AN EVALUATION OF THE SUITABILITY OF CERAMIC RAW MATERIALS IN KEBBI STATE FOR THE PRODUCTION OF TABLEWARE FOR SMALL SCALE INDUSTRY

BY

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A DISSERTATION SUBMITTED TO THE POSTGRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN INDUSTRIAL DESIGN

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DECLARATION

I declare that the work in the dissertaton entitled "An evaluation of the Suitability of Ceramic Raw Materials in Kebbi State for the Production of Tableware for Small Scale Industry" has been performed by me in the Department of Industrial Design under the supervision of Professor A. M. Ahuwan, Professor B.A. Kparevzua and Dr. Salihu Maiwada. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any university.

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Zauro, Tukur Dikko Muhammad Date

CERTIFICATION

This dissertation entitled "AN EVALUATION OF THE SUITABILITY OF CERAMIC RAW MATERIALS IN KEBBI STATE FOR THE PRODUCTION OF TABLEWARE FOR SMALL SCALE INDUSTRY" by Zauro, Tukur Dikko Muhammad meets the regulations governing the award of the degree of Doctor of Philosophy in Industrial Design of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation

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DEDICATION

This dissertation is wholeheartedly dedicated to my late Grand Father Alhaji Aliyu (Dikko Dan Umaru, the 4th Dikkon Zauro) who enrolled me into the school system at a very early age, encouraged and supported me in my educational struggle throughout his lifestime.

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ABSTRACT

The Industrial development of a nation could be achieved through the effective and efficient utilization of the available raw materials and Ceramic Industries are some of the enterprises that rely heavily on such raw materials. Kebbi State has been endowed with natural resources including ceramic raw materials. Data from geological documents and information received from respondents aided the identification of locations and subsequent collection of the raw materials. These are kaolin, ball clay, quartz, feldspar and limestone. Chemical analyses and physical property tests were conducted. The triaxial blend method was adapted to study the effect of the materials while slip casting technique was used to shape the sample wares and the samples were fired in the kerosene kiln. Based on the chemical analyses and physical tests performed, the study found that Kaoje, Koko and Giro Kaolins; Birnin Kebbi and Felande ball clays; Aliero, Dangamaji and Katanga limestones; Bena feldspar and Bena quartz are suitable raw materials for the production of table ware.

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ABBREVIATIONS

AD	-	After death
BC	-	Before Christ
cm	-	Centimetre
Fig.	-	Figure
gm	-	gramme
km	-	kilometre
mm	-	millimetre
NA	-	Not available
O^0c	-	Degree centigrade
ppm	-	Part Per Million

SIGN

(±)	-	Plus and minus
x	-	Multiplication
÷	-	Division
=	-	Equals
%	-	Percent

CHEMICAL SYMBOLS

SiO_2	-	Silica
Al_2O_3	-	Alumina
Fe_2O_3	-	Iron Oxide
MgO	-	Magnesia
CaO	-	Lime
Na_2O	-	Soda
TiO_2	-	Titania
MnO	-	Manganese

DEFINITION OF OPERATIONAL TERMS

Ball Mill – An apparatus which uses porcelain balls in a rotating cylinder to grind materials for bodies and glazes.

Bisque - Ware which has had one firing unglazed.

Biscuit.

Blunge - To mix a slip

Body - A clay for special purpose. It is created by blending different clays or by adding to clays other minerals, such as feldspar and flint, in order to produce a desired workability or finished result.

Calcination – To disintegrate by heat; the strong heating of a material resulting in a physical or chemical change.

Ceramic – Is described as any non-metallic and vitreous enamel which if exposed to high temperature becomes hardened.

The term ceramic covers a variety of domestic, sculptural architectural, sanitary and technical wares made from fired clay.

Cottle - A wall of stiff waterproof material used to contain liquid plaster until it hardens.

Deflocculate - The addition of electrolytes to slip to reduce the amount of water needed to make it pourable.

Earthenware – Pottery or other objects made from fired clay which is porous and permeable. Earthenware may be glazed or unglazed and is usually but not always buff, red, or brown in colour.

Electrolyte – An alkaline substance, usually soda ash or sodium silicate added to a clay slip to deflocculate it.

Flux - A substance which melts and causes other substance to melt inside the kiln.

Glaze - A layer of glass which is fused into place on a pottery body. The glaze provides a hygienic covering on pottery because it is smoother than the body it covers and it is non porous.

Glost Fire – Term used for the glaze firing of ceramics especially in the industry,

Industry – The production of goods for sale especially in factories or of materials that can be used in the production of goods

Jaw Crusher – A machine for crushing which is composed of one stationary and one movable Jaw.

Levigation – Refining clay by water floatation

Model - The natural clay of which a ware is formed. Materials mixed together for the work of ceramic or the main part of the ware as distinct from the glaze.

Oxide – Any element combine with oxygen.

Plaster Mould – An assembly of plaster of Paris pieces containing a cavity in which castings are formed.

Plasticity – The property of a material enabling it to be shaped and to hold its shape.

Porcelain – High temperature ware which is white and translucent. The body is by mixing china clay, China Stone and quartz together at definite rates.

Pottery – Objects, and especially vessels which are made from fired clay. The term "pottery" include earthenware, stoneware and porcelain.

Stoneware – Pottery or other objects made from fired clay which is dense and vitrified. Stoneware is fired at temperatures above 1200^0C, it may be dark or light in colour but is not translucent.

Slip – A homogenous mixture of ceramic raw materials and water used for casting.

Slip-casting – A pottery forming process which uses moulds to give the forms and uses liquid clay (slip) the slip is poured into porous moulds which absorb some of the water from the slip.

Table ware – A general term for ceramic directly concerned with serving of food and drinks.

Temperature – The intensity of heat as measured in degrees Fahrenheit or degrees centigrade.

Triaxial – A diagrammatic method of studying the effect of the various mixtures possible with three materials or colours

CHAPTER 1

INTRODUCTION

Industrial development is the keyword used to assess, evaluate and measure the living standards of people of a particular country. Probably, no nation or society can easily survive the prevailing hard and hash economic climate without proper strategies and planning for its industrial takeoff. The persistent economic recessions are sometimes attributed to the low level of industrialization.

Ibrahim (2002) confirmed that the Federal Government of Nigeria is doing everything within its powers to "strengthen and energize the economy by promoting industrial development especially the small scale sector." Already the government has made effort towards stimulating the Industrial growth by establishing the Federal Ministry of Industries and Federal Ministry of Solid Minerals Development. Established for a similar purpose are the National Directorate of Employment (NDE), Raw Materials Research and Development Council (RMRDC), and Industrial Development Centres located in different parts of the country. Others are Project Development Agency (PRODA) Enugu, Federal Institute of Industrial Research Oshodi (FIIRO) Lagos and other relevant agencies.

In another perspective, the central Bank of Nigeria (CBN) has created Small and Medium Industries Equity scheme (SMIES) as part of the banking industry’s contribution to the industrial development of Nigeria. The scheme requires all commercial banks to set aside 10 percent of their profit before tax for small and medium scale industries development. In the year, 2003, the Federal Government has established the Small and Medium Enterprises Development Agency (SMEDA) to promote and facilitate the development programme in the small and medium enterprises sub-sector of the nation’s economy.

Seemingly, all these steps and actions taken by the government are to ensure the smooth promotion of the small-scale industries for the simple reason that they play significant and tremendous role in the economic growth of Nigeria. Ibrahim (2002) described small-scale industries as catalysts to the economic and industrial development of any nation.

It is pertinent at this point to note that nations like USA, Britain, France, China, Japan became industrialized sequel to the development of small scale industries. The newly industrialized countries like Pakistan, Indonesia, Malaysia, South Africa and the likes attained their present economic and industrial growth as a result of the activities of the small-scale industries. Similarly, Randali (2003) revealed that over the years, different regimes in Nigeria have created policies that are designed to promote small-scale enterprises.

Mabawonku (1977) pointed out that small-scale industries could reduce rural urban migration and poverty. To this end, they enhance employment opportunities and encourage the use of locally sourced raw materials. Also these industries accelerate the improvement of national income better than the intensive large-scale sector. Ahuwan (1987) confirmed that, small-scale industries can be reliable source of creating employment to the ever increasing youths.

Essentially, industrial development of a nation could likely be realized with effective and efficient utilization of the available natural resources'. Indeed ceramic industries are the type of enterprises that require the use of such natural resources like kaolin, quartz, feldspar and limestone. Klien (2001) revealed that the main ingredients or components used in the ceramic industries are kaolin, clay, talc, felspar, quartz, limestone, dolomite and the likes. It is clear that one form of ceramic product or the other is being used to serve human needs. For example, Oliver (1997) explained that ceramic meets the need of almost every community in the area of cooking, storage, preservation and construction.

Apart from its essential utility at home, builders employed structural ceramic products such as bricks and tiles for execution of projects. Interestingly, electrical engineers depend greatly on ceramic products such as electrical insulators and sockets for their jobs. Based on this account, industrial development as the basis for meaningful economic growth can be promoted in Kebbi State by the establishment of industries especially for small-scale sector. However, to accomplish effective industrial take off, the presence of raw materials is of supreme importance.

Kebbi state is said to have been endowed with abundant natural resources. Suraj (2004) disclosed that Kebbi has a fair share of the Nigeria's known natural resources. The state has vast raw materials resources. In fact the size of the state, its strategic location and position in the country places it at a great advantage. Perhaps the most vital of these endowments as far as industrialization is concerned is the availability of raw materials in various parts of the state. Suraj (2004) further stated that there are records confirming the occurrence of variety of minerals in commercial quantities in Kebbi State. They include kaolin, refractory clay, gold, limestone, talc, phosphates, granite, marble and feldspar.

For this reason, the setting up of ceramic small-scale industries might be possible in Kebbi State because of the availability of the raw materials. Kebbi State may attain gradual industrial development if emphasis is laid on small-scale sector. Umar (2000) found out that;

> In the field of solid minerals resources, the state is well blessed with a lot of deposits, which have either been identified or expected to be present because of the geo-physical nature of our land. Such deposits are kaolin, gold, limestone, iron-ore, bauxite, clays, salt, potash, manganese, silica sand, mica and feldspar to mention just a few of the endowments. These resources when fully exploited will give Kebbi State a place of pride in the nation's economic system.

However, it is distressing to note that Kebbi State has no single functional ceramic industry despite the abundant raw material deposits in the state. Suraj (2004) observed that, Kebbi State remains among the least industrially developed states in the federation, even though it has been blessed with abundant mineral resources.

Against this background, the researcher is motivated to undertake a study on the Evaluation of the Suitability of Ceramic Raw Materials in Kebbi State for the Production of Tableware for to Small-Scale Industry.

1.1 Statement of the Problem

The problem of this study is the unidentification, unevaluation and unutilization of ceramic raw materials in Kebbi State into suitable products of porcelain as tableware.

1.2 Aim and Objectives

The aim of this study is to critically examine some of the selected ceramic raw materials in Kebbi State and to evaluate their suitability for the production of tableware for small scale industry.

The objectives of the study are as follows:

1. To identify the locations of ceramic raw materials in Kebbi State.
2. To identify through experiments the suitability of some of the selected ceramic raw materials.

3. To formulate good working porcelain body for the production of tableware.

1.3 Research Questions

1. What are the types of ceramic raw materials found in Kebbi State?
2. What is the adequacy of the raw material found in Kebbi State for ceramic Small-Scale Industry?
3. What are the Chemical and physical properties of the ceramic raw materials found from different locations in Kebbi State?
4. What is the role of ball clay in enhancing the plastic state of the slip produced from the ceramic raw materials found in Kebbi State for casting?
5. Could the slip produced from the ceramic raw materials found in Kebbi state be suitable for casting without the addition of deflocculants?
6. Could the ceramic raw materials found in Kebbi State be used to formulate glaze recipes for the study?

1.4 Basic Assumptions

The research is based on the following assumptions:

1. That raw materials identified would be suitable for ceramic production;
2. That adequate facilities to process the raw materials would be available;
3. That Information obtained from respondents and geological documents would facilitate identification of locations of the raw materials;.
4. That there would be availability of facilities to conduct tests.
5. That the finished products would or would not display all the characteristics of porcelains, particularly, translucency.

1.5 Limitation

1. There was lack of adequate facilities to process raw materials in the Department of Industrial Design, Ahmadu Bello University, Zaria. The study made contact with relevant agencies and organizations where facilities were available for the processing and testing of materials;
2. Consequent to the insufficient knowledge concerning the locations of ceramic materials, the study treated information obtained from geological documents and other respondents;

3. Only slip casting technique was used as shaping method for the production of sample tableware (simple shape only) for this study.

1.6 Delimitation

Kebbi State as earlier explained is naturally well endowed with various and varied mineral resources. However, the study is delimited both in scope and materials significantly to Kebbi State kaolin, quartz, feldspar and limestone.

1.7 Justification for the Study

Ceramic is one of the first useful arts to be developed by man. It has essentially maintained its usefulness Ahuwan (1987) revealed that ceramic besides its tradition of practice still meets the daily needs of every community or society. For example, people seek for the services of ceramic products for cooking, storage as well as for aesthetic values. Ceramics in the contemporary scene provides wide range of services.

Sullayman (1997) disclosed that there has been an increasing demand for ceramic wares throughout West African sub-region particularly in Nigeria. He re-iterated that the growing demand of ceramics in the modern world, has covered the field of “architectural, sanitary, electrical and even electronic". For instance, in architecture and construction, ceramic provides bricks, tiles and other structural clay products. Sanitary wares of all sorts are enhanced and in electrical work ceramic provides electrical insulators, sockets and other elements used in electrical services.

On the other hand, ceramic contributes in the automobile industry by providing spark plugs and cylindrical pipes for transporting water, sewage wastes and other liquids. The use of ceramic products are numerous. Thus the importance of ceramic in the industrialization of any nation cannot be over-stressed.

Opoku (2003) opined that the development of raw materials has an enormous role in the socio-economic life of the people of any nation. He further emphasized that its development as a sub-sector of the economy helps to advance the industrial growth and self-reliance through the effective use of the local raw materials as inputs for the industries. Raw materials that exist in Kebbi State are part of the wealth possession of the people of Kebbi State and the country in general. In this connection, the exploitation and utilization of the mineral resources are essential in the improvement of the standard of living of some people of the state.

Similarly, clarion calls and campaigns on the importance of self-reliance and industrialization have been vigorously pursued by the federal, state and local governments. Alkali (2003) in support of the above assertion stated that the problem of unemployment and poverty forced the Federal Government to establish the National Directorate of Employment (NDE) in 1986.

According to him, the organ is charged with the responsibility of mapping out strategies to curb the menace of unemployment in the country. Amongst the objectives of the National Directorate of Employment is the need to develop and groom young entrepreneurs who are properly equipped with technical and managerial skills to successful start and manage enterprises such as small-scale industries.

When industries are put in place, employment opportunities will be created for our teeming youths. As a result of this, the vital role of industrialization will be inculcated in the minds of entrepreneurs. By extension, it may encourage the entrepreneurs establish more industries in their respective localities. Thus, eventually reduce rural urban migration.

Therefore, the need for research on the Evaluation of the Suitability of Ceramic Raw Materials in Kebbi State for the Production of Tableware for Small-Scale Industry is not only relevant at this time of industrialization drive but quite significant in the development of ceramic in the country. Furthermore, it is expected that the outcome of this study will contribute towards the industrial and economic growth of Kebbi state. In addition, the study is also expected to contribute meaningfully to the development of ceramic literature in any higher institution of learning and research institutes.

Finally, it is hoped that the study will offer useful suggestions to manufacturers, entrepreneurs, investors and interested persons or organizations about ceramic raw materials in Kebbi State.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

In this chapter, some literature relevant to the study was reviewed. This review focuses mainly on topics such as basic ceramic raw materials, procedure for the formulation of ceramic bodies for tableware, casting glazing and firing as well as small scale industry and its advantages and prospects.

2.1 Ceramic raw Materials

The concept of contemporary ceramic in Nigeria started in 1952 at Abuja now named Suleja by Michael Cardew. Although an effort was made by R. Roberts to introduce modern pottery at Ibadan in 1904 but did not fully succeed (Ahuwan, 2002).

In another development, Akinbogun (2002) stressed that one of the significant strides achieved in the field of ceramics is the improvement of quality which creates high demand for the product. As much as there is high demand for ceramic wares, normally the supply should be increased or capacity utilization of the industries should be higher. For this reason, the utilization of raw materials is essential. Ahuwan (2002) further confirmed that there are large deposits of ceramic raw materials across the country. He cited an example of clay which is the basic raw materials employed in ceramic. Similarly, Oladipo (2004), revealed that, Nigeria is endowed with the materials resources. Clay is the commonest material found everywhere in Nigeria and it is the basic raw material in ceramics. According to him, large deposits of kaolin are found in the following places.

Kaoje	-	Kebbi State
Dawakin Tofa	-	Kano State
Jos	-	Plateau state
Ijero	-	Ekiti State
Ekeluse	-	Ondo State

Apart from clay, there are also deposits of feldspar, quartz and limestone widely distributed in the country. Both Gukas (2002) and Cardew (1956) observed that Nigeria has unlimited reserve of the chief raw materials required for ceramics. Bateman (1950) mentioned that the ceramic industry used minerals and manufacture porcelain and stoneware for utility purposes. The main raw material is clay and clay is alone required in the making of stoneware, however, in case of porcelain or white wares other non-plastic materials such as feldspar and quartz are necessary. Generally, mineral resources are the chief raw materials for industrialization. Nigeria has abundant minerals for the establishment of wide range of industries such as chemical and ceramic industries as well as other manufacturing and processing industries.

Klien (2001) classified ceramic raw materials in the following order.

Table 2.1: Ceramic Raw Materials

Ceramic Raw Materials

Plastic Raw Materials	Non Plastic Raw Materials
Kaolin	Feldspar, sand,
Clay	Quartz, Alumina,
Talc, steatite	Limestone, Dolomite.

On this basis, the role and some characteristics of the major important ceramic raw materials for making of tableware were reviewed. The raw materials are clay, feldspar, quartz and limestone.

2.2 Plastic Raw Materials

2.2.1 Clay

Clay is characterized as heavy, damp, plastic material and it becomes harden if dried. In addition, clay can be changed with the application of heat into hard and impervious material. Accordingly, Ahuwan (2002) supported that, clay as a hydrated silicate of aluminum has a definite chemical formula - Al_2O_3. $2SiO_2.2H_2O$. He further stressed that for clay to be workable, some addictives like grog, oxides, bentonite could be combined and mixed with clay. Another interesting behaviour of clay is its workability which gives easy forming and retention of shape. The particle size, the actual clay moisture content and particle bond "determine the clay plasticity".

In his study, Konta (2001) remarked that clay has always played a primary role in human life. Clay raw materials are utilized and their importance in the economic branches, notably, agriculture, civil engineering and environmental studies are recognized on account of their "wide ranging properties, high resistance to atmospheric conditions, geochemical purity, easy access to their deposits near the earth's surface and low price".

Furthermore, Worall (2007) elucidated that clay is undisputably the oldest raw material in ceramics and possibly the earliest ceramic articles were produced generally from natural clay. He further explained that clay normally becomes sticky mass if mixed with water; at wet state, it can be used to make items of different shapes. If dried, clay turns hard and brittle and maintains its shape but cannot resist the action of water at this stage. However, clay no longer changes because of the action of water if heated to the state of rediness.

In a similar way, Umar (2003) supported the fact that the plasticity of clay depends upon the fines of particle size. This characteristic makes clay to be formed into different ways. He added that "if clay is indeed the most widely available material, then it is probably the most widely used".

Possibly all clays contain impurities and the impurities are responsible for the plasticity of clay.

According to Kashim (2003), the dominant role of clay in the life of human beings from the period its usefulness was discovered cannot be over-stressed. Clay is the principal raw material in ceramic production. It is used to produce tableware, bricks, floor tiles, drain pipes, refractory bricks, roofing tiles and the likes. There are different varieties of clay all over Nigeria estimated in millions of tonnes. Manzueche (2003) added that clay is the "tenacious earthy material, hydrated aluminum silicate or earthy malleable substance found in abundance in the earth crust". Clay tends to be soft if wet and becomes hard if in dry state. If fired to high temperature, it becomes "rock like".

The socio-religious function of clay was highlighted, on this account, Gukas (2003) emphasized on the importance of clay in the socio-religions and economic activities of the different cultural and ethnic groups in Nigeria. He said that for centuries, clay has been used as an independable material for building of residential places, households and working structures. However, Manzuche (2003) described clay as one of the world's most important minerals. It is unique, abundant and man for long employed clay for different purposes more than any material, thus its use marked the starting point of technological development.

Ahuwan (2002) held the opinion that tests for plasticity, porosity, shrinkage, tensile strength among others could be conducted to determine clay properties. For easy identification of the plasticity of clay mineral, some coils are rolled and wrapped around the first finger. If the coils are broken, cracks indicate sign of non-plasticity but if the coils retain their proper shape, it means that the clay is plastic and workable.

Ewule (2003) further re-iterated that clay tends to hold any form that is given to it and also hold much water when wet. The main characteristic of clay is plasticity and this unique character is what makes possible the clay to be shaped into different forms. The plasticity of clay is likely as a result of the fineness of the grain size, aging and carboneous matter.

Commenting on the historical perspective of clay, Bateman (1950) agreed that one of the most widespread and early mineral substances used by man is clay. Records of part civilizations are carried along by clay through brick buildings, pottery, monuments and the likes. He further described clay as the earthy substances made up mainly of hydrous aluminum silicates with colloidal material and specks of rock fragments, which generally becomes plastic when wet and stone like under fire. The ability of clay to be moulded into almost any form justified its usefulness.

But Rhodes (1989) stated that clay is the product of geological weathering of the surface of the earth and this weathering process goes on every where. According to him, clay is the most common and readily available material in nature. Clay is the end product of weathered rocks. Rhodes (1989) believed that clay is seemingly pure and light burning and it possesses relatively high percentage of alumina and very low percentage of iron and other impurities.

Predominantly, clay is composed of aluminum and silica but all other oxides attached to it are regarded as impurities. The main advantage of clay is plasticity. The plasticity makes possible the clay to be formed into endless different shapes of ceramic items.

In another perspective, Primer (1974) stated that clay is formed by erosion and glacial action over the ages. It is composed of extremely fine particle size. When clay is heated above 500^0C the chemically combined water is driven off. At this stage clay becomes rigid and still porous and absorbs water. But, its condition will never be changed again by water.

Furthermore, Conrad (1974) said that clay is known to be widespread in nature and that various types of clay deposits having different properties and characteristics are found all over the world. In other words, clay is formed out of the decomposed rock and during the process of decomposition minerals and metals that give colour to the clay are absorbed by it. The most common metal found in clay is the iron oxides which in most cases produce gray, buff or brown colours, although the presence of other oxides and metals aid and influence the colour of the clay.

Generally, clay is the foundation of ceramics. Metallic oxides in clay are so vital that they could make marvellous effect especially as regards to glaze colour. Kashim (1992) revealed that large occurrences of clay have been established all over the country.

Table 2.2: Available Reserves of Some Known Clay Deposits in Nigeria.

S/No	Deposit	State	Types	Reserve in tonnes
1	Olubulu	Anambra	Kaolinite	4,200,00
2	Kaoje	Kebbi	Kaolinite	Very large
3	Tade	Oyo	Brick clay	1, 524, 000
4	Onibode	Ogun	Kaolinite	Large
5	Dawakin Tofa	Kano	Kaolinite	Not available

Source: Bolaji (1992)

Cclay is classified into two broad groups namely – Primary clay and Secondary clay.

Primary clay or residual clay: is found in its original site of decomposition. It is the clay that has been formed on the site of its parent rocks. This type of clay formed has not been transported either by wind or water. Primary clay is characterized by relative purity, whiteness, free from impurities and contamination. Consequently, it lacks relative plasticity. Kaolin is an example of primary clay.

Secondary clay: also known as *sedimentary clay* is the clay that has been transported from original site of decomposition or parent rock by water or wind. In the course of transporting the clay, other impurities such as leaves, grasses, dung and so on are carried along. This type of clay is characterized by its relative plasticity and lacks relative purity. Ball clay is an example of secondary clay.

On the availability of clay in the country, Onuzulike (2004) revealed that clay is abundant and almost sourced free in Nigeria. However, what a ceramist really needs is to excavate, transport and conduct possible tests on the clay.

2.2.2 Kaolin

Large deposits of kaolin have been located in different parts of Nigeria and the reserves are probably estimated at about 800 million tonnes. Accordingly, Grema (2004) declared that the kaolin deposits are found in States like Anambra, Bauchi, Borno, Enugu, Kaduna, Katsina, Kebbi, Niger, Ogun, Ondo, Oyo and other States.

Table 2.3: Kaolin Deposits in Nigeria

State	Location	Reserve Classification	Reserve M/Tonne
Anambra	Ozubulu	Probable	14.2
Enugu	Enugu	,,	769
Plateau	Major porter	Proven	19.0
Katsina	Kankara	Probable	20.0
Kaduna	Maraba-Rido	,,	5.5
Bauchi	Darazo	Proven	10.0
Bauchi	Jagawa	Probable	8.0
Kebbi	Giro/Illo/Kaoje	Not yet quantified	N.A.
Ogun	Abeokuta	Proven	10.0
Ogun	Bamojo	Net yet quantified	N.A.
Ogun	Onibode etc	Not yet quantified	N.A.
Oyo	Tade	Probable	1.5
Ondo	Ofon/Okitipupa	,,	2.0
Oyo	Ado Awaye	Not yet quantified	N.A.
Plateau	Nahuta	Proven	I.O
Plateau	Jos	Not yet quantified	N.A.
Niger	Kpaki, Pategi	,,	N.A.
FCT	Kwali, Dongara	,,	N.A.

Source: Grema, (2004)

According to the Federal Ministry of Solid Mineral Development (2006) Kaolin occurs in viable commercial quantities in every state of the country. Ibrahim and Na, Allah (2005) stated that kaolin or China clay can best be described as “pure, soft white clay” which has relatively low plasticity and when fired it enhances white colour. The main constituent of kaolin is the clay mineral which is formed as a result of de-sentigration of aluminium silicate notably feldspar.

In his opinion, Okoruwa (1986) mentioned that the clay aspect of porcelain is found in kaolin which he described as “a fine textured white primary clay”. Moreover, kaolin due to its geological origin is relatively free from impurities and thus, becomes refractory withstanding temperature up to 750^0C as a result of this property. However, the more the presence of impurities in kaolin, the less its refractoriness.

Highlighting on the significant of kaolin, Rhodes (1989) disclosed that kaolin or china clay is an essential component for the making of pure porcelain or china. Kaolin is a primary clay and hence it is deposited on the site of decomposition. Kaolin is non-plastic compared to most sedimentary clay. Since kaolin has not been transported, it is relatively pure and free from impurities. Kaolin has a melting point above 1800^0C, therefore, it is a highly refractory material. Consequent to its non-plastic and refractory characteristic, kaolin can hardly be used alone as such other materials are added to it to improve its plasticity and workability.

Kaolin is used in the manufacture of various objects and it is an indispensable material in the formulation of ceramic bodies (porcelain and whitewares) to enhance whiteness and strength. Kaolin controls the vetrification in bodies and it is also one of the main materials in glaze formulation.

According to Leach (1973) kaolin is composed of the following

Silica	46.64%
Alumina	39.45%
Water	13. 95%

While disclosing the presence of clay in Kebbi state, Yanko (2001) stressed that clay outcrops extensively in Kebbi state. There is Kaolin deposit in Kaoje and the bauxitic clay deposit near Giro town. Other sedimentary clay deposits are present around Dakingari, koko, Gwandu, Kalgo, Aliero, Tungar Doro and Vadako. It has been on the record that the clay deposit has proven reserve of 6.4 million metric tones and an estimated reserve of over 10 million metric tones.

The Kaoje kaolin deposit is located at Kasadi hill South East of Kaoje. Essentially, the clay is pure kaolin with occasional coarser fraction of silica. Apparently, the kaoje kaolin is white and possesses little or no colour impurities. “The projected volume of the deposit is put at over 87.5 million cubic metres”. Yet again, Yanko (2001) emphasized that the Bauxitic clay deposit extends from Kamba to south of Giro. The clay composition is relatively pure kaolin covering large area.

Different compositions of some kaolin found in Nigeria are as follows.

TABLE 2.4: Typical Chemical Compositions of Some Kaolin found in Nigeria.

Element	Clay Sample				
	Dass (BAS)	Darazo (BAS)	Kankara (KTS)	Kuburivu (BOS)	Wamba (NAS)
Al_2O_3	15.40	17.60	31.45	29.26	26.40
SiO_2	57.80	58.40	44.56	51.34	40.68
FeO	6.60	7.00	0.00	0.00	0.00
F_2O_3	0.00	0.00	1.07	1.60	0.41
TiO_3	0.66	0.40	0.14	0.00	0.00
CuO	0.00	0.00	0.00	0.00	0.00
MgO	2.56	2.50	0.87	0.00	0.00
K_2O	3.80	2.00	0.30	0.00	1.81
Na_2O	0.80	1.30	0.17	1.25	0.00
ZnO	0.00	0.00	0.00	0.00	0.03
M_nO_2	0.01	0.08	0.01	0.00	0.00
CaO	4.75	4.10	0.28	0.00	0.00
Pb_2O_3	0.20	0.20	0.00	0.00	0.02
SO_4	0.00	0.00	0.05	0.00	0.00
Rb_2O	0.00	0.00	0.00	0.00	0.00

Source: Ahuwan (1997), Gukas (1985), Grema (2004), Manzueche (2006)

Key - BAS – Bauchi State

BOS – Borno State

KTS – Katsina State

NAS – Nassarawa State

2.2.3: Ball Clay

Ball clay is secondary or sedimentary clay. It is the clay that has been transported from its parent rock (original site) by water glacier or wind. Ball clay is highly plastic but lacks relative purity like kaolin and it burns to a light gray or light buff colour. At raw state, ball clay is normally dark gray colour. When fired to maturity, ball clay tends to show excessive shrinkage therefore it is usually added to other clay such as kaolin to improve plasticity and workability. It is an important ingredient in the manufacture of porcelain or whiteware because of its plastic quality.

Similarly, ball clay is added to the body to substitute the non-plastic property of kaolin. For this reason, Rhodes (1989) recommended that about 15% of ball clay can be added to a clay body, if whiteness is desired. Addition of more than 15% of ball clay in the white body gives “gray, off white or buff colour”. Presence of much ball clay in porcelain body reduces its translucency. Generally, ball clay has a great role, in the manufacture of ceramic wares and it derives the name from the practice in England of forming the damp clay into large balls.

Table 2.5: Physical Properties of Some Ball Clay Samples in Nigeria

Test	Clay Sample		
	Zonkwa (KDS)	Zaria dam (KDS)	Bomo (KDS)
Plasticity	Good	Good	Good
Total Shrinkage	11%	9%	11%
Porosity	4.3%	1.4%	1.3%
Colour 1300^0C	Reddish to brown	Dark Brown	Dark Brown

Source: Gukas (1985)

2.3 Non - Plastic Materials

2.3.1 Feldspar

According to Klien (2001), feldspar is the most common mineral found on the earth crust. Feldspar is an essential raw material for ceramic industry. It is used in relevant batches for the making of fine ceramic products such as hard ware, vitreous china, porcelain and the likes. Feldspar serves as a fluxing agent. Rhodes (1989) re-iterated that feldspar is far the most common non-plastic ceramic raw material, it is the composition of feldspar which largely accounts for clay. Feldspar is one of the most widely spread minerals.

According to Rhodes (1989) the formulae of feldspar are as follows:

Orthoclase - $K_2O.Al_2O_3.6SiO_2$

Albite - $Na_2O.Al_2O_3.6SiO_2$

Anorthite - $CaO.Al_2O_3.2SiO_2$

Spodumene - $Li_2O.Al_2O_3.4SiO_2$

Feldspar that has high amount of potassium is better to be used for body formulation. While feldspar that has high amount of sodium is more useful in glaze formulation as a result of its relatively low melting point. At about 1250^0C most feldspar melt. If less fussion point is wanted, 5 to 10 percent of dolomite, talc or whiting is added to feldspar.

Both Rhodes (1989) and Grema (2004) reported that feldspar is often the only source of body flux. Indeed feldspar plays an important role as a fluxing agent and it forms liquid during firing. On cooling, the liquid forms a glass and brings the grains of clay and silica together. Feldspar is number 6 on Moh's scale of mineral hardness. In the words of Nelson (1978) feldspar is the main constituent of porcelain and other white bodies. On account of this, porcelain manufactures use feldspar to a great extent for body and glaze formulation.

In addition, Okoruwa (1986) stated that feldspar can be recognized by its cleavage, lustre, hardness and colour and feldspar has two cleavages. However Cardew (1969) revealed that potash feldspar is often pink in colour but that this is not due to iron oxide. Cardew (1969) observed that it always has a pure chemical composition. These consists of the elements oxygen, silicon and alumina with potash, soda and calcia.

In another revelation, Opoku (2003) disclosed that feldspar is abundant in commercial quantities in many states in the Northern part of Nigeria. In furtherance to this, Grema, (2004) reported that there are large deposits of feldspar in the granite rocks of Nigeria and that feldspar rich in pegmatites are found in different parts of the country.

Table 2.6: Feldspar Deposits in Nigeria

S/No	State	Location	Type	Reserve
1.	Kogi	Egbe	Potash	Accurate
2.	Kogi	Okene	Potash	Reserve
3.	Osun	Oshogbo	Potash	-
4.	Ondo	Ijero	Potash	-
5.	Kaduna	Kafanchan	Potash	-
6.	Borno	Gwoza	Potash	-
7.	FCT	Abuja	Potash	-
8.	Ogun	Abeokuta	Potash	-

Source: Grema (2004)

Furthermore, Yanko (2001) disclosed that the pronounced presence of major rock types-igneous, metamorphic and sedimatary provide the mineral potential of Kebbi State. These mineral resources include feldspar, quartz and limestone.

Table 2.7: Typical Composition of Some Nigerian Feldspar Mineral

Element	Feldspar Sample		
	Zaria Feldspar (KDS)	Gwoza Feldspar (BOS)	Unguwan Nungu Feldspar (KDS)
Al_2O_3	14.49	15.57	13.23
SiO_2	64.71	62.68	65.75
FeO	0.56	0.00	0.86
F_2O_3	0.81	1.68	0.80
K_2O	0.67	10.35	0.19
Na_2O	0.76	3.58	0.30
MgO	0.00	0.20	0.00
CaO	0.00	0.00	0.00

Sources: Gukas (1985), Grema (2004)

2.3.2 Quartz

Quartz is one of the main constituent used in the production of porcelain. Combines with other basic oxides of fluxing components to form a glass, which normally gives strength to the ware. Okoruwa (1986) observed that quartz enhances strength to the final fired ware and as a form of silica, it is active in reducing plasticity and shrinkage. Waye (1967) added that the grain size of quartz is very important and effects the working properties of the body. If the particle size of quartz is small, the process of fusion becomes easier. Quartz has a higher thermal expansion and it increases the strength of the porcelain body.

Quartz controls the vitrification of the body and dictates the degree of translucency in the porcelain body. Basically, quartz that is relatively free from iron oxide and other impurities facilitates more translucency. Quartz also promotes rapid drying and decreases the shrinkage rate in the body. Bateman (1950) added that quartz decreases plasticity, shrinkage and it also improve refractoriness.

Moreover, Gukas (1985) found that the crystal quartz possesses quite a number of distinct forms, however, it depends upon the temperature. Quartz crystals are re-arranged which is followed in volume whenever the temperature increases. The change occurrence is known as alpha beta quartz.

In his words, Rhodes (1989) stated that quartz used to undergo a transformation from alpha to beta quartz when a temperature of 573^0C is attained and this act increases the stability of silica. Okoruwa (1986) disclosed that quartz is hard to grind as such it needs to be calcined. Singer and singer (1963) supported the assertion that quartz is normally calcined and in the process of calcinations quartz is rendered weak and soft. Therefore the jaw-crushing of the quartz would become easy. Grema (2004) disclosed that Gwoza quartz in Borno State is composed of

Alumiina 0.32; Silica, 92.94; FeO, 1.60; K_2O 1.54; Na_2O, 2.93; MgO, 18.4; CaO, 17.46.

The craze tendency in glaze can be stopped, if correct amount of crystalline quartz is used in the body. And consequent to quartz tendency to cause dunting, lowering of mechanical strength and worsening of glaze appearance". Singer and Singer (1963) suggested that too much use of quartz should be avoided in glaze formulation. Quartz which is the main source of silica for body and glaze is number 7 on Moh's scale of mineral hardness. Apparently, quartz is colourless or white, transparent or translucent although in some cases it is coloured by impurities.

2.3.3 Limestone

Limestone (whiting) is most common source of calcium oxide or calcium carbonate. Based on this, Cardew (1979) disclosed that apart from clay, silica and feldspar another important and vital ceramic raw material is limestone Limestone is a rock which originated as chemical or organic deposits and are to a large extent pure. Cardew (1979) further emphasized that "some crystalline limestone are nearly 99 percent calcium carbonate-$CaCO_3$. lime-CaO.

Similarly, Yanko (2001) confirmed that the kalambaina (where the cement company of Northern Nigeria, Sokoto is located) formation in geological literature covers extensively some part of Kebbi state and within the formation, there is a large deposit of limestone. Part of Kebbi State where limestone is located includes Maiyama, Katanga, Mayalo, Andarai and Mungadi areas.

On the other hand, Yanko (2001) revealed that the limestone occurrence in Katanga and Mayalo areas display a high degree of purity. He further confirmed that the sample analysis showed between 94.5% and 99.94% of calcium carbonate. The limestone reserve in Katanga/Maiyama area is estimated at 750 million metric tones and that of Mayalo and Dangamaji is 654.72 million metric tones. In another perspective, Grema (2004) revealed that Yadi Gilam limestone in Borno State is composed of Al_2O_3, 3.00; SiO_2, 5.52; K_2O, 1.21; Na_2O, 1.40; CaO, 4.68; MgO, 2.62, Fe_2O_3, 2.40.

2.4 Identification of Minerals (Ceramic Raw Materials)

Although recognizing minerals is the main responsibility or job of experts like geologists, Cardew (1979) suggested ways or tests that could be employed to recognize different minerals. These tests required no sophisticated instruments to enable ceramists dictate or trace the right minerals for ceramic production. The tests include:

2.4.1 Fracture

According to Grema (2004), fracture is the manner a mineral breaks if it does not go along cleavage or parting surfaces. For instance “curved and smooth fracture" seen in quartz or glass. Cardew (1979) classified fracture in the following order.

Conchoidal	-	(like a shell)
Even	-	(Flat or nearly flat)
Uneven	-	(Example quartz rough with minute irregularities)
Hackly	-	(Set with spiky fragments)
Earthly	-	(Example chalk)

2.4.2 Lustre

Lustre of a mineral refers to its surface appearance especially in reflected light. Cardew (1979) specified lustre with an example as follows:

Vitreous	-	Quartz
Metallic	-	Prites
Resinous	-	Nepheline
Pearly	-	Feldspar
Silky	-	Talc
Adamantine	-	Diamond
Greasy	-	A mineral which exhibits a thin layer of oil such as massive quartz, (Grema, 2004)

2.4.3 Cleavage

Grema (2004) emphasized that "cleavage is the breaking of a crystal between atomic planes. It is also a directional properties and any parallel plane through a crystal is a potential cleavage". Cardew (1979) explained as follows:

Mica - easily cleaved parallel to the basal plane.

Quartz - no cleavage

Feldspar - two cleavage at right angles, producing sharp ectangular edges.

2.4.4 Hardness

A scale of mineral hardness invented by a German Mineralogist Friedrich Moh remained the most effective way of identifying minerals. The theory consists of ten common minerals from the softest mineral (Talc) and the hardest mineral (Diamond) assigned number one and ten respectively. It is supposed that each of the mineral will scratch the mineral of lower hardness.

Table 2.8 Moh's Scale of Mineral Hardness

Hardness	Mineral	
1	Talc	
2	Gypsum	
		Finger nail 2.5
3	Calcite	
4	Fluorite	
5	Apatite	
		Knife, blade, glass 5.5
6	Feldspar (orthoclase or microline)	
7	Quartz	
8	Topaz	
9	Corundum	
10	Diamond	

Source: Dietrich (1980) in Zauro (1988)

From the table above, diamond has the highest number. In this regard, diamond is referred the highest mineral. The lowest number is given to talc, therefore talc is the softest mineral. In the same vein, finger nail placed on hardness 2.5 could be used to scratch on talc or gypsum that are considered hardness 1and 2 respectively. Furthermore, knife, blade and glass positioned on hardness 5.5 could also be employed to scratch apatite of hardness 5.

2.4.5 Steak

Steak refers to the colour of the powdered mineral

2.4.6 Parting

The breaking characteristic of the mineral is known as its parting. Grema (2004) stated that if “minerals break along planes of structural weakness, they have parting”.

2.4.7 Tenacity

The resistance that a mineral shows to breaking, crushing, bending or tearing its cohesiveness is known as tenacity. Below are the examples.

Brittle	-	This is when a mineral is powered with little effort.
Maleable	-	It indicates the situation when a hammer is used on a mineral and the results given thin sheets.
Sectile	-	When thin shapings are achieved during cutting with knife.
Ductile	-	If the mineral is drawn into wire.
Flexible	-	A mineral that bends, however, its original shape cannot be regained again.

Plastic - If a mineral re-gains its original shape after being bent as a result of the release of pressure.

2.4.8 Crystal Form

Specifically, Cardew (1979) mentioned that there are six crystallographic systems, though he emphasized that recognizing the systems is indeed difficult for the beginner. The systems are stated below.

1. The cubic system
2. The tetragonal system
3. The hexagonal system
4. The orthorhombic system
5. The monoclinic system
6. The triclinic system

2.4.9 Specific Gravity

A number that expresses the ratio between the weight of a substance and the weight of an equal volume of water at 40^0C is known as the specific gravity, Grema (2004). But for Cardew (1979) specific gravity is rational only in the field especially if the size of the mineral is considerable.

2.5 Tableware

According to Faurnier (1973), tableware is a general term refers to ceramic products concerned with the serving of foods and drinks. Longman (2001) stated that tableware are the plates, glasses used “when eating a meal”.

In another view, Ahuwan (1981) revealed that different communities in Nigeria mainly used tableware not only for the purpose of serving of food and drinks but equally used them to decorate apartments inorder to display their economic powers. He said “the avarege middle class at times even lower class home has tea set, stoneware and porcelain”. The commodities are common sights during wedding ceremonies. The newly wed decorate their apartments with variety of ceramic wares call “Fadi ka mutu”.

Tableware products are cup, mug, plate, jug, dish and the like made from porcelain, stoneware, bone china and earthenware ceramic bodies. The shaping method in the making of tableware articles are slip casting, throwing, jiggering and jollying among others. Against this background, it is pertinent to highlight on one of the ceramic bodies from which tableware products are made, for instance porcelain.

2.5.1 Porcelain

Longman (2001) defined “porcelain as a hard shiny white substance that is used for making expensive plates and cups etc” and Faurnier (1973) said that porcelain is china clay (kaolin) and silica combined with little flux fired to vitrification point.

He propounded the basic recipe for porcelain as follows:

Material	Percent (%)
China clay (kaolin)	50
Feldspar	25
Quartz or flint	25

In his study, Faurnier (1973) observed that the presence of ball clay diminishes porcelain translucency, Rhodes (1989) noted that up to 15% of ball clay will improve the plasticity of kaolin in the composition though the impurities and shrinkage will be increased.

From the general description of porcelain, Hamer (1975) revealed that porcelain is a vitrified, white and translucent ware. But this description refers to the porcelain that is usually fired at 1300^0C and above, Rhodes (1989) stated that porcelain is a stoneware body that cannot be formulated from any known single material. Therefore, porcelain is formulated from a proportional mixture of ingredients such as kaolin, feldspar and flint. For

Braganza (2001) explained that:

> Procelain is a type of ceramics highly valued for its beauty and strength, whiteness, a delicate appearance and translucence characterize it. It is known primarily as a material for high-quality vases, tableware, figures and other decorative objects. Porcelain is produced mainly from three major raw materials namely clay, feldspar and silica.

Expressing a similar view, Gukas (1985) highlighted that porcelain is white, dense, vitreous translucent stoneware produced from a proportional mixture of kaolin, feldspar and flint fired at 1300^0C and above. While Conrad (1977) viewed that porcelain is a ceramic body compound which has different characteristic with stoneware. His words “Porcelain is a high temperature firing clay that is hard, dense and translucent when thin”. Braganza (2007) observed that “the higher firing temperature, the more translucent was the porcelain.

Furthermore, Waye (1967) noted that the usual composition of porcelain is generally considered as follows:

Material	Percent (%)
Clay	50
Feldspar (in a rational basis)	25
Quartz	25

Waye (1967) further stated the appropriate limits of composition for the three chief ingredients:

Material	Percent(%)
clay substance	40-60
Feldspar	20-35
Quartz	20-25

In addition, Singer and Singer (1963) and Rhodes (1989) suggested the use of whiting in the porcelain composition.

Material	Percent (%) (Rhodes)	Percent (%) (Singer)
Kaolin	30	37
Ball clay	15	7.5
Feldspar	18	18
Flint	35	36
Whiting	2	1.5

In another perspective, experiment on porcelain was conducted with raw materials obtained from different parts of Nigeria. Gukas (1985) used local materials from Kaduna and Katsina States; Okoruwa (1986) utilized locally sourced raw materials to produce porcelain, while Umar (1988) and (2000) experimented on ceramic raw materials from Kaduna and Kwara States to produce Bone China and employed Alkaleri Kaolin, Okene Quartz and Feldspar respectively to formulate porcelain. Zauro (1988) experimented on whiteware with materials from Sokoto and Kwara States and Grema (2004) experimented on porcelain from the mixture of Kuburivu kaolin, Gwoza feldspar and Gwoza quartz.

Table 2.9: Some Porcelains and Whitewares Recipes Experimented in Nigeria

Material	Experiment conducted				
	Gukas	Okoruwa	Umar	Zauro	Grema
	%	**%**	**%**	**%**	**%**
Feldspar	20	30	30	30	50
Kaolin	50	40	40	35	30
Quartz	20	20	30	25	20
Ball clay	10	10	-	10	5
Bentonite	-	-	-	-	5

Source: Gukas (1985), Okoruwa (1986); Umar (2000) Zauro (1988) Grema (2004)

Porcelain is said to have originated in China, the production begun during the Han Dynasty (206BC-220AD) thus marked the birth of ceramic development. The Chinese made experiments using petuntse and kaolin. Chinese achievement in this respect was as a result of their foresight to utilize the natural materials found in the environment. The perfection of porcelain production in terms of maturity, variations and beauty was recorded during the period (960 – 1223AD) Sung Dynasty. Porcelain has been playing a major role as an article of trade for china up to the present period.

Gukas (1985) revealed that the production of porcelain bodies from Nigeria's local raw materials will promote and enhance the technical aspect of ceramic. In this regard Nigeria may likely move towards technological self-reliance.

2.5.2 Body Formulation

Essentially, the formulation of porcelain body involves the blend of three main materials namely feldspar, kaolin and quartz. Each of the material has a vital and significant role in the composition.

Feldspar is the source of the flux in the body; therefore it helps the fusion of the body. Kaolin which covers the clay aspect in porcelain withstands temperature up to 1750^0C as a result of this; it gives refractoriness to the body as well as workability and white colour. The silica aspect is traced in quartz and as a glass former quartz determines the degree of translucency and controls the vitrification of the porcelain body Quartz helps the body to become hard and strong and together with feldspar, quartz decreases shrinkage and promotes rapid drying of the body.

Another literature that relates to the body formulation was in the study conducted by Okoruwa (1986). In the study, Okoruwa clearly mentioned that suitable body formulation can be achieved through step by step substitution of one ingredient by another which goes on until a desired outcome is accomplished. In addition Nelson (1958) in Zauro (1988) was of the opinion that “empirical experimentation and testing are the most practical methods to be adapted so as to obtain suitable blend of materials”. Singer (1963) suggested a triaxial blend involving three main ingredients.

A sixty-six triaxial blend diagram on distribution of porcelain materials is shown below.

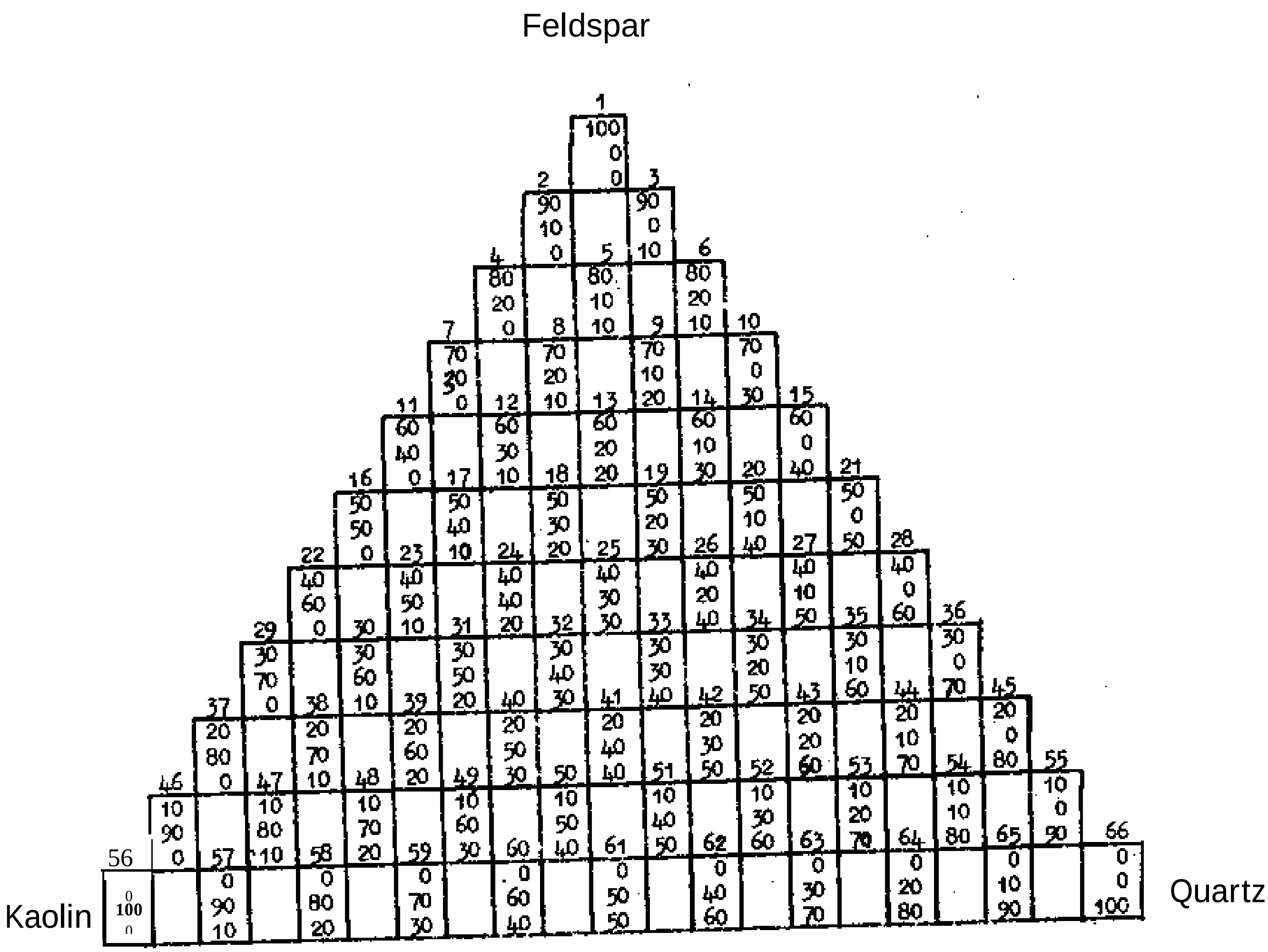

Fig 1: Distribution of porcelain body material in the triaxial blend,
Source: Okoruwa (1986) and Zauro (1988)

In a similar way, Okoruwa (1986) achieved a suitable blend of materials through the use of 36 member triaxial blend. In this case blend involving two materials in the sixty six member triaxial blend were avoided.

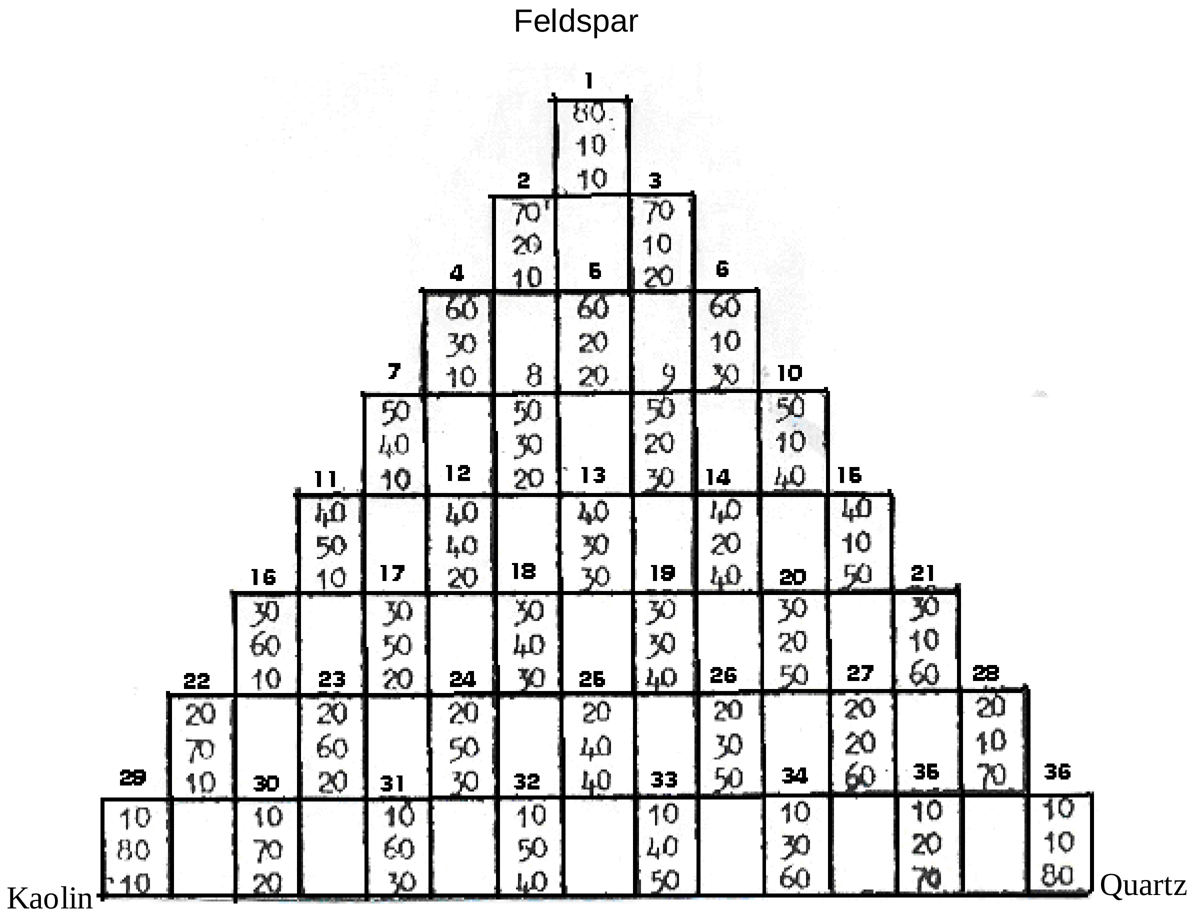

Fig 2. Distribution of materials in the triaxial blend.

Source: Okurowa (1986)

2.5.3: Slip Casting

Casting slip is a liquid made from mixing dry clay and other ingredients, water and deflocculants in certain proportions and it is poured into a mould produced from an absorbent material normally plaster of paris. The mould absorbs a high amount of water from the casting slip and through this, a layer of stiff clay is built on the cavity or inside of the mould. The casting slip is left in the mould for minutes to allow the required thickness of the layer which usually, depend upon the time given.

Furthermore, when the required thickness is achieved the excess slip is poured off. At this point the layer formed in the mould dries, shrinks, and gradually pulls away from the sides of the mould. The cast is removed from the mould as soon as the cast has loosened itself, when it is also confirmed that the cast is plastic and firm enough to maintain its shape if handled.

When the cast is finally removed, forming marks are fettled and it is allowed to dry slowly and evenly before it goes for the bisque firing. Cowley (1978) stressed that “slip casting has been associated with the manufacture of domestic tableware, sanitary ware and highly regulated technical and industrial ceramics” He further observed that great number of people in the field of ceramic have considered and admired slip casting as an effective method of expressing their creativity and ideas.

Discusion on casting slip, Okoruwa (1986) was of the opinion that it is necessary to develop a good casting slip that will enhance easy release of the cast from the mould as well as comfortable drain of the slip. To obtain slip fluid of good pouring consistency, it is normally made from about equal part of water and clay. According to Gukas (1985) clay mixed with water will make a slip however such slip may not obtain a satisfactory cast due to its tendency to high shrinkage, cracking in the mould and warpage. Clay particles with static electrical charge thus become stick, therefore to produce a clay fluid the particles need to be separated and broken up. To achieve this, a substance known as electrolyte or deflocculated is usually added to make a liquid suspension and also to electrical charge on clay particles. In this condition, the clay is deflocculated. A deflocculant is an alkali like sodium silicate or soda carbonate.

Naturally, the addition of the sodium silicate changes the state of the sticky mass of clay and water to a creamy smooth liquid and only small amount of deflocculant is necessary. Principally, deflocculant or electrolyte is added into the clay and water mixture purposely to decrease the amount of water needed to make a desired fluidity. Rhodes (1989) suggested one percent or less of either sodium carbonate or sodium silicate to be added to the dry weight of the clay. In another development Okoruwa (1986) employed 4 gram of deflocculant to every 500 grams of dry materials. But Nelson (1978) agreed with the use of 1 gram of electrolyte to the dry weight of the clay. Cowley (1978) recommended about 0.3%-0.5% of the weight of the material.

To mix the slip, ingredients in powdered form were weighed out and mix with required amount of water and the deflocculant weighed accordingly to be dissolved in hot or warm water and added to the mixture while stirring continuously. Cowley (1978) recommended about 35-50 parts of water to every 100 parts by weight of material.

The slip is ball billed after which it is left undisturbed to observe thixotropy and viscosity. Gukas (1985) observed 6 hours ball milling and left the slip undisturbed for 24 hours. Grema (2004) ball milled the slip for 4 hours and left the slip undisturbed for 2 days. The slip was sieved through 80 mesh screen. Okoruwa (1986) confirmed that grinding or ball milling of the slip improves translucency, promotes the dry strength and decrease porosity. The slip is stirred properly before the commencement of the actual casting operation.

2.5.4 Mould

Basically, ceramic mould required to be produced out of a porous material capable of absorbing moisture from clay cast. The absorption leads to drying and later shrinkage takes place which enhances easy release of the model from the cast.

The most common moulds are those made from Plaster of Paris. It is obtained from gypsum, a hard rock calcined until the chemically combined water is driven off. When the rock is heated, it tends to reduce to a soft substance which is easily crushed into a fine white powder. A hard white solid form is obtained when the mixture of plaster of Paris and water crystallized. It is called plaster of Paris because the original gypsum came from Paris.

The solidified plaster is porous and readily absorbs water. Primmer (1974) disclosed that plaster of Paris is an ideal material for mould due to its ability to support slip until a shell is formed given a permanent and predetermined shape. Moulds are indispensable for mass production of ceramic articles.

In order to make a mould, a model is necessary. The model is the intended shape of the cast. Normally, the model is solid and because of the cast tendency to shrink during drying and firing, it is made larger than the required finished cast. Depending upon the model a one piece, two piece and multiple piece plaster moulds are made. To make a plaster mould the mixed plaster is poured over the model.

2.5.5 Glaze

A glaze is a thin glass like effect that is melted by heat on the surface of the ceramic article. In other words glaze refers to the shiny surface on the ceramic ware formed as a result of fusion of silica and other materials. Counts (1973) defined glaze as “an ingenious solution of assorted oxides fused on or chemically combined under heat. Emodah (2006) reported that the “main materials that are needed in glaze formulation include silica, feldspar, limestone and the likes and that these materials are abundant in Nigeria.”

In his view Nelson (1978) observed that glaze formulation required no complexity and he acknowledged that the essential components include silica, flux, in addition a refractory material. Rhodes (1989) discovered that about 80% of feldspar and 20% of other components could form a fair start for the formulation of glaze. Glaze is a crux of ceramic and very important for this study. To make an acceptable ceramic piece there is need for the body and the glaze to fit.

Emphasizing on the relationship of body and glaze, Okoruwa (1986) pointed out that the body and glaze should be regarded as a single system, as such it is significant to ensure the balance between the body and glaze, Rhodes (1989) emphasized on the upper limit of glaze material which is aimed at making the body and glaze fused together. He expressed that quartz and feldspar should take about 70% and 30% to be made up from other ingredients.

Table 2.10: Upper Limit of Glaze Material

Material	Percent (%)
Feldspar	50
Quartz	20
Clay	0-15
Whiting	0-15
Barium carbonate	0-15
Magnesium carbonate	0-15
Dolomite	0-15
Talc	0-15
Zinc oxide	0-15

Source: Rhode (1989)

Emodah (2006) re-iterated that glaze materials should be ball milled to ensure proper blending of the ingredients. Conrad (1974) outlined a glaze rating scale of 10 to 0 as follows.

10 - Translucent, no flows in the glaze.

8 - Translucent, few flows in the glaze.

6 - Few cracks and bubbles.

4 - Mainly cracks, bubbles or craters: opaque rough glaze surface.

2 - Glaze burned away – flaked off.

0 - Chemical reaction or glaze corroded the clay.

There are different methods of glaze application on wares. They are: dipping, pouring, spraying and brushing.

2.5.6 Firing

Wares are subjected to heat so as to develop a vitreous bond. Normally, ceramic body undergoes two distinct firings. First firing is known as biscuit or bisque, the name is attached to a once fired ceramic body in which there is no glaze. In other words biscuit firing refers to body which has had only one firing unglazed. The second phase of firing is called glost or glaze firing which is the adjectival form of the word glaze. It is the state in which the glaze is fired on the body. The firing commences slowly and the temperature in the kiln gradually attains 200^0C. At this point any remaining physically combined water escapes. As the temperature rises to 350^0C organic impurities present disintegrate and begin to burn. The actual firing period begun when the temperature reaches 450^0C where the chemically combined water is driven off. This is the time which expansion and contraction take place.

The firing rate can be done much faster after 600^0C and advances until the maturity temperature of clay is reached when elements in the clay begun to fuse. With the increase in temperature vitrification is achieved and slowly the clay is melted. Primmer (1974) noted that clay body which has had biscuit fire to a temperature above the 600^0C point is safe to handle and cannot be affected by water since the main chemical change has taken place. In addition the body accepts the glaze easily because of its porous nature.

In glaze firing, Ware must be handled carefully to prevent distortion of the raw glaze coating. As soon as the firing commences, the first initial development in the glaze is the sudden change of carbon and sulphur. Whenever the temperature reaches the sintering point, the cohension of the materials must have started, thus marked the beginning of fusion in some of the components. The glaze becomes smooth, viscous liquid and covers the surface of the ware if fused or close to maturity temperature. Essentially at this stage the temperature starts to fall while cooling begins and for this reason the glaze eventually solidified. Rhodes (1989) noted that the period of cooling of the kiln should be the same as the period of heating.

Furthermore, Gukas (1985) disclosed that porcelain “reacts very much as any other type of clay body”. The uncombined water evaporates if the kiln attains 100^0C and that point the total dry state of the body emerges. The second change occurs at about 350^0C and at this stage the chemically combined water escapes. While at 500^0C the piece of clay is dehydrated and no longer disintegrate, meaning that the irreversible chemical change has begun. During this period, the clay particles would have lost its plasticity.

Porcelain needs proper vitrification therefore enough time as well as right temperature must be considered to facilitate easy vitrification. Rhodes (1989) stated that in true porcelain, the body and the glaze are expected to mature together in a high firing. Porcelain body should be vitreous and the glaze should also be very hard to scratch and at the same time the glaze should appear as “an integral part of the body”.

2.6 Small Scale Industry

The concept of Small Scale Industry often merge with that of medium scale industry. Thus, known as small and medium Industries (SMIs) and in other cases it is termed small and medium enterprises (SMEs).

The economic significance of small scale industries can not be over stressed; consequently, Olurunshola (2006) acknowledged that small and medium industries have been widely regarded as the spring board for sustainable economic development. He further re-iterated that the small and medium industries have the capabilities to contribute to a large extent in many developmental programmes which include the efficient utilization of available resource, job creation, enhancement of domestic savings for investment, promoting and development of local technology as well as entrepreneurslip.

Similarly, Udechukwu (2006) stated that SMEs are considered by government and other development agencies like UNIDO as “the main engine of growth and a major factor in promoting private sector development and partnerslip”. Udechukwu (2006) revealed that UNIDO has acknowledged the enormous contribution of SMEs to the economic growth of African nations and hence described SMEs “SMALL IS PROFITABLE IN AFRICA”. For this reason, the development of SMEs is necessary for the growth of the nation. Besides, SMEs contribute to the upliftment of living standard and enhance “substaintial local capital formation”. In addition, they are known for high capability and productivity. In respect to the equitable and sustainable industrial distribution and wide spread, SMEs are highly recognized. Olurunshola (2006) emphasized that apart from sustaining the indigenous technology SMEs supply home markets with locally made products. They are also able to withstand the difficult change of market situation due to their “typical low capital intensity”.

In view of the widespread of SMEs, they promote efficient resource utilization and equally facilitate an effective means of reducing rural-urban migration. Furthermore, SMEs made products for use in large scale enterprises, thus strengthening the industrial inter linkages. Apparently, SMEs are the reliable pillars for the sustainable economic development. Despite the fact that SMEs play significant role in poverty alleviation enroute their labour intensive nature, SMEs are great agents for the growth of employment. Olurunshola (2006) strongly emphasized that the SMEs have been very active in the manufacture of goods and services as well as product demanded for the construction industry. To this end, SMEs are therefore vital and fundamental for the overall development of the country.

In addition, Nwogu (2006) agreed with the fact that the advantages of SMEs are numerous. Apart from enhancing the “logical starting point” for the large business they encourage the entrepreneurial thrust”. The strength of SMEs is believed to be the backbone of the economy. In other words, the more active are the SMEs, the more vibrant is the economy.

In line with its fundamental role in the socio-economic life of the nation, SMEs manufacture goods and provide services in order to improve the living standard of the citizens. Udechukwu (2006) opined that the SMEs are vital sector that will bring about “the contribution of the private sector and provide the critical building blocks for industrialization and sustainable economic growth". On this account, there is need to create the required enabling environment for the development SMEs.

The definition of SMEs change from time to time. Again it depends on the nations level of economic development, as a result, the definition is dynamic. Generally what is regarded a small scale industry in one nation may be considered in another country a large scale or medium scale industry. The Central Bank of Nigerian which has the responsibility for the nations economic development made attempts to come out with a standard definition that will remove any form of ambiguity. To this end, it was agreed that the definition be revised in every four years.

Udechukwu (2006) stated that (at the 13th council meeting of the National Council of Industries held in July, 2001) Micro, Small and Medium Enterprises (MSMEs) were defined in the following order).

- *Micro/Cottage Industry:* An industry with a labour size of not more than 10 workers, or total cost of not more than N1.50 million including working capital but excluding cost of land.
- *Small Scale Industry:* An industry with a labour size of 11-100 workers or a total cost of not more than N50 million, including working capital but excluding cost of land.

- *Medium Industry:* An industry with a labour size of between 101-300 workers or a total cost of over N50 million but not more than N300 million, including working capital but excluding cost of land.
- *Large Scale:* An industry with a labour size of over 300 workers or a total cost of N200 million, including working capital but excluding cost of land.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.0 Introduction

To the best of the knowledge of the researcher, mineral resources that are available in Kebbi State have not been studied mainly for the purpose of producing tableware. In this respect, the study sought to evaluate the suitability of ceramic raw materials in Kebbi State for the production of tableware for small scale industry.

This chapter reveals how the entire study was conducted in order to accomplish the said objectives of the study. However, studies on the formulation of ceramic tableware earlier performed by research scholars like Ahuwan (1981), Gukas (1985), Okoruwa (1986), Umar (1988), Zauro (1988), Sullayman (1997), Grema (2004) and Braganza (2007) were found to be valuable documentary evidences that guided this research.

3.1 Research Design

According to Asika (2001) research means "the structuring of investigation" with a view to identifying variables as well as the relationship that exit among them. It is also used to collect data that assist the study test hypothesis and in the same manner, research design helps the study to answer questions. Specifically, research designs are used by researchers as a blue print to obtain data before the real study. According to Asika (2001) there are three important categories of research design namely: survey, experimental and expost facto.

In addition, Asika (2001) emphasized that research design is "an outline or a scheme that serves as a useful guide to the researcher in his efforts to generate data for his study". In the light of this, the study adapted survey research and experimentation research. In the survey research, the study carefully selected samples from the population employing some techniques of sampling for further study of the characteristics of the population. For this reason, the study considered the survey research to obtain information about ceramic raw materials in Kebbi State.

Similarly, the experimentation design allows the study to have control over all the independent variables and it could also facilitate detailed examination of the variables. Asika (2001) stated that "experimentation as a type of research explores whether relationslips exist among some identifiable variables and what the nature of these relationslip is". Consequently, the study adapted the experimental research purposely to conduct laboratory or studio experiments to evaluate the suitability of the ceramic raw materials in Kebbi State for the production of tableware for Small Scale Industry.

3.1.1 Population of the Study

Mbahi (2001) stated that "population denotes the whole of the large group from which the members of a sample are selected". In another perspective, Asika (2001) mentioned that "population is made up of all conceivable elements, subjects or observations relating to a particular phenomenon of interest to the researcher".

In this connection, the population of the study was the entire ceramic raw materials found in Kebbi State.

3.1.2 Sample

Sample is an important part of the population and the method of drawing samples is called sampling. Precisely, sampling is a subgroup drawn from population which is generally large. In otherwords, sampling is the representative of the population and a good sampling is expected to have similar characteristics of the actual population.

The main reason for sampling is to enable the researcher obtains possible accurate data that exhibits the characteristics of the entire population. The sampling technique adapted for the study was the random sampling. In this way, every item in the population has an equal opportunity to be chosen. Mbahi (2001) noted that in random sampling each of the elements in the population takes an equal probability for selection.

The study was delimited both in scope and materials to Kebbi State. Subsequently, out of the numerous ceramic raw materials found in Kebbi State, few were randomly selected for the purpose of this study. They are kaolin, ball clay, feldspar, quartz and limestone.

3.1.3 Pilot Study

Pilot study has a significant function particularly to obtain prior information required to support the original idea of the research. The result of the pilot study may help the study to achieve effectiveness in the main survery. The study desired to ascertain the types of ceramic raw materials used in some ceramic small scale industries/studios in Kaduna State, Niger State and FCT Abuja. They were selected at random.

To this end, a pilot study was conducted employing survery method inorder to gather information from respondents with a view to establishing the types of ceramic raw materials used in the ceramic small scale industries/studios. These include:

1. Ceramic Section, Department of Industrial Design, ABU, Zaria.
2. Maraba Jos Pottery, Kaduna
3. Dr. Ladi Kwali Pottery, Suleja
4. Habib Pottery, Minna
5. Ceramic Section, Niger State Council for Arts and Culture, Minna
6. Bwari Pottery Abuja.
7. Ushafa Pottery Centre, Abuja.

8. Ceramic Section Federal Capital Territory Abuja, Arts council.

9. National Council for Arts and Culture, Abuja.

Sample of the raw materials to be identified for the study were kaolin, ball clay, feldspar, quartz and limestone. The instrument of survey method employed for the pilot study was the questionnaire.

The questionnaire was administered to the official (Managers) of ceramic small scale industries or studios. Respondents indicated that the major raw materials used for the manufacture of ceramic wares in these industries or studios were kaolin, ball clay, feldspar and quartz.

Based on the findings from the pilot study, an attempt was made to determine if these raw materials could be located in Kebbi State. Once more, a survey method was adapted and a questionnaire designed was administered to 25 respondents. They were classified into two broad groups and they were also chosen at random.

Group I **–** Employees in the Federal, State and local Government Agencies (EGA) including Geologists responsible for industrial related matters. Example of such agencies are the Federal Ministry of Solid Minerals Development, Raw Materials Research and Development Council, Kebbi State Ministry of Commerce, Industry and Co-operatives; Kebbi investment Company Limited and also Local Government Councils in Kebbi State. It is assumed that as employees responsible for industrial matters and policies, they were expected to know about the mineral resources in Kebbi State.

Group II **–** Traditional Potters. The selection of traditional potters was on the assumption that being producers of traditional pottery, they should have knowledge about the deposit of clay and probably feldspar or quartz. Ahuwan (2003) stressed that traditional potters play much important role in locating clay deposits. He further suggested the following channels for prospecting clay deposits.

1. Use of geological maps – prepared by the Federal Geological Survey.
2. Traditional Potters
3. Road construction trail

Respondents were asked to give information, indicate or identify where kaolin, ball clay, feldspar, quartz, limestone, dolomite and talc might be found in Kebbi State. The names of the ceramic raw materials were translated in Hausa language particularly to serve and guide the traditional potters easily identify the raw materials. The use of tables for this study was considered. Zauro (1988) employed tables to provide clearly the presentation of data "through visual display of the number of respondents".

In this regard, responses from group I and group II. Knowledge about some raw materials are shown in table 3.1.

Table 3.1: Distribution on Respondents Knowledge about the Sampled Raw Materials in Kebbi State

Raw material	Respondents		Yes		No	
	EGA	Traditional potters	Total	%	Total	%
Kaolin	17	8	25	100	-	-
Ball Clay	17	8	25	100	-	-
Feldspar	17	8	25	100	-	-
Quartz	17	8	25	100	-	-
Limestone	17	8	17	68	8	32
Dolomite	17	8	4	16	21	84
Talc	17	8	4	16	21	84

Source: Zauro (2004)

The table above shows the arrangement of Raw Materials, Respondents and the Total Responses that were in favour of Yes or No. Out of twenty five respondents, all the seventeen from group I understood kaolin, feldspar and quartz, on the other hand, all the eight respondents in group. II equally understood kaolin, ball clay feldspar and quartz representing 100% for each material respectively. But for limestone only the seventeen respondents in group I representing 68% could describe limestone. All the eight respondents in group II had no knowledge about limestone.

As far as dolomite and talc are concerned, four respondents representing 16% had indicated knowledge of dolomite and talc respectively. While twenty one respondents representing 84% indicated no idea. For this reason, it was clear that majority of the respondents did not understand the minerals – Dolomite and Talc but knew kaolin, ball clay, feldspar, quartz and limestone.

Table 3.2: Location of Kaolin Mineral in Kebbi State.

Respondents		Location			
EGA	Traditional potters	Town/Village	Local Govt. Area	Total	Percent (%)
7	3	Kaoje	Bagudo	10	40
4	3	Giro	Suru	7	28
4	1	Koko	Koko/Besse	5	20
2	1	D/Gari	Suru	3	12
17	8			25	100

Source: Zauro (2004)

Table 3.2 above indicates ten people representing 40% mentioned Kaoje. Similarly seven people representing 28% favoured Giro while five people constituting 20% are for Koko. Dakin-Gari had three people stand for just 12%.

Table 3.3: Location of Feldspar Mineral in Kebbi State

Respondents		Location			
EGA	Traditional Potters	Town/ Village	Local Govt. Area	Total	Percent (%)
3	2	Bena	Danko/Wasagu	5	20
3	1	Kanya	Danko/Wasagu	4	16
3	1	Yauri	Yauri	4	16
2	1	Maga	Danko/Wasagu	3	12
1	1	Zuru	Zuru	2	8
1	1	Bagudo	Bagudo	2	8
1	1	Mahuta	Fakai	2	8
1	-	D/gari	Suru	1	4
1	-	Koko	Koko/Besse	1	4
1	-	Liba	Maiyama	1	4
17	8			25	100

Source: Zauro (2004)

Table 3.3 above shows respondents opinions about the location of feldspar mineral in Kebbi State. It reveals that five respondents representing 20% out of the total of 25 respondents cleared Bena. Kanya and Yauri had four people each representing 16% respectively. Three respondents representing 12% for Maga. While Zuru, Bagudo and Mahuta each had two respondents representing 8% each. Four persons each representing 1% each mentioned Dankingari, Koko and Liba.

Table 3.4: Location of Quartz Mineral in Kebbi State

Respondents		Location			
EGA	Traditional Potters	Town/Village	Local Govt. Area	Total	Percent (%)
5	3	Bena	Danko/Wasagu	8	32
3	1	Yauri	Yauri	4	16
2	-	Kanya	Danko/Wasagu	2	8
2	-	Bagudo	Bagudo	2	8
1	1	Danko	Danko/Wasagu	2	8
1	1	Ngaski	Ngaski	2	8
1	1	Liba	Maiyama	2	8
1	-	Dogon Daji	Maiyama	1	4
-	1	Marafa	Fakai	1	4
1	-	Zuru	Zuru	1	4
17	8			25	100

Source: Zauro (2004)

The above table 3.4 reveals the responses about the location of quartz mineral in Kebbi State. In all twenty five respondents were asked to furnish the study with possible information as to where quartz mineral can be located. While eight respondents representing 32% mentioned Bena, four people reperesenting 16% said Yauri. Two respondents each stated Kanya, Bugudo, Danko, Ngaski and liba and each representing 8%. The names of Dogondaji, Marafa villages and Zuru town were mentioned by one respondent each representing 4% each.

Table 3.5: Location of limestone Mineral in Kebbi State

Respondents		Location			
EGA	Traditional Potters	Town/Village	Local Govt. Area	Total	Percent (%)
4	-	Katanga	Maiyama	4	23.5
3	-	Maiyama	Maiyama	3	17.6
3	-	Aliero	Aliero	3	17.6
3	-	Dangamaji	Jega	3	17.6
2	-	Jega	Jega	2	11.7
1	-	Andarai	Maiyama	1	5.8
1	-	Mungadi	Maiyama	1	5.8
17	-			17	100

Source: Zauro (2004)

The table 3.5 above indicates different responses about the limestone deposit in Kebbi State. Out of the total number of seventeen respondents who claimed to have known about the mineral, four representing 23.5% found Katanga, three respondents representing 17.6% each declared Maiyama, Aliero, and Dangamaji. Two people representing 11.7% mentioned Jega while Andarai and Mungadi each has one respondent representing 5.8% each.

Table 3.6: Location of Ball Clay in Kebbi State.

Respondents		Location			
EGA	Traditional Potters	Town/Village	Local Govt. Area	Total	Percent (%)
5	2	B/Kebbi	B/Kebbi	7	28
3	2	Felande	Argungu	5	20
3	1	Argungu	Argungu	4	16
2	1	Zuru	Zuru	3	12
1	1	Gwandu	Gwandu	2	8
3	1	-	All LGA's	4	16
17	8			25	100

Source: Zauro (2004)

In summary, the ceramic raw materials locations as indicated by twenty five (25) respondents are expressed in percentage. Town/village with the highest percentage of respondents were selected for the sampling. In order to widen up the scope of the study, for each mineral, two or three locations were identified.

Table 3.7: Ceramic Raw Materials and Locations in Kebbi State

Material	Location	Local Govt. Area
Kaolin	Kaoje	Bagudo
Kaolin	Koko	Koko / Besse
Kaolin	Giro	Suru
Feldspar	Bena	Danko /Wasagu
Feldspar	Kanya	Danko /Wasagu
Feldspar	Yauri	Yauri
Quartz	Bena	Danko / Wasagu
Quartz	Kanya	Danko / Wasagu
Quartz	Yauri	Yauri
Limestone	Katanga	Maiyama
Limestone	Dangamaji	Jega
Limestone	Aliero	Aliero
Ball clay	Birnin Kebbi	Birnin Kebbi
Ball clay	Felande	Argungu

Source: Zauro (2004)

Table 3.7 above indicates the locations of ceramic raw materials and the local Government areas in Kebbi State. In addition to the information gathered from respondents and other related geological documents all assisted the study in identifying the locations of the raw materials.

3.2 Collection of Raw Materials

Field trips were carried out to the locations in order to procure the selected raw materials. Raw materials procured were kaolin, feldspar quartz, limestone and ball clay.

3.2.1 Kaolin

Kaolin samples were procured from:

1. Kasadi Hill area, Kaoje – Bagudo Local Government.
2. Koko Hill area, Koko– Koko/Besse Local Government.
3. Bayan Makaranta area (behind Model Primary School).
   Giro– Suru local Government.

3.2.2 Feldspar

Feldspar was found and collected from Twatsebani area, Bena – Danko/Wasagu Local Government but could not be traced in Yauri and Kanya.

3.2.3 Quartz

Quartz samples were obtained from:

1. Twatsebani area, Bena – Danko/Wasagu local Government.
2. Outskirts of Yauri along Yauri-Kontagora Road, Yauri Local Government.
3. Forest Reserve along Kanya-Wasagu Road, Kanya-Danko/Wasagu local Government.

3.2.4 Limestone

Limestone samples were sourced from:

1. Gandasamu area – Aliero – Aliero local Government.
2. Dangamaji Village – Jega local Government
3. Katanga Village – Maiyama local Government

3.2.5. Ball Clay

The study got ball clay samples from:

1. Goru village area – B/Kebbi – Birnin Kebbi local Government.
2. Felande Village – Argungu local Government.

3.3 Preliminary Physical Property Tests for Materials

The materials procured were exposed to a number of physical property tests to determine if they were the right materials. At each of the prospective location point, the study carefully considered the characteristics and physical appearance of each of the raw materials before it was picked. For example:

Kaolin: was recognized by its white appearance. When mixed with water it was relatively less plastic.

Ball clay: It was picked based on its brownish, grayish and buff appearance as well as its plastic quality.

Feldspar: The study was attracted by its pinky appearance and hardness. and when quartz was scratched on it a mark was noticed. Gukas (1985) revealed that feldspar can be easily traced by its hardness, colour and cleavage.

Quartz: It was obtained simply by its glassy and milky white appearance. When it was scratched on feldspar, it did not show any mark but the mark was clear on feldspar. It's harder than feldspar.

Limestone: On reaching the prospective location, hydrochloric acid was sprinkled on the suspected limestone and immediately the mineral begun to bubbles thus indicating the presence of calcium carbonate or lime.

Therefore, the procured minerals were taken to the Geology Department of Ahmadu Bello University, Zaria and the Centre for Energy Research and Training, Ahmadu Bello University, Zaria for further verification. All the materials were confirmed to be the right minerals.

Furthermore, other form of tests like shrinkage, porosity and colour were also carried out on the clay minerals. In addition, visual texture test, water required to make the clay into thick paste, in other words, the plasticity test were determined.

3.3.1 Water of Plasticity Test

Amount of water needed to develop the thick plastic state was determined by the following procedure.

Procedure – A 500gm of clay sample sieved through 80 mesh screen was poured into a glass slab. Drop by drop water from the 500cc graduate was added and mixed simultaneously into a glass slab with a spatula. The amount of water used to make relatively a modelling state was recorded and percentage water of plasticity was calculated, (Zauro, 1988).

$$\% \text{ water of plasticity}$$
$$\frac{\text{Wt of water used}}{\text{Wt of Dry clay}} \times 100$$

3.3.2 Plastic Test

The three kaolin samples and two ball clay samples were considered for plasticity tests.

Procedure – Pencil size rolls were made from the workable samples. Coils were made out of the pencil size rolls. The plastic clay maintained the shape without crack while the less plastic clay showed sign of cracks, Grema (2004).

3.3.3 Visual Texture Test

To determine the visual texture of the clay samples, they were fired and the tactile quality was noted by running the hand on the surface.

3.3.4 Linear Shrinkage Test

Procedure

Wet to dry shrinkage was known by producing 4 bars measuring

14 x 2 x 2cm from the different clay samples while still in the plastic conditions, a 10cm line was marked on each bar and each bar was carefully dried to prevent warping situation. Upon dry the 10cm line was measured again in order to find the new length.

Therefore % shrinkage determined as:

$$\% \text{ original - dry shrinkage}$$

$$\frac{\text{Original length - dry length}}{\text{Original length}} \times 100$$

Dry-fired-To determine the dry-fired shrinkage, the original 10cm line was again measured after the bars were fired at biscuit and glost firing respectively. Therefore the percentage dry-fired linear shrinkage was determined as follows.

$$\% \text{ fired shrinkage}$$

$$\frac{\text{original length - fired length}}{\text{Original length}} \times 100$$

3.3.5 Porosity Test

For effective use of the products, the porosity test was essential to determine if the end product seep water or absorbs much liquid. The porosity can be determined, thus.

Procedure – cubes were made for each clay sample. They were fired at biscuit and stoneware temperatures respectively. After each of the firing, weights were recorded and the cubes were soaked in water for 24 hours after which the weights were recorded again. The porosity was determined as follows.

Bisque porosity.

$$\%A \; \frac{SW - BW}{BW} \times 100$$

Glost porosity

$$\%A \; \frac{SW - FW}{FW} \times 100$$

Where A = Absorption

SW = Saturated weight

BW = Bisque weight

FW = Fired weight

3.4 Chemical Analysis

Chemical analysis was carried out by the Centre for Energy Research and Training, Ahmadu Bello University, Zaria to ascertain the chemical composition of the raw materials and for the purpose of selecting the most suitable constituents for tableware production. The raw materials were feldspar, quartz, limestone, kaolin and ball clay.

3.5 Plaster Mould

Besides throwing technique on the wheel employed in the making of ceramic articles, another most important method of production is slip casting in which articles of uniform and similar shape are made.

The technique of slip casting involves filling plaster mould with liquid clay or slip. In this process, a shell is formed through the absorption enhanced by the plaster. The importance of slip casting in industrial ceramic as a mass production technique cannot be over-stressed. The significance of plaster mould should be acknowledged because it is indispensable aspect in slip casting. Mould for this study were made from the plaster of Paris. Ideally, Plaster of Paris has proved to be the best material for making of moulds. To produce the mould, Plaster was mixed in a half full clean plastic bowl with water of room temperature. The plaster was sprinkled into the water slightly until it was formed. Cowley (1978) recommended the proportion of 3 plaster: 2 water. Avoidance and elimination of bubbles to achieve a lump free mixture should be observed.

When the mixture of plaster became thick, it was slightly poured into the cottle until it covers the apex part of the model. Immediately it was filled, the plaster was agitated to force it into all hollows and any air pocket or bubbles trapped were removed, The plaster of Paris was left for about 20-30 minutes to set. The cottle was removed and the plaster was carefully separated from the clay model. Sharp edges were filed while the mould was left to dry slowly. One piece or single (drop out) and two piece (multiple) plaster moulds were made.

Plate I: Plaster Moulds

3.6 Sample Processing

The materials procured require some treatment to remove impurities such as lumps of soil attached to quartz, feldspar and limestone and stones were picked out from clay. The treatment would also improve the standard of the materials for maximum use. The scheme of processing ceramic raw materials was followed accordingly. The processing involved washing, soaking, calcinations, crushing, ball milling, sieving and drying. Figure 3 is the procedure/scheme for the processing or preparation of raw materials.

Procedure for the Preparation for Raw Materials

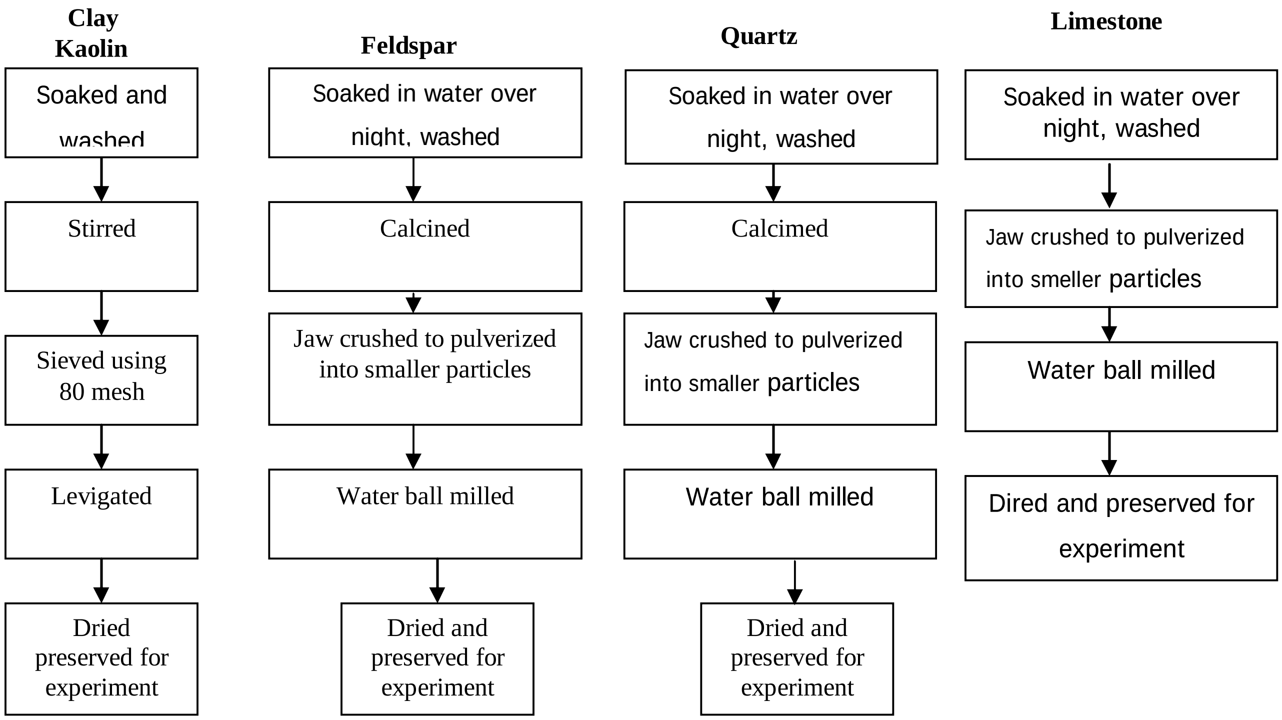

Fig. 3: Preparation of raw materials

3.6.1 Preparation of Plastic Materials

Kaolin and ball clay were soaked separately in plastic container over-night and stirred thoroughly for several times. The clay was sieved through 80 mesh screen to remove unwanted particles like stones, grasses and sand. Clay was allowed to settle after sieving and carefully the surface water was poured out. The clay slip was dried and preserved for use.

3.6.2 Preparation of Non-Plastic Materials

Feldspar, quartz and limestone were soaked separately in plastic containers and were washed later to remove impurities. Feldspar and quartz were calcined but limestone required no calcination because it is softer. A hammer was employed to break the materials into tiny sizes that could conveniently be positioned into the jaw crusher.

Each of the crushed material was ball milled and after the process the materials was poured out into a container to settle down. As the material settled down, the surface water was carefully drained out. The ground materials were removed from the containers, dried and stored readily for use.

Plate II: Ball Milling Of Materials

3.7 Body Formulation

Based on the information gathered from the literature review, formulation of bodies usually involves the combination of several ingredients. The constituents chiefly used in the formulation of ceramic bodies are kaolin, feldspar and quartz.

Each of the ingredients has an important role to play, kaolin a plastic material in the composition enhances refractoriness, workability and provides the white colour in the body. Feldspar and quartz are the non -

plastic components in the body. Feldspar gives translucency and decreases porosity and as a flux, it lowers the fusion point of the body. On the other hand, quartz assists the body to resist shrinkage, provides strength and improves translucency of the body.

3.7.1 Preliminary Body Composition

A preliminary body formulation tests were conducted prior to the use of the actual triaxial blend of feldspar, kaolin and quartz. The concept was developed out of the desire to ascertain the suitability of the materials for casting with reference to Waye (1967) appropriate limit of composition for the three main components.

Clay substance	40-60%
Feldspar	20-35%
Quartz	20-40%

Whiting (limestone) and ball clay were introduced into the body composition. Rhodes (1989) supported the use 1-2% of whiting or dolomite in porcelain body composition. Kaolin due to its relative low plasticity could not enhance sufficient plasticity therefore ball clay with a relative plasticity was added to the body composition.

In this experiment, three body compositions were considered. Deflocculant was not engaged with a view to determine the casting possibility of a slip involving dry materials and water only without deflocculant.

Both Rhodes (1989) and Okoruwa (1986) agreed with the addition of 10% ball clay. The study procured and examined two different ball clays. Birninkebbi clay is light cream and may not distort the body to a great extent. Felande clay is totally black and may distort the body. Birninkebbi clay is sufficiently plastic but Felande is much more plastic. They were found suitable for addition into the body compositions.

Ascertaining the appropriate amount of water in relation to the dry ingredients is necessary. While Rhodes (1989) stated that casting slip should contain about 35% to 50% parts of water to the weight of dry materials, Uduigwume (1986) in the study conducted by Zauro (1988) recommended the use of 40% to 50% of water to every 125gm of dry materials. Okoruwa (1986) and Zauro (1988) used 50% of water to every 500 gram of dry ingredients.

In respect to the body slip composition, the study used 50% of water to every 500gm of solid ingredients as shown in table 3.8.

Table 3.8: Body composition

Material	Body composition (%)		
	PB4	PB5	PB8
Feldspar	31	25	25
Kaolin	38	36	40
Quartz	20	28	24
Ball clay:			
Bikebbi	5	5	5
Felande	5	5	5
Whiting (limestone)	1	1	1
Water	50	50	50

Source: Studio Test (2006)

Key: PB = Porcelain body

The slip was prepared by weighing 500gm of dry ingredients and 250 gm of water representing 50% of the weight of dry materials. The mixture was thoroughly stirred and later ball milled for 4 hours. The slip was left undisturbed for 24 hours to check thixotropy of the slip. It was screened through 80 mesh sieve.

The sieved slip was poured into the mould to test casting behaviour. It was allowed to build against the mould cavity for 10 minutes. After which the surplus slip was poured out and the mould was drained. The cast was left in the mould for about 30 minutes with a view to allow it shrinks while the waste slip was trimmed off from the mould. The cast piece was removed from the mould so as to dry. The cast was carefully clean at the stage of leather hard.

3.7.2 Triaxial Blend

Again, it has been a tradition in ceramics that whenever three ingredients are to be blended, a triaxial blend diagram is used. Singer (1963) disclosed that the traditional ceramic bodies are “essentially made up of clay, flint or quartz and feldspar and can be represented by a triaxial diagram”. In the same vein Rhodes (1979) described that the triaxial blend diagram is of great use in tracing out variation in body and glazes. Gukas (1985) and Okoruwa (1986) re-iterated that the triaxial blend test is significant in conducting research on the formulation of porcelain bodies. Zauro (1988), Grema (2004) and Braganza (2001) considered and adapted the triaxial blend of materials in their respective studies.

Precisely, the literature reviewed revealed that formulation of ceramic bodies can be achieved through the sixty six numbers triaxial blend of three ingredients – feldspar, kaolin and quartz as shown in figure 4.

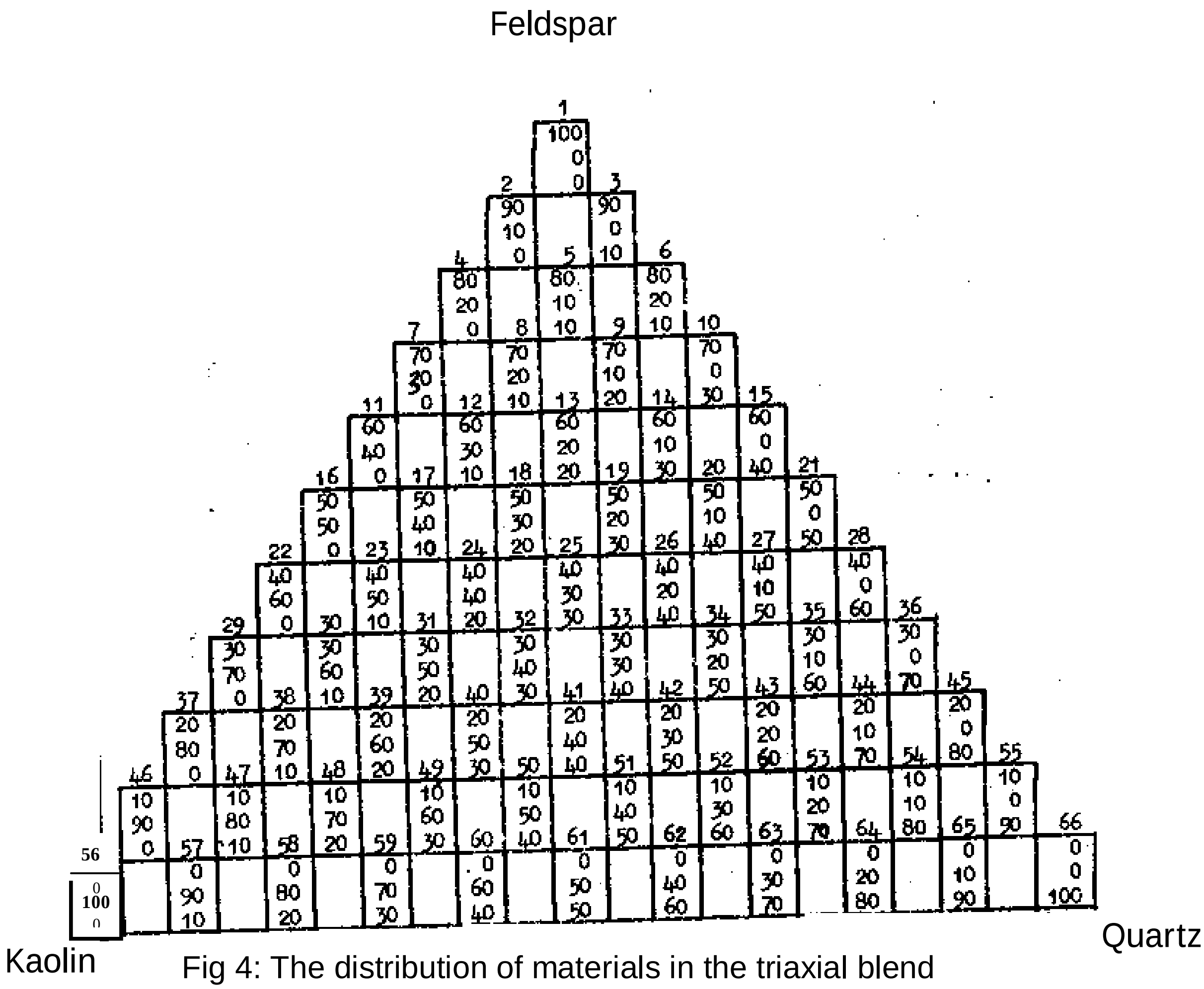

Fig 4: The distribution of materials in the triaxial blend

Source: Gukas (1985) and Zauro (1988)

In the diagram above, the rectangles have been numbered from 1-66. On top in the rectangle, the number represent feldspar, the middle number stands for kaolin while the bottom number refers to quartz.

For the purpose of this study, three triaxial blends were employed to accommodate the selected materials. Each triaxial blend is made up of only 36 different tests that actually involve the mixture of three ingredients instead of 66 number in the triaxial blend. It is important to note that the 66 number triaxial blend accomodates the combination of two and three materials.

The three triaxial blends considered are

1. Blend of Bena feldspar, Kaoje kaolin and Bena quartz
2. Blend of Bena feldspar, Koko kaolin and Bena quartz
3. Blend of Bena feldspar, Giro kaolin and Bena quartz

Triaxial Blend 1

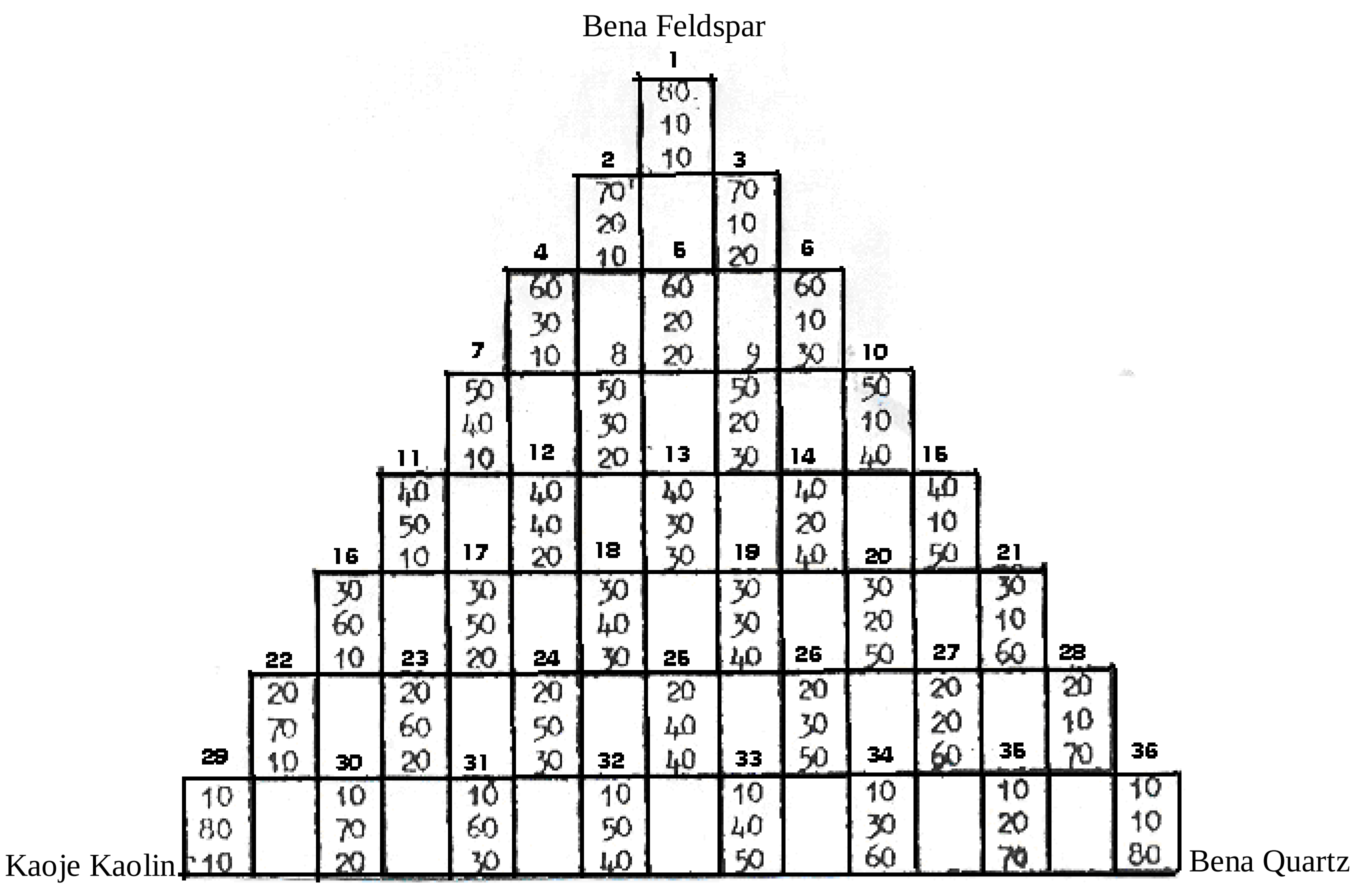

Fig 5. Distribution of materials in the triaxial blend.

The diagram above illustrates the distribution of the component. In each of the rectangle numbered 1- 36, the number on top, middle and bottom represents Bena feldspar, Kaoje kaolin and Bena quartz respectively.

For example on test number 2, the blend is made up of 70% feldpar, 20% kaolin, 10% quartz.

Triaxial Blend 2

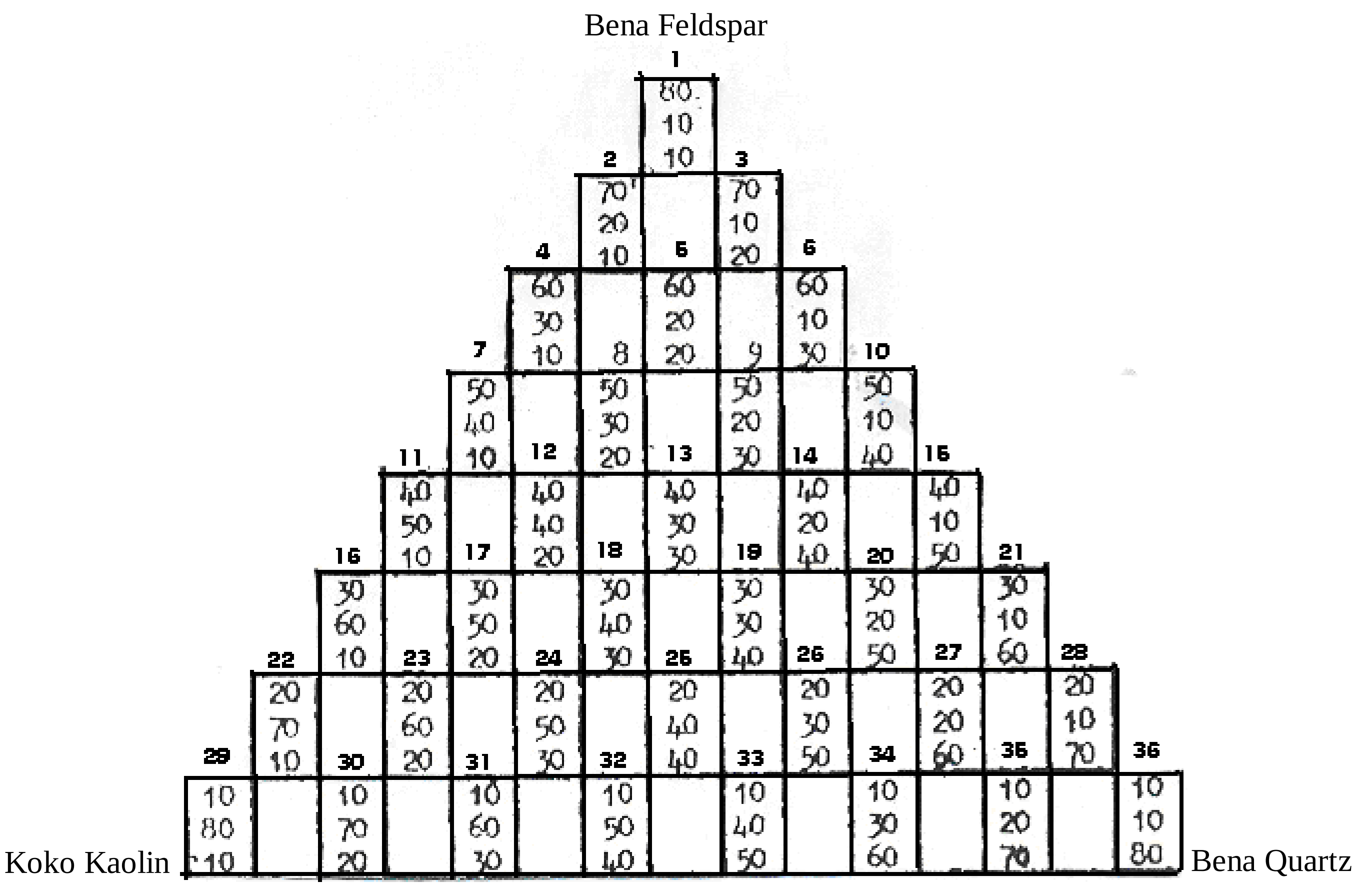

Fig.6: Distribution of materials in the triaxial blend

Once more, the diagram above displays the distribution of the ingredients. In each of the rectangles the number on top refers to Bena feldspars, the number in the middle represent Koko kaolin and the bottom number is for Bena quartz.

Triaxial Blend 3

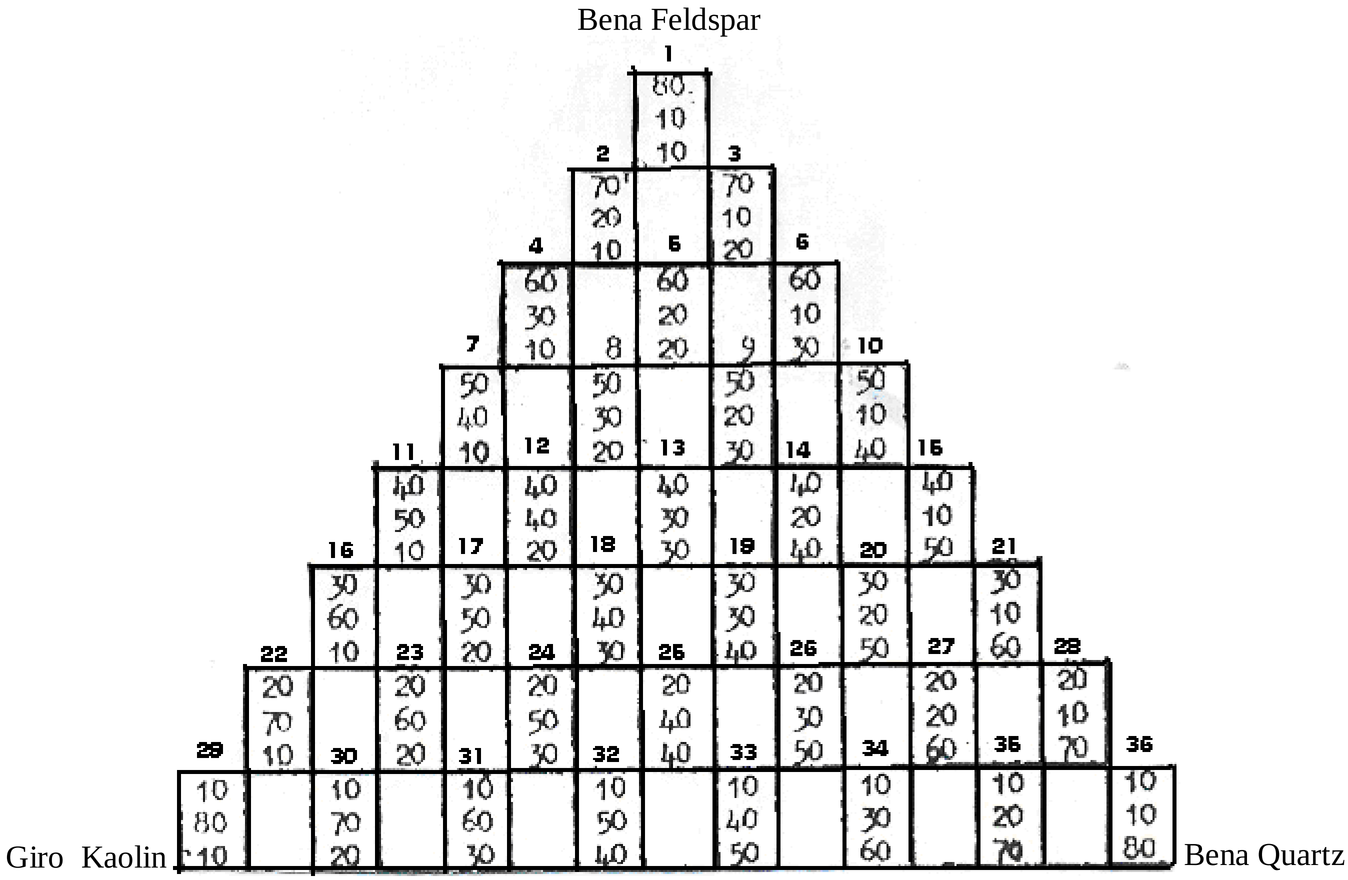

Fig .7: Distribution of materials in the triaxial blend.

In another perspective, the diagram above explains the distribution of the materials. In each of the rectangle, the top number is for Bena feldspar, the middle number refers to Giro kaolin and the bottom number represents Bena quartz.

Based on the result from triaxial blend 1,2 and 3, four body compositions that showed some characteristics of porcelain were selected from each of the triaxial blends.

3.7.2.1 Four Selected Body Compositions

Table 3.9: Triaxial Blend 1

Test No.	Compositions (%)		
	Feldspar (BN)	Kaolin (KJ)	Quartz (BN)
TN 8KJ	50	30	20
TN 12KJ	40	40	20
TN 13KJ	40	30	30
TN 14KJ	30	30	40

Source: Studio Test (2006)

Key:

BN - Bena

KJ - Kaoje

TN - Test Number

Table 3.9 above illustrates the composition of four bodies selected from triaxial blend 1. For example body TN8KJ is composed of:

Feldspar	50%
Kaolin	30%
Quartz	20%

Table 3.10: Triaxial Blend 2

Test No.	Compositions (%)		
	Feldspar (BN)	Kaolin (KK)	Quartz (BN)
TN 9KK	50	20	30
TN 10KK	40	20	40
TN 17KK	30	50	20
TN 18KK	30	40	30

Source: Studio Test (2006)

Key:

KK - Koko

The table 3.10 above indicates the compositions of four bodies selected from traxial blend 2. For instance TN17KK is made up of:

Feldspar 30%
Kaolin 50%
Quartz 20%

Table 3.11: Triaxial Blend 3

Test No.	Compositions (%)		
	Feldspar (BN)	Kaolin (GR)	Quartz (BN)
TN 4GR	60	30	10
TN 5GR	60	20	20
TN 7GR	50	40	10
TN 11GR	40	50	10

Source: Studio Test (2006)

Key:

GR - Giro

Table 3.11 above shows the composition for four bodies selected from traxial blend 3. For instance TN 11 consists of:

Feldspar	40%
Kaolin	50%
Quartz	10%

These compositions formed the background for further experiments.

Since kaolin the only plastic material in the composition could not provide adequate plasticity in the body. Rhodes (1989) recommended the addition of 10% ball clay into body compositions. Felande ball clay and BirninKebbi ball clays were introduced appropriately into the body compositions. Similarly, the right proportion of water in the composition is very important. Consequently, 50% of water was used to every 1000gm of dry ingredient. Uduigweme (1986) recommended the use of about 40% to 50% of water to dry ingredients. With these developments, therefore, the compositions of bodies are shown below.

3.7.2.2 Body Compositions by Weight

Table 3.12: Triaxial Blend 1

Materials	Bodies			
	TN8(KJ) (gm)	TN12(KJ) (gm)	TN13 (KJ) (gm)	TN14 (KJ) (gm)
Feldspar	400	350	350	300
Kaolin	300	400	350	300
Quartz	200	150	250	300
Ball clay:				
B / Kebbi	50	-	-	100
Felande	50	100	50	-
Water	500	500	500	500

Source: Studio Test (2006)

The table 3.12 above shows different body compositions selected from triaxial blend 1. In this case, ball clay was added into the compositions and the right proportion of water was determined. No deflocculat used.

Example, Body composition TN 13KJ is made up to of:

Feldspar	350gm
Kaolin	350gm
Quartz	250gm
Ball clay	50gm
Water	500gm

Table 3.13 Triaxial Blend 2

Materials	Bodies			
	TN9(KK) (gm)	TN10(KK) (gm)	TN17(KK) (gm)	TN18(KK) (gm)
Feldspar	250	200	300	350
Kaolin	400	400	400	350
Quartz	250	300	200	200
Ball clay:				
B / Kebbi	-	-	50	50
Felande	100	100	50	50
Water	500	500	500	500

Source: Studio Test (2006)

Table 3.13 above indicates the compositions of the four bodies selected from traxial blend 2, with addition of 50% water to the weight of dry ingredients and ball clay. For example, body composition TN 18 is made up of:

Feldspar	350gm
Kaolin	350gm
Quartz	200gm
Ball Clay	100gm
Water	500gm

Table 3.14: Triaxial Blend 3

Materials	Bodies			
	TN4(GR) (gm)	TN5(GR) (gm)	TN7(GR) (gm)	TN11(GR) (gm)
Feldspar	500	300	300	350
Kaolin	300	350	400	400
Quartz	100	250	200	150
Ball clay:				
B / Kebbi	-	50	-	50
Felande	100	50	100	50
Water	500	500	500	500

Source: Studio Test (2006)

Table 3.14 above shows the compositions of four bodies selected from the traxial blend 3. 50%. In addition, 50% of water was used in the composition. For instance, body composition TN5GR is composed of:

Feldspar	300gm
Kaolin	350gm
Quartz	250gm
Ball Clay	100gm
Water	500gm

3.8 Casting Slip

In preparation of slip for casting, 1000gm of dry ingredients were weighed and 500gm of water representing 50% of the dry ingredients was weighed. The mixture was thoroughly blended and the various body compositions were ball milled separately for 4 hours after which the slip was allowed to settle for 24 hours. The undisturbed condition of the slip was to ensure the thixotrophy of the slip.

3.8.1 Casting Procedure

The mould was positioned upwards while the prepared slip was stirred thoroughly and poured into the mould carefully. More slip was added into the mould as the plaster absorbed the slip. The slip was allowed to remain in the mould for 10 minutes in order to create a wall. The next step was the removal of the surplus slip and the draining of the mould in a slanting position to allow the slip drained out.

The top edge of the mould was trimmed of excess slip after the mould was turned upwards. The cast shrunk between 20 and 30 minutes and was then removed out from the mould. The cast was given time to hardened and was thoroughly cleaned. At this point the cast was allowed to dry. Samples were casted from one piece and two piece moulds.

3.9 Test for Cast Selected Bodies

The selected bodies from traxial blend, 1, 2, and 3 were physically tested. Tests conducted were shrinkage and porosity tests.

3.9.1 Shrinkage Test

Procedure

Wet to dry shrinkage was known by producing 4 bars measuring

14 x 2 x 2cm from the different body samples while still in the plastic conditions, a 10cm line was marked on each bar and each bar was carefully dried to prevent warping situation. Upon dry the 10cm line was measured again in order to find the new length. Therefore the percentage *original* **–** *dry length* was determined as

$$\% \text{ original - dry shrinkage.}$$
$$\frac{\text{Original length - dry length}}{\text{Original length}} \times 100$$

Dry-fired **-** To determine the dry-fired shrinkage, the original 10cm line was again measured after the bars were fired at biscuit and glost firing. Therefore the percentage dry-fired shrinkage was determined as.

$$\frac{\text{original length - fired length}}{\text{Original length}} \times 100$$

3.9.2 Porosity Test

For effective use of the products, the porosity test is essential to determine if the end product seeps water or absorbs much liquid.

Procedure–Bars were casted from body samples. They were fired at biscuit and stoneware temperatures. After each of the firing, weights were recorded and the bars were soaked in water for 24 hours after which the weights were recorded again. The bisque percent porosity was determined as:

Bisque porosity.

$$\% A = \frac{SW - BW}{BW} \times 100$$

The Glost percentage porosity was determined as

$$\% A = \frac{SW - FW}{FW} \times 100$$

Where A = Absorption

SW = Saturated weight

BW = Bisque weight

FW = Fired weight

3.10 Glaze

Information from the literature reviewed highlights that, glaze materials are normally ground to a fine powder blended with appropriate amount of water. Glaze compositions can be expressed in percentage.

In line with this, the selection of glaze for this study was based on some of the characteristics shown by the test number 2, 3, 4, and 5 fused at about 1300^0C from the triaxial blends. Rhodes (1989) upper limit of glaze materials in which feldspar and quartz constitute about 70% while the remaining 30% is made up of other materials was put into consideration for this study. Consequently four glaze batches were composed as follows.

Table 3.15: Glaze Compositions

Materials	Glaze compositions (%)			
	1	2	3	4
Feldspar	60	50	55	70
Kaolin	15KJ	20KK	15GR	10KJ
Quartz	10	15	15	10
Limestone	15DGJ	15ALR	15KTG	-

Source: Studio Tests (2006)

Key = DGJ - Dangamaji
ALR - Aliero
KTG - Katanga

Table 3.15, above shows four different glaze compositions. Each of the glaze composition 1, 2 and 3 is composed of four materials while glaze composition 4 is made up of three materials and all are expressed in percentage. For example, Glaze composition Batch 1 is made up of:

Bena feldspar 60%

Kaoje Kaolin 15%

Bena Quartz 10%

Dangamaji limestone 15%
100%

The glaze materials were weighed out in grammes and mixed with water. Each of the four batches was prepared separately and ball milled for 4hours. It was poured out into the plastic bowl. The bisque pieces were dipped into the glaze slip after it was thoroughly stirred. In order to prevent the glazed pieces from sticking to the shelves during firing, the glaze on the base was cleaned.

Plate III: Glazing of Wares

3.11 Firing

The casted pieces were fired. The first firing was the biscuit or bisque firing of the wares. After the biscuit firing, the cast pieces became hardened and porous for the glaze to be applied. The glaze was applied on pieces roughly in order to find out whether the glaze runs or not. The second firing was the glost firing. The biscuit wares were fired to about 1300^0C temperature. Kerosene was used to fire the wares in the kiln.

Plate IV: Sample Wares in the Kiln

CHAPTER 4

RESULTS

4.0 Introduction

Chapter four documents the analysis of results of tests conducted for the study. These include the Chemical analysis and physical property tests, triaxial blend, shrinkage and porosity tests, casting, glaze formulation and application as well as firing tests.

4.1 Samples Collection

The sample raw materials were obtained from various locations as seen in chapter three (table 3.7).

4.1.1 Kaolin Sample

Plate V: Kaoje, Koko and Giro Raw Kaolin Samples

4.1.2 Feldspar sample

PLATE VI: Bena Raw Feldspar Sample

4.1.3 Quartz Sample

Plate VII: Bena Raw Quartz Sample

4.1.4: Limestone Samples

Plate VIII: Aliero, Dangamaji and Katanga Raw Limestone Samples

4.1.5 Ball (Secondary) Clay Sample

Plate IX: Felande and Birnin Kebbi Raw Ball Clay Samples

4.2 Raw Materials Processing

The samples were processed accordingly.

4.2.1 Kaolin and Ball Clay

- Soaked and washed
- Stirred thoroughly and severally
- Sieved through 80 mesh
- Levigated

- Dried and preserved

Plate X: Processed Kaolin and Ball Clay

4.2.2: Feldspar and Quartz

- Soaked in water overnight and washed
- Calcined
- Jaw crushed
- Water ball milled
- Dried and preserved

PLATE XI: Processed Feldspar and Quartz

4.2.3 Limestone

- Soaked in water overnight
- Jaw crushed
- Water Ball Milled
- Dried and Preserved.

Plate XII: Jaw Crushing Of Non Plastic Material

4.3 Chemical and Physical Tests of the Raw Material Samples.

In an attempt to find out if the procured raw material samples were the suitable ingredients for porcelain, the following tests were carried out: chemical analysis and physical property test such as plasticity test, shrinkage test and porosity test.

4.3.1 Chemical Analysis Results

The chemical composition of the samples were conducted and expressed in percentage.

SAMPLE: Is9263 (Kaoje Kaolin)

MATRIX: [A0 (RES) = 11000]

WEIGHT [g/cm^2]: 0.132

Elements	**Concentration**	
Al_2O_3	20.63%	$\pm$o.06
SiO_2	46.11%	$\pm$0.17
Fe_2O_3	0.80%	$\pm$0.45
CuO	0.41%	$\pm$0.02
Cr	295	$\pm$20
Zr	781	$\pm$23
Ni	027	$\pm$1
As	391	$\pm$2.11

Other values in ppm

SAMPLE: Is9265 (Giro Kaolin)

MATRIX: [A0 (RES) = 11000]

WEIGHT [g/cm^2]: 0.067

Elements	**Concentration**	
Al_2O_3	26.37%	$\pm$0.02
SiO_2	40.68%	$\pm$0.06
K_2O	0.26%	$\pm$0.01
Fe_2O_3	0.22%	$\pm$0.03
Ca	341	$\pm$25.5
Zr	234	$\pm$11.1

Other values in ppm

SAMPLE: Is9257 (Koko Kaolin)

MATRIX: [A0 (RES) = 11000]

WEIGHT [g/cm^2]: 0.110

Elements	**Concentration**	
Al_2O_3	18.33%	$\pm$0.04
SiO_2	40.81%	$\pm$0.11
CaO	0.37%	$\pm$0.02
K_2O	0.41%	$\pm$0.02
TiO_2	1.57%	$\pm$0.38
Fe_2O_3	0.20%	$\pm$0.06
Cr	227	$\pm$54
Ni	302	$\pm$17
Zr	994	$\pm$27

Other values in ppm

SAMPLE: Is9261 (Aliero Limestone)

MATRIX: [A0 (RES) = 17827]

WEIGHT [g/cm^2]: 0.108

Elements	**Concentration**	
Al_2O_3	12.81%	$\pm$0.07
SiO_2	24.08%	$\pm$0.15
CaO	44.03%	$\pm$0.77
Cr_2O_3	0.38%	$\pm$0.08
K_2O	0.66%	$\pm$0.02
Fe_2O_3	0.25%	$\pm$0.03
Ca	413	$\pm$23
Ni	215	$\pm$13
As	181	$\pm$17

Other values in ppm

SAMPLE: Is9264 (Dangamaji limestone)

MATRIX: [A0 (RES) = 5389]

WEIGHT [g/cm^2]: 0.143

Elements	**Concentration**	
CaO	12.9%	$\pm$25
K_2O	0.18%	$\pm$0.07
Fe_2O_3	0.37%	$\pm$0.03
Ni	051%	$\pm$3
Zr	105	$\pm$12

Other values in ppm

SAMPLE: Is9261 (Katanga Limestone)

MATRIX: [A0 (RES) = 16692]

WEIGHT [g/cm^2]: 0.103

Elements	**Concentration**	
CaO	39.3%	$\pm$0.25
K_2O	3.83%	$\pm$0.51
Fe_2O_3	6.28%	$\pm$3.94
Sr	114	$\pm$17
Zr	401	$\pm$12

Other values in ppm

SAMPLE: Is9271 (Bena feldspar)

MATRIX: [A0 (RES) = 11000]

WEIGHT [g/cm^2]: 0.104

Elements	Concentration	
Al_2O_3	14.50%	$\pm$0.02
SiO_2	60.01%	$\pm$0.03
K_2O	10.41%	$\pm$1.50
Fe_2O_3	0.21%	$\pm$0.05
Rb_2O	0.14%	$\pm$0.02
SrO	107	$\pm$18

Other values in ppm

SAMPLE: Is9271 (Bena Quartz)

MATRIX: [A0 (RES) = 11000]

WEIGHT [g/cm^2]: 0.133

Elements	Concentration	
Al_2O_3	9.55%	$\pm$0.07
SiO_2	45.37%	$\pm$0.12
K_2O	0.25%	$\pm$1.02
Fe_2O_3	0.22%	$\pm$0.04
Ca	477	$\pm$34
Zr	031	$\pm$14

Other values in ppm

SAMPLE: Is9258 (Ya'uri Quartz)

MATRIX: [A0 (RES) = 11000]

WEIGHT [g/cm^2]: 0.121

Elements	**Concentration**	
Al_2O_3	17.08%	$\pm$0.10
SiO_2	41.87%	$\pm$0.21
K_2O	0.39%	$\pm$0.03
CaO	0.31%	$\pm$0.04
Fe_2O_3	0.31%	$\pm$0.04
Sr	327	$\pm$37

Other values in ppm

SAMPLE: Is9268 (Kanya Quartz)

MATRIX: [A0 (RES) = 11000]

WEIGHT [g/cm^2]: 0.067

Elements	**Concentration**	
Al_2O_3	7.22%	$\pm$0.05
SiO_2	44.36%	$\pm$0.07
K_2O_3	0.26%	$\pm$0.01
Fe_2O_3	0.22%	$\pm$0.03
Zr	316	$\pm$215

Other values in ppm

SAMPLE: Is9258 (Felande Secondary Clay)

MATRIX: [A0 (RES) = 11000]

WEIGHT [g/cm^2]: 0.102

Elements	**Concentration**	
Al_2O_3	17.20%	±0.05
SiO_2	40.85%	±0.13
TiO_2	1.82%	±0.30
Fe_2O_3	9.14%	±0.16
Rb	139	±41
Sr	147	±22
Y	84	±2
Zr	055	±25
Nb	177	±32

Other values in ppm

SAMPLE: Is9275 (B/Kebbi Secondary Clay)

MATRIX: [A0 (RES) = 13815.5]

WEIGHT [g/cm^2]: 0.101

Elements	**Concentration**	
Al_2O_3	7.8%	±0.06
SiO_2	54.06%	±0.04
CaO	28.68%	±0.03
Fe_2O_3	0.29%	±0.04
K_2O	2.07%	±25
Rb_2O	0.32%	±0.02
Sr	182	±20

Other values in ppm

4.3.2 Result of Physical Tests

These include the physical property test on clay samples, triaxial blend and shrinkage and porosity tests.

4.3.2.1 Plasticity Test

The weight of water used for each sample is shown below

Table 4.1: Water of plasticity Test

Material	Amount of water used (gm)	Weight of Dry clay (gm)
Kaoje Kaolin	124	500
Koko Kaoilin	125	500
Giro Kaolin	124	500
B/Kebbi Ball Clay	200	500
Felande Ball Clay	220	500

Source: Studio Test (2006)

Table 4.1 above shows the weight of dry material (clay) and the amount of water used to develop the thick plastic state of the clay sample.

Example: water of plasticity for Koko Kaolin

% water of plasticity is determined as

Amount of water used 125gm

Weight of dry clay 500gm

$\therefore$ %WP - $\frac{125}{500}$ x 100 = 25%

4.3.2.2 Shrinkage Test of Clay Samples

The shrinkage rate of clay samples was ascertained.

Table 4.2: Shrinkage Test of Clay Samples

Material	Original (wet) Length (cm)	Dry length (cm)	Bisque length (cm)	Fired length (cm)
Kaoje Kaolin	10	9.8	9.7	9.6
Koko Kaoilin	10	9.7	9.6	9.5
Giro Kaolin	10	9.8	9.7	9.6
B/Kebbi Ball Clay	10	9.7	9.5	9.1
Felande Ball Clay	10	9.5	9.3	8.8

Source: Studio Test (2000)

Table 4.2 above displays the material original (wet) length, dry length, biscuit length and fired length of the five clay samples. Example, Koko clay shrinkage was determined as:

Wet – dry shrinkage

Original length 10cm

Dry length 9.7cm

% Dry shrinkage $\frac{10-9.7}{10} \text{x} 100 = 3\%$

Biscuit shrinkage:

Original length 10cm

Biscuit length 9.6cm

% Biscuit shrinkage $\frac{10-9.6}{10} x100 = 4\%$

Shrinkage after glost firing

Original length 10cm

Fired length 9.5cm

% Fired shrinkage $\frac{10-9.5}{10} x100 = 5\%$

4.3.2.3 Porosity Test of Clay Samples

The porosity of the clay samples was determined:

Table 4.3 Porosity Test of Clay Samples

Material	Bisque weight (gm)	Saturation weight (gm)	Fired weight (gm)	Saturation weight (gm)
Kaoje	440	550	430	485
Koko	430	540	420	470
Giro	445	560	430	485
Birnin Kebbi	430	480	390	410
Felande	300	330	280	290

Source: Studio Test (2006)

Key: BW = Biscuit weight

SW = Saturated weight

The table 4.3 above indicates the materials involved in the test. The weight of the bisque cubes and the weight after soaking (saturation weight) in water for 24 hours. The percent porosity is determined as:

Example: Koko Kaolin

Bisque porosity for Koko Kaolin

% A = $\frac{SW - BW}{BW}\ x\,100$

Bisque weight = 430gm

Saturated weight = 540

% A = $\frac{540 - 430}{430}\ x\,100 = 25.5\%$

Fired porosity for Koko Kaolin

$$\%A = \frac{SW - FW}{FW} \times 100$$

% A = $\frac{470 - 420}{420} \times 100 = 11.9\%$

Table 4.4: Result of Physical Property Tests on Clay Samples

Type of test	KJK	KKK	GRK	BKC	FLC
Colour of Raw clay	White	White	White	Cream	Black
Texture visual	Fine	Fine	Fine	Fine	Fine
Tactile	Smooth	Smooth	Smooth	Fairly smooth	Fairly smooth
Water of plasticity (%)	24.8	25.0	24.8	40.0	44.0
Plasticity	Fair	Fair	Fair	Good	V. Good
Bisque porosity (%)	25.0	25.5	25.8	11.6	10.0
Fired porosity (%)	12.7	11.9	12.7	5.1	3.5
Dry shrinkage (%)	2.0	3.0	2.0	3.0	5.0
Bisque shrinkage (%)	3.0	4.0	3.0	10	7.0
Fired shrinkage (%)	4.0	5.0	4.0	9.0	12.0
Colour before firing	White	White	White	Cream	Brown
Colour after firing	White	White	White	Yellowish orange	Dark brown

Source: Studio Test (2005)

4.3.2.4 Preliminary Body Composition and Triaxial Blend Test Results

Experiments were carried out aim at selecting the suitable body composition for the production of tableware. Two different forms of experiments were put in place. First, the body composition (tagged, 1A) formulated in connection with Waye (1967) appropriate limit of body composition. Whiting was introduced in the body (Slip) composition without the use of deflocculant and second form of experiment was the triaxial blend experiments using three different Kaolin samples procured from Kaoje, Koko and Giro with Bena feldspar and Bena Quartz.

Table 4.5: Result of Body Compostions-1A

Body	Slip moisture colour	Slip character	Condition of slip in the mould	Cast dry colour	Glost firing
PB4	Light Cream	Cast well	No crack easy release	Cream	Fused
PB5	Light Cream	Cast well	No crack easy release	Cream	Fused
PB6	Light Cream	Cast well	No crack easy release	Cream	Fused

Source: Studio Test (2006)

Table 4.5 indicates the character of the three (3) body compositions for preliminary test. Each of the compositions had good flow after it was ball milted and kept to rest for 24 hours in a plastic bowl. The colour of the slip when wet was light cream. Later the slip was thoroughly stirred and screened through 80 mesh sieve. The slip was poured into the plaster mould and it quickly formed the cast within 10 minutes. The surplus slip was drained out of the mould and the top part was trimmed.

Furthermore, the cast was left in the mould for 30 minutes which enhanced easy removal of the cast when it shrunk. The cast was taken out and was alotted time to dry slowly. The colour of the dry cast was cream. After glost firing, the cast piece fused to a dense body.

Table 4.6: Result of Triaxial Blend 1

Test No.	Raw Colour	Fired colour
1	White	Gray (deep)
2 – 3	White	Gray (medium)
4 – 6	White	Very light grayish
7 – 10	White	Very light grayish cream
11 – 15	White	Creamy gray
16 – 27	White	Cream
24 – 33	White	Milky cream
34 – 36	White	Light brownish cream

Source: Studio Test (2006)

PLATE XIII: Result of Triaxial Blend 1.

The triaxial blend 1 involving Bena feldspar, Kaoje kaolin and Bena quartz revealed fascinating outcome. Most of the test blend fused. Test 1 composed of 80% feldspar, 10% each of kaolin and quartz produced fused gray (deep) colour indicating the presence of greater percentage of feldspar. Test 2 and 3 appeared gray (medium) while test 4 to 6 exhibited very light gray. Similarly very light grayish cream was seen on test 7 to 10.

While test 11 to 15 creamy gray was produced. Test 16 to 27 yielded cream effect. From test 24 to 33 milky cream was noticed and 34, 35 and 36 tests turned out to be light brownish cream.

Table 4.7: Result of Triaxial Blend 2

Test No.	Raw Colour	Fired colour
1	White	Gray (deep)
2 – 3	White	Gray (medium)
4 – 7	White	Variation of creamy Gray
8 – 9	White	Gray
10 -	White	Cream
11 – 13	White	Creamy Gray
14 – 15	White	Cream
16 – 18	White	Grayish Cream
19 – 20	White	Cream
21 – 24	White	Grayish cream
28	White	Cream
29	White	Reddish cream
30 – 34	White	Creamy white
35	White	Creamy medium
36	White	Light reddish cream

Source: Studio Test (2006)

Plate XIV: Result of Triaxial Blend 2.

Triaxial blend 2, result was interesting with variations of effects. Bena feldspar, Koko kaolin and Bena quartz were the main ingredients in the blend. Test 1 produced gray (deep) colour. Test 2 and 3 appeared gray (medium) but variation of creamy gray overwhelmed in test 4,5,6 and 7. While the outcome of test 8 and 9 was gray, test 10, 14, 15, 19, 20 and 28 all appeared cream. Test 11, 12 and 13 yielded creamy gray and 16, 17 and 18 were grayish cream. Test 21, 22, 23 and 24 were grayish cream and the only test that turned out as reddish cream was 29.

Furthermore test 30, 31, 32, 33 and 34 yielded creamy white and test 35 and 36 produced creamy (medium) and light reddish cream respectively.

Table 4.8: Result of Triaxial Blend 3.

Test No.	Raw Color	Fired color
1	White	Gray (deep)
2 – 6	White	Gray (medium)
7 – 8	White	Gray (light)
9 – 10	White	Gray (medium)
11 – 20	White	Creamy (deep)
21	White	Brownish cream
22 – 26	White	Light brownish cream
29 – 30	White	Milky white
31 – 34	White	Cream (medium)
35	White	Light reddish cream
36	White	Reddish cream

Source: Studio Test (2006)

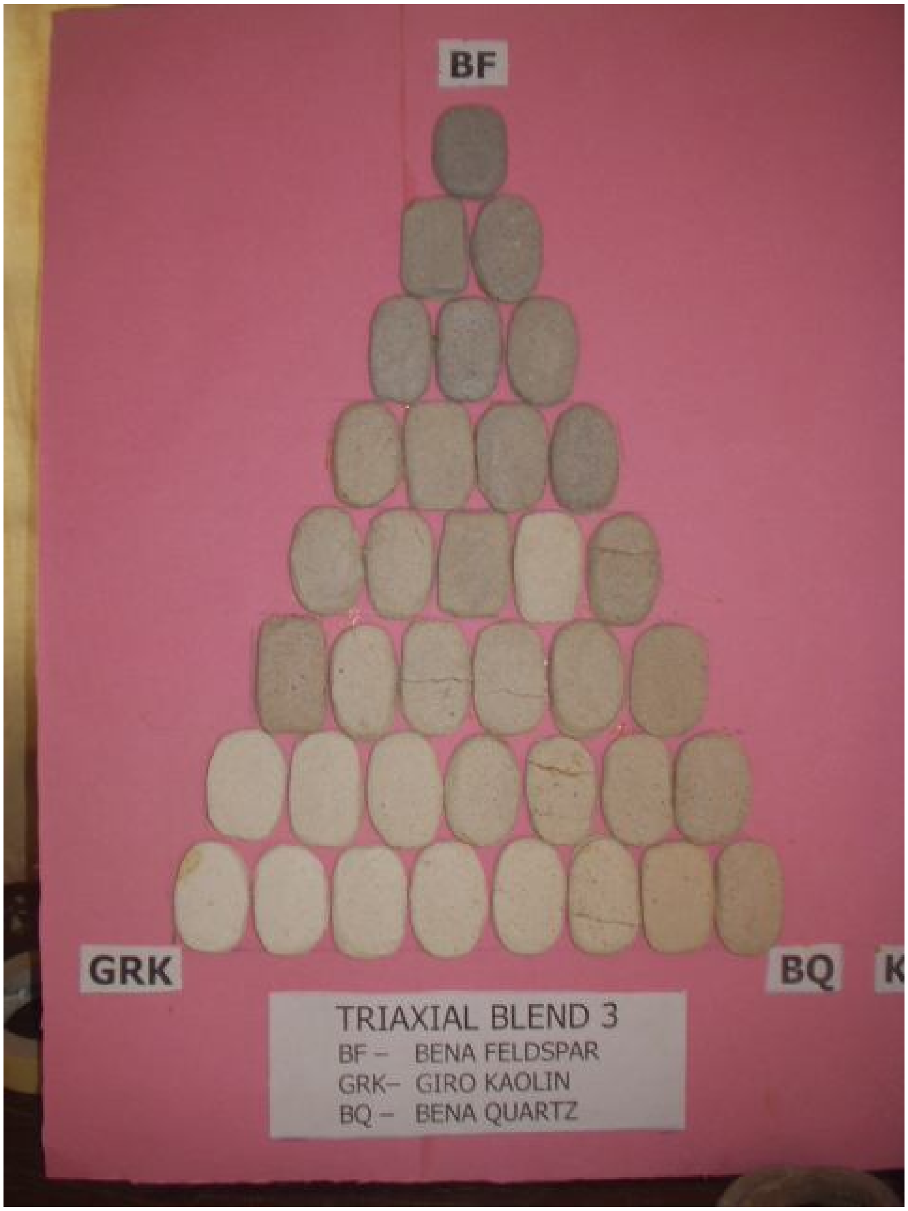

Plate XV: Result of Triaxial Blend 3.

Triaxial blend test table 4.8 above indicates the outcome of the triaxial blend 3, involving Bena feldspar, Giro kaolin and Bena quartz. Tile 1 produced gray (deep) effect as observed also in tile 1 of triaxial blend 1 probably it happened as a result of feldspar domination. From test 2 to 6, 9 and 10 gray (medium) effect overwhelmed but test 7 and 8 the outcome was gray (light). In addition, test 11, 12, 13, 14, 15, 16, 17, 18, 19 and 20 creamy (deep) dominated. Test 21 was brownish cream while in the case of test 22, 23, 24, 25, and 26 the presence of light brownish cream was noticed. Test 29 and 30 appeared milky white and cream (medium) effect covered test 31, 32, 33 and 34. Test 35 appeared light reddish cream and test 36 maintained reddish cream effect.

4.4 Shaping of Wares

4.4.1 Slip Casting Performance Result

Table 4.9: Triaxial Blend 1.

Test No.	Slip moisture colour	Slip character	Condition of slip in the mould	Cast Dry Colour	Glost firing
TN8KJ	Grayish cream	Good flow and Cast well	No crack and easy release	Cream	Fused
TN12KJ	Grayish cream	Good flow and Cast well	No crack and easy release	Cream	Fused
TN13KJ	Grayish cream	Good flow and Cast very well	No crack and easy release	Cream	Fused
TN14KJ	Grayish cream	Good flow and Cast well	No crack and easy release	Cream	Fused

Source: Studio Test (2006)

Table 4.9 shows the result of casting performance of four bodies selected from triaxial blend 1. All the bodies appeared cream at the dry stage, the casting character for all the bodies were similar. The condition of the body slips in the mould exhibited the same behaviour when fired all the bodies fused.

Table 4.10: Traxial Blend 2

Test No.	Slip moisture colour	Slip character	Condition of slip in the mould	Cast Dry Colour	Glost firing
TN9KK	Pinky cream	Cast well	No crack easy release	Cream	Fused
TN10KK	Pinky cream	Cast well	No crack easy release	Cream	Fused
TN17KK	Pinky cream	Cast very well	No crack easy release	Cream	Fuse
TN18KK	Pinky cream	Cast well	No crack easy release	Cream	Fused

Source: Studio Test (2006)

The above table 4.10 indicates the result of the triaxial blend 2. The colour at moisture stage was similar on all bodies just showing pinky cream while the color at dry stage for each composition was cream. The character of the slip during casting was well for all the bodies. Indeed there was no sign of crack in the bodies. All bodies fused producing hard and dense bodies.

Table 4.11: Triaxial Blend 3

Test No.	Slip Moisture Colour	Slip character	Condition of slip in the mould	Cast Dry Colour	Glost Firing
TN4GR	Grayish cream	Cast	No crack and slow release	Cream	Fused
TN5GR	Grayish cream	Cast	No crack and slow release	Cream	Fused
TN7GR	Grayish cream	Cast	No crack and slow release	Cream	Fused
TN11GR	Grayish cream	cast	No crack and released well	Cream	Fused

Source: Studio Test (2006)

The above table 4.11 displays the result of casting performance of the slip. All the four slip compositions produced grayish cream colour at the moisture condition. Casting was done successfully but the cast release from the mould was very slow in respect to body TN4, 5 and 7. In particular, TN11 had easy release from the mould. There were no cracks on the cast pieces and when dried the colour of all the pieces was pink. All the four bodies produced hard and dense effect after glost firing.

Plate XVI: Slip Casting

4.5 Body (Slip) Compositions by Weight and Casting Procedure

Body TN8KJ – Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	40	400
Kaolin	30	300
Quartz	20	200
Ball clay	10	100
Water	50	500

The slip was composed of 400gm of feldspar, 300gm of kaolin, 200gm of quartz 100gm of ball clay and 500gm of water. After it was ball milled, the slip was left undisturbed for 24 hours. It settled well then it was stirred and sieved. The colour of the moisture was cream, and it was very smooth. The slip was plastic indicating that the ball clay in the composition was sufficient.

The slip was poured into the mould and was given 10 minutes to form. It cast well and the speed of casting was rapid. The surplus slip drained freely. It remained in the mould for about 30 minutes and shrunk. The cast was taken out from the mould neatly. When fired the body vetrified and fused.

Body TN12KJ Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	35	350
Kaolin	40	400
Quartz	15	150
Ball clay	10	100
Water	50	500

Feldspar weighed 350gm and kaolin also weighed 400gm, quartz weighed 150gm and ball clay weighed 100gm mixed with 500gm of water. The mixture was ball milled. The slip was kept for 24 hours to settled. It was thoroughly stirred and sieved. The colour of the slip was grayish cream. The slip poured into the mould cast quickly within 10 minutes. The surplus slip was drained out and it was kept in the mould for 30 minutes. The top was trimmed and after it shrink it was carefully removed. The colour of the dry cast was cream and there was no crack. When fired, the body appeared dense.

Body TN13KJ Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	35	350
Kaolin	35	350
Quartz	25	250
Ball clay	5	50
Water	50	500

The materials were weighed. 350gm of feldspar, 350gm of kaolin, 250gm of quartz, 50gm of ball clay and 500gm of water were mixed. It was put into the ball milled which run for 4 hours. When it was poured out from the ball milled the slip was left undisturbed for 24 hours. Casting was made within 10 minutes after which the excess slip was drained out from the mould. The cast remained in the mould for 30 minutes and when it shrunk it was removed and kept to dry. The cast sample was bisque and glost fired. It yielded and dense body as well as smooth glaze appearance.

Body TN 14KJ Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	30	300
Kaolin	30	300
Quartz	30	300
Ball clay	10	100
Water	50	500

The ingredients were mixed with water and ball milled for four hours. It was poured out into the plastic bowl. The slip was kept undisturbed for 24 hours after which it was stirred and sieved ready for casting. The slip was smooth and grayish cream. It was poured into the mould for 10 minutes to cast and the casting was successful. After it was drained and trimmed, the cast was allowed to remain in the mould for about 30 minutes.

It was released and removed from the mould and when it dried the colour was cream. No crack noticed. It gave good and smooth appearance after firing.

Plate XVII: Draining of Surplus Slip

Body TN9KK Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	25	250
Kaolin	40	400
Quartz	25	250
Ball clay	10	100
Water	50	500

The slip when ball milled was left undisturbed for 24 hours. The colour of the slip was pinky cream and it was flowing smoothly. The slip was stirred and sieved through 80 screen mesh. The casting operation was executed successfully. After drying, the colour of the cast was cream. There were no cracks on the cast piece. After slow drying and bisque firing, the body was glost fired. It fused and became densed.

Body TN10KK Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	20	200
Kaolin	40	400
Quartz	30	200
Ball clay	10	100
Water	50	500

The dry materials were weighed and mixed with water. The slip was ball milled and after which it was poured out into the plastic bowl. The slip was left undisturbed for 24 hours. It was thoroughly stirred and screened through 80 mesh sieve. The slip flow was very good and the colour of the slip was pinky cream.

The slip was poured into the mould and within the period of 10 minutes it quickly built into the mould cavity. The casting operation was done smoothly. The surplus slip was drained and the top was trimmed when the cast shrunk in about 30 minutes. It was released easily and was kept to dry. The dry colour of the cast was cream and there was no crack.

The good casting behaviour of the slip clearly confirmed the right choice of materials. The plastic quality of the slip indicated the role of ball clay. When fired the body matured to a dense body.

Body TN17KK Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	30	300
Kaolin	40	400
Quartz	20	300
Ball clay	10	100
Water	50	500

Dry materials were mixed with water. The mixture was ball milled. It was kept for 24 hours in order to observe its flow character. The slip was smooth and pinky cream. After stirring and sieving, it was poured into the mould. The casting was done neatly and rapidly within 10 minutes.

The surplus slip was drained out and the cast shrunk. It was removed from the mould and allowed to dry slowly. When fired it vitrified well.

Body TN18KK Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	35	350
Kaolin	35	350
Quartz	20	200
Ball clay	10	100
Water	50	500

This body composition had the tendency to settle after 24 hours rest. The slip was ball milled, stirred, sieved and cast. The colour of the slip was pinky cream. Within 10 minutes a good cast was made. The slip was drained comfortable and satisfactorily. In addition, there was a good flow of the slip and the slip formed clearly within 10 minutes. The surplus slip was drained and the cast piece removed when it shrunk.

There was sufficient plasticity in the body composition which was an indication of the right proportion of ball clay. The moisture colour of the slip was pinky cream. At drying stage, the colour of the cast piece was cream. No crack seen during casting, when fired at glost temperature the body yielded smooth and dense effect.

Body TN4GRK Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	50	500
Kaolin	30	300
Quartz	10	100
Ball clay	10	100
Water	50	500

The mixture of dry ingredients and water were ball milled. The slip was left undisturbed for 24 hours and it was thoroughly stirred and sieved. The slip produced pinky cream and it had a good flow. The slip was poured into the mould for the purpose of building a shape in the mould cavity. The casting recorded no difficulty at all despite several efforts made earlier to produce bars to determine the porosity and shrinkage tests of this particular body composition which failed.

The slip had quick cast and when the surplus slip was drained from the mould the top was trimmed after wards. There was easy release of the cast from the mould when it shrunk. About 30 minutes was given to the cast to shrink. It was taken out neatly and kept to dry slowly. The cast was glost fired and yielded fused and dense body.

Body TN5GRK Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	30	300
Kaolin	35	350
Quartz	25	250
Ball clay	10	100
Water	50	500

The slip when ball milled was allowed to rest for 24 hours. At this stage, slip was thoroughly stirred and sieved. The slip colour at moisture was grayish cream. It was thoroughly poured into the mould to cast. The cast was slow and the surplus slip was drained out. The top of the mould was trimmed while the cast was kept still in the mould to shrink. The cast took about 45 minutes before it could be released. When taken out from the mould the base of the cast chipped a little

The cast was given adequate time to dry slowly. The colour of the dried cast piece was cream. It was fired to about 1300^0C and it fused and produced nicely dense, smooth and light body.

Body TN7GRK Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	30	300
Kaolin	40	400
Quartz	20	200
Ball clay	10	100
Water	50	500

As usual with casting slip, this body composition was ball milled and kept for 24 hours to rest undisturbed. It was observed and examined. The slip was found with good flow and the moisture colour was grayish cream.

The slip was poured into the mould and was given 10 minutes to form. The excess slip was drained freely and the top part of the mould was trimmed. The cast remained in the mould for about 45 minutes and after it shrunk it was taken out from the mould. The cast piece was allowed to dry slowly. The colour of the cast when dried was cream. The cast was glost fired and produced dense body.

Body TN11GRK Slip Composition

Material	Composition (%)	Weight (gm)
Feldspar	35	350
Kaolin	40	400
Quartz	15	150
Ball clay	10	100
Water	50	500

The slip composition after ball milling was kept for 24 hours to settle. Later on, it was stirred well and screened through 80 mesh sieve. The slip was smooth and grayish cream in colour. It had a good flow.

The slip was poured into the mould for 10 minutes and the casting was slowly. The cast was allowed to remain in the mould for about 45 minutes. When the cast shrunk, it was taken out from the mould. After it dried, bisque fired and glost fired, the body exhibited dense and hard body.

4.6 Result of Shrinkage Rate of the Body Compositions

Table 4.12: Body Compositions (1A)

Body	Original (wet) length (cm)	Dry shrinkage (cm)	Bisque shrinkage (cm)	Fired shrinkage (cm)	Total shrinkage (mm)	Total shrinkage (%)
PB4	10	9.9	9.8	9.7	0.3	3
PB5	10	9.9	9.8	9.7	0.3	3
PB8	10	9.9	9.8	9.7	0.3	3

Sources: Studio Test (2006)

Table 4.12 indicates the shrinkage rates of the body compositions (IA) Body PB 4 dry length was 9.9cm and the bisque length was 9.8 while the fired length was 9.7 cm. The total shrinkage of the body was 0.3mm representing 3%. Body PB5 dry length was 9.9cm and recorded 9.8cm and 9.7cm at bisque and fired length respectively representing 3%. Body PB8 displayed the same characteristics as in body PB4 and PB5.

Table 4.13: Triaxial Blend 1,2 and 3.

BODY	Original (wet) length (cm)	Dry shrinkage (cm)	Bisque shrinkage (cm)	Fired shrinkage (cm)	Total shrinkage (mm)	Total shrinkage (%)
TN8KJ	10	9.9	9.8	9.7	0.3	3.0
TN12KJ	10	9.9	9.8	9.7	0.3	3.0
TN13KJ	10	9.9	9.8	9.7	0.3	3.0
TN14KJ	10	9.8	9.7	9.6	0.4	4.0
TN9KK	10	9.9	9.8	9.7	0.3	3.0
TN10KK	10	9.9	9.8	9.7	0.3	3.0
TN17KK	10	9.8	9.7	9.6	0.4	4.0
TN18KK	10	9.9	9.8	9.7	0.3	3.0
TN11GR	10	9.9	9.8	9.7	0.3	3.0

Source: Studio Test (2006)

Table 4.13 shows the result of shrinkage test of the bodies selected from tiraxial blend 1, 2 and 3. The shrinkage test revealed that body TN8KJ had 9.9 cm dry length, 9.8cm bisque length and 9.7cm after glost firing. The total shrinkage of this body was 0.3mm representing 3%. Body, TN12KJ, TN13KJ, TN10KK, TN18KK and TN11GR showed similar shrinkage rates at dry, bisque and glost stages as body TN8KJ, all exhibited 3% total shrinkage.

However, TN14KJ and TN17KK displayed the same total shrinkage rate of 4% each. Each has dry length of 9.8cm, bisque length of 9.7cm, fired length of 9.6cm and total shrinkage of 0.4mm representing total shrinkage of 4%.

4.7 Results of Porosity Rate of Cast Bodies

Table 4.14: Body compositions -1A

Body	Wet weight (gm)	Dry weight (gm)	Fired weight (gm)	Saturation weight (gm)	Porosity (%)
PB4	65	65	50	50	0
PB5	65	55	50	50	0
PB8	70	65	60	60	0

Source: Studio Test (2006)

Table 4.14 above shows the result of porosity test carried out to determine if the cast body seeps water or not. The result revealed that each body has 0% absorption. In other words, none of the bodies is porous. In this respect, body PB4, 5 and 8 in composition 1A displayed the porosity characteristics of porcelain body. According to Peterson (1992) in Grema (2004) porcelain body normally shows 0 – 1 percent absorption.

Table 4.15: Triaxial Blend 1, 2 and 3.

Body	Wet weight (gm)	Dry weight (gm)	Fired weight (gm)	Saturation weight (gm)	Porosity (%)
TN8KJ	70	60	50	50	0
TN12KJ	70	60	50	50	0
TN13KJ	85	75	65	65	0
TN14KJ	100	90	80	80.5	0.6
TN9KK	65	55	45	45	0
TN10KK	90	75	70	70	0
TN17KK	65	55	50	50.5	1
TN18KK	85	78	70	70	0
TN11GR	60	55	45	45	0

Source: Studio Test (2006)

Table 4.16 indicates the result of porosity test of the bodies selected from the triaxial blend 1. 2 and 3 (fig. 3, 4 and 5). The porosity test made a remarkable revelation. After the bodies were soaked in water for 24 hours, body TN8KJ, TN12KJ, TN13KJ, TN9KK, TN10KK, TN18KK, and TN11GR all showed 0% absorption. This implies that none of these bodies seep water or liquid. Generally, these bodies had the same shrinkage rate and now showed the same porosity rate.

But bodies TN14KK and TN17KK had 0.6% and 1% absorption which was insignificant especially with reference to Peterson (1992) that porcelain body displays 0 – 1 percent absorption.

4.8 Result of Glaze Test

The glaze test was conducted to observe the behaviour of the glaze on bodies and the bodies response to glaze fit.

Glaze Batch - I

Material	Composition (%)	Weight gm)
Feldspar	60	300
Kaolin	15	75
Quartz	10	50
Limestone	15	75

This batch was ball milled for about 4 hours. It was strained through 80 mesh sieve and applied on the bisque body, then fired in a kerosene kiln to about 1300^0C. The outcome of this firing was successful and the glaze showed a good melt displaying white transparent effect as well as smooth appearance.

Initially, the glaze was roughly applied in order to observe its running behaviour. The glaze did not run and there were no any form of defects.

To this end, it was clear that the proportion of each material in the recipe was appropriate.

Glaze Batch - II

Material	Composition (%)	Weight (gm)
Feldspar	50	250
Kaolin	20	100
Quartz	15	75
Limestone	15	75

The composition was ball milled for about 4 hours. The bisque piece was dipped into the glaze after the glaze was screened through 80 mesh sieve and stirred thoroughly.

The glaze that adhered on the base of the cast piece was wiped off and it was later fired to about 1300^0C. The body and the glaze fit well. It vitrified, thus, producing a glassy smooth appearance. There was no any sign of deficiency, shortcoming and defects noted on the body. Since there was no fault recorded in the batch, therefore, it could be said that the choice of the ingredients was successfully.

Glaze Batch - III

Material	Composition (%)	Weight (gm)
Feldspar	55	275
Kaolin	15	75
Quartz	15	75
Limestone	15	75

About 4 hours was allotted for the ball milling of the glaze slip. It was applied on the bisque piece after it was agitated and stirred thoroughly. The glaze at the base was neatly cleaned and the bisque piece was dipped into the glaze. After necessary treatment, the piece was fired to about 1300^0C in the kiln using kerosene. The glaze matured with good melt showing smooth, glassy and transparent appearance indicating that the glaze matured with a good melt. The use of correct proportion of the materials appeared to have been achieved since there was no fault seen on the ware.

Glaze Batch - IV

Material	Composition (%)	Weight (gm)
Feldspar	70	350
Kaolin	20	100
Quartz	10	50
Limestone	-	-

The glaze batch was ball milted, for about 4 hours. When it was left in the plastic bowl, the glaze slip settled hard. It was stirred but good flow of the glaze slip was not sufficient. However, the bisque piece was dipped 3 times into the glaze slip but the glaze coat appeared very thin on the bisque piece. Nevertheless, the piece was fired to about 1300^0C and yielded matured glaze with brownish transparent effect. The recipe did not enhance the anticipated white transparent, therefore, it could not be considered suitable for the study.

Plate XVIII: Sample Products

CHAPTER 5

DISCUSSION

5.1 Discussion

All the raw materials for the study were obtained from Kebbi State. This are clay, feldspar, quartz and limestone.

Feldspar and quartz were collected from Bena town situated in the south east of Kebbi State and about 100km from Zuru along Ribah road. The exact location of the mineral is the rocky area of Bena town called Twatsebani. The location was conveniently accessible.

Kaolin samples were procured from three different locations namely: Kaoje, Koko and Giro. Firstly, Kaoje kaolin deposit situated at Kasadi hill (south east of Kaoje). Kasadi hill could be reached through bush path. It was not easily accessible because of the distance and there was no straight route to the deposit point. The kaolin deposit at Kasadi hill was very large covering a vast area. The area was surrounded by a thick forest. Inspite of the fact that the vital role of kaolin in the economic and industrial development of the nation is enormous and paramount, the Kaoje kaolin deposit at Kasadi hill seems to be neglected and abandoned by the authorities.

Secondly, Koko kaolin deposit situated in the Koko hill. Koko town is linked with Birnin Kebbi, the state capital of Kebbi State by a trunk ‘A’ road which also leads to Yauri, Kontagora to Abuja or Lagos. However, getting to Koko hill was a very difficult task due to the fact that it could only be reached through bush path. The distance from the trunk ‘A’ road point to the hill is about 10km and the area is largely surrounded by large shrubs and trees. The procurement of the Koko kaolin was indeed an unforgettable event for the study. Difficult and hard experiences were recorded in the course of obtaining the kaolin sample.

Thirdly, Giro kaolin occurrence located at the south west part of Kebbi State. Giro was reached through a trunk ‘A’ road from Birnin Kebibi. Again through a T. junction that leads to Suru town. From the trunk ‘A’ road to Suru is a tarred road. But from Suru to Giro is about 22km and the untarred road is covered with large shrubs and trees. The exact location of the kaolin deposit is about 2km away from the town through a bush path behind the Giro Model Primary School.

Similarly, limestone samples were got from three different deposits at Aliero, Dangamaji and Katanga. Limestone locations were accessible. The Aliero limestone is deposited at GandaSamu area about 4km away from the trunk ‘A’ Jega to Sokoto road. Katanga Limestone deposit is located along Katanga-Maiyama road on trunk ‘A’ Birnin Kebbi to Yauri and Abuja Road. In the case of Dangamaji, there are about 6km away from Jega to Dangamaji. Although the road was untarred, there was no difficulty encountered in the process of obtaining the Dangamaji limestone.

Two samples of ball clay were procured. The Birnin Kebbi deposit at Goru village is located just opposite the Kebbi State Radio Broadcasting Corporation. Apparently, the distance from the main trunk 'A' Birnin Kebbi Jega road and the ball clay deposit is just about 20 metres. Felande ball clay was the second sample of ball clay procured. Felande village is very much accessible. It is situated along Birnin kebbi to Argungu and to Sokoto trunk 'A' road. The clay deposit is very near to the village.

The raw materials procured were processed accordingly, the non-plastic materials like feldspar, quartz and limestone were washed, calcined with the exception of limestone, jaw crushed and ball milled, sieved and dired. On one hand, the plastic materials, kaolin and ball clay were soaked in water, sieved, levigated and dried.

The chemical analyses were carried out and were expressed in percentage. It was noted that Kaoje kaolin has alumina, 20.63, silica, 46.11 and with other impurities like iron oxide, 0.80; copper, 0.41 while Koko kaolin contains alumina, 18.33, Silica, 40.81; Calcia, 0.37; Potash, 0.41; Titania, 1.57; Iron oxide, 0.20. In addition, Giro kaolin has alumina, 26.37, Silica, 40.68; Potash 0.26; Iron oxide, 0.22.

Basically, the chemical components of the kaolin samples in Kebbi State show some degree of similarity especially silica content in Koko and Giro samples. Koko kaolin has silica, 40.81 while Giro kaolin silica, 40.68. Kaoje kaolin has the highest content of silica, 46.11. Notably, Giro kaolin is highest in alumina, 26.37, however, Kaoje and Giro samples have less concentration of alumina 20.63 and 18.33 respectively.

Clearly, iron oxide is presence in all the three kaolin samples. In particular, the iron content in Koko and Giro are closely the same, 0.20 and 0.22 but Kaoje kaolin has 0.80. Potash is available in Koko and Giro samples. Calcia and titania are seen in Koko only, yet copper oxide is present in Kaoje. Naturally, Kaoje and Giro samples contain less impurities compared to Koko sample which has iron oxide, calcia, titania and potash. Therefore, Koko kaolin has the highest concentration of impurities.

Emphatically, the silica and alumina concentrations in the kaolin samples are enough evidence to display the refractory qualities of the clay Ahuwan (1997) stated that for the chemical properties of kaolin "the percentage content of silica (SiO_2) and alumina (Al_2O_3) are considered paramount and impurities such as iron (FeO) manganese (MnO) Potash (K_2O) are considered undesirable". In earlier support of this assertion, Rhodes (1979) explained that alumina and silica are the essential components of clay.

Ideally, the concept of comparing the kaolin samples in Kebbi State with other samples may further highlight the quality state of the materials. It may also expose, if the materials are in conformity with the chemical properties of some similar materials found suitable for ceramic (tableware) production in related studies.

In regards to this, Kaoje, Koko and Giro chemical analyses were compared with the analyses of kaolin samples in Kankara (Katsina State) Dass and Darazo kaolins (Bauchi State) Kuburivo kaolin (Borno State) and Wamba kaolin (Nasarawa State).

The clays have different chemical compositions, it was noticed that only Kankara clay has a little significant difference of alumina content 31.45 higher than the Kebbi, three kaolin samples.

In the same perspective, Giro alumina content 26.37 is near to Kuburivo, 29.26. The Kebbi kaolin sample alumina content 20.63, 26.37 and 18.33 are higher than Dass kaolin, 15.40 and Darazo kaolin, 17.80 respectively.

The silica presence in Kaoje clay, 46.11 is a little higher than Kankara, 44.56 but Dass sample 57.0; Darazo samples, 58.40 and Kuburivo 51.34 have higher concentration of silica than all the Kebbi State samples. There are less presence of impurities such as iron, titania, calcia, potash, manganese and magnesia in Giro and Kaoje clay samples if compared with Dass and Darazo clays.

Precisely, Kuburivo clay has less amount of impurities than all the clay samples. For emphasis, Giro clay can be compared with Wamba clay, Giro has alumina, 26.37 while Wamba has alumina, 26.40. Equally, the silica concentration of Giro Kaolin is 40.68, Wamba has the same silica content, 40.68. Both kaolin samples have impurities such as potassium oxide and iron oxide.

In contrast, ball clay samples have concentrations of elements that are usually termed impurities. The impurities in ball clay are the main source of plasticity in the clay. Ball clay also known as secondary or sedimentary clay is characterized by its relative plasticity and lacks relative purity while kaolin is characterized by its relative purity but lacks relative plasticity.

The chemical analysis result of Birnin Kebbi clay indicates the presence of alumina, 7.8. Among all the clay samples in Kebbi State-Kaoje, Koko, Giro Kaolins and Felande clay, Birnin Kebbi clay has the highest concentration or silica, 54.06. Also, the calcia content constitutes, 28.68 and iron oxide 0.29 Birnin Kebbi clay is fairly plastic. The raw colour of the clay is cream just appearing like the emulsion paint used in coating buildings.

In the case of Felande clay, it has alumina 17.20 and silica, 40.85; titania, 1.82; iron oxide, 9.14. Indeed, Felande clay has the highest iron oxide concentration over all the clay samples. This singular clay sample is the most plastic and very dark in colour. These unique characteristics are likely caused by the high concentration of iron oxide, 9.14.

The chemical components of the two ball clays have shown no relative similarity as observed in the case of kaolin samples. Felande clay has alumina, 17.20 much high than BirninKebbi which has 7.8. Incidentally, the Felande alumina concentration is very much close to Koko kaolin, 18.33 despite their disparity since kaolin is primary clay and Felande is secondary clay. Nevertheless, Birnin Kebbi has high quality of silica concentration, 54.06 above all clay samples.

As Felande clay appears to have possessed more iron oxide, 9.14 the titania content, 1.82 in Felande and Koko, 1.57 are near in their proportions. Furthermore, BirninKebbi ball clay demonstrated high amount of CaO, 28.68 which is insignificantly traced in Koko sample, 0.37 as an impurity element. Possibly, the high concentration of lime in Birnin Kebbi clay is a predominant factor responsible for its creamy raw colour. Felande clay has no sign of lime in it.

From the outcome of the physical property test (table 4.4, expressed in percentage) it was observed that Felande ball clay was very plastic and Birnin Kebbi clay was also plastic, recording 44.0 and 40.0 respectively. Kaoje and Giro clays displayed similar plasticity state of 24.8 each while Koko clay had 25.0 plasticity. These clay samples had low plasticity quality.

The shrinkage rate of Felande clay at dry, bisque and glost firing temperatures were 5.0, 7.0 and 12.0. Birnin Kebbi clay had 3.0, 10.0 and 9.0 shrinkage at dry, bisque and glost firing temperatures. Equally, Kaoje and Giro which had the same plasticity quality displayed similar shrinkage rate at different stages. Based on the above mentioned reason, it was observed that the plastic state of clay determined the degree of its shrinkage. For instance, Kaoje and Giro had the lowest plasticity of 24.8 recorded 4.0 glost shrinkage. In the same manner, Felande clay which exhibited 44.0 plasticity recorded 12.0 shrinkage at glost firing temperature.

In case of porosity test, kaolin samples absorbed much more than the ball (secondary) clay samples. Kaoje kaolin at bisque and glost recorded 25.0 and 12.7 respectively. Koko kaolin showed bisque shrinkage 25.5 and 11.9 glost. Giro kaolin had 25.8 and 12.7 bisque and glost temperature.

Similarly, Birnin Kebbi clay exhibited bisque porosity 11.6 and 5.1 glost porosity. But Felande displayed 10.0 and 3.5 bisque and glost respectively.

Bearing these points in mind, it was clear that the more plastic the material the less absorption while the less plastic the materials the more it absorbs. Example, Felande clay which recorded 3.5 porosity but still maintained the highest plasticity rate of 44.0. Kaoje and Giro had 24.8 each plasticity yet it registered 12.7 each at glost porosity. Gukas (1985) further re-iterated that the absorption rate of the clay indicates that primary clay has high absorption at 1300^0C and the most plastic clay such as ball clay has less absorption rate at 1300^0C. This implies that the more the plastic the clay, the less absorption it records. The three kaolin samples have shown high absorption rate, 12.7, 11.0 and 12.7 respectively. And the two ball clay clearly displayed less absorption, 5.1 and 3.5 accordingly.

A comparison of the physical properties of Kebbi ball clays with other ball clays (Table 2.1) in Nigeria that have been identified, studied and employed in the production of ceramic tablewares is of enormous importance because it may further confirm the suitability of the ball clays.

The characteristics of two ball clay samples in Kebbi state and three ball clay samples in Kaduna state show close similarities in their physical characteristics. Birnin Kebbi clay has the same plasticity quality and shrinkage rate, 9.0 as found in Zaria dam clay. Felande Shrinkage, 12.0 is little high than Zonkwa and Bomo clays, 11.0 each. There is also close relationslip in terms of absorption rate. Birnin Kebbi has 5.1 absorption at 1300^0C compared to Zonkwa, 4.3 which is also high than the Felande clay, 3.5.

As the main ingredients used in the formulation of the body and glaze for the study are feldspar, clay, quartz and limestone, the physical tests uncovered that the kaolin samples appeared white after firing at 1300^0C. Giro sample burnt whitest, Kaoje whiter and Koko white. Consequently, it was assumed that the whitest effect of Giro kaolin was due to its refractory quality. One of the bisque cubes made from Giro kaolin dissolved within few minutes when soaked in water. Umar (2000) in

Grema (2004) revealed that a good refractory clay should have among other elements, the following

Alumina	25 – 45%
Silica	40 – 60%

However, the analysis of Giro kaolin showed that the clay has alumina, 26.37 and silica, 40.68. Based on this Giro kaolin may fall in the category of refractory clays.

The analysis also disclosed that, Kaoje kaolin has considerable amount of alumina, 20.68 and silica, 46.11. In this case, therefore, Kaoje has much concentration of silica which also falls within the range of silica requirement, 40 – 60 for porcelain body. Koko kaolin had the lowest concentration of alumina 18.33 and silica, 40.81 which is close to Kaoje kaolin. Ahuwan (1997) added that, the ideal kaolin should display physical properties as follows:

Shrinkage	- 12%
Water absorption	- 23%
Colour	- almost pure white colour

At any rate, the three kaolin samples were considered for the formulation of porcelain body on account of the chemical analysis and physical results.

Apart from the chemical analysis conducted on Birnin Kebbi and Felande clays, the physical tests result attests clearly the sufficient plasticity of the ball clays. As a result of this, about 10.0 was used in the body in order to increase the plasticity in the slip.

The chemical analysis of Bena feldspar is interesting. It has alumina content, 14.50 and silica content, 60.11 while potash presence represents, 10.41 and iron oxide, 0.21. The comparison of Bena feldspar found in Kebbi State with the feldspar available in Zaria and Unguwar Nungu (Kaduna State) and Gwoza feldspar (Borno State) exhibit some degree of similarity. Bena feldspar and Zaria feldspar contain almost the same alumina content, 14.50 and 14.49 and the Unguwar Nungu is closer having 13.23 while Gwoza feldspar has high alumina contents, 15.57.

As for the silica concentration, Unguwar Nungu feldspar has the highest amount of silica, 65.75 followed by Zaria feldspar, 64.71. Bena feldspar tends to be closed to Gwoza feldspar in Borno State, Nigeria. Gwoza feldspar has silica content, 62.68 and Bena feldspar silica presence stands at 60.01. The most interesting aspect of the analyses is the potash concentration in Bena feldspar 10.41 and Gwoza feldspar, 10.35 and potash feldspar is pink in colour. Gukas (1985) stated that feldspar that has high amount of potash is better to be used for body formulation while feldspar high in soda is more useful in glaze formulation. The most important components in feldspar are silica, potash and soda.

Three samples of quartz were obtained from Bena, Kanya and Yauri. Bena quartz silica concentration is 45.37 and alumina, 9.55, iron oxide and potash presence in Bena quartz represent 0.22 and 0.25. Kanya quartz has silica 44.36 and alumina 7.22; potash, 0.26 and iron oxide, 0.22. Kanya potash and iron oxide concentrations are almost similar as Bena quartz, for instance, Kanya quartz has potash, 0.26 compared to Bena quartz, 0.25. The iron oxide present in Kanya, 0.22 is the same as Bena, 0.22. The common characteristics found in Bena and Kanya quartz are remarkable. There are about 50km distance between Kanya and Bena.

In respect to Yauri quartz, silica content is 41.87 which is less compared to Bena and Kanya quartz. It is note worthy to observe that Yauri quartz has high alumina content, 17.08 over Bena and Kanya quartz 9.55 and 7.22. Other oxides seen in Yauri quartz are potash, calcia, and iron. Finally, Bena quartz was selected based on its high silica concentration and practical milky and glassy outlook.

A comparison of Bena quartz and Gwoza quartz has a lot of relevance. Bena quartz has more alumina concentration, 9.55 and Gwoza quartz has less amount of alumina, 0.32. Gwoza quartz overwhelmed Bena quartz in respect to silica content, 92.94 and 45.37. Besides, Gwoza quartz has about 2.93 of soda, magnesia, 18.41; calcia, 17.48 among others.

Yet, another vital raw material in the production of tableware is limestone. Three samples of limestone were obtained from Aliero, Dangamaji and Katanga in Kebbi State.

Limestone is an essential ingredient in the formulation of glaze for ceramic tableware. Okuruwa (1986) and Zauro (1988) employed about 15% of limestone in the glaze recipes for porcelain and white wares. Limestone widely regarded as whiting is the calcium carbonate or lime. Cardew (1969) in Zauro (1988) explained that, apart from clay, silica and feldspar another vital ceramic raw material is limestone.

Since the lime concentration is the most important in limestone all the three samples have significant content of lime. Aliero sample has the highest content, 44.03 then Dangamaji has the lowest concentration, 12.9. Despite, this shortcoming in the chemical analysis of the Dangamaji limestone, it performed well yielding smooth glaze and white glaze effect in the glaze recipe. Other oxides found in the limestone samples include alumina, silica, potash, soda, iron oxide magnesia and chromium oxide.

Comparison of Aliero limestone in Kebbi and Yadi-Gilam limestone in Borno State indicates that Yadi-Gilam limestone has lime, 44.48 with a little disparity as Aliero limestone, 44.03. However, Aliero sample has greater presence of alumina, 12.81 and silica, 24.08 if compared with Yadi-Gilam limestone, 3.00 and 5.52. Katanga limestone is the next sample with a relatively high lime content, 39.83 while Dangamaji has the lowest concentration of lime 12.98.

The study considered all the samples raw materials found in Kebbi State for the purpose of formulation of suitable bodies and glaze for the study. All the kaolin samples were discovered to be useful on account of their chemical and physical properties.

As regards feldspar mineral, it acts mainly as a fluxing agent in the body and glaze and potash feldspar is known to be more fruitful in the body formulation. Accordingly, Bena feldspar has a fairly good concentration of potash, therefore, Bena feldspar was considered as the fluxing agent in body formulation in respect to the study.

In order to ensure strength, decrease shrinkage, enhance good vitrification of the body, Bena quartz was chosen out of the quartz samples. Bena quartz was favoured in consideration of its high silica concentration. Apart from that, it appeared most transparent and whitest in the series of quartz samples. The rejected quartz samples were physically dull and stained, though chemically they possess reasonable content of silica.

In view of limestone role as an important ingredient in the glaze formulation, the three limestone samples were chemically analyzed and found to contain calcia or lime that was expected to be present in the limestone. Limestone plays a significant role as a fluxing agent in glaze. Aliero and Katanga have considerable amount of lime, 44.03 and 39.3 and Dangamaji has 12.9. In the light of the higher content of calcia 1% and 1.5% of Aliero limestone were used in body compositions. In the same manner, 15% each of Aliero Katanga and Dangamaji were used in the glaze formulations.

Experiments were conducted with a view to select suitable bodies. In this regard, a preliminary test was performed before the actual engagement into the traditional triaxial blend tests. The preliminary test involve three body compositions undertaken according to Waye (1967) "upper limit for ceramic body compositions" Each of the bodies was composed of feldspar, kaolin, quartz and limestone. Materials were weighed out together with some appropriate amount of water.

Essentially, each of the three compositions were separately ball milled. The slip was poured out from the ball mill into a plastic bowl. The slip was left undisturbed for 24 hours. Eventually, the casting was performed and positive result was accomplished. All the three different samples cast well and there was no fault or shortcomings noticed. The outcome of this particular experiment clearly formed a background testifying that casting could be made without the use of deflocculants and limestone can be part of the body composition.

This study evaluates the suitability of the ceramic raw materials in Kebbi State for the production of tableware for small scale industry. Hence, there was need to expand the scope of the study so that more room would be created to identify the variety of bodies for selection and consideration. On this note, the traditional triaxial blend of materials was adapted.

The materials involved in the triaxial blend experiments were:

1. Kaoje, Koko and Giro kaolin samples
2. Bena feldspar
3. Bena quartz

Three different triaxial blends were put under consideration. The first triaxial blend involved Bena feldspar, Kaoje kaolin and Bena quartz. The second triaxial blend was a mixture of Bena feldspar, Koko kaolin and Bena quartz while the third triaxial blend was a combination of Bena feldspar, Giro kaolin and Bena quartz. There were thirty six (36) member tests in each of the triaxial belnd and the total tests for the three samples were one hundred and eight (108) tests. Results show variety of effects in the triaxial blends.

The triaxial blend of Bena feldspar, Kaoje kaolin and Bena quartz yielded different and nice characters. In a portion where feldspar dominated in the triaxial blend, the tests fused into dense mass. An area where kaolin overwhelmed appeared refractory. Again, in the area where the proportion of quartz was greater than the other materials, wide range of effects were produced. From the triaxial blend I, four bodies TN8KJ, TN12JK, TN13KJ and TN14KJ that exhibited some characteristic of porcelain were selected for further experiments.

The selected body compositions could not enhance adequate plasticity in the slip, therefore the need for the introduction of a more plastic materials such as ball clay was desirable. In line with this, the body compositions were adjusted to accommodate 10% of ball clay in each. The slip was prepared and casting was successfuly executed even though without deflocculants.

The cast pieces from the selected bodies were fired to about 1300^0C. All the bodies fused well and with the application of glaze, the body and glaze fuse nicely.

The shrinkage rate of the bodies fall within the range of 3 – 4% while the porosity indicated 0.0% absorption for each of the bodies except TN14KJ which recorded 0.6% absorption. This implies that TN8KJ, TN12KJ and TN13KJ are not porous but TN14KJ has 0.6% insignificant absorption.

The second triaxial blend was the mixture of Bena feldspar, Koko kaolin and Bena quartz. In the triaxial blend, wide range of effects were produced. Four bodies were selected, TN9KK TN10KK, TN17KK and TN18KK. Sufficient plasticity was required to improve the plasticity of slip composition. About 10% of ball clay was added into each body composition. In this case, the initial compositions were changed and adjusted slip was prepared without deflocculant. Casting was made from the plaster mould.

The cast pieces were fired at about 1300^0C and the shrinkage rate of the bodies were determined and it stood in the range of 3 – 4%.

Similarly, three bodies displayed the absorption percentage of 0.0% indicating that none of the body was porous. But TN17KK exhibited 1% absorption. When glazed, the bodies were in harmony with the glaze.

The third triaxial blend was the combination of Bena feldspar, Giro kaolin and Bena quartz. The outcome of this triaxial blend when fired to 1300^0C revealed that variety of effects were achieved. From these effects, four composition that showed some characteristics of porcelain were considered for further experiments. The tests selected were TN4GR, TN5GR, TN17GR and TN11GR. In order to produce castable slip, 10% of ball clay was added into each of the body compositions. No consideration for deflocculants. As a result of the ball clay addition, the initial composition adjusted.

The casting slip was prepared and casting was done, but at the first stage of casting body TN4GR, TN5GR and TN7GR could not cast well, which was the main reason why the shrinkage rate of the bodies could not be ascertained. However, in the subsequent casting using different moulds these bodies cast well, although the process was a little bit slow. There was no casting fault in respect of TN11GR. It recorded 3% shrinkage rate and 0.0% absorption.

On the general note, the characteristics of porcelain were observed in the area where kaolin and feldspar overwhelmed quartz and the portion where feldspar and quartz were emphasized over kaolin, the characteristics of porcelain were not vivid as a result of the less or insufficient amount of kaolin. Furthermore, the part in the triaxial blend where kaolin was more pronounced than feldspar, that portion looked refractory. In order to enhance in the melting or fusion of such compositions more feldspar was required.

Fundamentally, the outcome of the glaze tests was noted. The glaze batches yielded smooth nice and transparent melts. Apart from the glaze batch 4 that produced brownish effect, glaze batch 1,2 and 3 produced the characteristics of porcelain glaze. At this point, it is appropriate to state that the attainment of suitable glaze batches was due to the quality of the materials and the use of the correct proportion of the ingredients in the compositions.

5.2 Findings

Based on the test and experiments carried out in respect of this study, the following findings were made:

1. Kaoje, Koko and Giro kaolin as well as Birnin Kebbi and Felande clays were found chemically suitable in terms of high concentration of silica and alumina required in ceramics. Ahuwan (1997) emphasized that the percentage content of silica and alumina are significant in the chemical properties of clay.

2. Bena feldspar was chemically established to have high concentration of potash as such it was considered as potash feldspar. Feldspar serves as a fluxing agent in body and glaze. Grema (2004) confirmed that potash feldspar is the purest type of feldspar and therefore good for porcelain formulation.
3. Bena quartz was chemically found to be higher in silica concentration. In quartz, silica content is fundamental. Principally, quartz serve as a source of silica.
4. Aliero, Dangamaji and Katanga limestone samples were identified having the right percentage of calcium carbonate comparable with limestones used in other studies. Example Grema (2004) Yadi-Gilam limestone has 44.86 calcia, and Aliero limestone has 44.03 calcia.
5. The physical tests carried out on the clay sample gave variations of effects as regards to colour, shrinkage and absorption which were found acceptable. Results of tests for this study have close similarities with results findings in related studies. For instance, Giro kaolin has almost the same properties as Wamba kaolin in Nasarawa State. And the shrinkage rate of Felande clay is about the same with Borno clay (Kaduna state).
6. The plasticity of casting slip is necessary to produce good cast. Therefore, the addition of 10% ball clay in varied proportion of

Birnin Kebbi and Felande clay into the casting slip significantly enhanced its plasticity.

7. Ball mill was used to grind feldspar, quartz and limestone into fine powders. It was also used to blend the materials into casting slip, therefore, ball milling was found to be an effective way for the grinding and mixing of ceramic ingredients for the study. Ball milling has been employed to process ceramic raw materials in various studies, Okuruwa (1986) and Grema (2004).

8. Casting operation was successful without the use of deflocculants, as a result of this, it was found that casting especially with body compositions developed for the study was possible without the use of deflocculants. Grema (2004) developed slip which cast well without the addition of deflocculants.

9. The shrinkage and porosity tests results of the selected bodies showed that the rate of porosity 0 – 1% and shrinkage rate 3 – 4% were good. Perterson (1992) in Grema (2004) explained that absorption of porcelain bodies should display 0 – 1%. Porcelain body developed by Grema (2004) exhibited 1 – 7% Shrinkage rate

10. The glost firing (about 1300^0C) in kerosene kiln was found to be sufficient to produce hard, dense bodies with good fusion.

11. The glaze compositions were found to be suitable and when fired to about 1300^{0}C the glaze adhered and fired nicely in the bodies.
12. Body composition PB4, PB5, PB8 and TN8KJ, TN12KJ, TN13KJ, TN14KJ and TN9KK, TN10KK, TN17KK, TN18KK and TN11GR developed for this study were found to be suitable bodies for the manufacture of tableware.
13. Consequently, it could be said that Kebbi State has good quality raw materials for the production of ceramic tableware in view of the results of chemical analyses and physical property tests of clay, feldspar, quartz and limestone used in this study.

CHAPTER 6

SUMMARY, CONCLUSION AND RECOMMENDATION

6.0 Introduction

This chapter highlights the summary, conclusion and recommendation based on the findings from tests and experiments that were carried out.

6.1 Summary

The study was able to gather information as regards to the availability and location of raw materials in Kebbi State from respondents (through questionnaires) such as employees in government agencies like the Raw Materials Research and Development Council and Traditional Potters as well as other geological documents available that disclose the occurrences of mineral resources in Kebbi State.

In consideration of the information received from respondents, a field trip was undertaken to the locations in order to obtain the samples raw materials. The study was able to identify the raw materials on the spot "using reference to Cardew (1969) suggestions on how to recognize different types of ceramic raw materials through simple tests. Such test needed no sophisticated equipments to enable the ceramist trace the right minerals. They are colour, fracture, hardness, cleavage and the likes.

The raw materials collected for the study were taken to experts (geologists) whose among their responsibilities is to study the rocks and minerals. In the light of this, the identification of the raw materials was aided by the Department of Geology, Ahmadu Bello University, Zaria where the raw materials were confirmed to be the right materials desired. The next line of action was the chemical analysis. The raw materials were forwarded to the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. The centre conducted the chemical analysis of the raw materials. The materials were feldspar, kaolin, quartz, limestone and ball clay.

The raw materials identified and analyzed by the relevant agencies were brought to the Department of Industrial Design, Ahmadu Bello University, Zaria for processing. The materials were treated according to the scheme of processing of ceramic raw materials. Other form of processes were done at the Department of Chemical Engineering, Ahmadu Bello University, Zaria.

The outcome of the chemical analysis of Kaoje Kaolin, Koko Kaolin and Giro Kaolin, Birnin-Kebbi and Felande clays had shown some interesting results, that exposed the state of purity and quality of the materials. The results of plasticity, colour, shrinkage and porosity tests of the clay samples had further confirmed and supported the outcome of the chemical analysis.

In the same case, Bena feldspar had indicated an encouraging result. Bena feldspar produces a pinky shiny effect just qualifying the material as the principal flux in the tableware production. Quartz chemical analysis further displayed the good quality of the Bena quartz especially due to its high concentration of silica. Physically, Bena quartz gave a glass and milky shiny effect.

The chemical analysis advanced to reveal the composition of limestone samples. The Aliero and Katanga limestone were of high purity and quality due to their calcium carbonate concentrations. Dangamaji limestone had less amount of calcium carbonate concentration.

In respect to the triaxial blends, different effects were produced. A portion of feldspar domination in the triaxial blend looked dense and hard. While an area where feldspar and kaolin were prominence produced dense bodies but whitish appearance was noted on the portion of kaolin dominance which actually showed no sign of fusion.

About 10% of ball clay was added to the respective selected bodies to increase plasticity of the slip. A good casting slip was produced which enhanced successful casting operation. The bodies fired had dense and hard fusion and the glaze fused well and fit properly on the body. In fact, there was no any form of defect or fault such as crawling crazing and the likes found in any of the glaze recipes.

6.2 Conclusion

The following conclusion was drawn based on the results of the study.

Kaoje Kaolin, Koko Kaolin and Giro Kaolin as well as Birnin-Kebbi and Felande clays are viable and good quality plastic raw materials that could be employed in the production of tableware.

Bena feldspar and quartz are good non-plastic ceramic raw materials that could be used widely to manufacture tableware. Aliero, Katanga and Dangamaji limestones could be reliable source of whiting for body and glaze formulations.

The use of deflocculant may not be necessary provided that the slip could produce good flow and cast well. In the same view, the 50% of water used to every 500gm or 1000gm of dry materials was effective. In addition, ball milling and sieving of slip before casting worked well and greatly improved the casting capability while the 10% of ball clay added to the plasticity of the slip to a large extent.

As far as slip casting is concerned, the role of Plaster of Paris is enormous. Moulds used for the study were made of Plaster of Paris. Normally, the plaster absorbs moisture from the slip, thus forming a wall that gives the exact shape of the model. In the light of this, Plaster of Paris was discovered to be an indispensable material in slip casting technique.

As for the glaze formulation, ceramic raw materials from Kebbi State are essential ingredients in producing suitable glaze.

6.3 Recommendation

The significance of ceramics in the national development need not to be over-emphasized. In view of this, the following recommendations were made:

1. Kebbi State Government should explore effective means to develop the mineral resources available in the state.
2. Ahmadu Bello University, Zaria should provide ceramic equipments and accessories to the Department of Industrial Design in order to facilitate, strengthen and encourage research.
3. It is specifically recommended to conduct research to ascertain the commercial quantity and viability of the materials used in this study. The outcome may attract local and foreign investors.
4. There is need for further research to be carried out to determine the toxic implication of the glazes formulated in this study.
5. Further research is needed to determine the mechanical strength of the bodies produced in this study.

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APPENDIX I:

TEST BARS

APPENDIX II

TEST SAMPLES

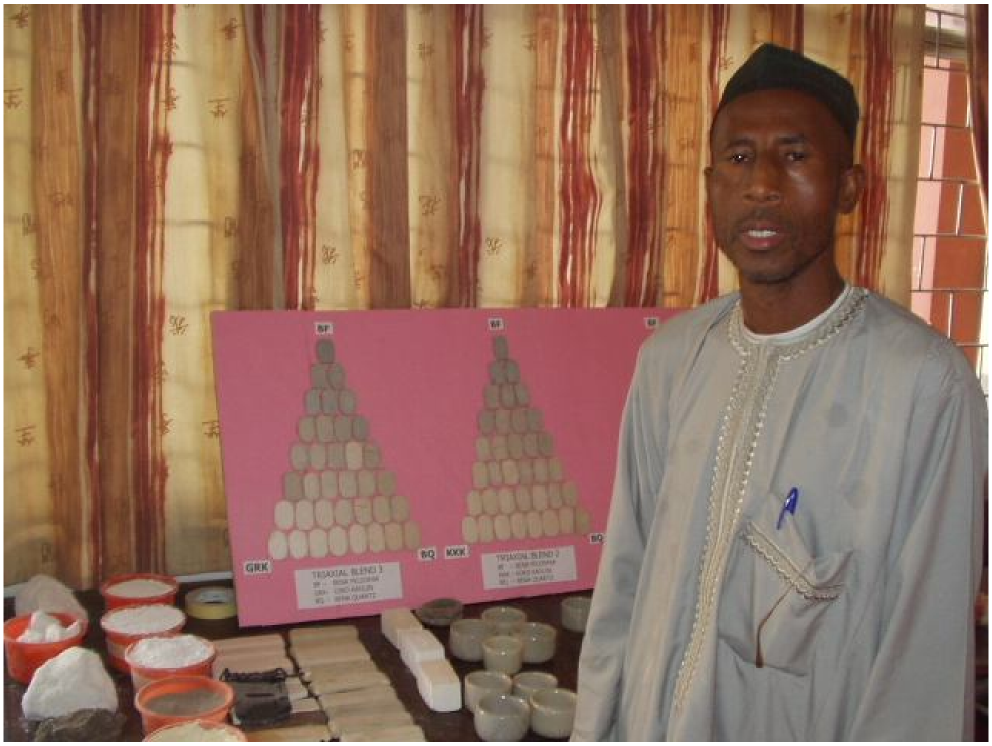
APPENDIX III

SEMINAR: EXHIBITS

APPENDIX IV

SEMINAR: EXHIBITS

APPENDIX V:



SEMINAR PRESENTATION SESSION

APPENDIX VI

APPENDIX VII

APPENDIX VIII:

QUESTIONNAIRE ONE

INTRODUCTION

This questionnaire is designed to document the activities of Ceramic Small Scale Industries or studios with a view to guide a research on the Evaluation of the Suitability of Ceramic Raw Materials in Kebbi State for the Production of Tableware for Small Scale Industry. Information supplied will be treated with utmost confidence.

1. Name of Industry or Studio
   ____
2. Location
   ____
3. Address
   a. Town______________________ b. Local Govt. Area______________
   c. State________________________ d. Tel. No.____________________
   e. P. O. Box/PMB________________ f. E-Mail_____________________
4. Type of Business Registration (Please tick as appropriate)
   i. Cooperative Society [ ]
   ii. Registered Enterprises [ ]
   iii. Limited Liability Company [ ]
5. Year of Establishment ____________________________________
6. State specific year of actual commencement of operation ________________
7. Name(s) of proprietors/Owners
   ____
   ____
   ____
8. Nature of Works Produced
   ____
9. What is the share capital of the business _______________________________
10. State raw materials
    ____
    ____
    ____
11. Sources(s) of raw materials
    ____
    ____
12. State specific location(s) of raw materials
    ____

____
____

13. State ways of procuring your raw materials

____
____
____

14. What are the difficulties encountered in sourcing of raw materials

____
____
____

15. How do you process each raw material? Describe procedure (Add separate sheet for details)

____
____
____

16. Do you import other raw materials?
If yes – name the raw materials – countries of import

____
____
____

17. Tick as appropriate the production technique used
    i. Slip casting [ ]
    ii. Jigger and Jollying [ ]
    iii. Throwing [ ]
    iv. Others (Specify) ____

18. Type of ceramic body (please tick)
    i. Porcelain [ ]
    ii. Stoneware [ ]
    iii. Earthenware [ ]
    iv. Others (specify)____

19. State raw materials for glaze

____
____
____

20. Firing techniques (tick as appropriate)
    i. Electric firing [ ]
    ii. Gas firing [ ]
    iii. Kerosene firing [ ]
    iv. Wood firing [ ]
    v. Others (specify) ____

21. State firing temperature
    i. Biscuit firing ____
    ii. Glaze firing ____

22. List the principal product of the industry or studio. See table below

Description of products	**Installed capacity**	**Actual output**		**Sale**	
		Qty	Value N:000	Qty	Value N:000

23. Are your machinery/equipment locally fabricated or imported? ________________
    i. If imported state sources of machinery/equipment
    ____
    ii. If fabricated locally, state source of machinery/equipment
    ____

24. State or describe your marketing strategies
____
____
____

25. What is the percentage of sales
    i. Within the state ____
    ii. Other states ____
    iii. Others (specify) ____

26. What is the share/size of market your enterprises/company control for your products ____

27. Do you export your products?
    a. If yes – mention counties of export
    ____
    ____
    b. If no – why
    ____

28. State your capacity utilization

i.At inception Year ( )	2001	2002	2003

ii. If your capacity utilization is low, please state reasons
____
____
____

29. Sate profit and loss account of your establishment

	Profit	Loss
Inception year ( )		
2001		
2002		
2003		
2004		

30. Explain reason(s) for either profit or loss ______________________________

____

____

31. Did your industry or studio experience any form of closure? State how many times and reasons____

32. Employment – Describe categories of persons engaged in the production

	No. of persons engaged	
	M	F
Categories of staff		
Management		
Technical		
Clerical		
Casual		
Total		

33. Please tick as appropriate (problem or no problem) amongst the under listed

Type of problem	Yes	No
Water supply		
Access road		
Power supply		
Skilled man power		
Raw material		
Funding		
Spare parts		
Labour		
Low sales		
Others (specify		

34. Pease suggest solutions for the constraint(s) mentioned above

____

____

____

35. Describe government policies that possibly affect the operations of your industry or studio. If favourable, state reason

____
If unfavourable, state reason
____

36. State the effects of some economic policies on your operations
    a. Access to foreign exchange
    ____
    b. Access to bank loan
    ____
    c. Import ban if applicable
    ____
    d. New import and export duty structure
    ____

37. Do you enjoy any form of incentive from government and to what extent does it affect the operation of your industry?
    ____
    ____

38. Do you pay tax to the Federal, State, Local Governments and other agencies? Describe the total number of taxes you pay
    ____
    ____
    ____

39. Is your industry a member of any business/industrial association?
    a. Name the association
    ____
    b. What sort of support do you receive from the associations activities especially in respect to solving your industry's operational problems?
    ____

40. State the problems you think are responsible for the slow industrial development in Nigeria
____
____

41. Please indicate any additional information you wish to provide
    ____
    ____
    ____
    ____
    ____

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APPENDIX IX

QUESTIONNAIRE TWO

TOPIC: AN EVALUATION OF THE SUITABILITY OF CERAMIC RAW MATERIALS IN KEBBI STATE FOR THE PRODUCTION OF TABLEWARE FOR SMALL SCALE INDUSTRY

This questionnaire is designed to gather some information about the occurrences/locations of some ceramic raw materials in Kebbi State. All responses will be treated confidentially.

1. Name of Respondent ____
2. Classification of Respondents (please tick as appropriate)
   - i. EGA [ ]
   - ii. Traditional Potter [ ]
   - iii. Others (Specify) ____

Note: EGA (Employees in Government Agencies responsible for industrial matters like Raw Materials Research and Development Council; Federal Ministry of Solid Mineral Resources, Kebbi State Ministry of Commerce and Industry, Tourism and Co-operatives; Kebbi Investment Company Ltd, etc).

3. Are you aware of any deposit or occurrence of any of the following raw materials in Kebi State? Yes or No (Tick as appropriate)
   - i. Kaolin (Karmatako)
   - ii. Feldspar (Jan Dutsi Mai Haske)
   - iii. Quartz (Dutsin Gilass/Kwalba)
   - iv. Limestone (Zarta/Kasar Marina)
   - v. Dolomite -
   - vi. Talc (Dutsin Hoda)
   - vii. Secondary Clay (Laka)
4. If yes – please indicate locations by filling in the blank
   - a. Kaolin: (Location)

     ____

     ____
   - b. Local Government(s)

     ____

     ____
   - c. Specific localities

     ____

     ____

ii. Feldspar: (Location)

- a. Town/villages

  ____

  ____
- b. Local Government(s)

  ____

c. Specific localities

iii. Quartz: (Location)
a. Town/villages

b. Local Government(s)

c. Specific localities

iv. Limestone: (Location)
a. Town/villages

b. Local Government(s)

c. Specific localities

v. Dolomite: (Location)
a. Town/villages

b. Local Government(s)

c. Specific localities

vi. Talc: (Location)
a. Town/villages

b. Local Government(s)

c. Specific localities

vii. Secondary Clay: (Location)
a. Town/villages

b. Local Government(s)

c. Specific localities

5. What are the roles you think the raw materials mentioned earlier can play in the industrial development of Kebbi State:

6. Please, state any additional information you wish to provide that will assist or guide this study

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APPENDIX X

Kaolin Deposits in Nigeria and their Estimated Reserve

State	Location	Estimated Reserve (Million Metric Tonnes)
Anambra	Ozubulu	142
Enugu	Enugu	768
Plateau	Major Parter, Jos, Naraguta	190
Katsina	Kankara	20
Kaduna	Maraba Rido	5.5
Bauchi	Darazo/Alkaleri	8.5
Kebbi	Giro, Illo, Kaoje	-
Ogun	Abeokuta, Bamgo, Onibode	-
Oyo	Tede, Ade-Awaye	-
Ondo	Ifan, Okitipupa	-
Niger	Kpaki, Pategi	-
FCT	Kwali, Dongara	-

Source: Aliyu et al., (1996) in Grema (2004)

APPENDIX XI

Important Clay Deposits in Nigeria.

State	Location	Type	Reserve (Tonnes)
Anambra/Enugu	Ozubulu, Ihiala & Nnewi L.G.A.	Kaolinitic	4,200,000.00
.Anambra/Enugu	Enugu	Fireclay	50,000,000.00
Katsina	Kankara	Kaolinitic	3,400,000.00
Kaduna	Maraba-rido	Brickclay	5,524,000.00
Ogun	Onibode, Lishabi, Bamajo Miroko	Kkaolinitic	2,800,000.00
Plateau	Jos & Ropp.	Kaolinitic	Very large
Borno	Maiduguri, Biu,	Brickclay	Large
Edo/Delta	Ukwunze	Brickclay	To be fully investigated
Imo/Abia	Bende Awomama, Nsu, Orlu Umuahia	Brickclay	To be fuly investigated
Tarba/Adamawa	Garkida	Kaolinitic	Not fully assesssed
Kano	Tsanyawa, Dawakin Tofa Minjibir	Kaolinitic	Large
Kebbi	Illo, Kaoje	Kaolinitic	Very large
Ondo	Ofon/Omiafora	Kaolinitic	40,000,000.00

Source: Raw Material Research and Development Council, Abuja, (1999) in Grema (2004)

APPENDIX XII

Known Minerals and Their Reserve in Nigeria

Mineral	Location	Estimated Reserve	Quality
Iron (for soda ash)	Gashua and Nguru (Yobe State), Zumo (Adamawa State)	3,400,000.00	62% Sodium carbonate
Kaolin	Kankara (Katsina State) major Parter (Plateau State) Ibeshe (Ogun Sate) Darazo, Alkaleri (Bauchi State), Efon, Ijero Akure (Ondo State)	19,000,000.00	Purity is as high as 90%
Talc	Kagara (Niger State), Ilesha (Osun State)	40,000,000.00	72% of Aluminum silicate
Phosphate	Sokoto (Sokoto State), Ilaro (Ogun State),		34 - 36% as P_2O_5
Limestone	Mfumosing (Cross River State), Nkalogu (Enugu State), Unpolla (Edo State), Yandev (Benue State), Bauchi & Sokoto States	12,000,000.00	85-95% as calcium carbonate
Gypsum	Potiskum, (Yobe State), Damboa (Borno State) Wurno (Sokoto Stae) Shelleng (Adamawa State) Gombe, Ifo (Ogon), Plateau, Imo, Edo & Benue States.	200,000,000.00	
Feldspar	Boro (Niger State),	1,200,000.00	

	Alawa (Niger State, Oshogbo (Osun State) Okene (Kogi state), Kwara and Ogun		
Bentonite	Gashua (Yobe state), Ishiagu (Abia State), Anambra Staate and Adamawa State	1,200,000.00	80% sodium/calcium montmorillonite
Barytes	Azara, Awe (Nassarawa State), Wukari (Adamawa State); Abakaliki (Ebonyi State) Cross River State.	2,000,000.00	Specific gravity of 4.09
Salt	Salt spring of awe (Nassarawa State), Ebonyi, Abakaliki Enugu and Ubulu (Imo) Rock Salt in Benue State		
Gemstone	Plateau, Bauchi, Yobe, Borno, Ogun, Ondo, Imo, Kaduna, Kano, Oyo, Ogun States	The reserve are yet to be determined	High purity
Coal	Enugu, Plateau, Kogi, Traba, Bauchi, Anambra, Abia and Edo States.		
Marble	Kogi, Oyo, Edo, Benue, and Plateau States	200,000,000.00	
Granite	Plateau, Ondo, Bauchi, Abuja (FCT), Kogi, Cross Rivers, Oyo, and Imo States.	300,000,000.00	High grade

Sand	Glass Sand in Ondo, Plateau, Lagos, Enugu, Anambra, rivers, Delta Foundry sand inOndo and Kogi State	300,000,000.00	High (SiO_2)
Kyanite	Birnin Gwari, Kaduna State	20,000,000.00	
Diatomite	Borno State	Commercial quantities	

Source: Aliyu et al., (1996) in Grema (2004)

APPENDIX XIII

Elements and Oxides Commonly Used in Ceramics

Element or Oxide	Symbol
Aluminium	Al
Antimony	Sb
Barium	Ba
Bismuth	Bi
Boron	B
Cadmium	Cd
Calcium	Ca
Carbon	C
Chromium	Cr
Cabalt	Co
Copper	Cu
Hydrogen	H
Iron	Fe
Lead	Pb
Lithium	Li
Magnesium	Mg
Neckel	Ni
Oxygen	O
Phospharus	P
Potassium	K
Selenium	Se
Silicon	Si
Silver	Ag
Sodium	Na
Strontium	Sr
Tin	Sn
Titanium	Ti
Uranium	U
Vanadium	V
Zinc	Zn
Zirconium	Zr
Aluminium oxide	Al_2O_3
Antimony oxide	Sb_2O_3
Barium oide	BaO
Boric oxide	B_2O_3
Calcium oxide	CaO
Chromium oxide	Cr_2O_3
Cobalt oxide	Co_2O_3

Copper oxide	CuO
Iron oxide	Fe_2O_3
Silicon dioxide	SiO_2
Lead oxde	PbO
Lithium oxide	Li_2O
Magnesium oxide	MgO
Manganese dioxide	MnO_2
Nickel oxide	NiO
Potassium oxide	K_2O
Sodium oxide	Na_2O
Strontium oxide	SrO
Tin oxide	SnO
Zinc oxide	ZnO
Zirconium oxide	ZrO_2

Source: Rhodes (1989)