

MINERALOGY, GEOCHEMISTRY AND INDUSTRIAL  
PROPERTIES OF NARAGUTA CLAY ON THE JOS PLATEAU,  
NIGERIA.

BY

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A thesis submitted to the Department of Geology, Faculty of Science,  
Ahmadu Bello University, Zaria, Nigeria in partial fulfilment of the  
award of the Master of Science degree in Mineral Exploration.

OCTOBER 2000.

**DECLARATION**

I hereby declare that this thesis titled "*Mineralogy, Geochemistry and Industrial Properties of Naraguta Clay on the Jos Plateau, Nigeria*" is my own work and that it has not been presented for another degree or diploma to any university or institution. Information utilised from both published and unpublished work is duly acknowledged in the text.

Solomon O. OBAJE

NAME OF STUDENT



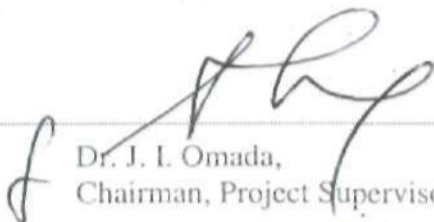
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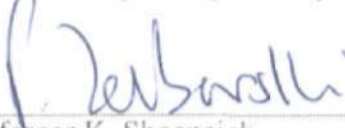
This thesis entitled "MINERALOGY, GEOCHEMISTRY AND INDUSTRIAL PROPERTIES OF NARAGUTA CLAY ON THE JOS PLATEAU, NIGERIA" by S. O. Obaje, meets the regulations governing the award of Master of Science degree in Mineral Exploration of the Ahmadu Bello University, Zaria, Nigeria, and it is approved for its contribution to scientific knowledge and application of geosciences to practical and technical problems.

  
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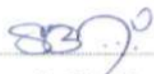
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## ABSTRACT.

In this study a detailed investigation was carried out into the mineralogy, geochemistry and industrial properties of Naraguta clay on the Jos Plateau, Nigeria located within latitudes  $8^{\circ}51''$  and  $8^{\circ}54''$ N and longitudes  $9^{\circ}57''$  and  $10^{\circ}00''$ E. Visually, the clays are classified as reddish-brown and greyish. Microscopic study of the samples reveals the presence of muscovite, quartz grains, feldspar and biotite in various proportions. The mineralogical studies show that the clay minerals present in the samples of both clay types are illite, smectite, kaolinite, chlorite, vermiculite, halloysite, palygorskite and montmorillonite, while quartz and opaque minerals are the non-clay components.

The samples contain high percentages of  $\text{SiO}_2$ ,  $\text{K}_2\text{O}/\text{Na}_2\text{O}$  and  $\text{Fe}_2\text{O}_3$  content ( $> 3.0\%$ ) contributed to the reddish-brown colour of some of the clays. These together with the mineralogy indicate that the clays probably originated from silica-rich rocks such as migmatite and granite that are abundant in the study area. The two clay types can easily be distinguished by their liquid and plastic limits. The average values of the liquid limit falls in the range of 49.67% for the reddish-brown clays and 47.63% for the greyish clays; the plastic limit is 29.48% for the reddish-brown clays and

33.19% for the greyish clays. The average plasticity index is 20.20 for the reddish-brown clays and 14.62 for the greyish clays. These results indicate that the brick products from these clays will have tensile strength and toughness. The average specific gravity of these clays (2.04 - 2.38g/cm<sup>3</sup>) suggests that the clays are made up of mixed clay minerals and heavy minerals like iron oxide. The assessment of the industrial suitability of these clays based on their physical properties indicates that they have sufficient mouldability and reddish-brown tones when fired. Also, the atterberg limits and linear shrinkage values of these clays are within the ranges of various industries such as the Naraguta Brickworks Factory and the Nigerian Mining Corporation Bricks Products Limited.

2.1	Geological Setting of Study Area.....	10
2.1.1	Migmatites/Gneisses.....	10
2.1.2	Older Granites.....	11
2.1.3	Younger Granites.....	13
2.1.4	Older Basalts.....	13
2.2	Sampling, Sample Preparation and Laboratory Procedures.....	16
2.2.1	Sampling.....	16
2.2.2	Sample Location and Clay Types.....	16
2.2.3	Sample Preparation.....	17
2.2.4	Laboratory Procedures.....	17
2.2.4.1	X-Ray Diffractometry.....	17
2.2.4.2	Atomic Absorption Spectrophotometry.....	22
2.2.4.3	Determination of Liquid Limit.....	23
2.2.4.4	Determination of Plastic Limit.....	24
2.2.4.5	Determination of Linear Shrinkage.....	24
2.2.4.6	Determination of Specific Gravity.....	25
 <b><u>CHAPTER THREE</u></b>		
MINERALOGY OF NARAGUTA CLAY SAMPLES.....		27
3.1	Visual Description of Clay Samples.....	27
3.1.1	Sample RNG2, Loc. 400m E Barakin Naraguta.....	27

3.1.2	Sample RNG3, Loc. 850m NW Barakin Naraguta.....	27
3.1.3	Sample RNG4, Loc. 1000m NW Naraguta Hausawa .....	29
3.1.4	Sample RNG5, Loc. 650m NW Naraguta Hausawa .....	29
3.1.5	Sample NG1, Loc. 1000m E, Barakin Russo .....	29
3.1.6	Sample NG2, Loc. 400m E Barakin Russo .....	30
3.2	Microscopic Studies of Clay Samples.....	30
3.3	Mineralogical characteristics.....	33
3.4	Specific Gravity.....	33

#### **CHAPTER FOUR**

GEOCHEMISTRY.....	34
4.1 Chemical Composition.....	34
4.1.1 Silica (SiO <sub>2</sub> ) .....	34
4.1.2 Alumina (Al <sub>2</sub> O <sub>3</sub> ) .....	39
4.1.3 Manganese (MnO) .....	39
4.1.4 Ferric Oxide (Fe <sub>2</sub> O <sub>3</sub> ) .....	39
4.1.5 Phosphorus (P <sub>2</sub> O <sub>5</sub> ) .....	40
4.1.6 Titanium (TiO <sub>2</sub> ) .....	41
4.1.7 Potash and Soda (K <sub>2</sub> O + Na <sub>2</sub> O).....	41

#### **CHAPTER FIVE**

GEOTECHNICAL PROPERTIES OF THE CLAY SAMPLES.....	42
--	----

5.1	Liquid Limit.....	42
5.2	Plastic Limit.....	42
5.3	Plasticity Index.....	43
5.4	Linear Shrinkage.....	43

## **CHAPTER SIX**

### **DISCUSION, CONCLUSION AND**

	RECOMMENDATION.....	45
--	---------------------	----

6.1	Discussion.....	45
6.2	Conclusion.....	48
6.3	Recommendation.....	50
	References.....	52
	Appendices.....	56 - 81

LIST OF TABLES

**TABLES**

2.1	Attitude of Joints in Migmatites/Gneisses in the Study Area.....	APPENDIX I, 56
2.2	Frequency Distribution of Joints in Older Granites of Study Area.....	APPENDIX II, 57
2.3	Attitude of Joints in Younger Granites of Study Area.....	APPENDIX III, 58
2.4	Frequency Distribution of Joints in Younger Granites.....	APPENDIX IV, 59
3.1	Sample Locations and Visual Description .....	28
3.2	Results of Microscopic Observation of Clay Samples.....	31
4.1	Chemical Analysis of Naraguta Clays in Comparison with Some Reference Samples.....	35
5.1	Physical Properties of Naraguta Clays.....	60
5.2 - 5.8	Atterberg Limits Results .....	61 - 67
5.9 - 5.15	Results of Linear Shrinkage.....	68 - 74
5.16 - 5.22	Specific Gravity Determination of Samples.....	75 - 81

## LIST OF FIGURES

### FIGURES

1.1	Geological Map of Study Area.....	AT BACK COVER
1.2	Solid Rock Geology, Clay Types and Sampling Location Map.....	2
2.1	Azimuthal Distribution of Joints in the Older Granites Showing Preferred Orientation In the NW-SE Direction.....	14
2.2	Azimuthal Distribution of Joints in the Younger Granites Showing Preferred Orientation In NNE-SSW Direction.....	15
2.3 - 2.5	X-Ray Diffractograms of Clay Samples.....	19 - 21
4.1-4.3	Chemical Plots of Selected Oxides.....	39a-c

## **CHAPTER ONE**

### **INTRODUCTION**

#### **1.1 LOCATION AND ACCESSIBILITY**

The area of study lies within latitudes  $8^{\circ}51''$  and  $8^{\circ}54''\text{N}$  and longitudes  $9^{\circ}57''$  and  $10^{\circ}00''\text{E}$ . The study area is very accessible by the Jos - Bauchi trunk 'A' road and by several secondary roads and footpaths (Figure 1.1).

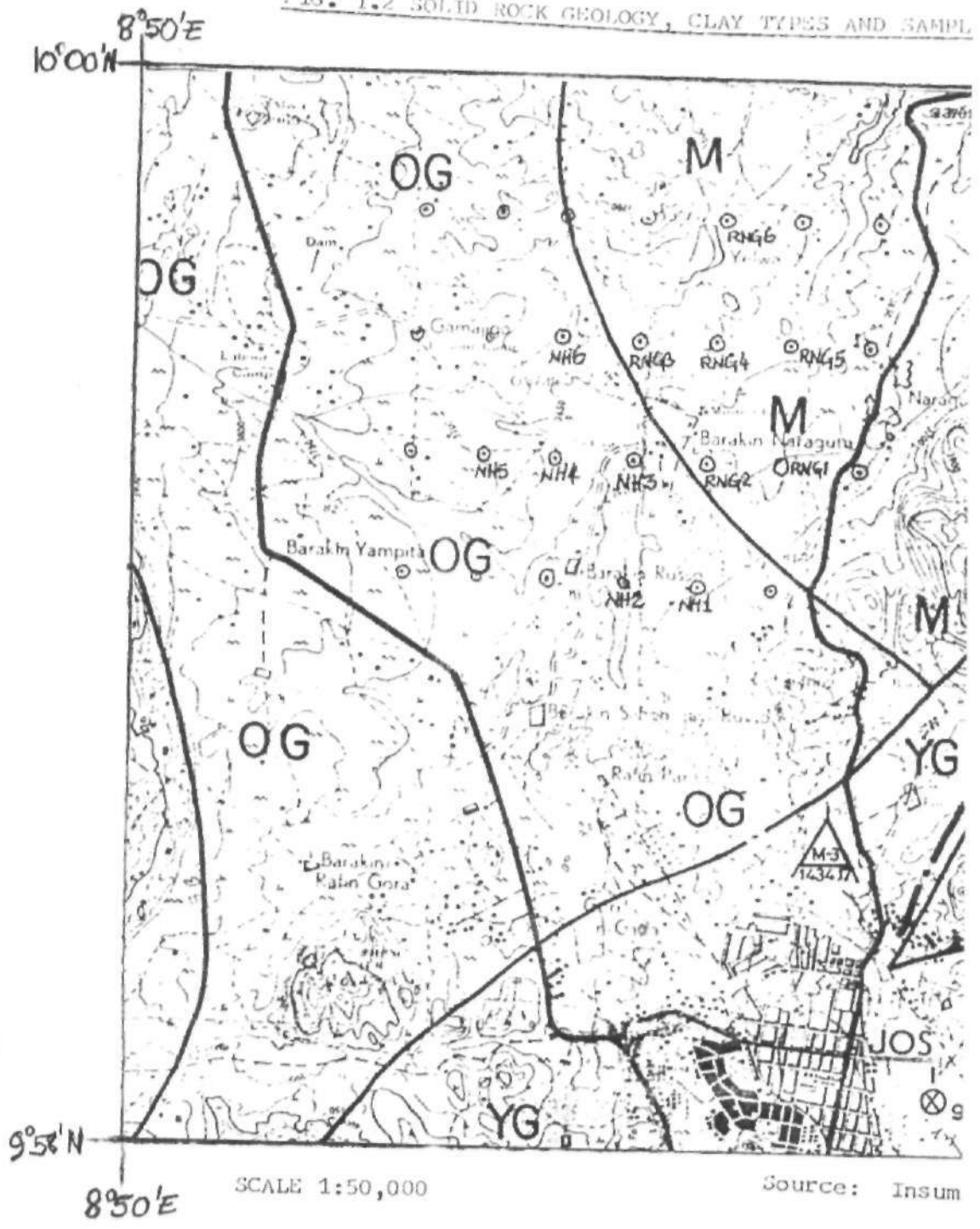
#### **1.2 RELIEF AND DRAINAGE**

The general relief of the study area comprises of plains surrounded by Older Granite intrusives and migmatites, which form isolated hills. The hills are affected by weathering and erosion. The hills are capped by laterite, which also occur in the surrounding plains. The study area is drained in a dendritic pattern, with principal direction of the flow in NW - SE direction (Fig. 1.1).


#### **1.3 CLIMATE, VEGETATION AND SOIL COVER**

The Naraguta area is on an elevation of about 1000m above mean sea level. It has cool climatic conditions compared to other towns in Northern Nigeria. The dry season, which starts usually from

FIG. 1.2 SOLID ROCK GEOLOGY, CLAY TYPES AND SAMPL



LEGEND

M	Migmatites
OG	Older Granites
YG	Younger Granites
RNG <sub>x</sub>	Reddish-brown clays
NH <sub>x</sub>	Greyish clays
	streamlet

November to March, is dominated by cold, dry and dusty harmattan winds. During this period, there may be little or no precipitation, and the relative humidity will be low (about 10%) (Alford and Tuley, 1974).

The rainy season usually commences from May to September annually. The relative humidity during this season is usually very high (> 85%) (Alford and Tuley, 1974). The vegetation in the study area is characterised by savannah-type shrubs, scattered trees and grasses. The soil types are generally tropical brownish and reddish-brown clays and alluvial sediments.

#### 1.4 SETTLEMENTS AND LANDUSE

The settlements in the study area include Naraguta Hausawa and surrounding villages called Yelwa, Barakin Russo, Barakin Yampita, Gamajigo, etc. The settlements are well populated and distributed. The main land use is farming. The common crops grown in the area include acha, millet, maize, guinea corn, potatoes, cocoyam, carrots and animal husbandry (goat, cattle and poultry).

## 1.5 LITERATURE REVIEW

Numerous workers have exhaustively researched the Jos Plateau Tinfields. Falconer (1911) made the earliest study of the Nigerian Basement Complex. Wilson (1922) described the general geology of the Basement Complex. Bain (1926, 1934) studied the geology of the Basement Complex around Bauchi and the Younger Intrusive rocks of Kudaru Hills in the northeast, respectively. Oyawoye (1959, 1962, and 1972) studied the geology of the area around Bauchi. The Basement Complex and the Younger Granite Province were mapped in detail by Falconer and Raeburn (1923), Raeburn (1924) and McLeod et. al. (1971). Researchers such as Bowden & Turner (1974); and Ike (1979) Aba'a (1976) undertook the geochemistry and petrology of specific research areas within Naraguta Sheet 168. Olayemi (1973) reported on the existence of suitable clays in Naraguta, which according to him met the industrial specification for bricks making. Kogbe (1975) carried out mineralogical analysis of the greyish-black clays of Sabon Gida Mine (Jos Plateau). Tukura (1990) discussing low-scale construction materials made mention of Naraguta clays as suitable for bricks production. Olubodun & Mogbo (1991) in their unpublished personal communication guide to the Naraguta

Brickworks Factory mentioned the existence of alluvial and residual clays in Naraguta.

Etu-Efeotor (1984) examined the mineralogical composition of the major clay deposits in the eastern Niger Delta and evaluated their suitability for industrial applications. He concentrated his investigation on the physical analysis and x-ray diffractometry of the clay samples. He concluded that the mineralogical composition and the physical characteristics of the major clay deposits were directly related to their economic and industrial utilisation. Emofurieta and Salami (1988) carried out a comparative study on two kaolin deposits in south-western Nigeria. In their investigation, the mineralogical and geochemical characteristics of two genetically different kaolin deposits were studied for comparison. The two deposits are the Ibadan residual kaolin deposit in Oyo State and the Oza-Nagogo sedimentary deposit in Edo State. Their study indicated that the results show a very high percentage (> 85%) kaolinite in both deposits. However, quartz was reported to occur in subordinate amount (= 14%) in both kaolin types whilst illite whose value was given to be less than 3% was restricted in occurrence in the Ibadan deposit. They concluded that geochemically, the total alkali contents, low amounts of  $\text{Fe}_2\text{O}_3 + \text{MgO} +$

TiO<sub>2</sub> and the non-active or non-corrosive nature of the clays were marks of their good quality.

Amadi and Teme (1989) carried out an investigation into the alteration scheme of some 2:1 layer clays from the Basement Complex around Abuja area. They reported that the x-ray diffraction and chemical analyses of the soils in Abuja area. They reported that the x-ray diffraction and chemical analyses of the soil in the Abuja area indicated the dominance of 2:1 and 1:1 layers clays. They claimed that 2:1 clays were found to be concentrated within the first 10 to 20 metres corresponding to the depth range occupied by both the lateritic and reddish-brown soils units. They also reported that the base saturation shows a progression decrease with depth beyond that 'active clay' zone and that the cation exchange capacity (C.E.C.) varied from 23.04 - 13.56 me/100g. In their conclusion, they indicated that the relationship between the pattern of variation in C.E.C. values and the concentration of the 1:1 layer clays with depth was attributed to changes in the topography in the Abuja area.

Elueze and Bolarinwa (1995) carried out an assessment of functional application of lateritic clay bodies in Ekiti environment located in southwestern Nigeria. They stated that the notable clay occurrences were those developed over the Precambrian Basement Complex. They identified

reddish-brown and brownish residual clay to overlie the migmatite gneiss near Isan and greyish clays over the Banded Biotite Gneiss in Ara-Ijero. Their mineralogical analyses portrayed kaolinite as the dominant clay mineral in the area, while illite and montmorillonite were present in lesser quantity.  $\text{SiO}_2$  59%,  $\text{Al}_2\text{O}_3$  18% and  $\text{Fe}_2\text{O}_3$  8% were identified to constitute more than 80% of the bulk chemical compositions of the clays. They also reported that the clay bodies generally had considerable chemical compositions through the Ara-Ijero clay, which was noted to indicate the presence of montmorillonite, show slight enhancement in CaO compared to the Isan body. In their assessment of the industrial suitability based on physical properties, they found that the clay bodies possessed adequate mouldability and reddish tones when fired. The loss in ignition, linear shrinkage and water adsorption capacity values of the samples were given to be within the ranges of various commercial specifications. In their conclusion, it was indicated that the general assessment of the chemical, mineralogical and physical characteristics of the residual bodies show that they are quite amenable to beneficiation. They suggested that with appropriate processing, the deposits could serve as raw materials for paint ceramic, bricks and structural wares. They gave rough reserve estimations

of 7.5 and 6.4 million tonnes for the Isan and Ara-Ijero occurrences, respectively.

#### 1.6 AIM, OBJECTIVE AND LIMITATION OF PRESENT STUDY

The main aim of this study is to carry out detail investigation into the mineralogy, geochemistry and industrial properties of Naraguta clay on the Jos Plateau, Nigeria. This project was taken because no researcher has worked on this aspect of the Naraguta clay deposits.

The objective of this study include:

- (i) to undertake a detailed study of the mineral components of the clay samples from the Naraguta area;
- (ii) to determine the elemental composition and relate same to (i);
- (iii) to ascertain the geotechnical properties of the clay samples;
- (iv) synthesis of the above with a view to deducing the quality and properties of the Naraguta clay.

To achieve these objectives, the clay samples were subjected to microscopic observation, mineralogical studies using x-ray diffractometer and geochemical analyses using atomic absorption spectrophotometer at the Centre for Energy Research and Training (C.E.R.T.) Laboratory, Zaria and the Kaduna Polytechnic, Mineral Resources Engineering Laboratory,

Kaduna, Nigeria, respectively. Also, representative samples from each location were tested in the laboratory for their geotechnical properties.

The major limitation to this study was the unavailability of depth drilling equipment. Though sampling was not limited to the surface of the clay bodies, nevertheless, due to the lack of deep depth drilling equipment, the measurement of the depth could not be ascertained for the purpose of the clay reserve computation.

## **CHAPTER TWO**

### **GEOLOGICAL SETTING, SAMPLING AND LABORATORY**

#### **PROCEDURE**

#### **2.1 GEOLOGICAL SETTING**

##### **2.1.1 MIGMATITE AND GNEISSES**

The migmatites and gneisses in the study area are Precambrian in age, and were affected by the Pan-African orogeny ( $600 \pm 150$  Ma) (Grant., 1971). They consist of alternating light and dark coloured bands. The bands vary in width from 10 cm to 22 cm and in colour from whitish, grey and cream. Though, they are largely obscured by surface soils in most parts of the study area, they outcrop at the outer boundary. The dominant minerals present are amphiboles, biotite, quartz and feldspars. Some of the feldspar grains were measured to range between 1.5 cm to 6.1 cm. Foliation is found in the migmatites and gneisses of the study area. Biotite is the main mafic mineral and it always shows good orientation whether in diffusely scattered flakes or as coarse aggregates that indicates foliation in NW-SE direction. Table 2.1 at Appendix I, page 56, shows the attitude of

joints in the migmatite and gneisses of the study area. Field evidence suggests that the joints assisted in the rapid decomposition of these rocks. Migmatites are one of the dominant rock types in the study area.

### 2.1.2 **OLDER GRANITES**

The Older Granites are found in the study area around Barakin Russo, Gamajigo, Yampita, etc. (Figure 1.1 at back cover). They are Pan-African in age (Grant, 1971; McLeod, et. al., 1971). Mineralogically, the Older Granites are composed mainly of quartz, plagioclase, microcline, biotite and muscovite. The feldspars were found to be greyish-white to pinkish in colour. Accessory minerals usually present include apatite, spene, epidote, tourmaline, garnet, chlorite and zircon. There are extremely few quartz dykes in the Older Granites and they have a preferred orientation of NNW - SSE direction, which is suggestive of the direction of the flow of the hydrothermal fluids (Figure 2.1). Data on joints in the Older Granites are shown in Table 2.2 at Appendix II, page 57. These data indicate that the dominant direction of the joints is in NW-SE (Fig. 2.1). The number of joints and their preferred orientation seem to have contributed greatly to the level of weathering in these rocks. The Older Granites are the second most dominant rock types in the study area.

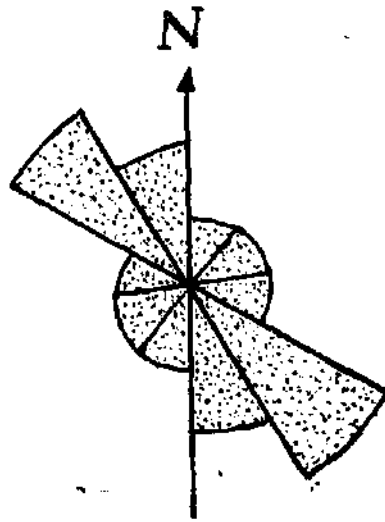


FIG 2.1 AZIMUTHAL DISTRIBUTION OF JOINTS IN THE OLDER GRANITE SHOWING PREFERRED ORIENTATION IN NW-SE

### 2.1.3 YOUNGER GRANITES

The Younger Granites are Jurassic in age (Jacobson 1947; Freeth, 1969). The Younger Granites cover a large extent of the Jos Plateau. They extend up to Aïr region of Niger Republic (Turner, 1963 and 1968). These rocks are petrologically distinctive series of granites commonly associated with minor gabbros, syenites and rhyolites. They occur as ring-complexes and they are distinguishable from the surrounding Older Granites. This is because Younger Granites usually occur as rocky hill massifs, whereas the Older Granites usually have smooth forms. The joints in the Younger Granites have variable orientation as indicated in Tables 2.3 and 2.4 at Appendices III & IV, pages 58 - 59. The frequency distribution of the joints shows a spread around  $0^{\circ}$  -  $30^{\circ}$  and  $300^{\circ}$  -  $330^{\circ}$  orientation. These data indicate that the dominant direction of joints is in NNE - SSW (Figure 2.2).

### 2.1.4 OLDER BASALTS

The Older Basalts occur as few outcrops in the western part of the quarter sheet in Tsofo, Gidan Hardo and Dangana villages. They have been weathered and now occur mainly as lateritic basalts. They are Tertiary in age (McLeod et. al., 1971). They are referred to as Older Basalts because

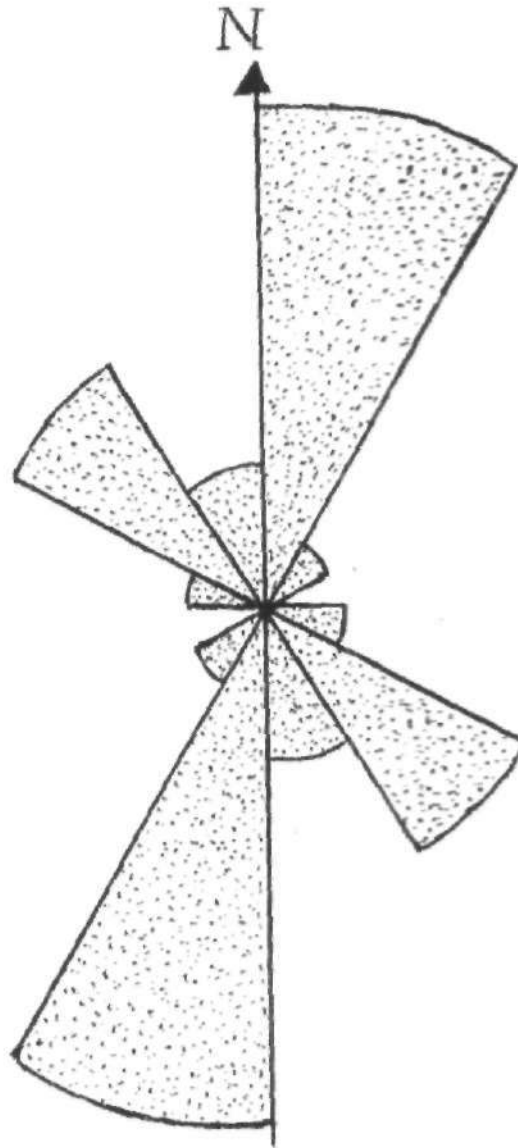


FIG. 2.2 AZIMUTHAL DISTRIBUTION OF JOINTS IN YOUNGER GRANITES SHOWING PREFERRED ORIENTATION IN NNE-SSW

other basalt types of latter geological age occur in the Younger Granite

Province of Nigeria.

## 2.2 SAMPLING, SAMPLE PREPARATION & LABORATORYPROCEDURE

### 2.2.1 SAMPLING

The fieldwork was conducted in February 1994. Samples were collected from different vertically exposed sections of the clay deposits (Figure 1.1 at back cover). Sampling was done at regular intervals of 0.25m in most cases with aid of a hammer and hand shovel. Sampling was done taking into cognisance variation in colour, grain-size and mineralogy. A total of thirty samples were collected and preserved in closed polythene bags.

### 2.2.2 SAMPLE LOCATION AND CLAY TYPES

The reddish-brown clays are found mostly distributed in the eastern part of Barakin Naraguta and in the north-western part of Naraguta Hausawa (Fig. 1.1 at back cover). On the other hand, the greyish clays are found widely distributed in the central part of the study area in such places as Barakin Russo and part of Barakin Naraguta. In terms of area of distribution relationship, the reddish-brown clay deposits occur outflanking the greyish clay deposits.

### 2.2.3 SAMPLE PREPARATION

Eight representative samples (labelled NH2, NH3, NH4, RNG1, RNG2, RNG4, RNG5 and RNG6) were removed from the thirty samples collected from the field. These eight representative samples were soaked in distilled water for three days, sedimented, dried and grounded in a hand mortar and then later sieved using mechanical shaker to 63 $\mu$ m grain fractions.

### 2.2.4 LABORATORY PROCEDURES

#### 2.2.4.1 X-RAY DIFFRACTOMETRY

The samples powders were analysed using the x-ray diffractometer model Phillips PM 9920/05 at the Centre for Energy Research and Training (C.E.R.T.) Laboratory, Zaria, Kaduna State, Nigeria. The instrument was adjusted and set at 3<sup>0</sup>/2 $\theta$ /minute from 0<sup>0</sup> to 30<sup>0</sup> using Ni-filtered FeK $\alpha$  radiation. Check results were obtained before the samples were run on the instrument. X-ray diffraction curves were interpreted using the America Society for Testing Materials (A.S.T.M.) powder data file and also by comparing peaks of notable intensities with those of standard minerals established by Brown (1951) and Carrol (1971) (Figs. 2.3 - 2.5): The

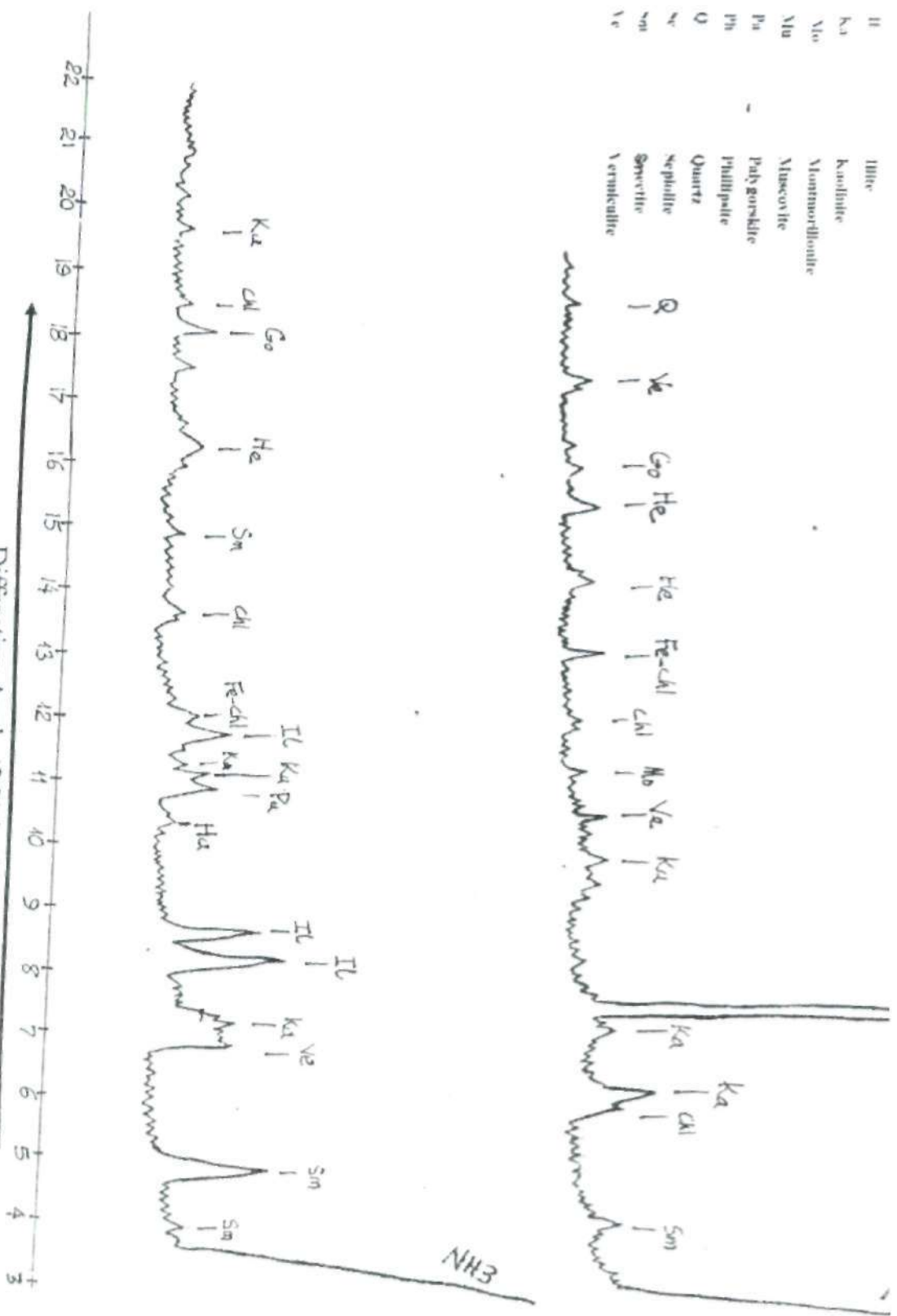


FIGURE 2.3 X-RAY DIFFRACTOGRAMS OF CLAY SAMPLES

# LEGEND

Fe-Chl	Iron Chlorite
Go	Goethite
Ha	Halloysite
He	Heulandite
Il	Illite
Ka	Kaolinite
Mu	Montmorillonite
Mu	Muscovite
Pa	Palygorskite
Ph	Phillipsite
Q	Quartz

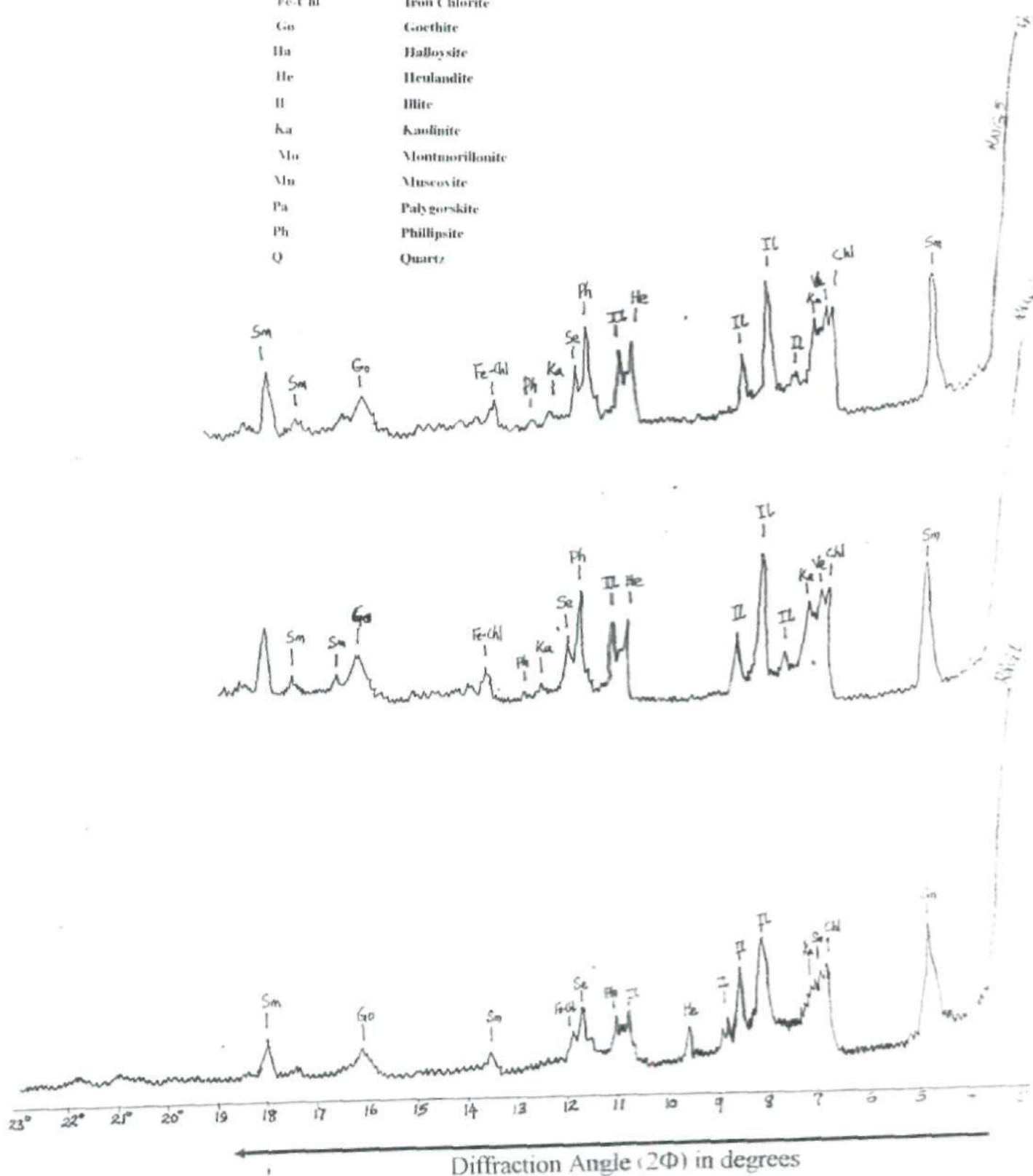


FIGURE 2.4 X-RAY DIFFRACTOGRAMS OF CLAY SAMPLES

# LEGEND

Fe-Chl	Iron Chlorite
Go	Goethite
Ha	Halloysite
He	Heulandite
Il	Illite
Ka	kaolinite
Mo	Montmorillonite
Mu	Muscovite
Pa	Palygorskite
Ph	Phillipsite
Q	Quartz
Se	Sepiolite
Sm	Saponite
Ve	Vermiculite

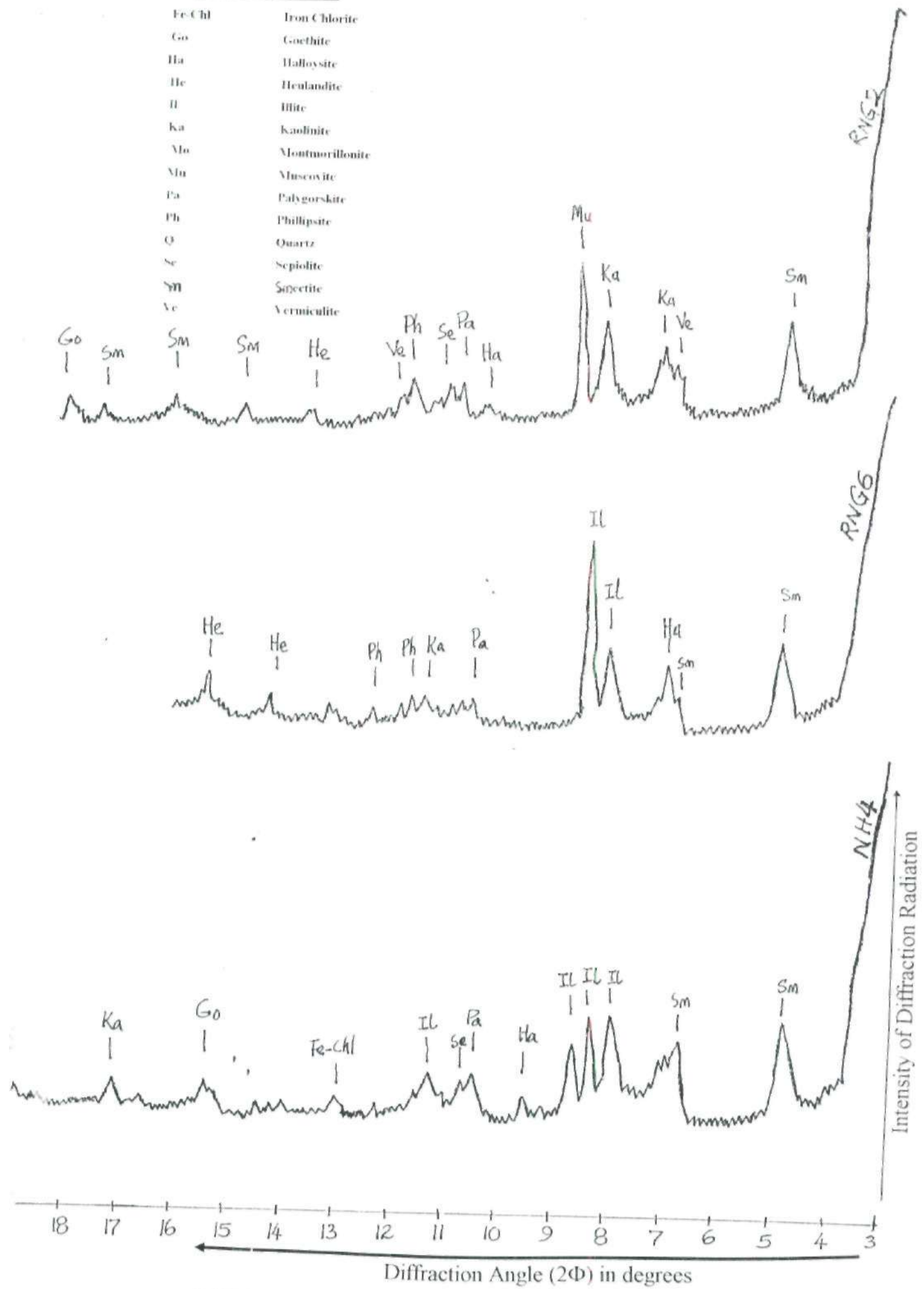


FIGURE 2.5 X-RAY DIFFRACTOGRAMS OF CLAY SAMPLES

various identified mineral species in the samples are presented and discussed in Chapter Three.

#### 2.2.4.2 ATOMIC ABSORPTION SPECTROPHOTOMETRY

A total of seven different clay samples (NH2, NH3, NH4, RNG1, RNG2, RNG4, RNG5 and RNG6) were prepared for analyses. One gram of each sample was weighed into a Teflon crucible, and moistened with distilled water. Hydrofluoric acid was then added and the content in the crucible was evaporated to dryness on a sandbath at 300<sup>0</sup>C. The residue was then dissolved in 10ml 1:1 HCl and distilled water. Then 10ml of saturated boric acid was added to stabilise the ions in the solution. It was then made up to 100ml by adding distilled water, shaken vigorously using a mechanical shaker until a uniform solution was obtained. The atomic absorption spectrophotometer machine GBC model 903, donated to the Kaduna Polytechnic, Nigeria by the Centre for Immigration Services (C.I.S.), Germany, was employed in these investigations to determine the following elements: Si, Al, Mn, Fe, P, Ti, Ca, Mg, Na and K. These elements were determined as oxide percentages using their equivalent weights. Before the samples were fed into the atomic absorption spectrophotometer machine, known standards were run on it and the results were recorded for calibration. The results of the geochemical analyses of the clay samples are presented and discussed in Chapter 4, page 34.

#### 2.2.4.3 DETERMINATION OF LIQUID LIMIT

The BS 1377 method was used for the liquid limit determination using Casagrande apparatus (Capper et al., 1971). A paste of the test soil was prepared and placed in the cup levelled off horizontally and divided by cutting a groove using a standard grooving tool. The two halves of the soil gradually flow together as the cup was repeatedly dropped into the base at the rate of two drops per second. The number of drops (blows) required to close the bottom of the groove over a distance of 13mm was recorded. The water content in the clay sample was then determined. The test was repeated five times and the water content of the paste (sample) was increased each time for each sample test. Care was taken so that the number of blows lied within the range of 10 to 60. A graph was then plotted of water content (WC) against number of blows (N) for the test. The liquid limit (LL) is defined as the water content (WC) at which 25 blows are required to close the bottom of the groove over a distance of 13mm. Table 5.1 and Tables 5.2 - 5.8 (Appendices V - XII, pages 60 - 67) show the results of liquid limits tests for the samples.

#### 2.2.4.4 DETERMINATION OF PLASTIC LIMIT

Employing BS 1377 method, 20 gram of each sample was used for the determination of the plastic limit (PL) (Capper et al., 1971). The moisture content for each sample was adjusted so that a thread  $\frac{1}{3}$  inch in diameter was formed. Uniform roll pressure was maintained throughout. The thread was placed in a container and oven-dried, cooled and weighed. The moisture content was later determined and recorded. The plastic limit results for the clay samples are shown in Table 5.1 and Tables 5.2 - 5.8 (Appendices V - XII, pages 60 - 67 ).

#### 2.2.4.5 DETERMINATION OF LINEAR SHRINKAGE

The BS 1377 method was used by taking a portion of the sample at (or very close to) a semi-cylindrical container of 14 cm length (Capper et al., 1971). The weight of each sample mould was recorded. Then the samples were placed in an oven at temperature of  $105^{\circ}\text{C}$  for a period of 24 hours. The samples were then allowed to cooled and the changes in length were measured and the samples were re-weighed (Table 5.1 and Tables 5.9 - 5.15 at Appendix V and Appendices XIII - XIX, pages 60 and 68 - 74). The linear shrinkage (ls) is given as the ratio of the decrease in length of samples to the original length and it is expressed in percentage.

Mathematically,  $l_s = ((l_o - l_f) \times 100\%) / l_o$

where

$l_s$  = linear shrinkage;

$l_o$  = original length of channel;

$l_f$  = final length of channel.

Using the above formula, the linear shrinkage was computed for all the samples and the results are recorded in Tables 5.9 - 5.15 at Appendices XIII - XIX, pages 68 - 74.

#### 2.2.4.6 DETERMINATION OF SPECIFIC GRAVITY

The standard procedure given by the Geotechnical Committee on Nomenclature for Soil Mechanics was used in the determination of the specific gravity of the clay samples (Bowles, 1984). Three different specific density-measuring bottles, which were labelled BN1, BN2 and BN3 were used. Each bottle was weighed in grammes and the values were recorded and the measured weight was designated as 'w1'. Chosen quantity of the clay samples were then added into these bottles and weighed and the new weights were designated as 'w2'. Water at temperature of 4<sup>0</sup>C was then added to fill the entire bottles with clay samples inside them and re-weighed and the new weights were designated as 'w3'. Finally, the

specific density measuring bottles were emptied, cleansed and filled with water at 4<sup>0</sup>C and weighed and the new weights were designated as 'w4'.

The specific gravity (Gs) in g/cm<sup>3</sup> units for each clay sample was computed using the formula given below:

$$G_s = \frac{\text{Wt. of unit vol. of any solid (clay sample)}}{\text{Wt. of unit volume of water at 4}^0\text{C}}$$

$$\text{i.e., } G_s = \frac{(w_2 - w_1)}{[(w_4 - w_1) - (w_3 - w_2)]}$$

where

$$(w_2 - w_1) = \text{Wt. of soil (clay sample)}$$

$$\begin{aligned} [(w_4 - w_1) - (w_3 - w_2)] &= \text{Wt. of water displaced by soil at 4}^0\text{C} \\ &= \text{Wt. of unit volume of water at 4}^0\text{C}. \end{aligned}$$

The results of the specific gravity determinations of the clay samples are given in Tables 5.16 - 5.22 at Appendices XX - XXVI, pages 75 - 81.

## CHAPTER THREE

### MINERALOGY OF THE NARAGUTA CLAY SAMPLES

#### 3.1 VISUAL DESCRIPTION OF THE CLAY SAMPLES

Below are the detailed visual descriptions of the partially weathered samples. The summary on locations and visual description is given in Table 3.1.

##### 3.1.1 SAMPLE RNG2, LOC. 400M E BARAKIN NARAGUTA

The colour of this sample is reddish-brown. It has fine-grained texture, and there is an even distribution of fine-grained minerals.

##### 3.1.2 SAMPLE RNG3, LOC. 850M, NW BARAKIN NARAGUTA

This sample has reddish-brown colour and it is fine-grained. The major megascopic mineral in this sample is quartz. The other mineral types were virtually unidentifiable.

**TABLE 3.1 SAMPLE LOCATIONS AND VISUAL DESCRIPTION**

SAMPLE NO.	LOCATION	SAMPLE COLOUR	IDENTIFIED MINERALS	% ESTIMATE	REMARKS
RNG2	400m E Barakin Naraguta	Reddish-brown	None	-	Very fine-grained minerals and evenly distributed.
RNG3	850m NW Barakin Naraguta	Reddish-brown	Quartz	20	Massive lumps.
RNG4	1000m NE Barakin Naraguta	Reddish-brown	Quartz, Biotite, opaques	35 10 5	Component grains medium-grained.
RNG5	650m NW Naraguta Hausawa	Reddish-brown	Feldspar grains	25	Feldspar partially weathered, sample is fine-grained.
NH1	1000m E Barakin Russo	Greyish	Quartz, Feldspar, Muscovite	15 30 5	Fine-grained texture.
NH2	400m E Barakin Russo	Greyish	Quartz, Muscovite	20 5	Massive, earthy lumps.

### **3.1.3 SAMPLE RNG4, LOC. 1000M NW NARAGUTA HAUSAWA**

This sample is reddish-brown in colour. Some grains included in the sample are medium-grained in texture. Some of these grains were identified as quartz, biotite and opaques. The opaques appear granular in form and also it has sub-conchoidal fracture. They seem to have metallic lustre. The biotite present is black in colour and it has lamella plates without crystal outline, and it appears to have perfect cleavage. It implies that the clay in this sample did not reach maturity.

### **3.1.4 SAMPLE RNG5, LOC. 650M NW NARAGUTA HAUSAWA**

This sample is reddish-brown in colour. It is fine-grained. There is an abundant distribution of the fine clayey matrix and partially weathered feldspar grains.

### **3.1.5 SAMPLE NH1, LOC. 1000M E BARAKIN RUSSO**

The colour of this sample is grey. The texture is fine-grained. Quartz, feldspar and muscovite flakes were seen as megascopic minerals in the sample. They were easily identified in comparison to the finer grained unidentified clayey materials. The muscovite flakes are white in colour and have massive form. The muscovite flakes are translucent. Quartz grains

seen are white in colour and have massive form. Vitreous lustre was observed. The feldspar grains are pinkish in colour and they are granular in form. They possess perfect cleavage planes and vitreous lustre.

#### 3.1.6 **SAMPLE NH2, LOC. 400M E BARAKIN RUSSO**

This sample is grey in colour and earthy. It also contains massive lumps. Though the finer grained materials could not be identified visually, the identified megascopic minerals included quartz and muscovite.

### 3.2 **MICROSCOPIC STUDIES OF THE CLAY SAMPLES**

Though it was difficult to distinguish clay mineral types using this method, it was necessary to note the presence of megascopic minerals that could be used to study the probable provenance of the clays. The major minerals identified in the samples are muscovite, quartz, feldspar and opaques (Table 3.2). Microscopically identified minerals are generally in the minor component of the total volume of the sample. The muscovite is silvery white in colour and present as aggregates of minute flakes. Quartz is colourless and has regular to sub-angular form. The identified K-feldspar is pinkish in colour and it is massive in form. Some of the unidentified

TABLE 3.2 RESULTS OF MICROSCOPIC OBSERVATION OF CLAY SAMPLES

MINERAL	RNG2 REDDISH- BROWN %	RNG3 REDDISH- BROWN %	RNG4 REDDISH- BROWN %	RNG5 REDDISH- BROWN %	NH1 (GREY) %	NH2 (GREY) %	REMARKS
Muscovite	-	-	10	-	3	5	
Quartz	-	30	5	-	10	25	
Feldspar	-	-	-	30	5	-	
Opagues	-	-	1.5	1.5	-	-	
Others (Bulk fines)	100	70	83.5	68.5	82	70	

opaques minerals appear black in colour, with rounded, tabular, massive or granular forms with metallic lustre.

### 3.3 MINERALOGICAL CHARACTERISTICS

The x-ray diffractogram results (Figures 2.3 - 2.5, pages 18 - 20) show that the dominant mineral content of the clays are illite, smectite, kaolinite, chlorite, vermiculite, palygorskite, halloysite, montmorillonite, while goethite and quartz constitute the non-clay components.

### 3.4 SPECIFIC GRAVITY

The reddish-brown clay samples have an average specific gravity of  $2.15\text{g/cm}^3$  and the values ranged between  $1.64 - 2.43/\text{cm}^3$ . The specific gravity determinations of the samples were carried out at the Soil Mechanics Laboratory, Ahmadu Bello University, Zaria, Nigeria. The greyish clay samples have lower specific gravity values which ranged between  $2.10 - 3.39 \text{ g/cm}^3$  with an average value of  $2.28 \text{ g/cm}^3$  (Table 5.16 - 5.22 at Appendices XX - XXVI, pages 75 - 81). It is here assumed that the iron oxide content in the clay types may be responsible for the difference in specific gravity values. These results suggest that the samples have mixed clay minerals and other heavy metallic (oxide) minerals.

## **CHAPTER FOUR**

### **GEOCHEMISTRY**

#### **4.1 CHEMICAL COMPOSITIONS**

The results of the major element analysis of the representative samples from the study area in comparison with some reference samples are shown in Table 4.1. The chemical plots (Figs. 4.1 - 4.3, pages 36 - 38) show the distribution of the selected oxides in the samples in relation to the reference samples, thereby aiding the classification of the clay types vis-à-vis the chemical compositions. A more detailed discussion on these oxide components analysed is given below:

##### **4.1.1 SILICA (SiO<sub>2</sub>)**

The reddish-brown clays have an average SiO<sub>2</sub> of 47.93%, which is lower to the SiO<sub>2</sub> (57.00%), value in the greyish clay samples. The SiO<sub>2</sub> content of the greyish clays compares favourably with the values for refractory bricks (Parker, 1967; Emofurieta et al., 1992).

TABLE 4.1 CHEMICAL ANALYSIS OF NARAGUTA CLAYS IN COMPARISON WITH SOME REFERENCE SAMPLES

OXIDE/ SAMPLE NO.	Greyish Clays			Reddish-Brown Clays						Reference Samples				
	NH2	NH3	NH4	RNG1	RNG4	RNG5	RNG6	S	M	P	E			
SiO <sub>2</sub>	60.50	56.20	54.29	48.03	49.30	47.70	46.70	67.50	38.67	51.00-70.00	59.97			
Al <sub>2</sub> O <sub>3</sub>	24.21	29.25	28.01	33.81	33.98	34.22	30.28	26.50	9.45	25.44	24.66			
MnO	Trace	Trace	Trace	Trace	Trace	Trace	Trace	-	-	-	0.01			
Fe <sub>2</sub> O <sub>3</sub>	1.90	1.50	2.30	2.30	2.80	3.70	3.80	0.50-1.20	2.70	0.50-2.40	3.32			
P <sub>2</sub> O <sub>5</sub>	0.03	0.02	0.03	0.03	0.05	0.02	0.02	-	-	-	-			
TiO <sub>2</sub>	1.12	1.10	1.14	1.23	1.24	1.27	1.24	0.10-1.00	-	1.00-2.80	20.20			
CaO	0.50	0.75	0.65	0.62	0.75	0.88	0.80	0.18-0.30	15.84	0.10-0.20	0.46			
MgO	-	0.09	-	0.50	0.08	0.08	0.10	0.10-0.19	8.50	0.20-0.70	0.27			
K <sub>2</sub> O	1.50	1.57	2.08	1.30	1.29	1.08	1.00	1.10-3.10	2.76	-	0.48			
Na <sub>2</sub> O	1.98	1.35	1.45	1.20	1.20	1.15	1.20	0.20-1.50	2.76	0.80-3.50	1.78			
LOI	6.38	6.25	7.04	8.30	8.30	7.30	8.09	-	-	-	16.14			

<sup>A</sup>S Ceramics (Singer and Sonja, 1971)    P Refractory Bricks (Packer, 1967)

M Brick Clay (Murray, 1960)    E Ubulu-Uku Clay (Emofurieta et al., 1992)

*Naraguta clay samples were taken from Barakin Russo, Barakin Naraguta and Naraguta Hausawa areas (Fig. 1.1)*

FIG. 4.1 PLOT OF  $\text{SiO}_2$  Vs  $\text{Al}_2\text{O}_3$

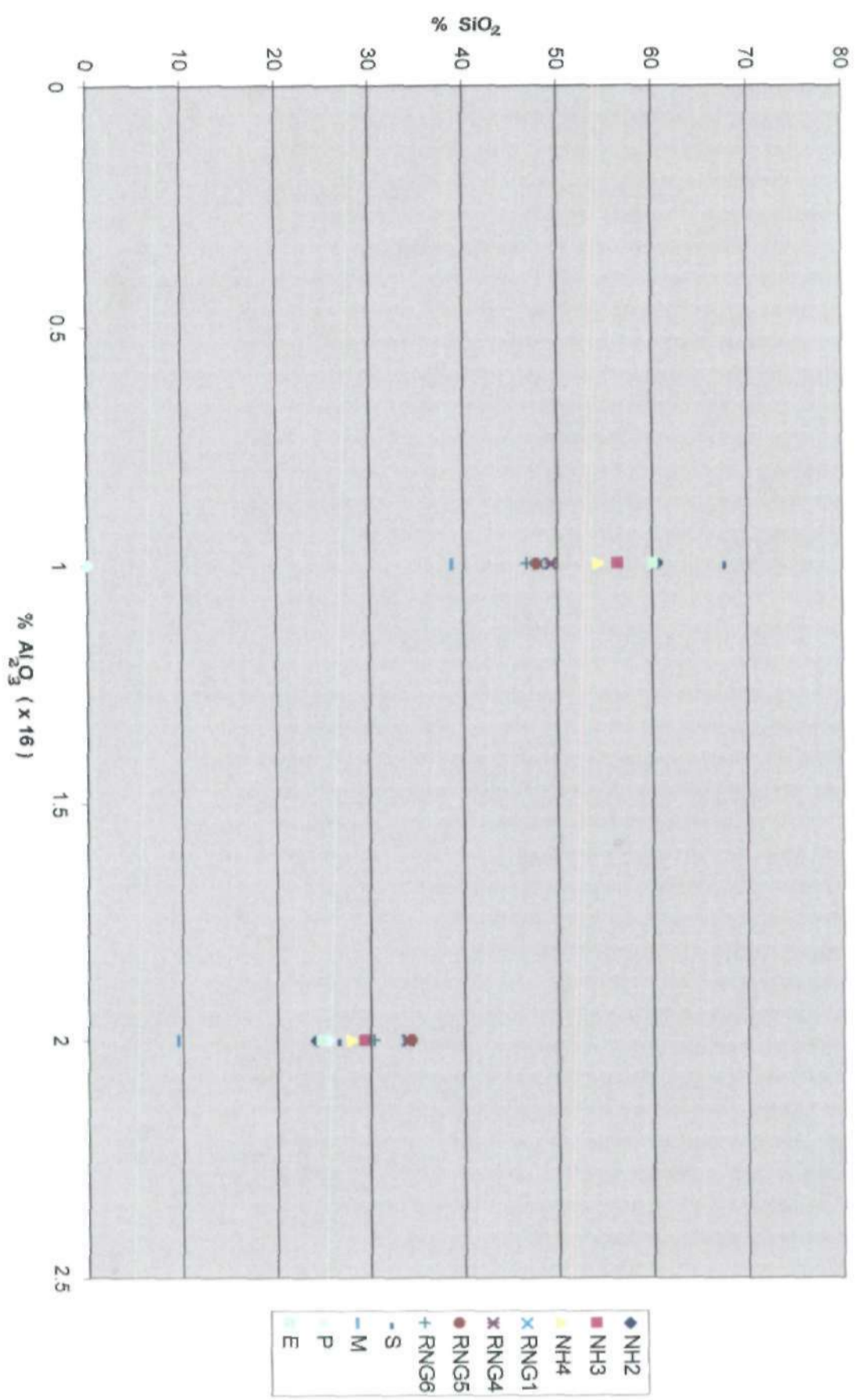


FIG. 4.2

PLOT OF TiO Vs Fe<sub>2</sub>O<sub>3</sub>

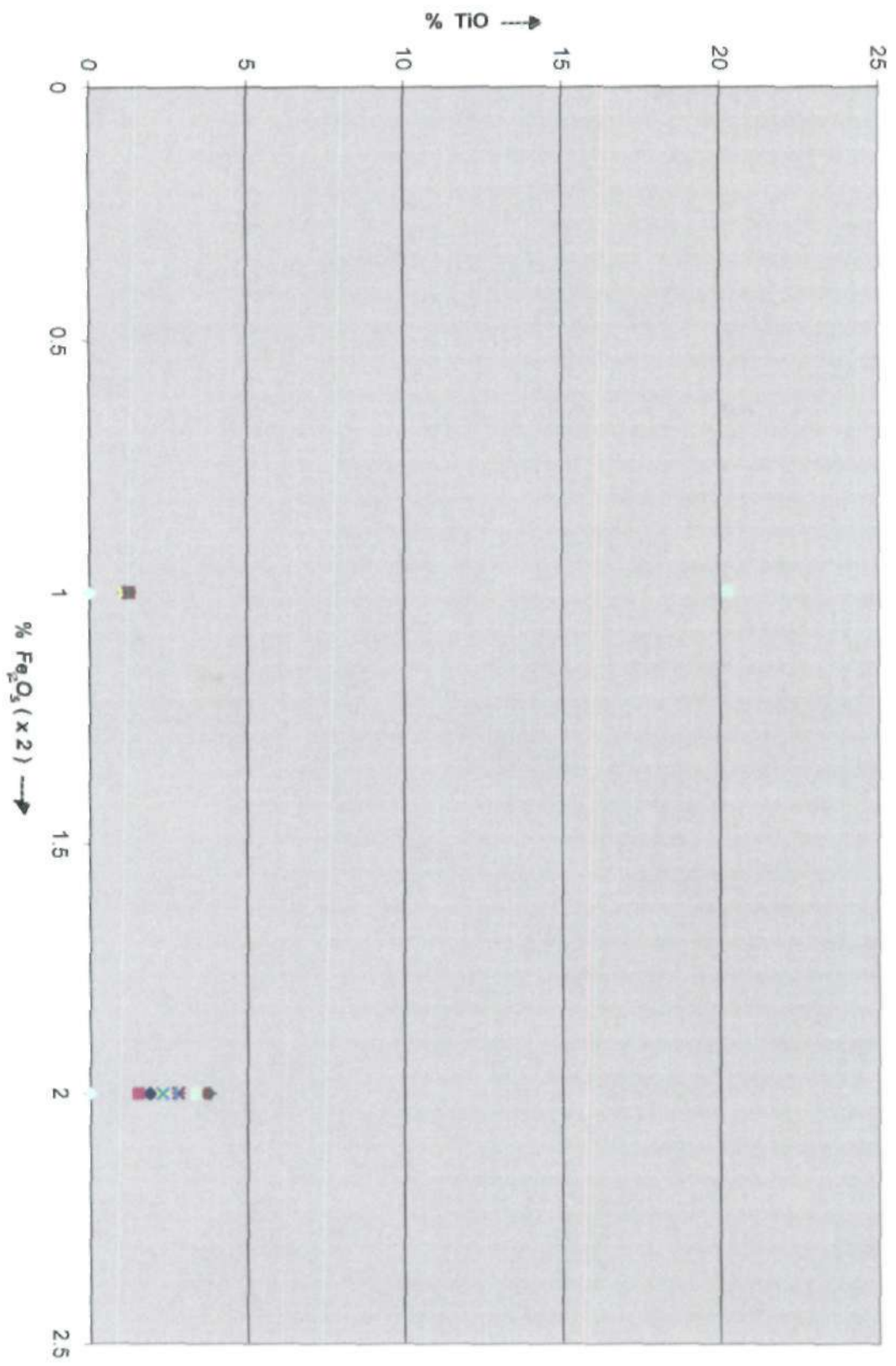
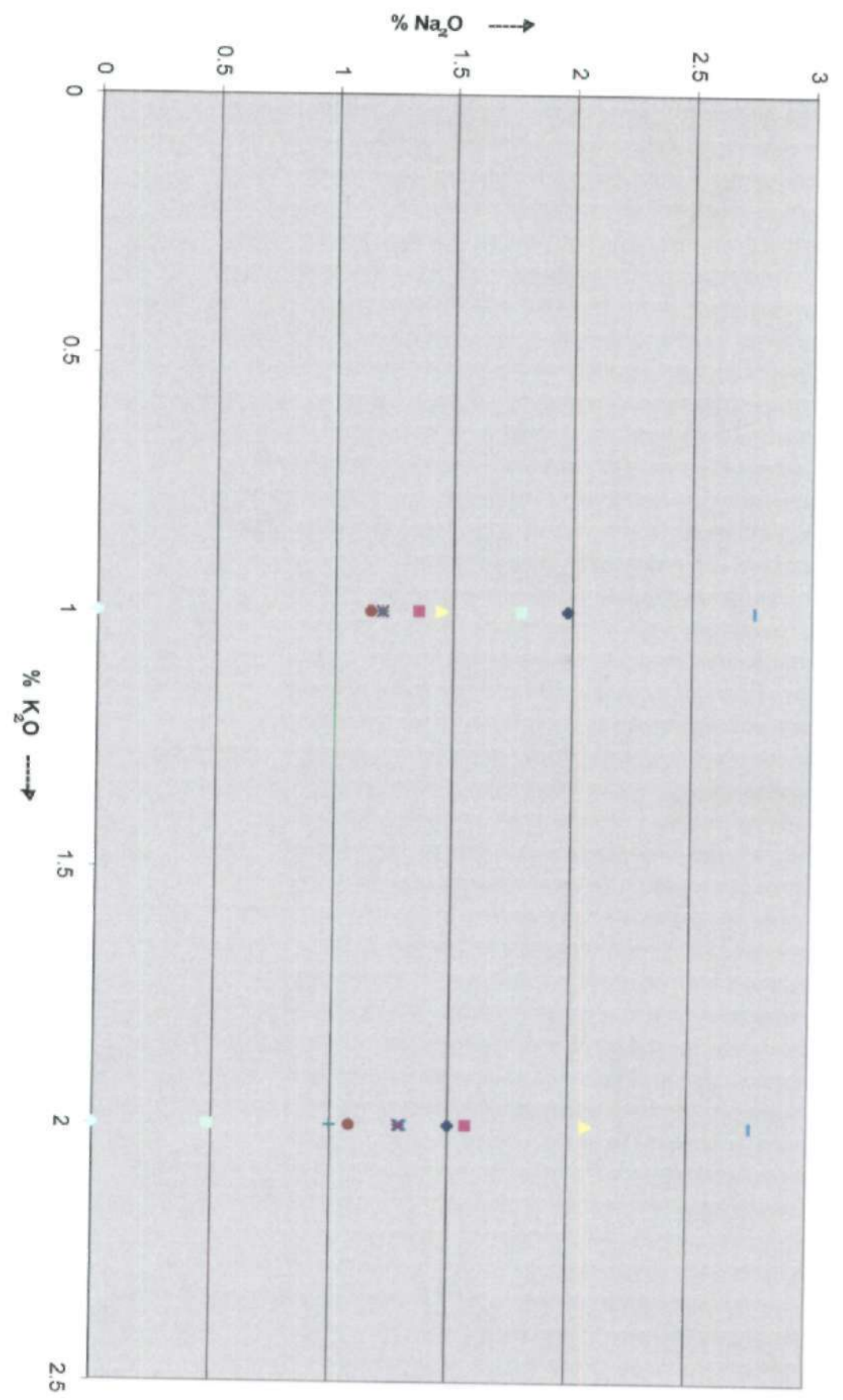


FIG. 4.3 PLOT OF Na<sub>2</sub>O Vs K<sub>2</sub>O



- ◆ NH2
- NH3
- ▲ NH4
- × RNG1
- × RNG4
- RNG5
- + RNG6
- S
- M
- P
- E

#### 4.1.2 ALUMINA (Al<sub>2</sub>O<sub>3</sub>)

The reddish-brown clays have an average Al<sub>2</sub>O<sub>3</sub> of 33.07%. The greyish clays, on the other hand, have an average of 27.16% Al<sub>2</sub>O<sub>3</sub>. The individual and average oxides content of the greyish clays meet the industrial specifications for ceramics and refractory bricks (Table 4.1, page 35). On the other hand, the average oxide content in the reddish-brown clays is higher than those in all the reference samples. Al<sub>2</sub>O<sub>3</sub> is usually a product of the chemical weathering of silicate rocks. It is usually present as elemental oxide composition of kaolinite.

#### 4.1.3 MANGANESE OXIDE (MnO)

The content in all the samples is in trace amount. This has significant implication to the industrial specifications, wherein there are no recorded values in Nigeria except for Ubulu-Uku clay, which has 0.01% value.

#### 4.1.4 FERRIC OXIDE (Fe<sub>2</sub>O<sub>3</sub>)

The reddish-brown clays have an average Fe<sub>2</sub>O<sub>3</sub> content 3.40%, which is higher than that of the greyish clays (1.90% Fe<sub>2</sub>O<sub>3</sub>). The values for the reddish-brown clays satisfy the industrial specification for brick clays. On the other hand, the ferric oxide content in the greyish clays satisfies the

industrial specifications for ceramics (Singer and Sonja, 1971; Murray, 1960). The enrichment of the reddish-brown clays in  $\text{Fe}_2\text{O}_3$  have resulted from the selective removal or leaching of silica and other soluble elements by water. This qualifies the clay to be used in the burnt bricks industry at Naraguta, Jos, Nigeria, where the clay is currently being exploited. The reddish-brown colour of burnt bricks is apparently due to the presence of free ferric oxide in the refractory clay samples. According to Plummer and Rowmary (1947), clays with  $\text{Fe}_2\text{O}_3 > 2 - 3\%$  fire to pinkish and/or reddish-brown colour, whereas clays of lesser  $\text{Fe}_2\text{O}_3$  content develop cream or buff shades. Nevertheless, appropriate mixing of the two clay types yields firing reddish-brown colour.

#### 4.1.5 **PHOSPHORUS OXIDE ( $\text{P}_2\text{O}_5$ )**

The  $\text{P}_2\text{O}_5$  content in the samples ranged between 0.02 - 0.05%. The reddish-brown clays have a higher average  $\text{P}_2\text{O}_5$  content of 0.03%, while the greyish clays have an average  $\text{P}_2\text{O}_5$  (0.027%) value.

#### 4.1.6 TITANIUM OXIDE (TiO<sub>2</sub>)

The reddish-brown clays have a higher average TiO<sub>2</sub> (1.25%) content than the greyish clay types, which have an average content of TiO<sub>2</sub> (1.12%). The two clay types satisfy the industrial specification for refractory bricks (Table 4.1, page 35). Parker (1967) gave acceptable industrial specified ranges for refractory bricks to lie between 1.00% to 2.80%.

#### 4.1.7 POTASH AND SODA (K<sub>2</sub>O + Na<sub>2</sub>O)

The average content of K<sub>2</sub>O + Na<sub>2</sub>O in the samples is 2.76%. This content is in agreement with the industrial specifications listed in Table 4.1, page 35, for brick clays. The industrial specification value given by Searle (1957) for brick clays corroborates the average K<sub>2</sub>O + Na<sub>2</sub>O (2.76%) content obtained for Naraguta clays on the Jos Plateau, Nigeria.

## **CHAPTER FIVE**

### **GEOTECHNICAL PROPERTIES OF NARAGUTA CLAYS**

#### **5.1 LIQUID LIMIT**

The liquid limit of the reddish-brown clay samples ranged between 38.00% to 60.00% with an average value of 49.70%. On the other hand, the liquid limit of the greyish clays ranged from 41% to 52% with an average value of 47.63%. The reddish-brown clay has higher liquid limit value compared to the greyish clays. The liquid limit of the Naraguta clays meets the industrial specification for burnt bricks, ceramics and pottery production (Table 5.1 at Appendix V, page 60).

#### **5.2 PLASTIC LIMIT**

The reddish-brown clay samples have an average plastic limit of 29.50% and the ranges of the values are between 24.50% to 33.11%. The greyish clay samples have a higher average plastic limit of 32.94%. It ranged between 23.43% to 46.97%. The average plastic limit value of Naraguta clays meet the industrial specification (12.60% - 37.90%) for burnt bricks and pottery production (Table 5.1 at Appendix V, page 60).

### 5.3 PLASTICITY INDEX

The reddish-brown clay samples have an average plasticity index of 20.20 and the values ranged between 13.46 to 29.25. On the other hand, the greyish clays have an average plasticity index of 14.62 and the values ranged between 5.03 to 26.07. The average plasticity index value for the reddish-brown clays are closer to the values for the Erusu residual clay reference sample. These results suggest that the reddish-brown clays are probably residual in origin. On the other hand, the average plasticity index value of 14.62 for the greyish clays is quite close to the 15.00 given for the Abraka Amai brick clay (Table 5.1 at Appendix V, page 60). By implication, therefore, the results of the plasticity index for the Naraguta clays suggest that proper mixing of the two different clay types would yield better burnt brick products.

### 5.4 LINEAR SHRINKAGE

The average percentage shrinkage data correlate very well with the data obtained in plasticity index. It is obvious from the results that the reddish-brown clay samples have an average linear shrinkage of 4.52% and the values ranged between 2.14% to 7.86% while the greyish clays have average linear shrinkage of 8.57% to 12.86% (Table 5.1 and

average percentage shrinkage than the reddish-brown clay samples. As a result of the difference in the physical characteristics of these clays, mixing of the greyish clays to the reddish-brown clays in an acceptable ratio of 1:2 have been demonstrated by the Naraguta Burnt Brickworks Factory to yield better, durable and crack resistant burnt bricks, which are usually fired at very high temperatures of  $> 900^{\circ}\text{C}$ .

## CHAPTER SIX

### DISCUSSION, CONCLUSION AND RECOMMENDATIONS

#### 6.1 DISCUSSION

Visual observation of the partially weathered samples revealed the presence of the following minerals: quartz (15% - 35%), feldspar (25% - 30%), biotite (10%), muscovite (5%) and opaques (5%). The result of the binocular microscopic observations of the partially weathered samples is in agreement with that of the visual observation. It is assumed that the central areas of the clay deposits went through complete chemical decomposition because feldspar was not detected in the diffractograms of the samples. Muscovite and biotite were probably decomposed to chlorite and halloysite, while feldspar was probably decomposed to kaolinite. Mineralogical result shows that the dominant clay minerals present in the samples are illite, smectite, kaolinite, chlorite, vermiculite, halloysite, palygorskite and montmorillonite. The palygorskite and montmorillonite clay minerals are rare in the reddish-brown clays, while they are conspicuous in the greyish clays. It may be inferred that palygorskite and montmorillonite and the higher content of kaolinite in the greyish clays could have resulted in the increase of the average plastic limit value of

32.94% compared to the reddish-brown clays, which have average plastic limit value of 29.50%. The average specific gravity values of the reddish-brown and the greyish clays agree with the mineralogical result in confirming that there are wide ranges of mixed clay minerals present in the samples along with heavy metallic minerals probably magnetite and ilmenite.

The geochemical results corroborated the mineralogical data. A comparison of the chemical compositions of the reddish-brown clays with brick clays (Murray, 1960) shows that the average  $\text{SiO}_2$  percentages are almost similar. The alumina contents are quite high. Nevertheless, the reddish-brown clays meet the industrial specification for brick clays (Table 5.1 at Appendix V, page 60). On the other hand, a comparison of the compositions of the grey clays with refractory brick clays (Parker, 1967) indicates that the greyish clays have a lot of chemical similarity to the industrial specification for refractory brick clays (Table 5.1 at Appendix V, page 60). The absence of feldspar in the mineralogical data is suggestive of the complete chemical decomposition of the source rocks. This is reflected in the excessive increase in  $\text{Al}_2\text{O}_3$  content in the samples.

According to Emofurieta and Salami (1988), the dominant contribution of  $\text{Al}_2\text{O}_3$  in any clay deposit is kaolinite [ $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ ].

They further stated that  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  could be used as direct reflectors of the purity of any clay deposit. The contents of  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  in Naraguta clays (24.21% - 34.22% and 46.70% - 60.50%, respectively) suggest that these clays are pure and suitable for burnt bricks and refractory applications.

Elueze and Bolarinwa (1995) stressed that mouldability and reddish-brown coloration after firing are among the most relevant physical parameters for bricks and refractory brick clays. The industrial properties of the Naraguta clays suggest that linear shrinkage increases with increasing depth of clay occurrence (Table 5.1 at Appendix V, page 60). This might not be unconnected with the gradational increase in clay size materials coupled with the greater concentration of illite and smectite at depth. This observation agrees with the findings of Kogbe (1975).

The geotechnical properties investigated revealed that the reddish-brown clays have a lower mouldability compared to the greyish clays. The results further confirmed that the greyish clays have a higher plastic limit than the reddish-brown clays. The reddish-brown and greyish clays meet the industrial specifications for burnt brick and refractory brick clays, respectively. As a result of the differences in the physical properties of these clays, mixing of the greyish clays to the reddish-brown clays in an

acceptable ratio of 1:2 have been demonstrated by the Naraguta Burnt Brickworks Factory to yield better, durable and crack-resistant burnt brick products, which are usually fired to 900°C. The average percentages of silica (SiO<sub>2</sub>) in the clays proffer an explanation for the crushing strength of the clays.

The field evidence, visual and binocular microscopic observations of partially weathered samples, laboratory investigations and analyses of completely weathered samples confirmed that two major types of clays, namely: reddish-brown and greyish clays occur in Naraguta. Also, the results suggest that the reddish-brown clays are residual and originated as weathering products of migmatites, while the greyish clays were transported and they probably originated from the Older Granites of the study area.

## 6.2 CONCLUSION

Muscovite flakes, quartz, feldspar and biotite were usually identified in the partially weathered samples. Binocular microscopy also confirmed the presence of these minerals. The mineralogical data shows that the dominant clay minerals present in the samples are illite, smectite, kaolinite, chlorite, vermiculite, halloysite, palygorskite and montmorillonite. The

higher average percentage plastic limit and mouldability of the greyish clays than that of the reddish-brown clays is traceable to the distribution and of palygorskite and montmorillonite. Specific gravity results on the samples indicated that there is wide range of mixed clay minerals present along with heavy metallic minerals, which were observed as opaques.

The geochemical results corroborated the mineralogical data. The comparison of the geochemical results of the clays with the industrial specifications indicates that the reddish-brown clays meet the industrial specifications for brick clays, while the greyish clays meet the specifications for refractory clays. The result also shows that the clay samples are pure and suitable for bricks and refractory applications.

The average liquid limit of the reddish-brown clays is 49.70%, while that of the greyish clays is 47.63%. The reddish-brown clays have a higher average liquid limit value compared to that of the greyish clays. The reddish-brown clays have an average plastic limit of 29.50%, whereas the greyish clays have a higher average value of 32.94%. These results are in agreement with the crushing strength of these clays: the greyish clays have higher crushing strength compared to the reddish-brown clays. The reddish-brown clays have an average plasticity index of 20.20, whereas the greyish clays have an average value of 14.62. The reddish-brown clays

have a higher plasticity index than the greyish clays. The reddish-brown clays have a lower average percentage linear shrinkage 4.52% compared to the greyish clays, whose value is 8.57%. The physical properties investigation of these clays indicated that they met the industrial specifications for bricks and refractory applications.

Field evidence and the various investigations and results indicated that there are two major types of clays in the study area, namely: the reddish-brown and the greyish clays. In addition, the results suggest that the reddish-brown clays are probably residual and originated from the migmatites. On the other hand, the evidence also suggests that the greyish clays may have been transported and therefore sedimentary with Older Granites origin.

### **6.3 RECOMMENDATION**

A company called Naraguta Burnt Brickworks Factory is presently exploiting these clay deposits. The company's specifications and research findings, if any, were not available for comparative study despite efforts made towards that end. The Naraguta Burnt Brickworks Factory utilises these clays in the production of burnt bricks on a large industrial scale. The research findings of this project would be to the benefit of this company

and interested investors in these clay deposits. It has, however, been observed that certain burnt brick products from the Factory had cracks in them. Against this background, the following recommendations are made:

- Δ further investigation is needed as follow-up of this present study;
- Δ detailed research into the thermal characteristics of Naraguta clays should be carried;
- Δ research into better processing and appropriate beneficiation of the various deposits is required for improvement of the mineralogical, chemical and industrial qualities of the deposits;
- Δ deep depth sampling of the deposits should be carried out;
- Δ closely spaced exploratory drilling with a view to establishing the accurate clay reserves is urgently required.

## REFERENCES

- ABA'A, S. I. (1976). Geochemistry, Petrology and Mineralisation at Ririwai, Gindi Akwati and Dutse Wai in the Nigerian Younger Granite Province. Unpublished M.Sc. Thesis, Ahmadu Bello University, Zaria, Nigeria, 675 pp.
- ALFORD, M. T. and TULEY, P. (1974). The Land Resources of Central Nigeria, Phase I, Vol. 2. Land Resources Division, Tolsworth Tower, England, pp. 4 - 19.
- AMADI, U. M. P. and TEME, S. C. (1989). The Alteration Scheme of Some 2:1 Layer Clays from the Basement Complex. Jour. Min. and Geol. Vol. 25 Nos. 1 and 2, Nigeria., pp. 33 - 41.
- BAIN, A. D. N. (1926). The Geology of Bauchi Town and Surrounding District. Geol. Surv. Nigeria, Bull. No. 9., 109pp.
- BAIN, A. D. N. (1934). The Younger intrusive Rocks of Kudu Hills, Nigeria. Q. Jour. Geol. Soc., London, 90, pp. 201 - 239.
- BOWDEN, P. and TURNER, D. C. (1974). Peralkaline and Associated Ring-complexes in the Nigeria-Niger Province, West Africa. *In* SORENSEN, H. (Ed.) Alkaline Rocks. Q. Jour. Geol. Soc., London, 210, pp. 330 - 351.
- BOWLES, J. E. (1984). Physical and Geotechnical Properties of Soils. 2<sup>nd</sup> Ed. McGraw-Hill Int'l. Book Company, Tokyo, Japan, 578 pp.
- BROWN, G. (1951). The X-Ray Identification and Crystal Structures of Clay Minerals. Min. Soc. London, pp. 489 - 516.
- CAPPER, P. L. CASSIE, W. F. and GEDDES, J. D. (1971). Problems in Engineering Soils. E & F. N. Spon Ltd., London, 350 pp.
- CARROL, D. (1971). Clay Minerals: A guide to their X-Ray Identification.

Geol. Soc. Am. Special Paper 126, pp. 12 - 25.

- ELUEZE, A. A. and BOLARINWA, A. T. (1995). Assessment of Functional Applications of Lateritic Clay Bodies in Ekiti Environs, Southwest Nigeria. Jour. Min. and Geol. Vol. 31, Nos. 1 and 2, Nigeria, pp. 79 -87.
- EMOFURIETA, W. O. and SALAMI, A. O. (1988). A Comparative Study of Two Kaolin Deposits in South-western Nigeria. Jour. Min. and Geol. Vol. 24, Nos. 1 and 2, Nigeria, pp. 15 - 20.
- EMOFURIETA, W. O., KAYODE, A. A. and COKER, S. A. (1992). Mineralogy, Geochemistry and Economic Evaluation of the Kaolin Deposits near Ubulu-Uku, Awo-Omama and Buan in Southern Nigeria. Jour. Min. & Geol. Vol. 28, pp. 211 - 220.
- EMOFURIETA, W. O., OGUNDIMU, T. O. and IMEOKPARIA, E. G. (1994). Mineralogical, Geochemical and Economic Appraisal of some Clay and Shale Deposits in South-western and South-eastern Nigeria. Jour. Min. & Geol. Vol. 30, No. 2, pp. 151 - 159.
- ETU-EFEOTOR, J. O. (1984). Mineralogy and Evaluation of Recent Clays from Eastern Niger Delta. Jour. Min. and Geol. Vol. 1 and 2, Nigeria, pp. 50 - 52.
- FALCONER, J.D. (1911). The Geology and Geography of Northern Nigeria, McMillan, London, 350 pp.
- FALCONER, J.D. and RAEBURN, C. (1923). The Northern Tinfields. Bull. Geol. Surv. Nigeria, No. 4, 108 pp.
- FREETH, S. J. (1969). Chemical Analyses of Nigeria Igneous and Metamorphic Rocks and Minerals up to 1968. Jour. Min. and Geol., 4, pp. 83 - 110.
- GRANT, N. K. (1971). A Compilation of Radiometric Ages from Nigeria.

Jour. Min. & Geol., 6, pp. 37 - 55.

- IKE, E. C. (1979). The Structure, Petrology and Geochemistry of the Tibchi Younger Granite Ring-complex, Nigeria. Unpubl. Ph.D. Thesis, Scotland Univ. of St. Andrews, 548 pp.
- INSUMMA, G.C. GWE (1978). Pre-Drilling Hydrogeological Investigations Phase I, Area IV Published Reports for the Federal Military Government of Nigeria, Federal Ministry of water Resources, Lagos.
- JACOBSON, R. R. E. (1947). The Younger Granite Complex of Liruei Hills, Nigeria. Unpubl. Ph.D. Thesis, London, 658 pp.
- KOGBE, C. A. (1975). Mineralogical Analysis of the Greyish-Black Clays in Sabon Gida Mine (Jos Plateau). Jour. Min. & Geol., Vol. 12, Nos. 1 & 2, pp. 33 - 45.
- MACLEOD, W. N., TURNER, D. C. and WRIGHT, E. P. (1971). The Geology of the Jos Plateau. Geol. Surv. Nigeria, Bull. No. 32, Vol. 1.
- MURRAY, H. H. (1960). Clay Industrial Minerals and Rocks. 3<sup>rd</sup> Ed., Publ. Am. Inst. Of Min., Metall. And Petrol. Eng., New York, Seeley, W. Mudd Series, pp. 259 -284.
- OLAYEMI, C. (1973). Preliminary Search for Clay in Naraguta. Unpubl. Geol. Surv. Nigeria Papers, 10 pp.
- OYAWOYE, M. O. (1959). Petrology of the Older Granites around Bauchi, Nigeria. Unpubl. Ph.D. Thesis, Univ. Durham, 650 pp.
- OYAWOYE, M. O. (1962). The Petrology of the District around Bauchi, Northern Nigeria, Jour. Geol., 70, pp. 604- 615.
- OYAWOYE, M. O. (1972). The Basement Complex of Nigeria. In Africa Geology, (Eds.) Desiauvagie, T. F. and Whiteman, A. J., Ibadan University Press, Nigeria, pp. 67 - 99.

- PARKER, E. R. (1967). Materials Data Book for Engineers and Scientists. Publ. McGraw-Hill Book Co., New York, 283 pp.
- PLUMMER, N. and ROWMARY, J. F. (1947). Kansa Clay, Dakota Formation. Kansas Geol. Surv. Bull. 67, 241 pp.
- RAEBURN, C. (1924). The Tinfields of Nasarawa and Ilorin Provinces. Bull. Geol. Surv. Nigeria No. 5.
- SEARLE, B. A. (1957). Refractory Materials: Their Manufacture and Uses. Charles Griffins and Co. Ltd., London, 1184 pp.
- SINGER, F. and SONJA, S. S. (1971). Industrial Ceramics. Publ. Chapman and Hall, London, 56 pp.
- TUKURA, M. (1990). Naraguta Burnt Bricks: A case Study. Unpubl. B.Sc. Geol. Seminar Paper, Univ. Jos, Nigeria, 10 pp.
- TURNER, D. C. (1963). Ring Structures in the Sara-Frier Complex, Northern Nigeria. Q. Jour. Geol. London, 119, pp. 345 - 366.
- TURNER, D. C. (1968). Volcanic and Intrusive Structures in the Kila-Warji Ring-complex, Northern Nigeria. Q. Jour. Geol. Soc. London, 124, pp. 81 - 89.
- WILSON, R. C. (1922). The Geology of the Western Railway Section 1: Iddo to Ikuku, Nigeria. Nigeria Geol. Surv. Bull. 2, 63 pp.

APPENDIX I

**TABLE 2.1 ATTITUDE OF JOINTS IN MIGMATITE/GNEISS IN  
STUDY AREA AROUND NARAGUTA HAUSAWA**

AZIMUTH	DENSITY	ROCK UNIT
N75 <sup>0</sup>	1/metre	Gneiss
N305 <sup>0</sup>	2/metre	Gneiss
N28 <sup>0</sup>	2/metre	Gneiss
N330 <sup>0</sup>	3/metre	Migmatite
N350 <sup>0</sup>	3/metre	Migmatite
N295 <sup>0</sup>	1/metre	Migmatite
N310 <sup>0</sup>	2/metre	Gneiss
N58 <sup>0</sup>	3/metre	Gneiss
N345 <sup>0</sup>	1/metre	Migmatite

APPENDIX II

**TABLE 2.2 FREQUENCY DISTRIBUTION OF JOINTS IN OLDER  
GRANITES AT BARAKIN RUSSO**

CLASS	FREQUENCY	%
$0^{\circ} - 30^{\circ}$	25	10.64
$30^{\circ} - 60^{\circ}$	20	8.51
$60^{\circ} - 90^{\circ}$	15	6.38
$270^{\circ} - 300^{\circ}$	25	10.64
$300^{\circ} - 330^{\circ}$	75	31.91
$330^{\circ} - 360^{\circ}$	75	31.91

APPENDIX III

TABLE 2.3 ATTITUDE OF JOINTS IN THE YOUNGER GRANITES AROUND NARAGUTA STUDENTS VILLAGE

AZIMUTH	DENSITY	ROCK UNIT
N33 <sup>0</sup>	1/metre	Younger Granite
N312 <sup>0</sup>	2/metre	"
N14 <sup>0</sup>	2/metre	"
N4 <sup>0</sup>	2/metre	"
N25 <sup>0</sup>	2/metre	"
N5 <sup>0</sup>	1/metre	"
N10 <sup>0</sup>	1/metre	"
N350 <sup>0</sup>	1/metre	"
N310 <sup>0</sup>	2/metre	"
N7 <sup>0</sup>	2/metre	"
N288 <sup>0</sup>	3/metre	"
N348 <sup>0</sup>	3/metre	"
N308 <sup>0</sup>	3/metre	"
N315 <sup>0</sup>	1/metre	"

APPENDIX IV

TABLE 2.4 FREQUENCY DISTRIBUTION OF JOINTS IN  
YOUNGER GRANITES AROUND NARAGUTA STUDENTS  
VILLAGE

CLASS	FREQUENCY	%
$0^{\circ} - 30^{\circ}$	63	48.84
$30^{\circ} - 60^{\circ}$	12	9.30
$60^{\circ} - 90^{\circ}$	6	4.65
$270^{\circ} - 300^{\circ}$	6	4.65
$300^{\circ} - 330^{\circ}$	30	23.26
$330^{\circ} - 360^{\circ}$	12	9.30

APPENDIX IV

TABLE 5.1 PHYSICAL PROPERTIES OF NARAGUTA CLAYS

SAMPLE TYPE	REDDISH-BROWN CLAYS					GREYISH CLAYS					REFERENCE SAMPLES	
	RNG1	RNG2	RNG6	NH2	NH3	NH4	NH5	A	B			
Profile Sampling Depth	0.50	0.25	0.25	0.50	1.00	1.25	0.50	A	B			
Liquid Limit	38.00	51.00	60.09	41.00	52.00	49.50	48.00	-	-			
Plastic Limit	24.54	33.11	30.84	25.22	46.97	23.43	36.13	38 (29.80-43.00)	52.50			
Plasticity Index	13.46	17.89	29.25	15.50	5.03	26.07	11.87	12.60-37.90	24.30			
% Shrinkage	7.86	2.14	3.57	7.14	10.71	12.86	3.57	15 (0.25-1.23)	28.20			
Average Specific Gravity (g/cm <sup>3</sup> )	2.09	2.33	2.04	2.27	2.32	2.14	2.38	0.29 (0.25-1.23)	0.50			

A Abraka Amnai Clay (Emofurieta et al., 1994)

B Erusu Clay (Residual) (Emofurieta et al., 1994)

APPENDIX VI - TABLE 5.2 RMC ATTENDING LIMITS RESULT

Liquid Limit: 38% Plastic Limit: 24.54% Plasticity Index: 13.46% Linear Shrinkage: 7.86%

Soil Description: Reddish-brown clay

Type of Test	LL	LL	LL	LL	LL	LL	PL	PL	PL
No. of blows/shrinkage %	46	35	22	18	11				
Container No.	15	46	135	96	41				
Wt. of wet soil and container %	22.00	22.90	20.90	19.00	22.80				
Wt. of dried soil and container %	18.80	19.10	17.90	15.90	17.90				
Wt. of container %	8.80	8.90	8.00	8.40	4.80				
Wt. of dry soil (Wd) %	10.00	10.20	9.90	7.50	12.70				
Wt. of moisture (Wm) %	3.20	3.80	3.00	3.10	5.30				
Moisture content 100 (Wm/Wd) %	32.00	37.25	30.30	41.33	41.73				
Type of Test							PL	PL	PL
No. of blows/shrinkage %									
Container No.							17	12	16
Wt. of wet soil and container %							15.20	15.10	16.50
Wt. of dried soil and container %							13.80	13.80	15.00
Wt. of container %							8.20	8.20	9.10
Wt. of dry soil (Wd) %							5.60	5.60	5.90
Wt. of moisture (Wm) %							1.40	1.30	1.50
Moisture content 100 (Wm/Wd) %							25.00	23.21	25.42

APPENDIX VII - TABLE 5.3 (Contd.) ATTERBERG LIMITS RESULTS

Liquid Limit: 51 %      Plastic Limit: 33.11 %      Plasticity Index: 17.89 %      Linear Shrinkage: 2.14 %

Soil Description: Reddish-brown clay

Type of Test	LL	LL	LL	LL	LL	LL	PL	PL	PL
No. of blows/shrinkage %	43	35	22	18	12				
Container No.	43	34	158	08	42				
Wt. of wet soil and container %	29.10	26.00	23.20	22.80	20.20				
Wt. of dried soil and container %	22.50	20.50	18.00	17.60	14.90				
Wt. of container %	8.10	8.20	8.00	8.40	4.89				
Wt. of dry soil (W <sub>d</sub> ) %	14.40	12.30	10.00	9.20	10.10				
Wt. of moisture (W <sub>m</sub> ) %	6.60	5.50	5.20	5.20	5.30				
Moisture content 100 (W <sub>m</sub> /W <sub>d</sub> ) %	45.83	44.71	52.00	56.52	52.48				
Type of Test							PL	PL	PL
No. of blows/shrinkage %									
Container No.							132	151	145
Wt. of wet soil and container %							14.20	14.60	13.80
Wt. of dried soil and container %							12.50	12.80	12.00
Wt. of container %							2.40	8.00	8.00
Wt. of dry soil (W <sub>d</sub> ) %							10.10	4.80	4.00
Wt. of moisture (W <sub>m</sub> ) %							1.70	1.80	1.80
Moisture content 100 (W <sub>m</sub> /W <sub>d</sub> ) %							16.83	37.50	45.00

APPENDIX VIII - TABLE 5.4 RING ATTERBERG LIMITS RESULT

Liquid Limit: 60.09% Plastic Limit: 30.84% Plasticity Index: 29.25% Linear Shrinkage: 3.57%  
 Soil Description: Reddish-brown clay

Type of Test	LL	LL	LL	LL	LL	LL	PL	PL	PL
No. of blows/shrinkage %	46	35	24	19	12				
Container No.	74	39	150	24	55				
Wt. of wet soil and container %	24.50	21.80	21.70	22.00	22.50				
Wt. of dried soil and container %	18.60	17.00	16.50	16.80	16.00				
Wt. of container %	8.50	8.50	8.00	8.00	8.50				
Wt. of dry soil (W/d) %	10.10	8.50	8.50	8.80	7.50				
Wt. of moisture (W/m) %	5.90	4.80	5.20	5.20	6.50				
Moisture content 100 (W/m/W/d) %	58.42	56.47	61.18	59.09	86.67				
Type of Test							PL	PL	PL
No. of blows/shrinkage %									
Container No.							35	180	175
Wt. of wet soil and container %							12.60	13.50	14.00
Wt. of dried soil and container %							11.50	12.50	12.50
Wt. of container %							8.40	8.80	7.50
Wt. of dry soil (W/d) %							3.10	3.70	5.00
Wt. of moisture (W/m) %							1.10	1.00	1.50
Moisture content 100 (W/m/W/d) %							35.48	27.03	30.00

63

APPENDIX IX - TABLE 5.5 NH2 ATTERBERG LIMITS RESULT

Liquid Limit: 41% Plastic Limit: 25.22% Plasticity Index: 15.50% Linear Shrinkage: 7.14%  
 Soil Description: Greyish-brown clay

Type of Test	LL	LL	LL	LL	LL	LL	PL	PL	PL
No. of blows/shrinkage %	47	35	25	18	11				
Container No	173	177	137	179	29				
Wt. of wet soil and container %	24.70	25.70	20.40	23.20	25.80				
Wt. of dried soil and container %	19.80	20.50	16.80	18.50	19.80				
Wt. of container %	7.90	7.50	7.90	8.00	7.90				
Wt. of dry soil (Wd) %	11.90	13.00	8.90	10.50	11.90				
Wt. of moisture (Wm) %	4.90	5.20	3.60	4.70	6.00				
Moisture content 100 (Wm/Wd) %	41.18	40.00	40.45	44.76	50.42				
Type of Test						PL	PL	PL	
No. of blows/shrinkage %									
Container No						111	61	35	
Wt. of wet soil and container %						26.90	26.70	26.90	
Wt. of dried soil and container %						25.50	25.50	25.80	
Wt. of container %						20.50	20.90	20.70	
Wt. of dry soil (Wd) %						5.00	4.60	5.10	
Wt. of moisture (Wm) %						1.40	1.20	1.10	
Moisture content 100 (Wm/Wd) %						28.00	26.09	21.57	

66

47

APPENDIX X - TABLE 5.6 NH3 ATTERBERG LIMITS RESULT

Liquid Limit: 52% Plastic Limit: 46.97% Plasticity Index: 5.03% Linear Shrinkage: 10.71%  
 Soil Description: Greyish-brown clay

Type of Test	LL	LL	LL	LL	LL	LL	PL	PL	PL
No. of blows/shrinkage %	46	35	22	18	11				
Container No.	128	172	164	164	57				
Wt. of wet soil and container %	13.90	16.10	15.00	15.00	16.70				
Wt. of dried soil and container %	12.00	13.90	12.50	12.50	13.80				
Wt. of container %	8.00	8.00	7.90	7.90	8.50				
Wt. of dry soil (Wd) %	4.00	5.90	4.60	4.60	5.30				
Wt. of moisture (Wm) %	1.90	2.20	2.50	2.50	2.90				
Moisture content 100 (Wm/Wd) %	47.50	37.29	54.35	54.35	54.72				
Type of Test						PL	PL	PL	PL
No. of blows/shrinkage %									
Container No.						89	68	3	
Wt. of wet soil and container %						13.50	13.90	14	
Wt. of dried soil and container %						12.00	11.60	12	
Wt. of container %						8.00	8.00	8	
Wt. of dry soil (Wd) %						4.00	3.60	4	
Wt. of moisture (Wm) %						1.50	2.30	1	
Moisture content 100 (Wm/Wd) %						37.50	63.89	39	

65

APPENDIX XI - TABLE 5.7 NH4 ATTERBERG LIMITS RESULT

Liquid Limit: 49.50% Plastic Limit: 23.43% Plasticity Index: 26.07% Linear Shrinkage: 12.86%  
 Soil Description: Greyish-brown clay

Type of Test	LL	LL	LL	LL	LL	LL	PL	PL	PL
No. of blows/shrinkage %	48	35	25	17	11				
Container No.	132	128	172	158	164				
Wt. of wet soil and container %	14.10	17.20	17.50	18.00	23.10				
Wt. of dried soil and container %	12.50	13.60	13.70	14.50	17.00				
Wt. of container %	8.00	8.10	7.80	8.00	7.90				
Wt. of dry soil (Wd) %	4.50	5.50	5.90	6.50	9.10				
Wt. of moisture (Wm) %	1.60	3.60	3.80	3.50	6.10				
Moisture content 100 (Wm/Wd) %	35.56	65.45	64.41	53.85	67.03				
Type of Test							PL	PL	PL
No. of blows/shrinkage %									
Container No.							193	151	163
Wt. of wet soil and container %							12.60	12.50	12.80
Wt. of dried soil and container %							11.90	11.50	11.80
Wt. of container %							7.90	7.90	7.80
Wt. of dry soil (Wd) %							4.00	3.60	4.00
Wt. of moisture (Wm) %							0.70	1.00	1.00
Moisture content 100 (Wm/Wd) %							17.50	27.78	25.00

6

11 271

APPENDIX XII - TABLE 5.8 NHS ATTERBERG LIMITS RESULT

Liquid Limit: 48%      Plastic Limit: 36.13%      Plasticity Index: 11.87%      Linear Shrinkage: 3.57%  
 Soil Description: Greyish-brown clay

Type of Test	LL	LL	LL	LL	LL	LL	PL	PL	PL
No. of blows/shrinkage %	44	33	21	17	12				
Container No.	71	34	149	54	163				
Wt. of wet soil and container %	15.90	20.60	15.50	20.50	16.00				
Wt. of dried soil and container %	13.50	16.50	13.00	16.00	13.00				
Wt. of container %	8.50	8.50	8.00	8.30	7.90	*			
Wt. of dry soil (Wd) %	5.00	8.00	5.00	7.70	5.10				
Wt. of moisture (Wm) %	2.40	3.50	2.50	4.50	3.00				
Moisture content 100 (Wm/Wd) %	48.00	43.75	50.00	58.14	58.82				
Type of Test							PL	PL	PL
No. of blows/shrinkage %									
Container No.							178	27	13
Wt. of wet soil and container %							12.50	12.80	13.20
Wt. of dried soil and container %							11.00	11.50	12.50
Wt. of container %							7.90	8.50	8.30
Wt. of dry soil (Wd) %							3.10	3.00	4.20
Wt. of moisture (Wm) %							1.50	1.30	0.70
Moisture content 100 (Wm/Wd) %							48.39	43.33	16.67

67

67 50

APPENDIX XIII

TABLE 5.9 SAMPLE RING LINEAR SHRINKAGE RESULT

Wt. of dried soil + container	=	267.80g
Wt. of container	=	235.80g
Original channel length before shrinkage	=	14.00g
Final channel length after shrinkage	=	12.90g

APPENDIX XII

TABLE 5.10 SAMPLE RNG2 LINEAR SHRINKAGE RESULT

Wt. of dried soil + container	=	258.10g
Wt. of container	=	251.50g
Original channel length before shrinkage	=	14.00g
Final channel length after shrinkage	=	13.70g

APPENDIX XII

TABLE 5.11 SAMPLE RING6 LINEAR SHRINKAGE RESULT

Wt. of dried soil + container	=	253.80g
Wt. of container	=	251.50g
Original channel length before shrinkage	=	14.00g
Final channel length after shrinkage	=	13.50g

7D

APPENDIX XVI

TABLE 5.12 SAMPLE NH2 LINEAR SHRINKAGE RESULT

Wt. of dried soil + container	=	291.80g
Wt. of container	=	253.80g
Original channel length before shrinkage	=	14.00g
Final channel length after shrinkage	=	13.00g

APPENDIX XVII

TABLE 5.13 SAMPLE NH3 LINEAR SHRINKAGE RESULT

Item	Value
Wt. of dried soil + container	289.50g
Wt. of container	253.00g
Original channel length before shrinkage	14.00g
Final channel length after shrinkage	12.50g

APPENDIX XVIII

TABLE 5.14 SAMPLE NH4 LINEAR SHRINKAGE RESULT

Wt. of wet soil + container	g
Wt. of dried soil + container	= 290.00g
Wt. of container	= 253.00g
Original channel length before shrinkage	= 14.00g
Final channel length after shrinkage	= 12.20g

APPENDIX XIX

TABLE 5.15 SAMPLE NH5 LINEAR SHRINKAGE RESULT

Wt. of dried soil + container	=	291.20g
Wt. of container	=	254.90g
Original channel length before shrinkage	=	14.00g
Final channel length after shrinkage	=	13.50g

74

APPENDIX XX

TABLE 5.16 SPECIFIC GRAVITY DETERMINATION OF SAMPLE RNG1 (IN G/CM<sup>3</sup> UNITS)

Bottle No.	BN1	BN2	BN3
Wt. of Bottle + Water (Full)	w4 354.50	344.80	344.30
Wt. of Bottle + Soil + Water	w3 364.20	360.40	356.00
Wt. of Bottle + Soil	w2 121.70	127.00	121.50
Wt. of Bottle	w1 104.00	99.20	94.90
Wt. addit. Of Water	(w4 - w1) 250.50	245.60	249.40
Wt. of Water added to Soil	(w3 - w2) 242.50	233.40	234.50
Wt. of Soil	(w2 - w1) 17.70	27.80	26.60
Wt. of Water displaced by Soil	(w4 - w1) - (w3 - w2) = ww 8.00	12.20	14.90
Specific Gravity of Soil Particles (g/cm <sup>3</sup> )	(w2 - w1)/ww 2.2125	2.28	1.785

APPENDIX XXI

TABLE 5.17 SPECIFIC GRAVITY DETERMINATION OF SAMPLE RNG2 (IN G/CM<sup>3</sup> UNITS)

Bottle No.	BN1	BN2	BN3	
Wt. of Bottle + Water (Full)	w4	354.50	344.80	344.30
Wt. of Bottle + Soil + Water	w3	365.50	363.50	356.20
Wt. of Bottle + Soil	w2	124.00	132.00	115.10
Wt. of Bottle	w1	104.00	99.20	94.90
Wt. addit. Of. Water	(w4 - w1)	250.50	245.60	249.40
Wt. of Water added to Soil	(w3 - w2)	241.50	231.50	241.10
Wt. of Soil	(w2 - w1)	20.00	32.80	20.20
Wt. of Water displaced by Soil	(w4 - w1) - (w3 - w2) = ww	9.00	14.10	8.30
Specific Gravity of Soil Particles (g/cm <sup>3</sup> )	(w2 - w1)/ww	2.22	2.33	2.43

76

APPENDIX XXII

TABLE 5.18 SPECIFIC GRAVITY DETERMINATION OF SAMPLE RNG6 (IN G/CM<sup>3</sup> UNITS)

Bottle No.	BN1	BN2	BN3
Wt. of Bottle + Water (Full)	w4 354.50	344.80	344.30
Wt. of Bottle + Soil + Water	w3 360.80	357.80	252.60
Wt. of Bottle + Soil	w2 120.10	122.80	109.80
Wt. of Bottle	w1 104.00	99.20	94.90
Wt. addit. Of Water	(w4 - w1) 250.50	245.60	249.40
Wt. of Water added to Soil	(w3 - w2) 240.70	235.00	242.80
Wt. of Soil	(w2 - w1) 16.10	23.60	14.90
Wt. of Water displaced by Soil	(w4 - w1) - (w3 - w2) = ww 9.8	10.60	6.60
Specific Gravity of Soil Particles (g/cm <sup>3</sup> )	(w2 - w1)/ww 1.64	2.23	2.26

for 77

APPENDIX XXIII

TABLE 5.19 SPECIFIC GRAVITY DETERMINATION OF SAMPLE NH2 (IN G/CM<sup>3</sup> UNITS)

Bottle No.	BN1	BN2	BN3
Wt. of Bottle + Water (Full)	w4 354.50	344.80	344.30
Wt. of Bottle + Soil + Water	w3 364.20	361.20	354.50
Wt. of Bottle + Soil	w2 122.50	128.00	112.50
Wt. of Bottle	w1 104.00	99.20	94.90
Wt. addit. Of Water	(w4 - w1) 250.50	245.60	249.40
Wt. of Water added to Soil	(w3 - w2) 241.70	233.20	242.00
Wt. of Soil	(w2 - w1) 18.50	28.80	17.60
Wt. of Water displaced by Soil	(w4 - w1) - (w3 - w2) = ww 8.80	12.40	7.40
Specific Gravity of Soil Particles (g/cm <sup>3</sup> )	(w2 - w1)/ww 2.10	2.32	2.38

APPENDIX XIII

TABLE 5.20 SPECIFIC GRAVITY DETERMINATION OF SAMPLE NH3 (IN G/CM<sup>3</sup> UNITS)

Bottle No.	BN1	BN2	BN3
Wt. of Bottle + Water (Full)	w <sub>4</sub> 354.50	344.80	344.30
Wt. of Bottle + Soil + Water	w <sub>3</sub> 369.80	360.00	358.50
Wt. of Bottle + Soil	w <sub>2</sub> 132.10	125.50	119.40
Wt. of Bottle	w <sub>1</sub> 104.00	99.20	94.90
Wt. addit. Of Water	(w <sub>4</sub> - w <sub>1</sub> ) 250.50	245.60	249.40
Wt. of Water added to Soil	(w <sub>3</sub> - w <sub>2</sub> ) 237.70	234.50	239.10
Wt. of Soil	* (w <sub>2</sub> - w <sub>1</sub> ) 28.10	26.30	24.60
Wt. of Water displaced by Soil	$\frac{(w_4 - w_1) - (w_3 - w_2)}{w_4 - w_1} = w/w$ 12.80	11.10	10.30
Specific Gravity of Soil Particles (g/cm <sup>3</sup> )	(w <sub>2</sub> - w <sub>1</sub> )/w/w 2.20	2.37	2.39

APPENDIX XXV

TABLE 5.21 SPECIFIC GRAVITY DETERMINATION OF SAMPLE NH4 (IN G/CM<sup>3</sup> UNITS)

Bottle No.	BN1	BN2	BN3
Wt. of Bottle + Water (Full)	w <sub>4</sub> 354.50	344.80	344.30
Wt. of Bottle + Soil + Water	w <sub>3</sub> 363.50	363.20	357.00
Wt. of Bottle + Soil	w <sub>2</sub> 119.70	131.60	124.00
Wt. of Bottle	w <sub>1</sub> 104.00	99.20	94.90
Wt. addit. Of Water	(w <sub>4</sub> - w <sub>1</sub> ) 250.50	245.60	249.40
Wt. of Water added to Soil	(w <sub>3</sub> - w <sub>2</sub> ) 243.80	231.60	233.00
Wt. of Soil	(w <sub>2</sub> - w <sub>1</sub> ) 15.70	32.40	29.10
Wt. of Water displaced by Soil	(w <sub>4</sub> - w <sub>1</sub> ) - (w <sub>3</sub> - w <sub>2</sub> ) = ww 6.70	14.00	16.40
Specific Gravity of Soil Particles (g/cm <sup>3</sup> )	(w <sub>2</sub> - w <sub>1</sub> )/ww 2.34	2.314	1.77

APPENDIX XXVI

TABLE 5.22 SPECIFIC GRAVITY DETERMINATION OF SAMPLE NH5 (IN G/CM<sup>3</sup> UNITS)

Bottle No.	BN1	BN2	BN3
Wt. of Bottle + Water (Full)	354.50	344.80	344.30
Wt. of Bottle + Soil + Water	363.90	361.00	353.90
Wt. of Bottle + Soil	120.00	128.10	111.10
Wt. of Bottle	104.00	99.20	94.90
Wt. addit. Of Water	250.50	245.60	249.40
Wt. of Water added to Soil	243.90	232.90	242.80
Wt. of Soil	16.00	28.90	16.20
Wt. of Water displaced by Soil	6.60	12.7	6.60
Specific Gravity of Soil Particles (g/cm <sup>3</sup> )	2.42	2.275	2.46

81

81