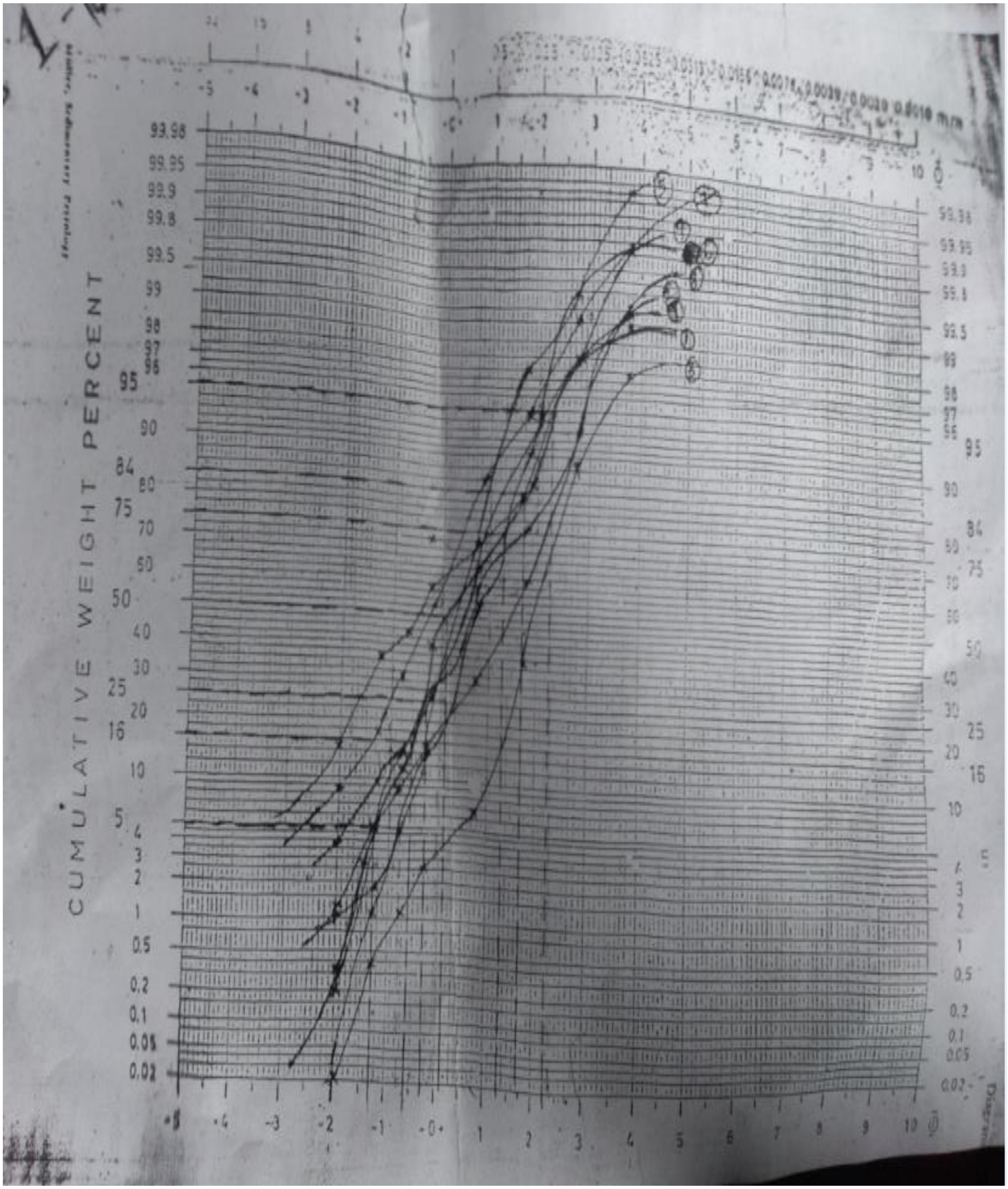
Photomicrograph of Bed 6

Photomicrograph of Bed 7

Photomicrograph of Bed 8

Photomicrograph of Bed 9

Photomicrograph of Bed 10



CUMULATIVE SIEVE WEIGHT PERCENT (Of bed 1 to 10)

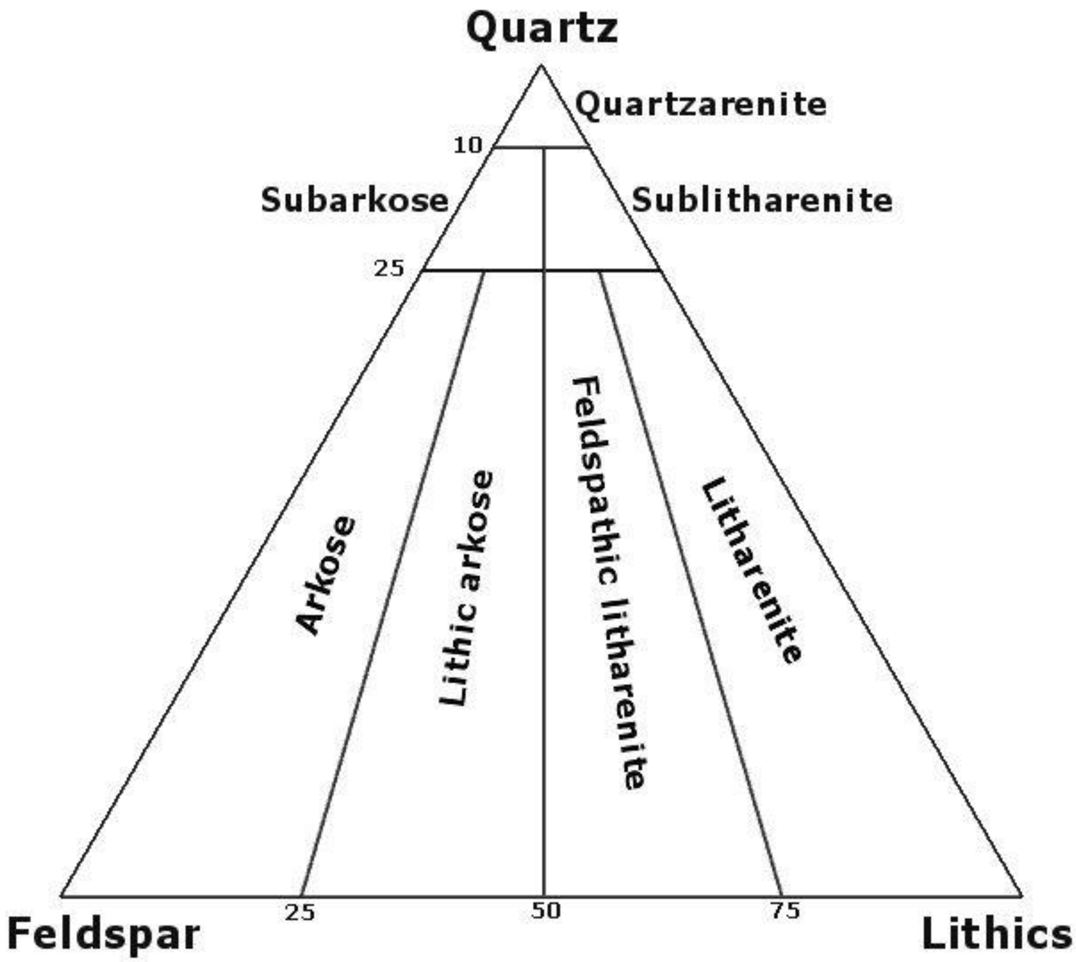
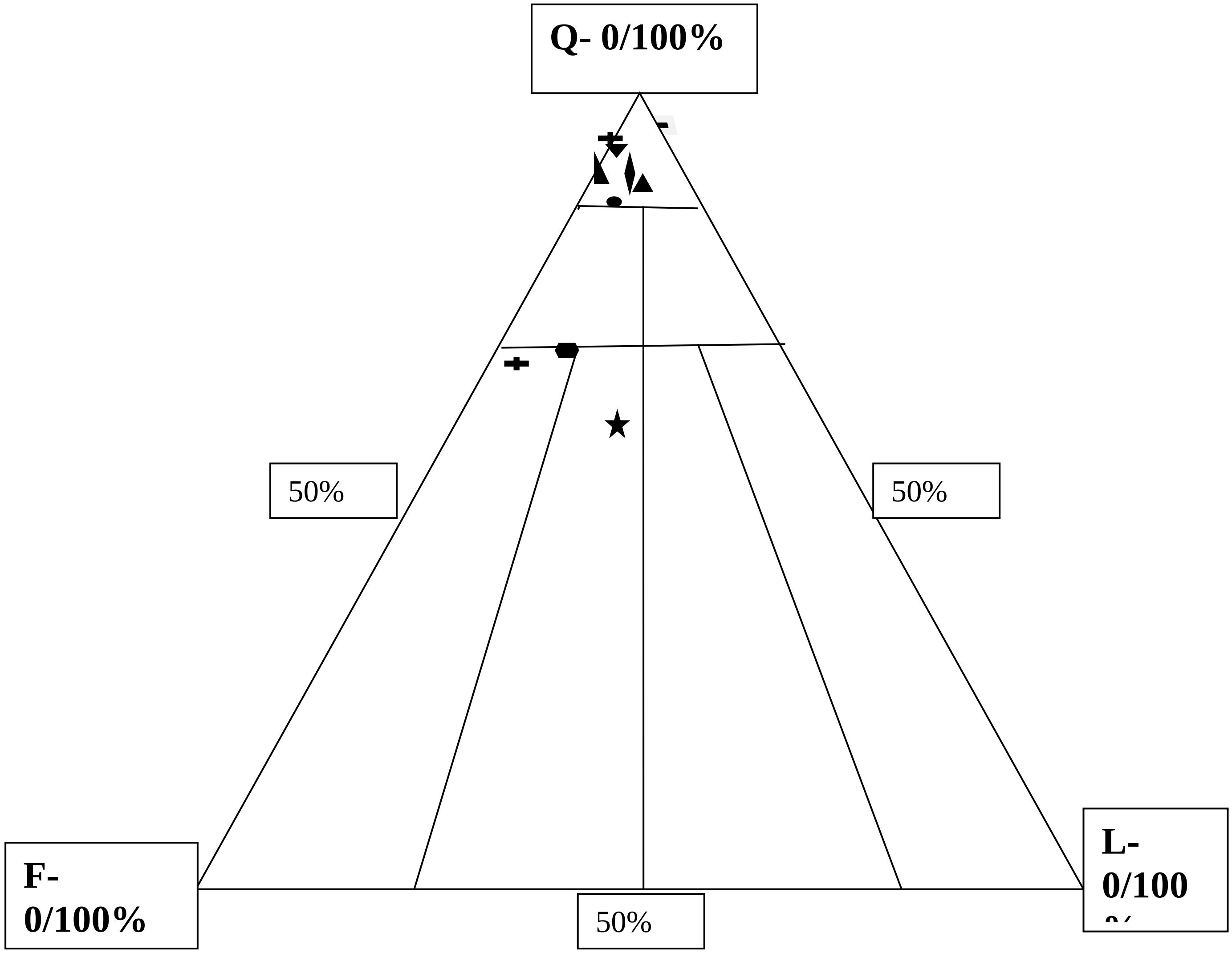


Figure 9: QFL Diagram Plot, (Pettijohn, 1975).

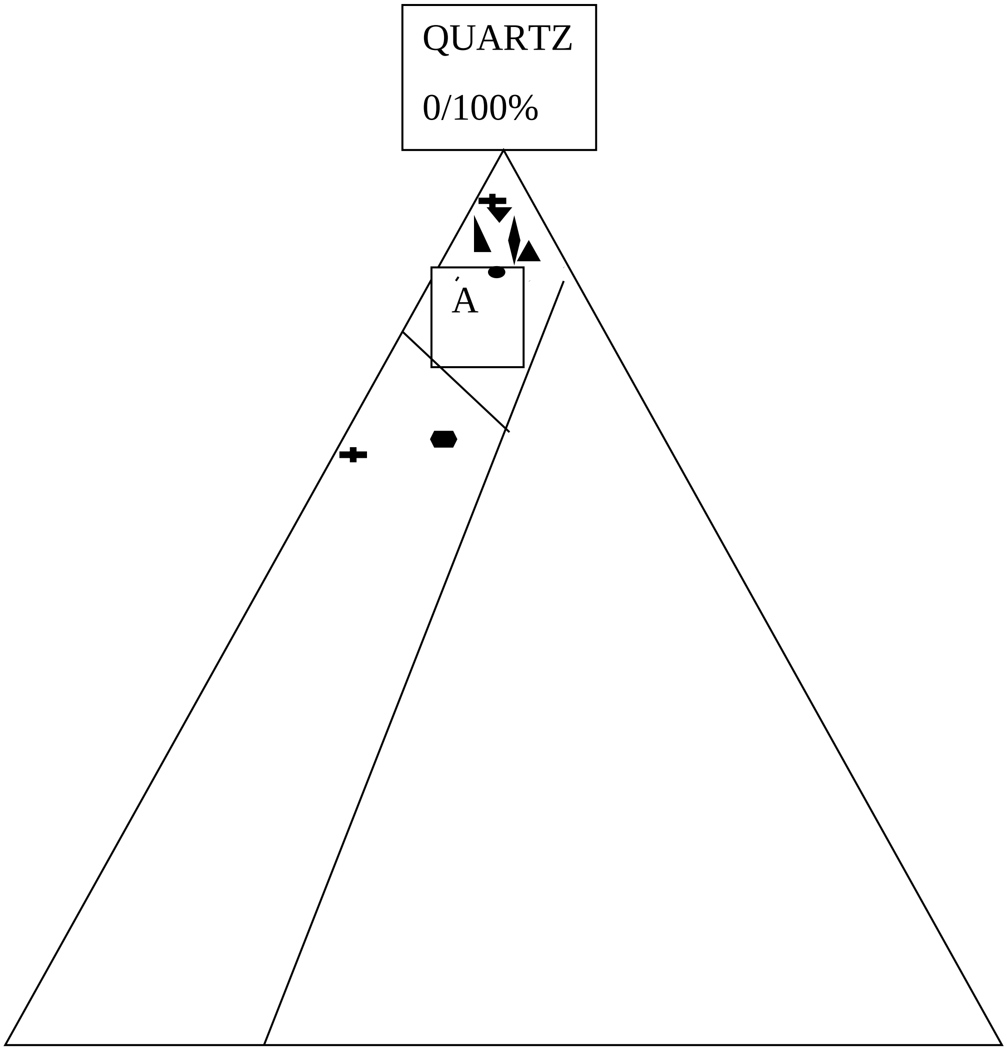


Q-QUARTZ

F- FELDSPAR

L- LITHIC

Figure 10: QFL Diagram Plot of Bed Samples, (After, Pettijohn, 1975).



KEYS

A-CRATON INTERIOR

B- TRANSITIONAL CONTINENTAL
C- BASEMENT UPLIFT
D- DISSECTED ARC
E- TRANSITIONAL ARC
F- UNDISSECTED ARC

Figure 11: Provenance Arc Interpretation (After Dickinson *et al*., 1983).

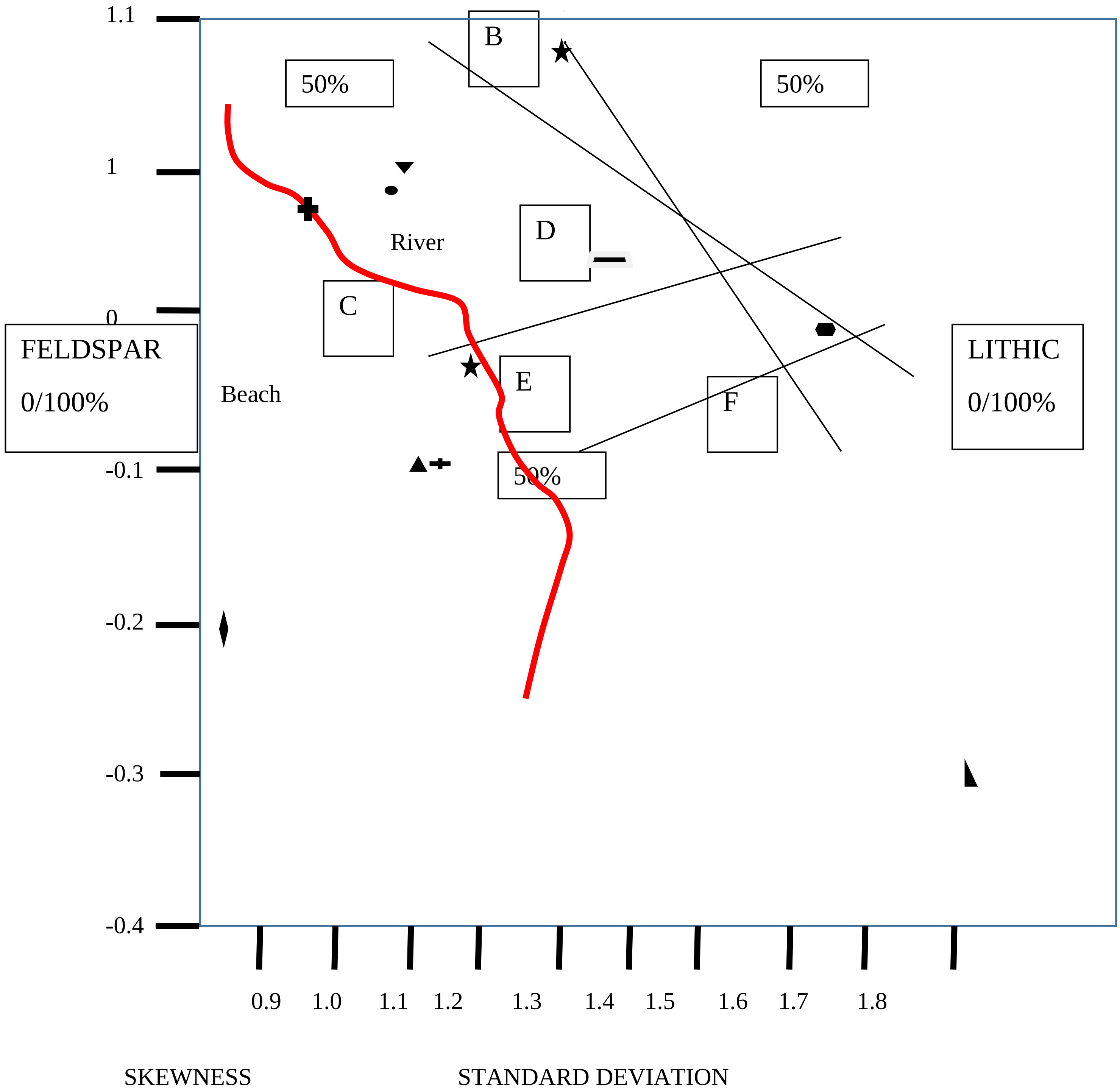


Figure 12: Bivariant Plot of Skewness vs Incisive Standard Deviation, after Friedman (1967).

LEGEND/KEYS:

BED 1 ▼

BED 2 ♦

BED 3 ⬣

BED 4 ▬

BED 5 ✚

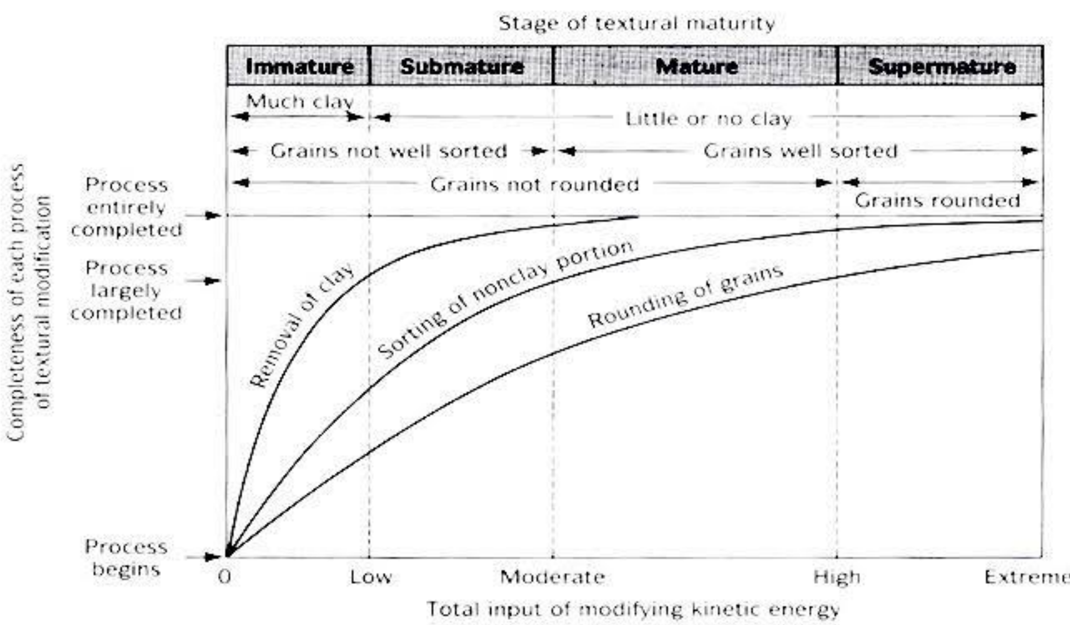
BED 6 ●

BED 7 ◣

BED 8 ⌣

BED 9 ▲

BED 10 ★



A

Figure 13: Comparism of grain sorting to maturity of sediments (Pettijohn 1975, P. 491).

Table 1: showing ϕ5, ϕ16, ϕ25, ϕ50, ϕ75, ϕ84, ϕ95 as well as Mean, Standard Deviation, Skewness, Kurtosis

SAMPLES	BED1	BED2	BED3	BED4	BED5	BED6	BED7	BED8	BED9	BED 10
ϕ5	-1.1	-0.65	-2.85	-1.25	-1.2	-1.85	-4.2	-2.1	-1.4	-1.5
ϕ16	-0.4	-0.1	-1.75	-0.55	-0.6	-1.2	-2.5	-1.7	-0.45	-0.55
ϕ25	-0.1	0.3	-1.1	-0.25	-0.3	-0.75	-1.7	-1.35	-0.05	-0.25
ϕ50	0.7	1.1	-0.05	-0.7	0.35	-0.2	-0.2	-0.7	0.7	0.45
ϕ75	1.55	1.7	1.2	1.4	1.05	0.6	0.7	0.3	1.4	1.05
ϕ84	1.9	1.9	1.7	1.74	1.35	0.9	1.1	0.7	1.7	1.4
ϕ95	2.5	2.3	2.5	2.4	2.05	1.8	1.9	2.65	2.3	2.0
MEAN	0.73	0.97	-0.03	0.63	0.37	-0.17	-0.53	-0.57	0.65	0.43
SD	1.12	0.95	1.67	1.13	0.98	1.08	1.82	1.32	1.1	1.08
SKEWNESS	1.02	-0.19	-0.02	-0.08	0.04	0.07	-0.3	0.29	-0.1	-0.07
KURTOSIS	0.89	0.86	0.95	0.91	0.99	1.11	1.04	1.18	1.05	1.10

Table 2: showing the Percentage of the mineral composition of each beds containing the minerals (Quartz, Feldspar and Lithic Fragment).

SAMPLES	BED 1	BED2	BED3	BED4	BED5	BED6	BED7	BED 8	BED9	BED 10
QUARTZ	93%	92%	80%	93%	75%	90%	94%	96%	91%	77%
FELDSPAR	2%	3%	5%	2%	20%	6%	4%	3%	2%	3%
LITHICFRAGMENT	5%	5%	15%	7%	5%	4%	2%	1%	7%	20%
DEGREE OF ROUNDNESS	AG	SR	RD	SA	SR	SA	SR	AG	SR	AG

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 Discussion

1 Mean of the Samples

- Bed 1 has a mean value of medium to coarse sands.
- Bed 2 has a mean value of medium coarse sands
- Bed 3 has a mean value of gravel
- Bed 4 has a mean value of coarse to very coarse sands
- Bed 5 has a mean value of very fine sand
- Bed 6 has a mean value of coarse sands
- Bed 7 has a mean value of very coarse sands (gravel sand)
- Bed 8 has a mean value of very coarse sand (gravel)
- Bed 9 has a mean value of medium to coarse sands
- Bed 10 has a mean value of coarse sands

2 Standard Deviation of the Samples

Standard Deviation is a measure of how much variation in grain size is present within a sample.

The Sorting Coefficient of each sample are:

- Bed 1 is moderately sorted
- Bed 2 is well sorted
- Bed 3 is poorly sorted
- Bed 4 is poorly sorted
- Bed 5 is moderately well sorted
- Bed 6 is well sorted
- Bed 7 is moderately well sorted
- Bed 8 is poorly sorted.
- Bed 9 is well sorted
- Bed 10 is well sorted

3 Skewness of the samples.

Skewness measures the symmetry of the distribution. The Skewness interpretations of each of the samples are as follows:

- Bed 1 is fine skewed
- Bed 2 is coarse skewed
- Bed3 is near symmetrical
- Bed 4 is near symmetrical
- Bed 5 is coarse skewed
- Bed 6 is coarse skewed
- Bed 7 is fine skewed
- Bed 8 is fine skewed
- Bed 9 is coarse skewed
- Bed is coarse skewed

4 Kurtosis of the samples

Kurtosis measures the peakedness of the distribution. The Kurtosis interpretation of each of the samples are as follows:

- Bed 1 is platykurtic
- Bed 2 is platykurtic
- Bed 3 is near mesokurtic
- Bed 4 is near mesokurtic
- Bed 5 is near mesokurtic
- Bed 6 is leptokurtic
- Bed 7 is leptokurtic
- Bed 8 is leptokurtic

- Bed 9 is light leptokurtic
- Bed 10 is leptokurtic

The paleoenvironment of deposition can be inferred from the Bivariant plot of inclusive skewness against inclusive standard deviation, (Friedman, 1967). The environment of deposition of most of the beds in Figure 10 is fluvial. This is suggestive of a river system.

5 Petrographic Analysis of the Samples.

The samples consist of quartz, feldspar and lithic Fragments. Results of the plots on the QFL diagrams in figure 10 shows that the sandstones facies of Bed 1, Bed 2, Bed 4, Bed 6, Bed 7, Bed 8 and Bed 9 are classified as quartz arenites, Bed3 is classified as sub-arkoses, Bed 5 is arkose, and Bed 10 is lithic arkose (Pettijohn, 1975; Folk, 1980). The results of the mineral assemblage based on the percentage of quartz, feldspar and lithic fragment reveal that the beds are quartz arenite, subarkose, arkose and lithic arkose, (Folk, 1980).

6 Sedimentary Cycle

This is the weathering of an existing rock followed by the erosion of minerals from it, their transport and deposition, and their burial.

They are classified into two (2):

- First cycle: the sediments contain resistant minerals and rock fragments (lithic fragments),
- Second cycle: contains less resistant minerals.

The samples of each Beds are of the First Cycle because they contain quartz mineral which is resistant to weathering, transportation and deposition and contains detrital or lithic fragments.

7 Mineralogical Composition of the Samples.

Sandstones are composed of mostly quartz, feldspar and lithic fragments. It is these minerals that makes up the provenance studies (origin of the grains)

Quartz: Quartz is the highest occurring mineral, averaging from 75% in Bed 5 to 93% in Bed 8 of the total samples (Table 2). Quartz occurs as both monocrystalline grains and polycrystalline grains. Most of the samples occur as monocrystalline quartz and few polycrystalline quartz. Grain sizes are mostly medium to coarse, with some fine grains in Bed 5. Grain shape is mostly angular and subrounded, with few rounded and sub angular.

Feldspar: The occurrence of feldspar on each sample varies across the depositional facies with a range of 2% in Bed 1 and 9 to 20% in Bed 5. The facies association. K- Feldspar is more common including microcline. The low percentage of feldspars in the beds is probably due to the unstable nature of the mineral.

Lithic Fragments: Lithic fragments are generally unstable in sedimentary environment based on the parent rock.

5.1.1 Provenance

Plots of the QmFLt ternary diagram in figure 11 suggests that there are craton interior (Bed 1, Bed 2, Bed 4, Bed 6, Bed 7, Bed 8 and Bed 9), transitional continental (Bed3) and dissected arc (Bed 10) provenances, (Dickinson, *et al.*, 1983), QtFL ternary plot). The main source for the craton/continental- derived quartzose sands are low lying granite and gneissic exposures.

Paleoclimate can be defined as the climatic conditions of the earth at a specified point in geologic time. Paleoclimatic conditions of the study area shows that the samples accumulate in humid conditions to semi humid conditions during the Paleogene as indicated in figure 14 in Nigeria.

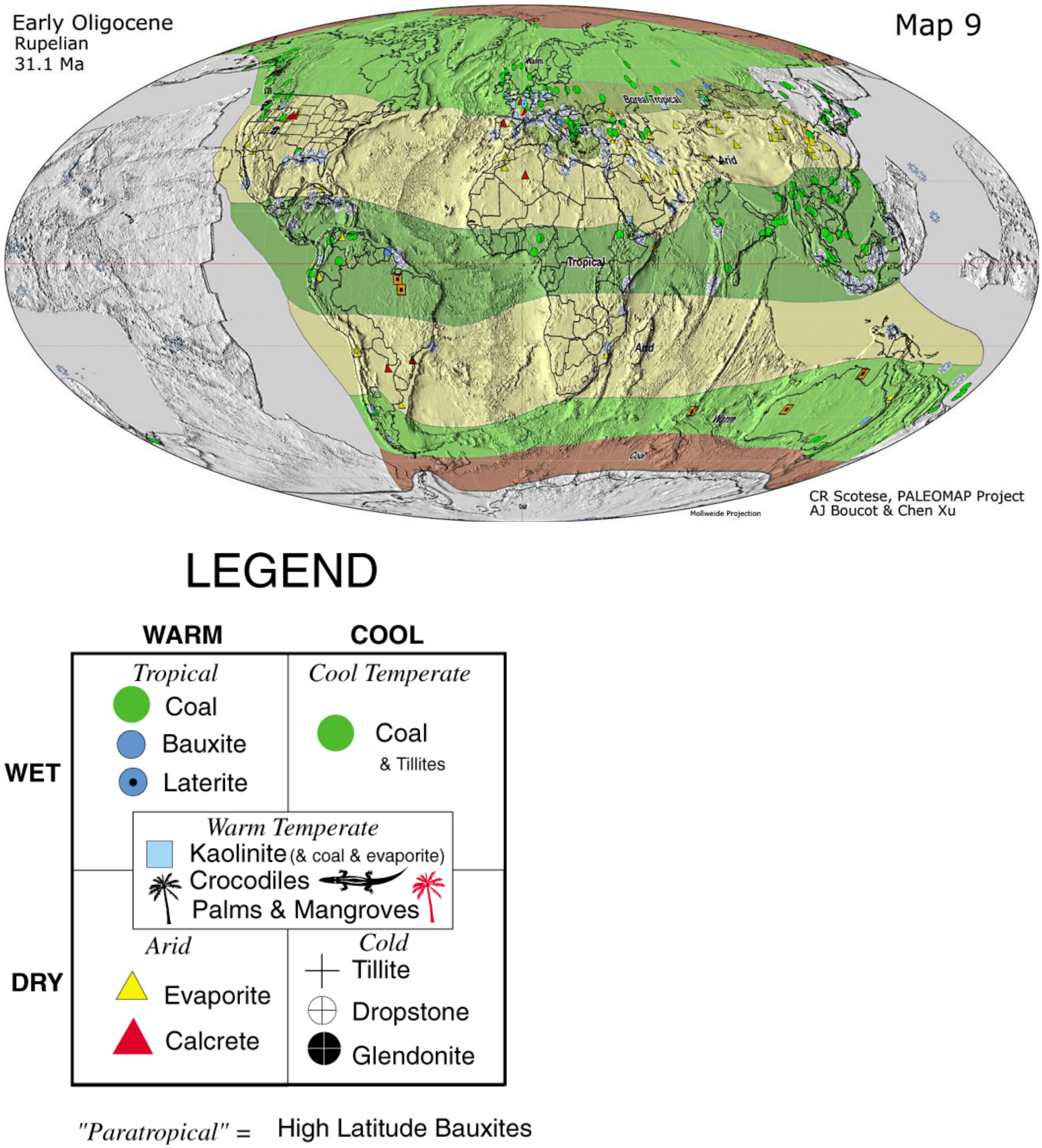


Figure 14: Paleo-temperature chart during the Paleogene

5.1.2 Maturity

The sorting can be used to infer the maturity of the bed samples (Figure 13): the samples range from immature (BED 3, 4 and 8) to submature (BED 1, 5 and 7) to mature (BED 2, 6, 9 and 10).

5.1.3 Economic Importance

The sands serve as the main aquifer in Benin Formation, (Akujieze,2004; Imasuen *et al.*, 2016).

The abundance of quartz makes it a potential for use in glass making.

The sands are mined/excavated and used in construction viz; concrete making, moulding of blocks, etc.

5.2 Summary

A total of ten (10) beds exposed at the Ekosodin/Evbuomore were obtained and studied. These beds belong to the Benin Formation of the Niger Delta Basin. Sieve analysis was carried out on them, with the results plotted and the mean, standard deviation, skewness and kurtosis calculated. These calculations were used to interpret the provenance, depositional process and environment of deposition. The beds mainly contain quartz, feldspar and detrital fragments revealing their igneous and metamorphic origin.

5.3 Conclusion

In conclusion, from the study results and interpretation, it can be said that:

1 The sediments of the beds belonging to the Benin Formation and exposed at Ekosodin/Evbuomore are composed almost entirely of quartz, feldspar and lithic fragments (beds of gravels and gravelly sands).

2 The sediments are of igneous and metamorphic origin, meaning they are of the basement complex rocks.

3 The beds were deposited in a fluvial environment with low energy, hence, the poor sorting, angular to little amount of rounded grains.

4 The sediments can be utilized for construction and manufacturing purposes.

5.4 Suggestions for Further Studies

My suggestions for further studies are, thus:

1. More detailed study should be done with morphoscopic and petrographic analysis to ascertain the minerals present in traces.
2. Environmental studies should be done in the area under study to ascertain the presence of any heavy minerals that is a potential health hazard to the subsurface water.

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