2026 Volume: 02 Issue: 02 www.ijrpa.com ISSN 2456-9995 Research Article

International Journal Research Publication Analysis

Page: 01-28

INTEGRATED GEOTECHNICAL, GEOCHEMICAL, AND MINERALOGICAL EVALUATION OF IGO CLAY FROM THE NIGER DELTA SEDIMENTARY BASIN FOR INDUSTRIAL APPLICATIONS

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Article Received: 28 December 2025
Article Revised: 17 January 2026
Published on: 06 February 2026

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DOI: https://doi-doi.org/101555/ijrpa.4053

ABSTRACT

This study investigates the industrial suitability of Igo clay deposit in Edo State, Nigeria, through an integrated assessment of its geotechnical, geochemical, and mineralogical characteristics. Geotechnical analysis shows that the clay is predominantly fine-grained, with high proportions of clay and silt and negligible sand content. The liquid limit ranges from 28.5-85% with a mean value of 58.9%, while the plasticity index varies between 9.35-34.49%, indicating medium to high plasticity and cohesive soil behavior. These properties suggest good mouldability and low to moderate expansivity, characteristic of kaolinitic clays. Geochemical analysis reveals that the clay is dominated by SiO_2 and Al_2O_3, confirming its aluminosilicate nature, with moderate Fe_2O_3 content responsible for its reddish-brown colour. Loss on ignition values averaging 11.9% indicate the presence of structurally bound water and minor organic matter. Trace element concentrations (Cu, Ni, Cr, Zn, and Ba) are generally within acceptable limits for ceramic and construction applications. Mineralogical analysis using X-ray diffraction shows that quartz is the most abundant mineral, while kaolinite is the dominant clay mineral, with minor amounts of illite/muscovite, feldspars, anatase, and hematite. This mineral assemblage closely compares with clay deposits previously reported from southern Nigeria that have been successfully utilized for brick, tile, and structural ceramic production. The combined results indicate that Igo clay is suitable for bricks, roofing tiles, earthenware, and other structural ceramic products, though it is less suitable for high-grade whitewares without beneficiation.

KEYWORDS: Igo clay, Edo State, Geotechnical properties, Geochemistry, Mineralogy, Industrial suitability, Kaolinite

1. INTRODUCTION

Clays are among the most important and versatile natural industrial raw materials, owing to their wide application in ceramics, construction materials, refractories, paper production, paint, pharmaceuticals, and environmental engineering. The suitability of clay for these applications is primarily governed by its geotechnical behavior, chemical composition, and mineralogical characteristics, which are, in turn, controlled by the geological history, degree of weathering, and physicochemical conditions of the parent material (Bowles, 2012; Mitchell & Soga, 2005). Comprehensive characterization of these properties is therefore essential for determining the industrial value of any clay deposit.

In tropical and subtropical environments, such as southern Nigeria, intense chemical weathering, high rainfall, and prolonged lateritisation processes favour the breakdown of aluminosilicate rocks and the formation of kaolinitic clay deposits. These deposits are commonly associated with residual quartz, iron oxides, and minor feldspars, reflecting incomplete leaching and relict minerals from the parent rock (Deer et al., 2013). Kaolinite-rich clays formed under such conditions are generally characterized by moderate plasticity, low swelling potential, and good thermal stability, making them particularly suitable for structural ceramics such as bricks, roofing tiles, and earthenware products (Mitchell & Soga, 2005).

Several studies on clay deposits in southern Nigeria have demonstrated that kaolinite-dominated, quartz-rich clays constitute the most common clay type within the region. These clays typically exhibit medium to high plasticity, low expansivity, and red-burning characteristics due to the presence of iron oxides, especially hematite. Such properties are favourable for structural ceramic applications but may limit their use in high-purity industries such as porcelain manufacture, paper coating, and pharmaceutical formulations, which require clays with very low iron content and high whiteness (Bowles, 2012; Deer et al., 2013).

Detailed investigations of clay deposits within the Southern Anambra Basin have shown that the combined influence of geotechnical parameters, oxide geochemistry, and mineralogical composition plays a critical role in determining industrial suitability. Studies carried out on the Imiegba clay deposit revealed that quartz and kaolinite are the dominant mineral phases, with minor illite, feldspars, and iron oxides. The authors reported that such mineralogical assemblages promote good mouldability and firing behavior for bricks and tiles, while the elevated iron content results in reddish-brown fired products and limits suitability for whiteware applications (Ejime et al., 2025).

Despite the widespread occurrence of clay deposits across Edo State, many of these resources remain underutilised due to insufficient scientific evaluation and lack of industrial characterization. Igo clay, located in Edo State, represents one such deposit whose geotechnical, geochemical, and mineralogical properties have not been adequately documented. Without proper characterization, the industrial potential of this clay remains uncertain, thereby limiting its contribution to local industrial development and sustainable resource utilization.

This study therefore adopts an integrated approach involving geotechnical testing, major and trace element geochemistry, and mineralogical analysis using X-ray diffraction to evaluate the industrial suitability of Igo clay in Edo State. The results are interpreted in comparison with established standards and previous studies, particularly those conducted on similar clay deposits in southern Nigeria. The outcome of this research is expected to provide a scientific basis for the potential utilization of Igo clay in ceramics and related industries, as well as to identify possible beneficiation requirements for enhanced industrial performance.

2.0 Geological setting / Study area

2.1 Tectonic evolution of the Niger Delta Basin

Several workers including Burke *et al* (1971), Whiteman (1982) and Olade (1975) has summarized the structural and tectonic setting of the Niger Delta. According to these authors, the structural evolution of the Niger Delta began with the formation of the Benue trough in the Early Cretaceous as a failed arm of a triple rift junction associated with the opening of the South Atlantic. Olade (1975) contends that the initial stage of the evolution involves the rise of a mantle plume in the region of the present Niger Delta, which led to the doming and rifting in the Benue region, developing an RRR triple junction.

Three major tectonic phases or epirogenic movements were suggested by Murat (1972) to have influenced the geologic history of the Benue Trough system, which he subdivided into three paleogeographic areas or sub-basins; the Abakaliki–Benue Trough, the Anambra Basin and the Niger Delta basin. The initial rifting resulted to rapid subsidence and deposition of the Asu River Group during the Albian times. During the Cenomanian, a mild deformational event led to the compressive folding of the Asu River Group and restriction of the Odukpani Formation to the Calabar flank. Continued mantle upwelling and rifting during the Early

Turonian resulted to the deposition of the Ezeaku Formation. When mantle upwelling finally ceased and migrated westward by the Santonian, the trough collapsed.

The second tectonic phase started during the Santonian as a gentle widespread compressive folding, uplifting the Abakaliki-Benue Trough. The Anambra Basin and the Afikpo Syncline subsequently subsided and were filled by two deltaic sedimentary cycles through to Paleocene. The last tectonic phase resulted from the uplift of the Benin and Calabar flanks during the Paleocene - Early Eocene (Murat, 18 1972). These movements initiated the subsidence and progressive outbuilding of the Eocene - Holocene sediments of the Niger Delta along the Northeast-Southwest fault trend of the Benue Trough. The structural evolution of the Niger Delta has been controlled by basement tectonics as related to crustal divergence and translation during the Late Jurassic to Cretaceous continental rifting. It has also been influenced by isostatic response of the crust to sediment loading. The Niger Delta has been rapidly subsiding because of sediment accumulation, flexural loading, and thermal contraction of the lithosphere (Onuoha, 1982, 1986; Onuoha and Ofoegbu, 1988). According to Caillet and Batiot (2003), throughout the geological history of the delta, its structure and stratigraphy have been controlled by the interplay between rates of sediment supply and subsidence. Subsidence itself has been controlled both by driving subsidence of the basement as well as differential sediment loading and compaction of unstable shales.

2.2 Stratigraphy of the Niger Delta Basin

The Tertiary Niger Delta covers an area of approximately 75,000 sq. km and consists of a regressive clastic succession, which attains a maximum thickness of 12,000m (Orife and Avbovbo, 1982). The Niger delta is located in the Gulf of Guinea, Central West Africa, at the culmination of the Benue Trough and is considered one of the most prolific hydrocarbon provinces in the world (Corredor *et al*, 2005). The Anambra basin and Abakaliki High to the north, the Cameroun volcanic line to the east, the Dahomey Embayment to the west and the Gulf of Guinea to the south define the boundaries of the Niger Delta. Burke (1972) remarked that the siliciclastic system of the Niger Delta began to prograde across pre-existing continental slope into the deep-sea during the Late Eocene and is still active today. The lithostratigraphy of the Tertiary Niger Delta can be divided into three major units: Akata, Agbada and Benin formations, with depositional environments ranging from marine, transitional and continental settings respectively. The Akata, Agbada and Benin formations overlie stretched continental and oceanic crusts (Heinio and Davies, 2006). Their ages range from Eocene to Recent, but they transgress time boundaries. These prograding depositional facies can be distinguished mainly on the basis of their sand-shale ratios.

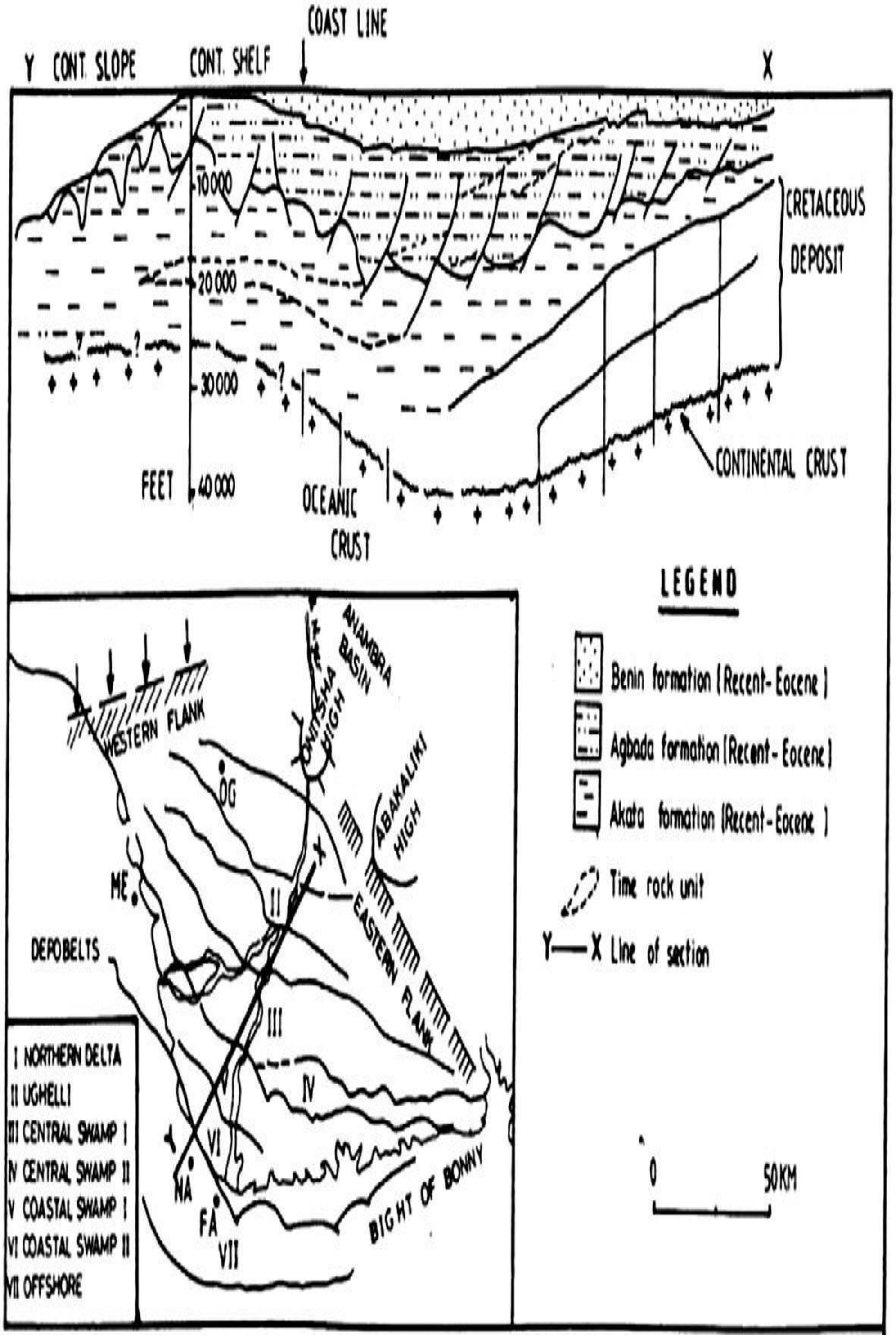

Fig 1: Niger Delta: Stratigraphy and Depobelts (Ekweozor and Daukoru, 1984.*)*

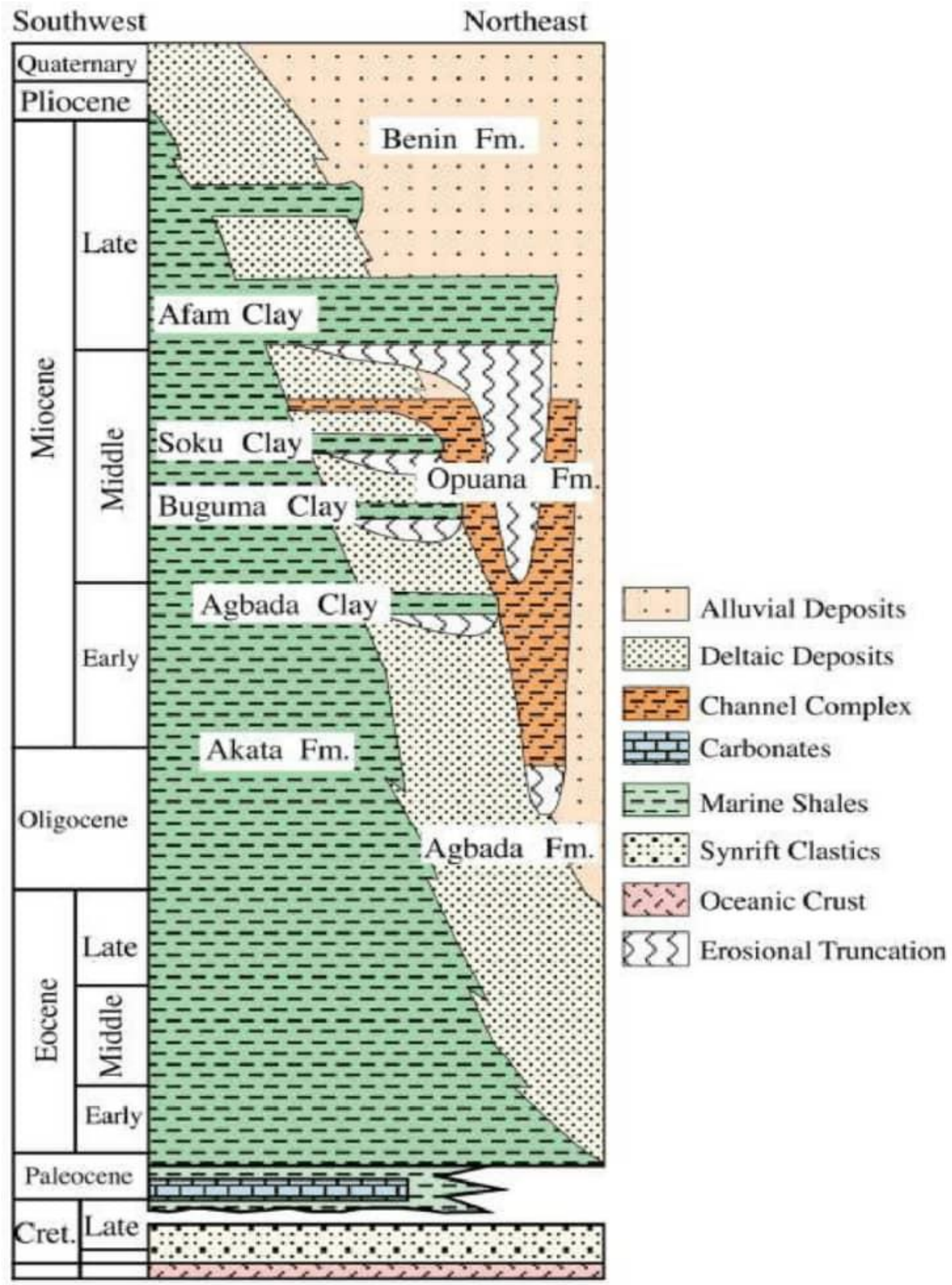

Fig 2: Regional Stratigraphy of the Niger Delta (Lawrence *et al,* 2002; Corredor *et al,* 2005)

2.2.1 The Akata Formation

The Akata Formation is the basal sedimentary unit of the delta. It consists of uniform dark grey over-pressured marine shales with sandy turbidites and channel fills. Its age ranges from Late Eocene to Recent. In deep-water environments, these turbidites are the potential reservoirs. Whiteman (1982) suggested that the Akata Formation may be about 6,500m (21,400 ft.) thick, while Doust and Omatsola (1990) suggested that the thickness ranges from 2000 m (6600 ft.) at the most distal part of the delta to 7000 m (23,000 ft.) beneath the continental shelf. Corredor *et al* (2005) also suggested a thickness of about 5000m (16,400 ft.) for the deep fold and thrust belts in the offshore Niger Delta. The Akata Formation has generally been regarded as the main source rock for oil in the delta.

2.2.2 The Agbada Formation

This is the major petroleum-bearing unit in the Niger Delta. It overlies the Akata Formation and consists of alternations of sand and shale layers. The Agbada Formation is characterized by parallic to marine-coastal and fluvial-marine deposits mainly composed of sandstone and shale organized into coarsening upward off-lap cycles (Pochat*et al*, 2004). According to Corredor *et al* (2005), the Agbada Formation consists of parallic siliciclastic that are more than 3500 m (11,500 feet) thick and they represent the actual deltaic portion of the succession that accumulated in delta front, delta-top set and fluvio-deltaic environments. The first occurrences of shale with marine fauna usually characterize the top of the Agbada Formation while the deepest significant sandstone body characterizes the base. The Agbada Formation can be subdivided into upper, middle and lower units. The upper unit is made up of 60 - 40 percent sand. The middle unit consists of 50 – 30 percent sand and is the main objective of oil and gas exploration in the delta. The lower unit is made up of 20 percent sand inter-bedded with under-compacted shales.

2.2.3 The Benin Formation

The top most Benin formation extends from the west across the whole Niger Delta region and southward beyond the coastline. It is over 90% sandstone with shale intercalations. It is coarse grained, gravelly, locally fine grained, poorly sorted, sub-angular to well-rounded with lignite streak and wood fragments. Onshore and in some coastal regions, the Benin Formation overlies the Agbada Formation. The Benin Formation consists of Late Eocene to Recent deposits of alluvial and upper coastal plain deposits that are up to 2000 m (6600 feet) thick (Avbovbo, 1978).

3.0 Materials and Methods

3.1 Field sampling/ sourcing of materials

A field trip was embarked upon to collect rock samples. Clay and lateritic soil samples were collected from Igo community (Ovia North East Local Government Area) near Benin City, Edo state.

The following materials aided in the collection of the field samples:

1. **Global Positioning System (GPS):** The function of the GPS is to receive signals from satellites and get the exact location of the GPS receiver based on the coordinates.
2. **Sampling bags:** Polythene and sac bags were used to store the collected samples from the field.
3. **Camera:** The camera is used for taking photographs on the study area.
4. **Cutlass:** For clearing bush pathways.
5. **Hammer:** The geologic hammer is used for splitting and breaking rocks. On the field, they are used to obtain a fresh surface of a rock to determine its composition, bedding orientation, nature, mineralogy, and history and field estimate of rock strength. The geologic hammer is also used for scale in a photograph. The hammer also serves as an extension of the senses, permitting the geologist to perceive the rocks granularity, soundness and resistance to fracturing that may be relevant to its use or identification.
6. **Chisel:** The chisel is useful for splitting rocks parallel to bedding or foliation and to free fossils or specific mineral samples from unfoliated rocks.
7. **Field note and pen:** The field note and pen are used for recording observations on the field.

After the Clay samples were collected; they were stored in various polythene bags, labelled and then put in a sack.

Plate 1: Clay Exposure at Igo community.

3.2 Geotechnical analysis of Clay

3.2.1 Atterberg Limits

The following moisture conditions – liquid limit, plastic limit, along with shrinkage limit are referred as the "Atterberg Limits. It is also called consistency test. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic and liquid. In each state, the consistency and behavior of a soil is different and consequently so are its engineering properties. Thus, the boundary between each state can be based on a change in the soil's behavior.

3.2.2 Liquid Limit Test Procedure

The liquid limit is defined as the moisture content at which soil begins to behave as a liquid material and begins to flow. The liquid limit is determined in the laboratory as the moisture content at which the two sides of a groove formed in a sample come together and touch for a distance ½ inch after 25 blows. Since it is very difficult to get this to occur exactly, the test is repeated until the groove closes ½ inch with over 25blows and under 25 blows. The results are plotted as blow count versus moisture content.

- **Apparatus**

Liquid Limit Device is a mechanical device consisting of a brass cup suspended from a carriage designed to control its drop onto a hard rubber base. The device may be operated by either a hand cranks electric motor.

1. Cup brass with mass (including cup hanger) of 185 to 215g.
2. Cam designed to raise the cup smoothly and continuously to its maximum height, over a distance of at least 180^0 of csm rotation, without developing an upward or downward velocity of the cup when the cam followed leaves the cam.
3. Flat Grooving Tool is a tool made of plastic or non-corroding metal having specified dimensions.
4. Gage a metal gage block for adjusting the height of the drop of the cup to 10mm.
5. Pulverization apparatus – mortar and rubber – cover pestle.
6. U.S. No. 40(0.425mm) sieve.
7. Spatula, about 3 in. (75mm) long and approximately ¾ in. (19mm) wide.
8. Watering bottle, with distilled, demineralized or tap water.
9. Clay sample

- **Preparation of Sample**

1. It is preferable that soil used for liquid limit determination be in their natural or moist state, because drying may alter the natural characteristics of some soils, Organic soils in particular undergo changes as a result of oven-drying or even extended air-drying. Clay may agglomerate, lose absorbed water which is not completely regained on rewetting, or be subject to some chemical change.
2. If it is determined that the soil is organic or fine –grained, containing no plus No. 40 (0.425mm) material, the liquid limit shall be run on the sample in its natural state.
3. If the soil contains sand or large size particles, provision must be made to separate the minus No. 40 (0.425mm) material for testing despite the possibility that drying may alter the characteristics of some soils. The fine fraction of granular soil is normally free of organic matter or contains a minimal amount which does not affect the liquid and plastic limit result. The soil shall be thoroughly dried in an oven at a temperature not exceeding 230 ± 9^{o}F (110±5^{o}C). The pulverizing apparatus and the No. 40(0.0425mm) sieve shall then be utilized for separation of the minus No. 40(0.425mm) fraction.
4. Care should be exercised to insure that the pulverizing apparatus does not reduce the natural size of the individual grains. If the sample contains brittle particle, the pulverization operation shall be done carefully and with just enough pressure to free the fine material adhering to the coarser particles. The ground soil shall then be separate into two fractions by means of the No. 40 (0.425mm) sieve. The plus No. 40 (0.425mm) component shall be reground as before. When repeated grinding produces only a minimal quantity of minus No. 40 (0.425mm) soil, the material retained on the No. 40 (0.425mm) sieve shall be discarded and further pulverization of the fraction should be suspended.
5. The material passing the No. 40 (0.425mm) sieve obtained from the grinding and sieving operations described above shall be thoroughly mixed together and set aside for us in performing the physical test. Approximately 0.31b. (100g) would generally suffice for the liquid limit test.

- **Procedure**

1. About 100g of dry sample sieved through 0.425mm keeping a couple of tablespoons of dry soil aside) was thoroughly mixed with water in a metal mixing bowl until it was in aplastic condition.

2. A portion was transferred into a brass cup of the liquid limit machine (casagrande apparatus). The sample was then squeezed and spread into position with as few strokes of the spatula as possible. Care was taken to prevent entrapment of air bubbles within the mass.
3. The drop height of the liquid limit device was adjusted to1cm using the block end of the grooving tool. With the spatula, the c lay sample was levelled and at the same time trims it to depth of 0.3937in. (10mm) at the point of maximum thickness. The excess sample was returned to the evaporating dish.
4. The clay sample in the cup was divided equally by a firm stroke of the grooving tool along the diameter through the centerline of the cam follower so that a clean, sharp groove of the proper dimensions will be formed. To avoid tearing of the sides of the groove or slipping of the clay cake on the cup, up to six strokes, from front to back, or from back to front counting as one stroke, is permitted. The depth of the groove should be increased with each stroke and only the last stroke should scrape the bottom of the cup.
5. At this point, the crank was turned at a rate of 2 turn per second until the two halves of the sample flow together and come in contact at the bottom of the groove along a distance of ½ in. (12.7mm). Keep track of the blow count. The number of drops required to close the groove is recorded and moisture content was gotten by removing a slice of clay sample approximately the width of the spatula, extending from the edge to edge of the soil cake at right angles to the groove and including that portion of the groove in which the sample flowed together.
6. If the blow count is greater than 25 blow, add some water and repeat. If less than 25 blows were obtained, add dry soil, mix extremely well, and repeat. The liquid limit is the water content at which it will takes 25 blow to close the groove over a distance of 13mm (1/2in).
7. The procedure was repeated for other samples and the moisture content was taken each time.

Plate 2: Casagrande Instrument used for Liquid Limit Test.

Plate 3: Apparatus for plastic Limit Test

3.2.3 Plastic Limit test procedure

- **Apparatus**

1. Pulverizing apparatus -mortar and rubber covered pestle.
2. Evaporating dishes - porcelain or similar mixing dishes approximately 4½ in. (114mm) in diameter.
3. No. 40 (0.425 mm) sieve.
4. Spatula, about 3 in (75mm) long and approximately ¾ in. (19mm) wide.
5. Watering bottle, which distilled water, demineralized or tap water
6. Surface for rolling - a ground glass plate or piece of glazed or unglazed paper on which to roll the clay sample.

7. A 1/8 inch (3 mm) diameter rod may be used as a guide to help the estimate the thread size.
8. Clay sample

- **Procedure**

1. About 15g of sample was mixed with water in an evaporating dish until it become plastic to be handled easily.
2. The test sample was squeezed and rolled into an ellipsoidal shaped mass. The mass was rolled between the fingers or palm of hand and the ground glass plate with just sufficient pressure to form the mass into a thread of uniform diameter.
3. When the diameter of the thread 1/8 in. (3mm), the thread is broken into six or eight pieces. The pieces are then squeezed together between the thumbs and fingers into a uniform mass roughly ellipsoidal in shape, and are rerolled again.
4. Alternate rolling to a thread 1/8 in. (3mm) in diameter and gathering together, kneading and re-rolling continues until the thread crumbles under the pressure required for rolling and the clay soil can no longer be rolled into a thread.
5. Crumbling may occur when the thread has a diameter greater than 1/8 in. (3mm). This shall be considered satisfactory end point, provided the soil has been previously rolled into a thread 1/8 in. (3mm) in diameter.

3.3 Determination of Plasticity Index (Pi)

The moisture contents determined for the liquid limit (LL) and plastic limit (PL) tests were used to compute the plasticity index. Plasticity index (PI) is the difference between the LL and PL gave the PL for each clay, to the nearest whole number. The plasticity index may be considered as a measure of the cohesion possessed by a soil and is a dimensionless number.

Plasticity Index = Liquid Limit – Plastic Limit

PI = LL – PL

Soil with medium to high plasticity index tends to be clay, those with lower plasticity index to be silt, and those with a plasticity of zero (0) i.e. non plastic tends to have little or no silt or clay.

3.4. Determination of Specific gravity of the Clay

This test is done to determine the specific gravity of fine-grained soil density bottle method as per IS: 2720 (part III/Sec 1) – 1980. The test to determine the specific gravity of solid will be used to assist in the hydrometer-analysis test. Specific gravity is the ratio of the weight in air of an equal volume of distilled water at the same state temperature.

- **The apparatus used.**

1. Two density bottles of approximately 50ml capacity along with stoppers
2. Constant temperature water bath (27.0 + 0.2^{0}c)
3. Vacuum desiccators
4. Oven, capable of maintaining a temperature of 105 to 110^{0}c
5. Weighing balance, with an accuracy of 0.001g
6. Spatula.

3.4.1 Preparation of Sample

The clay soil sample (50g) was grounded to pass through a 2mm IS Sieve. 10g of sub-sample was obtained by riffling and oven-drying at a temperature of 105 to 110^{0}c.

3.4.2 Procedure to determine the specific gravity

1. The density bottle along with the stopper, was dried at a temperature of 105 to 110^{0}c, cooled in the desiccators and weighed to the nearest 0.001g (W1).
2. The sub-sample, which had been oven-dried, was then transferred to the density bottle directly from the desiccators in which it was cooled. The bottles contents together with the stopper were weighed to the nearest 0.001g (W2).
3. Distilled water from the glass wash bottle was added to the density bottle and allowed to say for a period of 2 to 3hrs for soaking. Water was then added to fill the bottle to about half.
4. The entrapped air can be removed by heating the density bottle on a water bath.
5. The bottle without the stopper was kept in vacuum desiccators for about 1 to 2hrs, until there is no further loss of air.
6. The soil in the density bottle was gently stirred with a clean glass rod, carefully wash off the adhering particles from the rod with some drops of distilled water and see that no more soil particles are lost.
7. The constant temperature in the bottles was observe and recorded
8. The stopper in the density bottle was then inserted, wiped and weighed (W3).
9. Lastly, the density bottle was emptied, cleaned thoroughly and filled with distilled water at the same temperature. The stopper in the bottle was then, wiped dried from the outside and weigh (W4).

3.4.3 Reporting the results

The specific gravity G = w2 – w1÷ (w4 w1) – (w3 – w2)

The specific gravity should be calculated at a temperature of 27^0c and reported to the nearest 0.01. If the room temperature is different from 27^0c, the following correction should be done:

$G^{'} = KG$

Where: $G^{'}$ = corrected specific gravity at 27^0c

G = Average specific gravity.

K = Relative density of water at room temperature ÷ Relative density of water at 27^0C.

Relative density of water at various temperatures is taken from a standard table.

3.5 Mineralogical analysis of rock samples

The Clay samples were pulverized and homogenized in order to be analyzed using X-ray Diffraction technique.

3.5.1 X-ray diffraction Analysis for Mineral Identification

Powdered samples were pelletized and sieved to 0.074mm. These were later taken in an aluminum alloy grid (35mm x 50mm) on a flat glass plate and covered with a paper. Wearing hand gloves, the samples were compacted by gently pressing them with the hand.

Each sample was run through the Rigaku D/Max-lllC X-ray diffractometer developed by the Rigaku Int. Corp. Tokyo, Japan and set to produce diffractions at scanning rate of 2 ^{0}/min in the 2 to 50^0 at room temperature with a CuKa radiation set at 40kV and 20mA. The diffraction data (d value and relative intensity) obtained was compared to that of the standard data of minerals from the mineral powder diffraction file, ICDD which contained and includes the standard data of more than 3000 minerals.

Similar diffraction data means the same minerals to standard minerals which exist in the soil sample.

3.5.2 Principle of Diffraction

The XRD analysis is based on passing X-ray beam through a clay sample. The X-ray identifies the structural layers which is dependent on the d-spacing of the clay minerals. The d-spacing is the exact spacing of the staking of the crystal lattices which indicates the arrangement of the atoms in a mineral. The X-ray on passing through the clay samples gives peaks that is typical of each type of diffracted along a group of planes and the way they are diffracted is characteristics of the arrangement of the atoms within the mineral.

3.5.3 Diffractometer Technique

The less than 2-micron clay fraction was grouped and the powder was pressed into an aluminum sample holder and rim through a wide angle Phillips P.W. 1011 goniometer connected to a PM 8220 recorder.

The scanning was done from 2’ to 40’ under the following instrumental setting conditions.

Nickel filtered Fek and radiation

1. Recording/scanning rate = 1’ 20cm/min.
2. Time = constant 4.
3. Range = 4 x 10 C.P.S
4. Voltage is 28kv/12mH

The interpretation of the diffractograms was done by using the reference conversion table to 20 to d-values for the Fek alpha radiation.

4.0 RESULTS AND DISCUSSIONS

4.1. Geotechnical properties of Igo Clay

Table 1: Geotechnical properties of Igo clay.

SAMPLES	CLAY	SILT	SAND	LL	PL	PI	SG
Igo 1	20	46	0	45	14.24	30.7	2.66
Igo 2	35	65	0	54	19.51	34.49	2.68
Igo 3	63	36	0	85	60.00	25	2.67
Igo 4	65	34	1	74	56.00	18	2.80
Igo 5	45	50	1	41	19.04	21.96	2.79
Igo 6	58	41	1	85	51.50	33.5	2.71
LAS	14	19	67	28.5	19.15	9.35	2.80
MEAN	42.8	41.6	10	58.9	34.20	22.36	2.73

Table 2: Atterberg Limit of Different Clay Minerals. (Mitchell and Soga, 2005)

Mineral	Liquid Limit (%)	Plastic Limit (%)
Montmorillonite	100-900	50-100
Illite	60-120	35-60
Kaolinite	30-110	25-40

Table 3: Plasticity index classification of soils. (ASTM D4318, 2017)

Plasticity Index (PI)	Description
0	Non plastic
1-5	Slightly plastic
5-10	Low plasticity
10-20	Medium plasticity
20-40	High plasticity
>40	Very high plastic

Table 4: Typical values of specific gravity of soils. (Bowles, 2012)

Type of soil	**Specific gravity**
Sand	2.65-2.67
Silty sand	2.67-2.70
Inorganic clay	2.70-2.80
Soil with mica or iron	2.75-3.00
Organic soil	1.00-2.60

4.2 Geochemistry of Major Oxides of Igo Clay

Table 5: Geochemistry of major oxides of Igo clay.

Oxide	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**TiO_2**	**CaO**	**P_2O_5**	**K_2O**	**MnO**	**MgO**	**Na_2O**	**LOI**
Sample											
Igo 1	55.38	30.21	2.34	1.26	0.52	0.76	0.95	0.01	1.42	0.76	12.44
Igo 2	55.4	30.4	1.78	1.21	0.53	0.6	0.86	0.0I	1.32	0.66	12.2
Igo 3	54.3	31.3	2.3O	1.19	0.41	0.6	0.99	0.01	1.31	0.65	11.8
Igo 4	55.91	27.78	1.87	1.42	0.3	0.53	1.02	-	2.04	1.03	12.32
Igo 5	52.32	26.77	1.88	1.32	0.22	0.64	1.07	-	2.00	1.4	12.47
Igo 6	54.86	27.9	1.66	1.11	0.43	0.55	0.85	0.01	1.98	1.06	12.5
LAS	52.97	28.42	3.65	1.14	1.85	-	0.94	-	0.08	0.05	10.2
AVERAGE	**54.9**	**28.9**	**2.2**	**1.2**	**0.61**	**0.5**	**0.95**	**0.01**	**1.45**	**0.8**	**11.9**

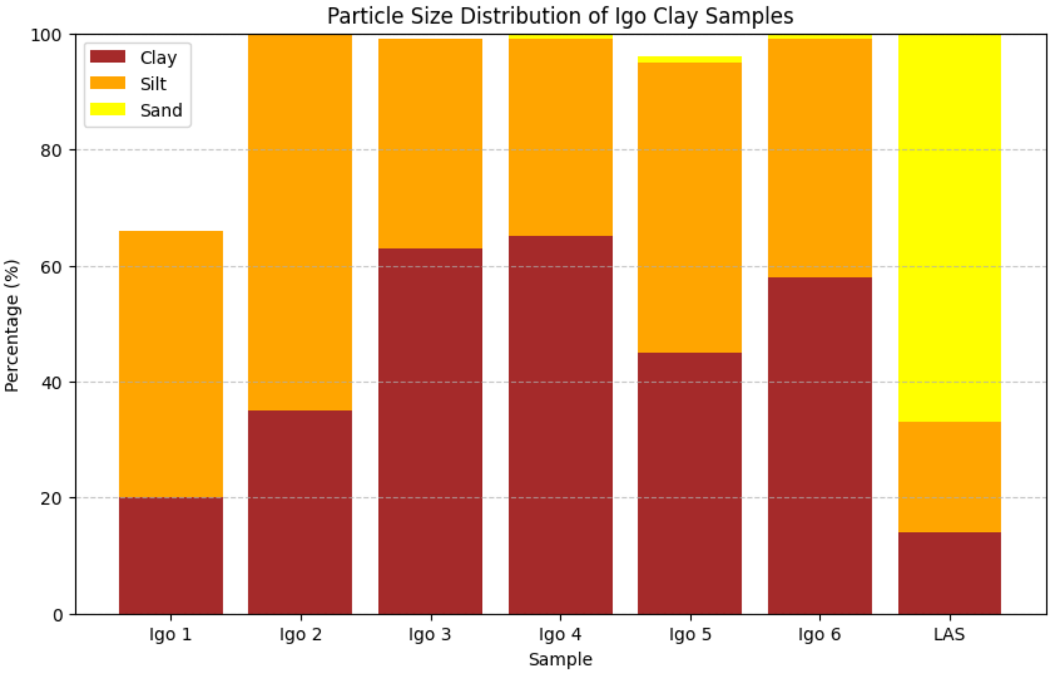

Fig 3: Particle Size Distribution of Igo Clay Samples.

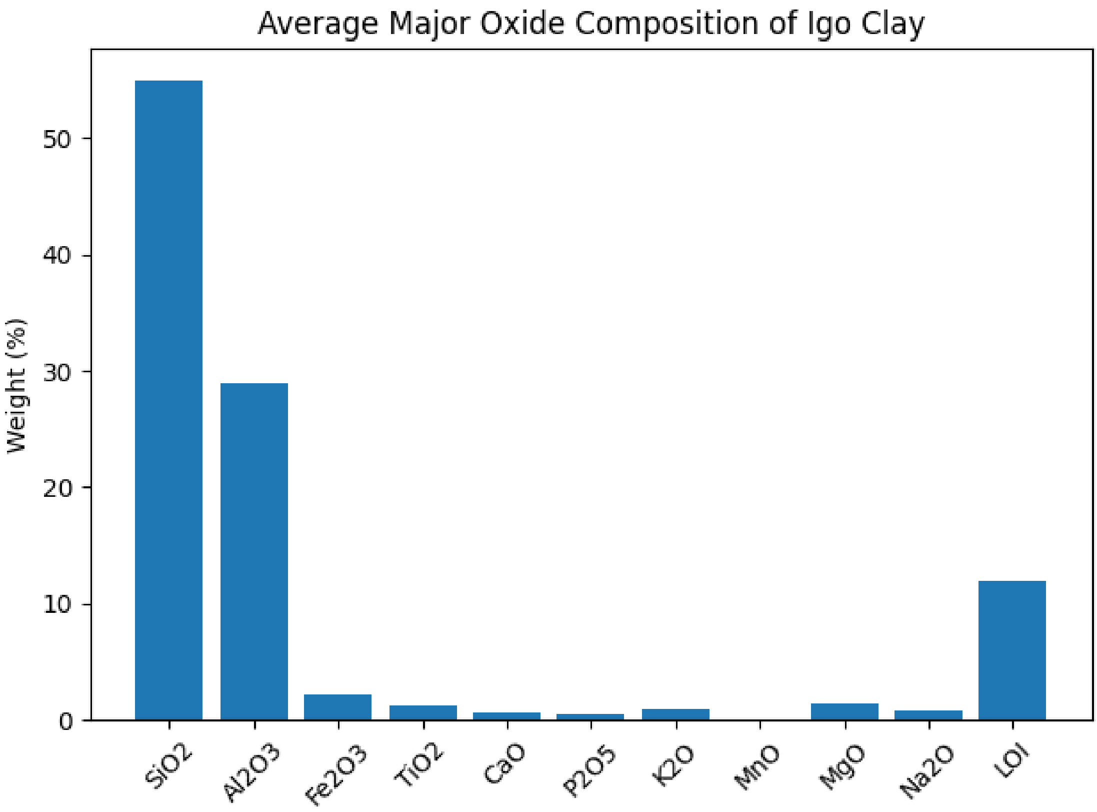

Fig 4: Mean Graph of major oxides of Igo clay.

Table 6: Trace elements of Igo clay.

TRACE ELEMENT	**Cu**	**Ni**	**Cr**	**Zn**	**Ba**
SAMPLE					
Igo 1	23.26	30.55	110.22	211.4	714.85
Igo 2	23.33	32.55	112.4	210.44	770.62
Igo 3	24.33	31.6	100.3	210.45	699.61
Igo 4	22.18	30.7	110.14	210.45	705.52
Igo 5	22.36	31.65	111.2	210.45	672.67
Igo 6	21.8	30.8	109.1	210.38	686.53
LAS	28.36	31.65	100.3	210.39	662.67
AVERAGE	**23.7**	**31.3**	**107.7**	**210.6**	**701.8**

4.3 Clay mineralogical analysis

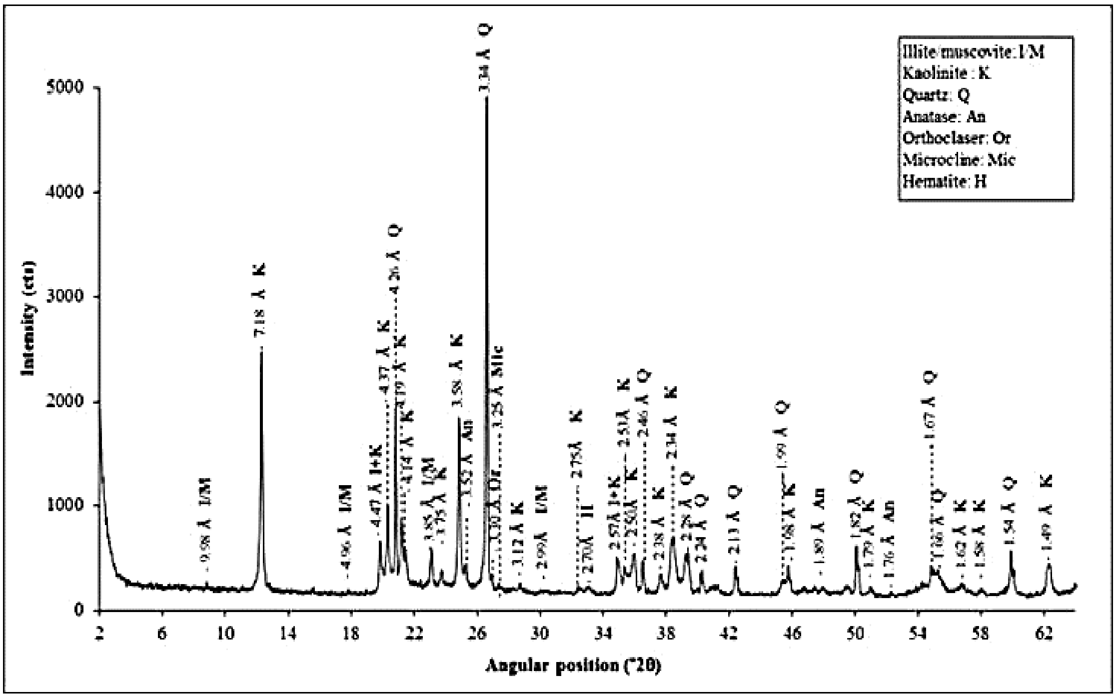

Figure 5: Igo clay diffractogram.

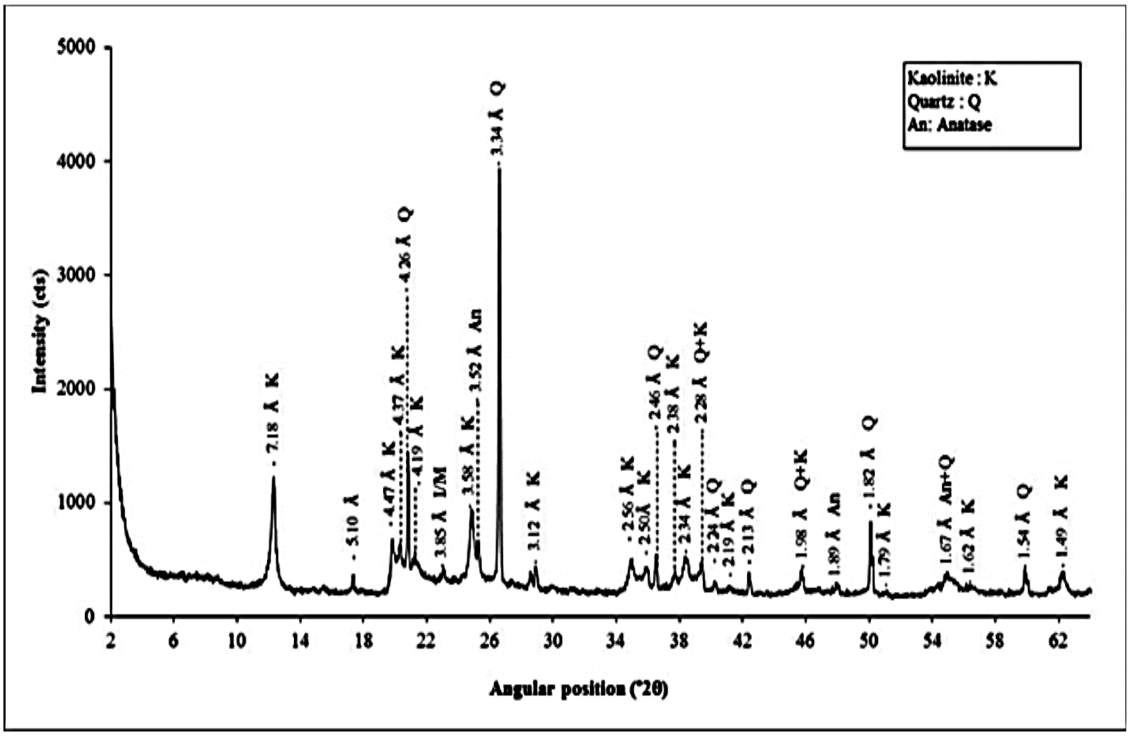

Figure 6: Igo clay Diffractogram.

4.4 Lateritic soil mineralogy (Diffractogram)

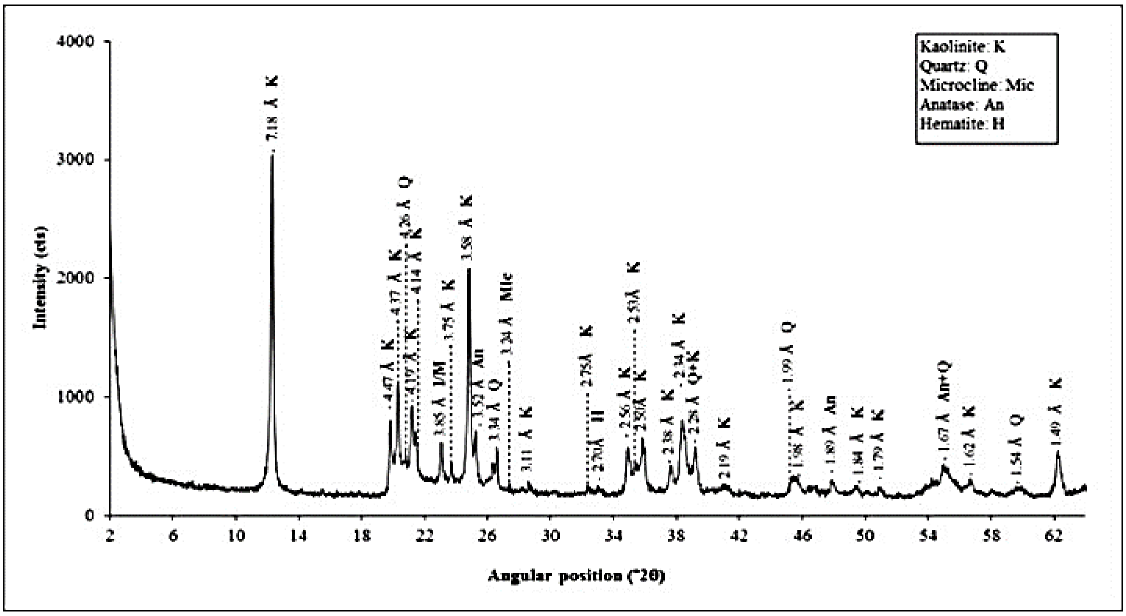

Figure 7: Lateritic soil diffractogram.

5. DISCUSSION OF RESULTS

5.1 Geotechnical Characteristics of Igo Clay

The geotechnical analysis of Igo clay indicates that the material is predominantly fine-grained, consisting mainly of clay and silt with an insignificant proportion of sand. Such particle size distribution is typical of cohesive soils and is favourable for industrial applications that require good mouldability, workability, and shape retention, particularly in ceramic and structural clay products.

The liquid limit (LL) of the Igo clay ranges from 28.5% to 85%, with an average value of 58.9%. The liquid limit represents the minimum water content at which the soil behaves as a liquid. When compared with the Atterberg limits of common clay minerals (Mitchell and Soga, 2005), the average LL strongly suggests that kaolinite is the dominant clay mineral. Kaolinitic clays are widely preferred in ceramic and brick industries because they provide sufficient plasticity for shaping while maintaining dimensional stability during drying and firing.

The plastic limit (PL) ranges from 14.24% to 60%, with an average value of 34.2%. This range, in comparison with standard values, further supports kaolinite dominance, with minor illite contributions in samples 3, 4, and 6. From an industrial perspective, this level of plastic limit indicates adequate water tolerance during processing, reducing the risk of excessive cracking during forming and drying stages.

The plasticity index (PI), calculated as the difference between the liquid limit and plastic limit, ranges from 9.35% to 34.49%, with a mean value of approximately 22.6%. According to ASTM D4318, these values place the Igo clay predominantly within the medium to high plasticity class. This degree of plasticity is desirable for ceramic, brick, and tile manufacturing, as it ensures good cohesion, ease of shaping, and mechanical integrity of green bodies prior to firing.

Having established kaolinite as the dominant clay mineral, the expansivity potential of the Igo clay is expected to be low. Kaolinite is a non-expansive clay mineral, unlike smectite-group minerals such as montmorillonite, bentonite, and vermiculite, which exhibit high swelling behavior. Low expansivity is an important industrial advantage, as it minimizes drying shrinkage, warping, and cracking, thereby improving product quality and yield in fired clay products.

The specific gravity (Gs) of the Igo clay ranges from 2.66 to 2.80, with an average value of 2.73. Specific gravity reflects the mineralogical composition and density of soil solids. When compared with standard values for soils (Bowles, 2012), these results indicate that the Igo clay is predominantly inorganic. Inorganic clays are generally more thermally stable and chemically consistent, making them suitable for high-temperature applications such as bricks, tiles, and structural ceramics.

Overall, the geotechnical properties of Igo clay-moderate to high plasticity, fine-grained and cohesive nature, low expansivity, and inorganic composition-demonstrate that the material is well suited for industrial applications including brick manufacturing, roofing tiles, earthenware, and other structural ceramic products. However, its kaolinitic nature limits its suitability for applications requiring high swelling or adsorption capacity, such as drilling muds or bentonite-based products.

5.2 Geochemistry of Igo Clay

The major oxide composition of Igo clay shows a dominance of silicon dioxide (SiO_2) and aluminium oxide (Al_2O_3), indicating a strong aluminosilicate signature typical of kaolinitic clays. Aluminosilicates are fundamental components of kaolin and many industrial clays, and their abundance in Igo clay aligns with standard classifications of industrial raw materials for ceramics and bricks (Akinyemi & Ogunniyi, 2011; Adekeye et al., 2019). In similar work on clay deposits in the Southern Anambra Basin of Nigeria, Ejime, et al.,2025 also found quartz and kaolinite to be the dominant phases, with high SiO_2 and Al_2O_3 concentrations indicative of aluminosilicate clay suitable for various industrial uses, including glazes and ceramic wares. (IRE Journals)

The average SiO_2 (≈ 54.9 %) and Al_2O_3 (≈ 28.9 %) contents of Igo clay are within the broad range observed in Nigerian kaolinitic clays used for bricks, tiles, and ceramics. In the Imiegba clay study by Ejime *et al.2025*, quartz also emerged as the most abundant mineral phase with kaolinite as the dominant clay mineral, supporting the view that these local clays share a comparable geochemical framework. (IRE Journals) Both studies affirm that such aluminosilicate compositions are favourable for structural ceramics and similar products.

The Fe_2O_3 content in Igo clay (≈ 2.2 %) is moderate and is consistent with values reported for other Nigerian clay deposits intended for red-burned ceramic products. Moderate iron oxide content imparts desirable colouration and firing behavior, without the excessive darkening associated with high iron clays. Comparative analyses of Igo clay with other regional samples also show that the low concentrations of fluxing oxides such as CaO, MgO, Na_2O, and K_2O are typical of kaolinitic materials that require elevated firing temperatures. In the study by Odion et al. (2023) on clays near Igo and Oduna, a similar oxide distribution was found, and those clays were regarded as suitable for refractory brick production after beneficiation to remove impurities. (Science and Education Publishing)

Loss on ignition (LOI) in the Igo clay averages about 11.9 %, which falls within the range reported for many natural kaolinitic clays. This suggests the presence of structural hydroxyl water and minor organic matter. Previous studies of Nigerian clays have interpreted similar LOI values as primarily reflecting bound water in clay minerals rather than problematic organics, reinforcing the notion that the Igo clay is suitable for conventional ceramic and brick manufacturing without deleterious firing defects.

5.2.1 Trace Element Geochemistry: Context and Comparisons

Trace elements detected in the Igo clay -including copper (Cu), nickel (Ni), chromium (Cr), zinc (Zn), and barium (Ba) - occur in moderate concentrations. While elevated barium can raise environmental concerns, studies of other Nigerian clay deposits have similarly noted these elements at comparable levels without ruling out industrial use, provided appropriate environmental controls are in place. In the Imiegba clay study by Ejime et al.,2025 trace concentrations were likewise within ranges typical of aluminosilicate clays used in ceramic industries. (IRE Journals)

5.3 Mineralogical Characteristics

The X-ray diffraction (XRD) patterns of the Igo clay presented in Figures 5 and 6 reveal a multi-mineral assemblage dominated by quartz and kaolinite, with subordinate amounts of illite/muscovite, anatase, orthoclase, microcline, and hematite. Quartz occurs as the highest intensity peak in the diffractograms (Figures 5 and 6), indicating that it is the most abundant mineral phase. Quartz is widely recognized as the most abundant and stable mineral at the Earth's surface and commonly persists as a relic mineral derived from the weathering of silicate parent rocks.

This mineralogical assemblage closely compares with findings reported by Ejime et al.,2025 in their studies on the industrial suitability of clay deposits in parts of southern Nigeria. In their work on Imiegba and related clay deposits, quartz was similarly identified as the dominant non-clay mineral, occurring as sharp, high-intensity peaks on XRD diffractograms. They attributed this dominance to intense tropical weathering, where resistant quartz survives chemical alteration while feldspars and mafic minerals decompose into clay minerals. The comparable abundance of quartz in Igo clay suggests a similar genetic origin and weathering history.

Kaolinite is identified as the dominant clay-forming mineral in the Igo clay and is labelled "K" on the diffractograms of Figures 5 and 6. The dominance of kaolinite is a key mineralogical feature that directly supports the geotechnical inference of moderate to high plasticity with low expansivity. Ejime et al.,2025 also reported kaolinite as the principal clay mineral in the clays they studied and concluded that kaolinitic dominance is characteristic of clays formed under tropical climatic conditions with strong leaching. Their studies emphasized that kaolinite-rich clays are particularly suitable for ceramic, brick, and structural clay products due to their thermal stability and non-expansive nature.

Minor amounts of illite/muscovite identified in the Igo clay are consistent with observations made by Ejime et al.,2025 earlier clay studies, where illite occurred as a secondary clay mineral. In those studies, the presence of illite was interpreted as contributing limited alkali content, which can act as a natural flux during firing without causing excessive melting. This interpretation aligns with the Igo clay mineralogy, where illite and feldspar minerals such as orthoclase and microcline occur in minor proportions and correspond with the low but measurable alkali oxides observed in the geochemical analysis.

Hematite is also identified in the Igo clay diffractograms and is responsible for the brownish to reddish coloration of the clay. Ejime et al.,2025 similarly reported hematite as a common accessory mineral in lateritic and kaolinitic clays, particularly those derived from iron-rich parent materials. They noted that hematite enrichment enhances the red-burning characteristics of clays, making them suitable for bricks and roofing tiles but less appropriate for whiteware ceramics. The presence of hematite in Igo clay therefore explains both its colour and its moderate iron oxide content and places it in the same industrial category as the clays studied by these authors.

The diffractogram of the lateritic soil (Figure 7) shows dominant kaolinite, quartz, monocline, anorthite, and hematite. This mineralogical association is typical of lateritic soils developed under prolonged tropical weathering and closely mirrors the lateritic clay assemblages. The similarity between the mineralogical compositions of the lateritic soil and the Igo clay suggests a genetic relationship and confirms that Igo clay evolved under comparable weathering conditions.

5.3.1 Mineralogical Implications for Industrial Suitability

When compared with the clay deposits studied by Ejime et al.,2025, the mineralogical composition of Igo clay falls within the range of clays considered suitable for structural ceramic applications. The dominance of kaolinite ensures low shrink–swell behavior and dimensional stability during drying and firing, while quartz enhances thermal resistance and mechanical strength of fired products. The presence of hematite supports the production of red-burning ceramic products such as bricks and roofing tiles.

However, as noted by Ejime et al.,2025, clays with significant quartz and iron oxide content are generally unsuitable for high-grade whitewares, porcelain, or paper coating applications without beneficiation. The mineralogical composition of Igo clay therefore supports similar industrial recommendations: suitability for bricks, tiles, earthenware, and structural ceramics, but limited applicability in industries requiring high purity and low iron content.

Overall, the strong mineralogical similarity between Igo clay and the clay deposits previously studied by Ejime and Ochu Abdulmajeed validates the classification of Igo clay as a kaolinitic, quartz-rich clay of proven industrial relevance within tropical environments.

5.4. Industrial Implications

The combined geotechnical, geochemical, and mineralogical characteristics of Igo clay suggest favourable performance for ceramic-based industries. The moderate to high plasticity ensures good mouldability, while the dominance of kaolinite and quartz favours dimensional stability during firing. The iron content enhances colour development in fired products, making the clay suitable for bricks, roofing tiles, earthenware, and structural ceramics.

However, the absence of swelling clay minerals such as montmorillonite limits its application in industries requiring high adsorption or expansive properties, such as drilling muds or bentonite-based products.

6.0 CONCLUSIONS

Based on the results obtained from this study, the following conclusions are drawn:

1. Igo clay is predominantly fine-grained, consisting mainly of clay and silt fractions with negligible sand content, classifying it as a cohesive soil with good moulding characteristics.
2. The liquid limit and plasticity index values indicate medium to high plasticity, which is favourable for ceramic shaping processes, while the dominance of kaolinite suggests low expansivity and good dimensional stability.
3. Geochemical analysis shows that the clay is rich in SiO_2 and Al_2O_3, confirming its aluminosilicate and kaolinitic nature. Moderate Fe_2O_3 content accounts for the reddish-brown colour and favours red-burning ceramic products.
4. Trace element concentrations are generally within acceptable ranges for industrial use, although elevated barium content requires environmental consideration during mining and processing.
5. Mineralogical analysis reveals quartz as the most abundant mineral and kaolinite as the dominant clay mineral, with minor illite, feldspars, anatase, and hematite.
6. The combined geotechnical, geochemical, and mineralogical characteristics confirm that Igo clay is suitable for bricks, roofing tiles, earthenware, and structural ceramics, but is less suitable for high-grade whiteware applications without beneficiation.

7.0 RECOMMENDATIONS

1. Igo clay should be considered for commercial production of bricks, roofing tiles, and structural ceramic products, given its favourable plasticity, mineralogy, and firing characteristics.
2. Beneficiation techniques such as washing, sieving, and magnetic separation are recommended to reduce quartz and iron contents where improved product quality is required.
3. Further studies on firing behavior, shrinkage, water absorption, and mechanical strength of fired products are recommended to fully establish performance under industrial conditions.
4. Environmental impact assessments should be conducted prior to large-scale exploitation, particularly in relation to trace element mobility and dust generation.
5. Comparative studies involving blending Igo clay with other local clays or flux-rich materials are recommended to enhance vitrification and broaden its industrial applicability.

REFERENCES

1. **Adeleye, D. R.** (1975). Nigeria late Cretaceous stratigraphy and paleography. *Bulletin of the American Association of Petroleum Geologists, 59*(12), 2302–2313.
2. **Agagu, O. K., Fayose, E. A., & Petters, S. W.** (1985). Stratigraphy and sedimentation in the Senonian Anambra Basin of Eastern Nigeria. *Journal of Mineralogy and Geology, 22,* 25–36.
3. **Akande, S. O., Hoffknecht, A., & Erdtmann, B. D.** (1992). Rank and petrographic composition of selected Upper Cretaceous and Tertiary coals of Southern Nigeria. *International Journal of Coal Geology, 71*, 209–224.
4. **Akpokodje, E. G.** (1986). Engineering geological characteristics and classification of the superficial soils of the Niger Delta. *Engineering Geology, 23*, 193–211.
5. **Akpokodje, E. G.** (1989). Preliminary studies on the geotechnical characteristics of the Niger Delta subsoils. *Engineering Geology, 26*, 247–259.
6. **Akinyemi, S. A., & Ogunniyi, S. O.** (2011). Geochemical and mineralogical characterization of some Nigerian kaolinitic clay deposits for ceramic applications. *Journal of Minerals and Materials Characterization and Engineering, 10*(10), 883–891.
7. **Asseez, L. O.** (1979). Review of the stratigraphy, sedimentation and structure of the Niger Delta. In C. A. Kogbe (Ed.), *Geology of Nigeria* (pp. 311–324). Elizabeth Press.
8. **ASTM International.** (2017). *ASTM D4318–17: Standard test methods for liquid limit, plastic limit, and plasticity index of soils.* ASTM International.
9. **Avbovbo, A. A.** (1978). Tertiary lithostratigraphy of the Niger Delta. *AAPG Bulletin, 62*(2), 295–300. https://doi.org/10.1306/C1EA47C416C911D7864500102C1865D
10. **Bowles, J. E.** (2012). *Engineering properties of soils and their measurement* (4th ed.). McGraw- Hill Education.
11. **Brindley, G. W., & Ertem, G.** (1971). *Clay and clay minerals* (pp. 19, 129).
12. **Brown, J., & Sobsey, M. D.** (2007). Microbiological effectiveness of locally produced ceramic filters for drinking water treatment in Cambodia (pp. 1–10).
13. **Burke, K., Dessauvagie, T. F. J., & Whiteman, A. J.** (1971). Opening of the Gulf of Guinea and geological history of the Benue Depression and Niger Delta. *Nature Physical Sciences, 233*, 51–55. https://doi.org/10.1038/physci233051a0
14. **Caillet, G., & Batiot, S.** (2003). 2D modelling of hydrocarbon migration along and across growth faults: An example from Nigeria. *Petroleum Geoscience, 9*(2), 113–124. https://doi.org/10.1144/1354-079302-499

15. **Corredor, F., Shaw, J. H., & Bilotti, F.** (2005). Structural styles in the deep-water fold and thrust belts of the Niger Delta. *AAPG Bulletin, 89*(6), 753–780. https://doi.org/10.1306/02170504074
16. **Deer, W. A., Howie, R. A., & Zussman, J.** (2013). *An introduction to the rock-forming minerals* (3rd ed.). The Mineralogical Society.
17. **Doust, H., & Omatsola, E.** (1990). Niger Delta. In J. D. Edwards & P. A. Santogrossi (Eds.), *Divergent/passive margin basins* (AAPG Memoir 48, pp. 239–248). American Association of Petroleum Geologists.
18. **Ekweozor, C. M., & Daukoru, E. M.** (1984). Petroleum source bed evaluation of the Tertiary Niger Delta: Reply. *AAPG Bulletin, 68*(3), 390–394.
19. **Ejime, C. F., Abdulmajeed, O., Favor, E. C., Adedeji, O. C., Uduma, A. E., & Gift, D. O.** (2025). Industrial suitability of Imiegba clay deposits in the Southern Anambra Basin, Nigeria: A geochemical, mineralogical, and geotechnical approach. *Iconic Research and Engineering Journals, 8*(8), 907–915.
20. **Grim, R. E.** (1962). *Applied clay mineralogy*. McGraw-Hill.
21. **Grimshaw, R. W.** (1971). *The chemistry and physics of clays and allied ceramic materials.* Ernest Benn Limited.
22. **Heiniö, P., & Davies, R. J.** (2006). Degradation of compressional fold belts: Deep-water Niger Delta. *AAPG Bulletin, 90*(5), 753–770.
23. **Holtz, R. D., & Kovacs, W. D.** (1981). *An introduction to geotechnical engineering.* Prentice-Hall.
24. **Mermut, A. R., Mermunt, A. R., & Cano, A. F.** (2001). Baseline studies of Clay Minerals Society source clays: Chemical analysis of major elements. *Clay and Clay Minerals, 49*(5), 381–386.
25. **Mitchell, J. K., & Soga, K.** (2005). *Fundamentals of soil behavior* (3rd ed.). John Wiley & Sons.
26. **Murat, R. C.** (1970). Stratigraphy and paleogeography of the Cretaceous and Lower Tertiary in Southern Nigeria. In T. T. J. Dessauvagie & A. J. Whiteman (Eds.), *African Geology* (pp. 251–266). University of Ibadan Press.
27. **Newman, A. C.** (2000). *Chemistry of clays and clay minerals* (2nd ed.). Oxford University Press.
28. **Odion, O. J., Samson, A. E., & Owenvbiugie, E. M. (2023).** *Geochemical and Industrial Potentials of Some Clay Deposits from Oduna and Igo Community in Ovia*

North East Area of Edo State, Nigeria. **World Journal of Environmental Engineering, 8(1), 1–5.** https://doi.org/10.12691/wjee-8-1-1

29. **Olade, M. A.** (1975). Evolution of Nigeria's Benue Trough (Aulacogen): A tectonic model. *Geological Magazine, 112*(6), 575–583.
30. **Onuoha, K. M.** (1986). Basin subsidence, sediment decompaction, and burial history modelling techniques: Applicability to the Anambra Basin. Proceedings of the 3rd Annual Conference of the Nigerian Association of Petroleum Explorationists (NAPE), 2, 6–17.
31. **Onuoha, K. M., & Ofoegbu, C. O.** (1988). Subsidence and evolution of Nigeria's continental margin: Implications of data from Afowo 1 well. *Marine and Petroleum Geology, 5*(2), 175–181.
32. **Orife, J. M., & Avbovbo, A. A.** (1982). Stratigraphic and unconformity traps in the Niger Delta. In M. T. Halbouty (Ed.), *The deliberate search for subtle traps* (pp. 251–265). American Association of Petroleum Geologists Memoir 32.
33. **Pochat, S., Castelltort, S., & Van Den Driessche, J.** (2004). A simple method of determining sand/shale ratios from seismic analysis of growth faults: An example from upper Oligocene to lower Miocene Niger Delta deposits. *AAPG Bulletin, 88*(10), 1357–1367. https://doi.org/10.1306/04290403117
34. **Short, K. C., & Stauble, A. J.** (1967). Outline of geology of Niger Delta. *AAPG Bulletin, 51*, 761–779.
35. **Whiteman, A. J.** (1982). *Nigeria: Its petroleum geology, resources and potential.* Graham and Trotman.