Comparative Study of Soil Profiles of Ceramic Stoves Production Clays of Sierra Leone: (Case Study of Four Traditional Pottery Communities)

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Abstract: ***Sierra Leone soils are mainly ultisols in which the accumulated clay has long been recognized as an important raw material for building and manufacturing of ceramic utensils. The basis for classification and understanding ceramic clays is the soil profile description made in the field, where soils occur. Laboratory investigations only supplement understanding of soil profile descriptions made in the field. For ceramic products to be appreciated in Sierra Leone, which has a high potential for the establishment of ceramic industry due to her huge deposit of clay, research has to be done to provide information on the various clay deposits with reference to their ceramic suitability and to do so an understanding of the soil profiles from which this clays are extracted is essential. Two hundreds or more years have passed since the discovery of ceramics and many civilizations in the world have developed this industry to economically viable and environmentally sound levels. Where Sierra Leone stands in all this development is yet to be determined. The development of ceramics at the traditional level in Sierra Leone has regrettably not advance beyond the first basic stage discovered by primeval man. To this day, sun-dried mud instead of firm relatively indestructive fired bricks are used for building houses in rural communities. This study aims at identifying some properties of soil profiles whose clays could be used in ceramics production of tiles, bricks and household utensils so as to establish small scale ceramic industries that could improve the livelihoods of pottery communities in Sierra Leone. Three soil profiles, representing taxonomic units, were sampled from each of the four sites (Pa Loko, Niagorehun, Yengema and Mabettor). The sampled soil profiles from each unit were described using freshly exposed vertical pits and fresh auger boring at depth within horizons. Clay samples were collected from the "B" Horizon and both the physical and chemical properties of these clays were analyzed. From the results of both the physical and chemical analyses of the clay samples collected from the various soil profiles, a conclusion could be made that the clays are suitable for the production of ceramic building materials, especially fired bricks. For manufacture of ceramic wares, these clays need further processing through addition of grog and other additives to improve it firing characteristic.***

Keywords: Soil profile, horizons, clay, ultisol, ceramic industry, physiography, landscape, granite and acid gneiss, kaolinite, feldspar, physical and chemical analyses

1. Introduction

Self-sufficiency and self-reliance have become the two foremost requirements of every developing country. Bearing this in mind, Sierra Leone should study the possibility of efficiently utilizing her natural resources to establish industries that play a fundamental role in not only accelerating economic growth but generating employment and hence improving livelihoods of communities. One of such industries is the ceramics industry due to the huge deposit of clay, which is the primary material for the production of ceramics and bricks. Clay defined as a fine-grained rock which when suitably crushed and pulverised becomes plastic when wet, leather hard when dried and on firing is converted to a permanent rock-like mass. Sierra Leone soils are mainly ultisols (Odell and Dijkermann, 1974) in which the accumulated clay has long been recognized as an important raw material for building and manufacturing of household utensils.

Like most civilization, the discovery of ceramics ranks amongst one of the earliest scientific achievements of ancient Sierra Leonean potters. Evidence of this may be readily found in the Sierra Leone National Museum. Proudly displayed in this museum are different forms of earthen wares used as household utensils and sculptures of human forms and spirits used in acts of worship.

1.1 Problem Analysis

Two hundreds or more years have passed since the discovery of ceramics and many civilizations in the world have developed this industry to economically viable and environmentally sound levels. Initially, the sun was exclusively used for drying and later fire was discovered to be more effective in producing harder and less indestructible products. It is from this basic stages that many civilizations, through ceramic research, have discovered new raw materials, invented new treatment methods, locate new deposits, and developed efficient machines and equipment that have advanced this technology to its present complex scientific standard, economic importance, and architectural advantage. Many varieties of ceramic products have been developed in different part of the world, where Sierra Leone stands in all this development is yet to be determined. The development of ceramics at the traditional level in Sierra Leone has regrettably not advance beyond the first basic stage discovered by primeval man. To this day, sun-dried mud instead of firm relatively indestructive fired bricks are used for building houses in rural communities.

For ceramic products to be appreciated in Sierra Leone, which has a high potential for the establishment of ceramic industry, research has to be done to provide information on the various clay deposits with reference to their ceramic suitability and to do so an understanding of the soil profiles from which this clays are extracted is essential. The basis for classification and understanding ceramic clays is the soil profile description made in the field, where soils occur. Laboratory investigations only supplement understanding of soil profile descriptions made in the field. The differences may range from very striking texture variations to more subtle minor variations of color. Soil differences dictate that the soils must be managed differently and will behave differently when used for ceramic engineering, agriculture, forestry, foundations and even pavements.

A soil profile is a vertical cross-section of the soil, made of layers running parallel to the surface. These layers are known as soil horizons. A soil horizon is a layer parallel to the soil surface whose physical, chemical and biological characteristics differ from the layers above and beneath. Horizons are defined in many cases by obvious physical features, mainly colour and texture. Soils are named and classified based on their horizons.

The soil profile has five distinct horizons or layers: 1) O horizon; 2) A horizon; 3) E horizon, 4) B horizon, or subsoil; and 5) C horizon, or soil base (R is used to denote bed rock). Each horizon represents a distinct zone with unique properties such as color, texture, structure, and composition. By examining the soil profile, ceramic engineers can gain valuable insight into the physical, chemical and mineralogical compositions of clays suitable for ceramics production.

1.2 Aim and Objectives of the Study

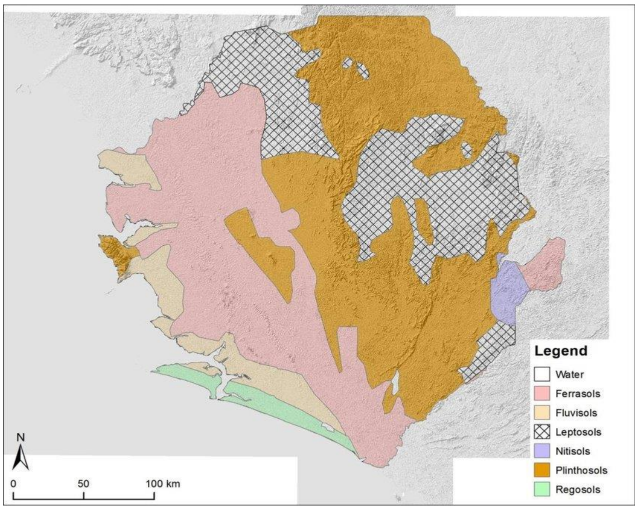
This study aims at identifying some properties of soil profiles whose clays could be used in ceramics stoves production so as to establish small scale ceramic industries that could improve the livelihoods of pottery communities in Sierra Leone.

The following objectives are pertinent to this study (a) Soil profiles descriptions of the clays extractions sites (b) Physiographic and landscape characteristics of sampled areas (c) Physical and chemical characterization of the clays collected from the various soil profiles.

2. Methodology

2.1 Geological Description of study area

Clay samples were collected from four regions in Sierra Leone based on past pottery activities in these area. The regions were Pa Loko (Western Area), Niagorehun (Southern Region), and Yengema (Eastern Region) and Mabettor (North West Region).



Soil map of Sierra Leone (soil data from Jones et al 2013)

2.1.1 Pa Loko

Pa Loko is defined by latitude 9^0 W, situated along the coast 5km from Waterloo in the Western Area of Sierra Leone. The geology of Pa Loko is dominated by the Bullum series, Pleistocene and Recent alluvium, whose unconsolidated sediments are mainly clay of estuarine, marine and fluvial origin (Dixey 1925). Consequently, the mineral content of these materials is variable depending on the source area of the sediment and the mode of deposition. The topography is nearly flat with many swamps.

2.1.2 Niagorehun

Niagorehun is situated in the Bargbo Chiefdom, 45 km from Bo and 11 km from Koribondo towards Jimmi in the Southern Region of Sierra Leone. On Latitude 12^o S. the geology shows granite and acid gneiss as major rock types, with kaolinite as the predominant clay mineral (Swarajasingham, 1968).

2.1.3 Yengema

Yengema is a very important diamond mining centre in Sierra Leone, situated about 8 km from Koidu, the headquarter town of Kono District in the Eastern Region of Sierra Leone on Latitude 13^O E. the area is covered by the interior plateau and hill regions and mostly underliain by granite and acid gneiss, although some smaller areas consist of basic schists, amphibolites and serpents belonging to the Kambui series of Precambrian age (Dixey, 1925).

2.1.4 Mabettor

Mabettor may be regarded as a potters' village, as majority of the people are potters. The area sampled is situated in the Buya Romenda Chiefdom in the Port Loko District about 2.2 km from Lunsar, towards Makeni city.

Mabettor is defined by Latitude 12^0N the geological record of Mabettor reveals properties of Marampa schist, granite and acid gneiss, with acid and intermediate igneous and metamorphic rocks, quartz, alkali feldspars, acid plagioclase, biote, muscovita, hornblende, haematite, garnet and sericite are the chief minerals in this assemblage (Odell and Dijkerman 1974). All these rocks are of Precambrian age. As a result of the present of feldspars (which are rich in alumina, silica and alkalies) over the years weathering has washed away the alkalies thereby giving rise to the deposition of clays mainly kaolinite, high in alumina and silica.

2.2 Field Sampling

2.2.1 Profile description

Three soil profiles, representing taxonomic units, were sampled from each of the four sites (Pa Loko, Niagorehun, Yengema and Mabettor). The sampled soil profiles from each unit were described using freshly exposed vertical pits and fresh auger boring at depth within horizons as shown in Tables 1-4. The morphological descriptions were done according to the Soil Resources Development and Conservative Service, Land and Water Development Division (FAO, 1977).

Table 1: Pa Loko Soil Profile

Pit #	Horizon Type	Depth (cm)	Color		Texture	Structure	Consistence	Mottling	Boundary
PL1	Ap	0-34	10YR3/1	Very dark gray	SL	Class 0	Class 0	-	sc
	E	34-51	10YR5/1	Gray	S	Class 0	Class 0	-	wa
	Bhs	51-105	10YR6/2	Light brownish gray	SC	Class 1	Class 1	FFF	wa
	Bs	105-187	10YR6/4	Light yellowish brown	SIC	Class1	Class 1	CFD	sg
	Btg1	187-230	10YR6/6	Brownish yellow	C	Class 1	Class 1	CFD	A
	Btg2	>230	710YR6/6	Brownish yellow	C	Class 1	Class 1	CFD	A

Table 2: Niagorehun Soil Profile

Pit #	Horizon Type	Depth (cm)	Color		Texture	Structure	Consistence	Mottling	Boundary
Nia 2	Ap	0-21	10YR5/1	Gray	SL	Class 0	Class 0	-	dw
	E	21-43	10YR5/2	Grayish brown	SL	Class 0	Class 0	-	dw
	Bh	43-72	10YR6/2	Light brownish gray	SC	Class 1	Class 1	-	cs
	Bhs1	72-87	10YR6/2	Light brownish gray	SC	Class 1	Class 1	FFF	cs
	Bhs2	87-100	10YR6/4	Light yellowish brown	SIC	Class 1	Class 2	CCD	cs
	Bt1	100-130	10YR6/8	Brownish yellow	C	Class 1	Class 2	CFD	sw
	Bt2	130-200	10YR6/8	Brownish yellow	C	Class 1	Class 2	CFD	A

Table 3: Yengema Soil Profile

Pit #	Horizon Type	Depth (cm)	Color		Texture	Structure	Consistence	Mottling	Boundary
Yen3	Ap	0-32	10YR7/1	Light gray	SL	Class 0	Class 0	-	dw
	E	32-74	10YR7/4	Very pale brown	S	Class 0	Class 0	-	dw
	Bhs	74-150	10YR7/4	Very pale brown	SC	Class 1	Class 1	FFD	as
	Bt	150-200	10YR7/6	Yellow	SIC	Class 1	Class 2	FFF	gs
	Btg	200-234	10YR7/8	Yellow	SIC	Class 1	Class 2	CFD	A

Table 4: Mabettor Soil Profile

Pit #	Horizon Type	Depth (cm)	Color		Texture	Structure	Consistence	Mottling	Boundary
Mab1	Ap	0-12	10YR3/1	Very dark gray	VFSL	Class 0	Class 0	FFF	dw
	E	12-32	10YR5/1	Gray	FSL	Class 0	Class 0	-	as
	Btg1	32-49	10YR6/2	Light brownish gray	SC	Class 1	Class 1	MFD	cs
	Btg2	49-70	10YR6/3	Pale brown	SC	Class 1	Class 1	MFD	cs
	Bs	70-104	10YR7/3	Very pale brown	SIC	Class 2	Class 1	CMD	gs
	Bt1	104-180	10YR7/6	Yellow	C	Class 2	Class 1	FFD	gs
	Bt2	180-200	10YR7/8	Yellow	C	Class 2	Class 1	FFD	A

Texture: SL – sandy loam; S – sand; SC – sandy clay; SiC – silty clay; VFSL – very fine sandy loam, FSL – fine sandy loam; C – clay; CL – clay loam; gravelly loam
Structure: Class 0 – structureless; Class 1 – weak; Sg – single grain
Consistence: Class 0 – loose (non-coherent); Class 1 – very friable; Class 2 - friable
Mottling: FFF – few fine faint; FFD –few fine distinct; FMD few medium distinct; MFD – many fine distinct; FCD –few coarse distinct; CFD – common fine distinct; CCD – common coarse distinct; MMD – many medium distinct; CMD – coarse medium distinct
Boundry: a – abrupt; c – clear; g – gradual; d – diffuse; s – smooth; w – wavy; A - sampled by augur

2.2.2 Clay samples collection

Fragmented clay samples were taken from the B horizon of the sampled soil profile. At Pa Loko, three sites namely Matankay, Masantigie and UMC Agricultural swamp were selected and a profile excavated at each site. Matankay (Profile# PL1) was excavated 3m east of Matankay village and clay samples collected at the depth of 230cm. Clay samples from Masantigie (Profile # PL2) was collected 180m north of the village at a depth of 230cm. At UMC farm, the profile PL3 was excavated 260m north-east of the administrative building and clay samples collected at the depth of 230cm.

The Niagorehun clay samples were collected from the inland valley swamp (Profile# Nia 1, Nia 2 and Nia 3) north-east of the village at a distance of 50cm between pits and at a depth of 200cm.

Clay samples from Yengema were collected from three profiles (Yen1, Yen 2 and Yen 3) excavated on the inland valley swamp running through the town at a depth of 230cm at a distance of 50m between pits.

At Mabettor, clay samples were collected at depth of 200cm from three profiles (Mab1, Mab2 and Mab3) excavated from the inland valley swamp 1 km north-west of Mabettor village with 100m distance between pits.

The clay samples collected from the four sites were transported to Njala University in polythene bags for analysis after preliminary profile investigation involving type of horizon/layer, depth in centimeter, color, texture, structure, consistency, mottling and boundary were recorded.

Table 5: Equipment used in the sample collection

No.	Purpose	Equipment
1	Topographic data (altitude, slope angle)	Prismatic samples, abney level, ranging poles
2	Linear measurement	Steel tape and cloth tape
3	Digging and preparing of soil profile pit	Shovels, pickaxe, hand towel, T-shape screw auger
4	Determination of color	The Munsell Color chart
5	Collection of soil samples and storage	Polythene bags

2.2.3 Experimental Procedures

(a) Determination of Physical Properties

Plasticity, wet-dry shrinkage**,** firing Shrinkage, water absorption, bulk density were the main physical properties determined from the clays.

Plasticity

Plasticity in the processing of clay-based materials is a fundamental property since it defines the technical parameters to convert a ceramic mass into a given shape by application of pressure. Plasticity, in this case, and particularly in clay mineral systems, is defined as the property of a material which allows it to be repeatedly deformed without rupture when acted upon by a force sufficient to cause deformation and which allows it to retain its shape after the applied force has been removed (Aravind et al 2011).

The plasticity of the clay samples collected from the various soil profiles was determined by the absorption of methylene blue (mg of dye per 100g of dry sample) as described by BS EN 933-9 +A1:2013. 200g of clay sample with grain size of < 2mm was oven dried at 105^0 C and allowed to cool to room temperature. The cooled sample was put into a beaker and 500ml of distilled water added and the mixture was blended using a speed adjustable blender for 5 minutes at 600rpm.

A solution of methylene blue was prepared by thoroughly mixing 10g of methylene blue power with distilled water for 45 minutes at room temperature. 5ml of the methylene blue solution was added to the mixed clay sample and blended for 1 minute for 400rpm. One drop of suspension was extracted with a glass rod and dripped on to a filter paper. A dark blue stain and surrounding water circle was observed during the first drip. The process was repeated adding solution until a light-blue circle (halo) is obtained around the blue central stain. 5ml of solution was added in the first 5 minutes. After these 5 minutes, the amount of solution is reduced to 2ml and stirred for 1 minute and one drop of suspension is extracted using a glass rod and dripped on a filter paper in order to observe the circle formation. Experiment was completed when a light blue circle formed around the central blue stain and if it does not vaporize for 5 minutes and the total amount of volumetric solution is calculated in ml below and results presented in Table 6.

$$MB = (V_1 / M_1) \times 10$$

Where:
MB = Methylene blue value (%);
V_1 = Total volume of the methylene solution added (ml);
M_1 = Mass of the experiment sample (g).

Factor 10 = A factor used to convert the volume of stain solution used to the mass of stain per kilogram of the mass tested (BS EN 933-9+A1).

Wet-dry shrinkage

3kg of each of the clay samples were mixed with water to optimum plasticity. Five test pieces of dimension 10mm×500mm×800mm were made from each clay sample by de-airing of the plastic bodies and subsequently cutting the flat de-aired mass with a rectangular copper tile cutter. Two parallel lines exactly 503mm (wet length, L_w) apart joined by a diagonal line were marked across all the test pieces and the pieces were oven dried at 110ºC for 18hours. Measurements were taken for the dry length (***L_d*)**.

$$S_w = \frac{L_w - L_d}{L_w} \times 100$$

where S_w is the wet-dry shrinkage expressed as vol.-%, L_w is the wet length, and L_d is the dry length.

Determination of Firing Shrinkage

Following the wet-dry shrinkage test, the oven dried tile pieces for each clay sample were fired at 1000ºC, 1150ºC, and 1250ºC and dry- firing shrinkage (S_f) calculated from the measured values obtained as shown below.

$$S_f = \frac{L_d - L_f}{L_d} \times 100 \ (\%)$$

where L_f is the fired length

Determination of Water Absorption, Bulk density and Porosity of the Clay Samples

The ISO/TC 187, Part 3 standard test for determination of water absorption, bulk density and porosity was used. In these determinations, the Archimedes Immersion Technique was used. Ten tile pieces of dimension (8mm×50mm×70mm) were prepared from each clay sample and were allowed to dry at room temperatures for 48 hours and then dried in a moisture oven at 110ºC for 18 hours. The weight of the dried tile pieces G_0 were measured by an electric balance and then fired in an electric kiln at 500ºC, 1000ºC, 1150ºC, and 1250ºC with a socking time of 30mins. The fired tile samples were boiled in water for two hours and allowed to cool for three hours at room temperature. The wet weight, G_1 in grams of all the tile samples were measured by electric balance followed by the determination of the weight of water displaced G_2 by the tile samples when immersed in a beaker of water.

Paper ID: SR24512200359 DOI: https://dx.doi.org/10.21275/SR24512200359

Water Absorption (WA) Vol.-% was obtained using the equation below

$$WA\ (\%) = \frac{G_1 - G_0}{G_0} \times 100$$

Bulk density (Bd) g/cm^3

$$Bd\ (g/cm^3) = \frac{G_0}{G_1 - G_2}$$

Apparent Porosity (AP) vol.-%

$$AP\ (vol.-\%) = \frac{G_1 - G_0}{G_1 - G_2} \times 100$$

b. Determination of Chemical Properties of Clay Samples

The clay materials used in the fabrication of the tile bodies were chemically analyzed for Al_2O_3, SiO_2, TiO_2, Fe_2O_3, and CaO, MgO, Na_2O, and K_2O by XRF using a lithium tetra-borate fusion technique. The American National Bureau of Standards (NBS) 98 was used.

3. Analytical Procedure

The clay samples as received were milled to less than 180-mesh in a tungsten-carbide-line vibromill. One gram of the milled sample and 5g of lithium tetra-borate ($LiB_4O_7.5H_2O$) were weighed (± 0.5mg) into a plastic vial, thoroughly mixed, then fused in a carbon crucible for 30min. at 1000^{o}C. The fusion was poured into a water-cooled platinum dish, thereby quenching the glass and avoiding devitrification. The glass bead was milled for 10 min. in the vibromill; 0.5g of "one shot" phenol formaldehyde powder resin was added and milling continued for further 5 min. The powder was then loaded into a hardened and polished steel mould of 1¼ diameter and pressed at 9000 p.s.i. The pressed pellet was cured in a laboratory oven for 30 min. at 150^{o}C. After cooling, the compact was placed in the spectrograph for examination.

Table 1: Order of Chemical Analysis by XRF

	Fe_2O_3	TiO_3	Al_2O_3	CaO	SiO_2	MgO	Na_2O	K_2O
Standard	NBS98							
Operation	Vacuum							
Tube volts (kV)	20	20	40	20	40	20	20	20
Current (mA)	6	6	20	6	20	6	6	6
Crystals	LiF	LiF	EDDT	LiF	EDDT	LiF	LiF	LiF
Counter	Scintillation 980V		Gas flow proportional 1630V. 100cm^3 P1gas/min					
2θ ($K\alpha_1\alpha_2$)	57.52^o	86.15^o	142.46^o	113.08^o	108^o	54.36^o	96.14^o	96.32^o
Actual setting	57.55^o	86.18^o	112.62^o	113.40^o	78.02^o	54.52^o	88.06^o	88.00^o
Discrimination:								
Attenuation	2	1	2	2	2	2	2	2
Amplitude (V)	23.5	17	25.5	64	32	64	18	17.8
Channel (V)	24	24	32	32	32	32	24	24
	Integrated time constant (I.T.C.) 0.2; differential time constant (D.T.C.),∞							
Fixed count	256,000	32,000	64,000	256,000	64,000	256,000	256,000	256,000

4. Discussion of Results

4.1 Physiographic and Landscape Characteristics of sampled areas

Landscape is defined as a system composed of abiotic (relief, atmosphere, water) and biotic (plants and animals) elements as well as soil, which is a bridge between the two (Ostaszewska et al 2011).

The relationship between physiography and landscape elements (land facets) of an area and soils has been widely recognized as the factors involved in the physiographic processes corresponding close to that of soil formation (Denis et al 2022). The Physiographic and Landscape characteristics of the studied areas are presented in Table 6.

This relationship between landscape features and soil conditions makes it possible for predicting the nature and distribution pattern of different soils in a landscape. In the present study, three major physiographic units, namely upland, undulating midlands and lowlands, with land facets comprising of crests, side slopes (shoulder and back slopes), terraces (foot slopes and toe slopes) and adjacent inland valley swamps were identified using on-screen visual interpretation of satellite images and in-situ terrain feature characterization.

Table 6: Physiographic and Landscape Characteristics of sampled areas

Features	Soil Profile			
	PL 1	Nia 2	Yen3	Mab1
Area	Pa Loko	Niagorehun	Yengema	Mabettor
Location	200m off Matankay village	5m NE of Niagorehun village	Swamp leading to Yengema Junction	120m NW of Mabettor
Coordinates	30^0 NW	26^0 E	32^{0}NE	34^0 NW
Physiography	Mangrove river flood plain	Inland valley swamp	Inland valley swamp	Inland valley swamp (IVS)
Topography (Relief)	Low level plain	Very low level plain	Very low level plain	Very low level plain
Slope	5%S-N	2% NS	1%	2% NS

Parent materials	Apparently derived "in situ" from deeply weathered feldspar rocks	Colluvium/Alluvium	Colluvium/Alluvium	Colluvium/Alluvium
Land use	Paddy rice cultivation	Paddy rice and vegetable cultivation	Paddy rice and vegetable cultivation	Paddy rice, and vegetable cultivation
Vegetation	Mangrove trees, shrubs, and grasses	Remains of rice stalk and few wild trees	Grasses and rice straws	Remains of rice stalk and few wild trees.
Drainage condition	Very poorly drained	Very poorly drained	Poorly drained	Very poorly drained
Ground water depth	73cm below surface	70cm from the surface	80cm	70cm from the surface
Moisture	Moist throughout the year	Moist throughout the year	Moist throughout the year	Moist throughout the year
Salinity	Saline	Not observed	Not observed	Not observed
Root distribution	0-80cm	70cm	90cm	70cm
Biological activities	Very high in "Ap" and low in "B" horizon	High in Ap horizon	Very high in Ap horizon	Very high throughout the Ap horizon
Human activities	Very high throughout the profile(Ap for cultivation; B for clay extraction	Very high in Ap horizon, B for clay extraction	High in Ap horizon, B for clay extraction	Very high in A horizon, B for clay extraction
Weather condition	Sunny	Sunny	Sunny	Sunny
Stoniness	Class 0	Class 0	Class 1	Class 0

The Physiography of the studied areas, with the exception of Pa Loko which has a mangrove river flood plain, all the other three areas are characterized by inland valley swamps with a very low level plain Topography. While the parent materials of Pa Loko are apparently derived "in situ" from deeply weathered feldspar rocks, Niagorehun, Yengama and Mabbettor are made up of Colluvium/Alluvium with very poorly drained conditions

The sampled soil profiles from the four communities, namely Pa Loko, Niagorehun, Yengema and Mabettor, were tallied and horizon type, depth in centimeter of the profiles and soil color characteristics were compared. This was to ascertain the ceramic suitability of the clays obtained from the various profiles under field condition.

4.2 Comparison of the sampled soil profiles

Table 6: Soil profile characteristics compared for type of horizons, depth and color

#	Pa Loko soil profile			Niagorehun soil profile			Yengema soil profile			Mabettor soil profile		
	Horizon Type	Depth (cm)	Color	Horizon Type	Depth (cm)	Color	Horizon Type	Depth (cm)	Color	Horizon Type	Depth (cm)	Color
1	Ap	0-34	Very dark gray	Ap	0-21	Gray	Ap	0-32	Light gray	Ap	0-12	Very dark gray
2	E	34-51	Gray	E	21-43	Grayish brown	E	32-74	Very pale brown	E	12-32	Gray
3	Bhs	51-105	Light brownish gray	Bh	43-72	Light brownish gray	Bhs	74-150	Very pale brown	Btg1	32-49	Light brownish gray
4	Bs	105-187	Light yellowish brown	Bhs1	72-87	Light brownish gray	Bt	150-200	Yellow	Btg2	49-70	Pale brown
5	Bt1	187-230	Brownish yellow	Bhs2	87-100	Light yellowish brown	Bt	200-234	Yellow	Bs	70-104	Very pale brown
6	Bt2	>230	Brownish yellow	Bt1	100-130	Brownish yellow				Bt1	104-180	Yellow
7				Bt2	130-200	Brownish yellow				Bt2	180-200	yellow

All the soil profiles investigated are characterized by an Ap horizon. This is a horizon that have been cultivated, plowed or disturbed by man (McDonald, et al, 1990). It is the mineral subsurface horizon after the O horizon; it is the zone of intense eluviation (leaching or removal) and it is primarily characterized by a loss of clay, iron, and constituent that may be moved by water. The horizon depths vary with soil color ranging from very dark gray for Pa Loko and Mabettor; gray for Niagorehun and light gray for Yengema.

For ceramics production, the B horizon is the primary horizon of interest. A soil B horizon is a mineral horizon that has undergone processes that result in changes in the physical or chemical nature of the soil from the original parent material. The B horizons is commonly referred to as the subsoil. They are a zones of clay accumulation where rain water percolating through the soil has leached material from above and it has precipitated within the B horizons. The B horizon consisting of one or more mineral layers differing to the A Horizon by: clay, iron, aluminum or organic matter concentrations; structure and/or consistence and color.

The B horizons of the soil profiles investigated are typically characterized by *Bh, Bhs, Bs, Bt, and Btg* sub-horizons., which depths and clay colors varied among profiles as presented in Table 6.

Bh horizon: A subsoil horizon notation whereby the 'B' refers to the B Horizon and the 'h' to the humic horizon. Organic matter and aluminum compounds are strongly dominant with very little or no trace of iron compounds (Isbell, R.F. 2002)
Bhs horizon: A subsoil horizon notation whereby the 'B' refers to the B Horizon and the 'hs' to the humosesquic horizon. Iron and organic compounds (often referred to as 'coffee rock') are prominent within the horizon and the organic compounds are distributed as streaks, patches or lumps.
Bt horizon: A Bt horizon is one that contains illuvial layer lattice clays. It forms below an eluvial horizon but may occur at the surface of a soil that has been partially truncated. It usually has a higher ratio of fine clay to total clay.
Btg horizon: A gleyed, illuvial B horizon characterized by dull, grayish colors (chroma usually ≤ 2) and/or prominent mottling within 50 cm of the soil surface, indicating permanent or periodic intense reduction.
Bs horizon: This is a B horizon with an accumulation of illuvial, amorphous, dispersible organic matter and sesquioxides.

The color variance in these clay samples could be attributed to the chemical compositions, especially the presence of iron oxides and other organic compounds, which are present in part as mottles presented in Table 7.

Table 7: Soil profile characteristics compared for texture, structure, consistence and mottling

#	Pa Loko soil sample					Niagorehun soil profile					Yengema soil profile					Mabettor soil profile				
	HT	T	S	C	M	HT	T	S	C	M	HT	T	S	C	M	HT	T	S	C	M
1	Ap	SL	0	0	-	Ap	SL	0	0	-	Ap	SL	0	0	-	Ap	VFSL	0	0	FFF
2	E	S	0	0	-	E	SL	0	0	-	E	S	0	0	-	E	FSL	0	0	-
3	Bhs	SC	1	1	FFF	Bh	SC	1	1	-	Bhs	SC	1	1	FFD	Btg1	SC	1	1	MFD
4	Bs	SiC	1	1	CFD	Bh1	SC	1	1	FFF	Bt	SiC	1	2	FFF	Btg2	SC	1	1	MFD
5	Bt1	C	1	1	CFD	Bh2	SiC	1	2	CCD	Bt	SiC	1	2	CFD	Bs	SiC	2	1	CMD
6	Bt2	C	1	1	CFD	Bt1	c	1	2	CFD						Bt1	C	2	1	FFD
7						Bts	c	1	2	CFD						Bt2	C	2	1	FFD

HT – Horizon Type; T –Texture; S – Structure (class); C – Consistence (class); M - Mottling

Soil texture (T) describes the proportion of the soil particles and the fineness or coarseness of a soil. The textural class of a soil is determined by the percentage of sand, silt, and clay. Soils can be classified as one of four major textural classes: (1) sands; (2) silts; (3) loams; and (4) clays.

The texture of a clayey soil determines clay characteristics that affect the quality of the fired ceramic ware, brick or tile. Three of these characteristics are water-holding capacity, permeability, and clay workability.

The small size of the particles and their unique crystal structures give clay materials special properties. These properties include cation exchange capabilities, plastic behavior when wet, catalytic abilities, swelling behavior, and low permeability. As a result of these, clays are used in the ceramics industries largely because of their contribution to the molding and drying properties of the wares being produced.

4.3 Results of Physical Properties of clay sampled from the soil profiles

Physical characterization, i.e. plasticity, shrinkage, vitrification, particle size distribution, among others, determines the quality of the final product. The results of an assessment of the grain size distribution of the clay samples is presented in Table 8. Pa Loko has the highest grain yield (66.72%) at <0.002mm sieve fraction as compared to the other clay samples. This could be attributed to its textural and structural classes, characterized by high concentration of the clay fractions with very friable consistence in its Bt horizons. Niagorehun clay sample has the lowest grain yield of 10.40% at <0.002 which reflects to its Class 2 friable consistence. Unlike Pa Loko, which has a grain yield of 0% at 0.10 -2.0mm sieve fraction, Niagorehun has the highest grain yield of 53.60% at 0.10 – 2.0mm.

Table 8: Grain size distribution of clay sample

Fraction (mm)	Grain yield(wt.%)			
	Pa Loko	Niagorehun	Yengema	Mabettor
>2.0	0.00	0.00	0.00	0.00
0.10 - 2.0	0.00	53.60	14.00	15.60
0.05 – 0.10	0.89	2.90	7.05	8.37
0.20 - 0.05	4.30	2.40	2.05	2.41
0.005 – 0.20	18.45	11.29	31.90	27.41
0.002 – 0.005	9.54	11.20	17.20	19.07
< 0.002	66.72	10.40	27.80	27.37

An investigation into the physical properties of the clay samples revealed that all the clays collected from the various soil profiles have high plasticity with excellent molding property suitable for ceramics works as shown in Figure 2. There is an inverse relationship between bulk density and porosity of the clay samples. Mabettor which has comparatively lowest bulk density (1.23g/cm^2) exhibited the highest porosity (52.70%) and Niagorehun which has the highest bulk density (1.64 g/cm^2) showed the lowest porosity (31.55%). The physical properties (plasticity, water absorption, porosity, and bulk density) exhibited by these clays could be attributed to the variance in percentage of mineral occlusions and cation exchange capacity of the free metallic ions in the crystal lattice of these clays as presented in Table 10.

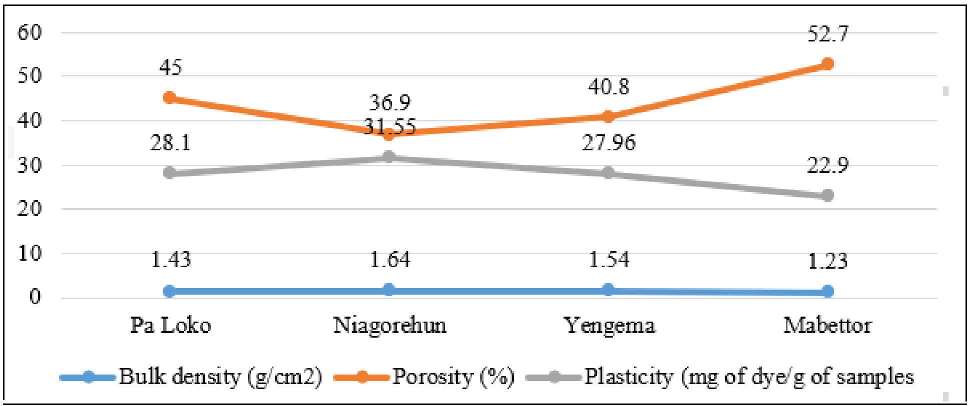


Figure 2: Results of bulk density and porosity and plasticity of the clay samples

Clays have a high water adsorption capacity owing to their high specific surface area (Kumari & Mohan, 2021;Martin, 1960). The platelike structure and high cation exchange capacity of the free metallic ions in the crystal lattice give clay a high water absorption capacity, which induces substantial swelling (Cases et al., 1992; Hatch et al., 2012). The plastic characteristics of clay are due to adsorbed water due to the cations distribution around the negative charge surface of clay particles with the greater density near the surface. Furthermore, clay minerals have a strong adsorption regime at low water content (Schuttlefield et al., 2007), which consequently reduces the amount of water available for gas/water contact at low water saturation. Figure 3 presents results of wet-dry shrinkage, water absorption and crushing strength of the clay samples

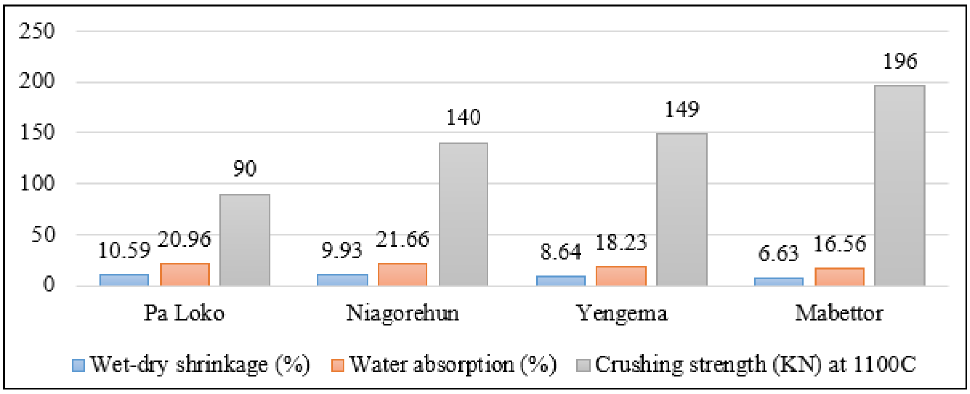


Figure 3: Results of wet-dry shrinkage, water absorption and crushing strength of clay samples

4.5 Results of the Chemical Properties of the clay samples

The chemical analysis results presented in Table9 revealed SiO_2 (40-54%), Al_2O_3 (22-27%) and a reasonable percentage of Fe_2O_3 as the primary compounds identified in the clay samples followed by traces of TiO_2, K_2O, Na_2O, CaO, and MgO. The Fe_2O_3 content is relatively high, which could contribute to a decrease in firing temperature of the ceramics (Meseguer et al 2011). The chemical composition can be used to determine the usefulness of clays according to the quantity of SiO_2 and Al_2O_3 (Dondi et al 2014).

Table 9: Results of the chemical properties of clay samples

Compound	% Analyzed in sample			
	Pa Loko	Niagorehun	Yengema	Mabettor
SiO_2	40.06	52.15	48.68	54.22
Al_2O_3	22.30	26.62	22.64	26.35
Fe_2O_3	4.40	3.77	4.07	4.20
TiO_3	1.18	0.87	0.98	1.92
MgO	0.16	0.73	0.77	0.33
CaO	0.05	0.25	0.15	0.08
Na_2O	0.10	0.14	0.13	0.04
K_2O	0.21	0.58	0.58	0.22
Total	79.54	85.11	78.00	87.36

The content of potassium oxide, K_2O, and magnesium oxide, MgO, were low; indicating that high level of densification will not be possible at temperatures below 1000°C because they are fluxing agents (Baioumy et al 2014).

Table 10: Cation exchange capacity and exchangeable cations of clay samples

Sample	Exchangeable cations (mmol/kg)				Cation exchange capacity (NH^{4+}/kg)
	Mg^{2+}	Ca^{2+}	Na^{+}	K^{+}	
Pa Lako	5.21	5.71	5.00	1.06	27.90
Niagorehun	12.90	14.85	0.89	4.07	62.96
Yengema	15.32	17.21	0.65	4.07	66.30
Mabettor	16.74	19.35	4.60	4.78	81.92

5. Conclusion

Sierra Leone soils are mainly ultisols in which the accumulated clay has long been recognized as an important raw material for building and manufacturing of ceramic utensils. The basis for classification and understanding ceramic clays is the soil profile description made in the field, where soils occur. Laboratory investigations only supplement understanding of soil profile descriptions made in the field.

The soil profile has five distinct horizons or layers: 1) O horizon; 2) A horizon; 3) E horizon, 4) B horizon, or subsoil; and 5) C horizon, or soil base (R is used to denote bed rock). Each horizon represents a distinct zone with unique properties such as color, texture, structure, and composition. By examining the soil profile, ceramic engineers can gain valuable insight into the physical, chemical and mineralogical compositions of clays suitable for ceramics production.

The Physiography of the studied areas, with the exception of Pa Loko which has a mangrove river flood plain, all the other three areas are characterized by inland valley swamps with a very low level plain Topography. While the parent materials of Pa Loko are apparently derived “in situ” from deeply weathered feldspar rocks, Niagorehun, Yengama and Mabbettor are made up of Colluvium/Alluvium with very poorly drained conditions.

The small size of the particles and their unique crystal structures give clay materials special properties. These properties include cation exchange capacity, plastic behavior when wet, catalytic abilities, swelling behavior, and low permeability. As a result of these, clays are used in the ceramics industries largely because of their contribution to the molding and drying properties of the wares being produced.

From the results of both the physical and chemical analyses of the clay samples collected from the various soil profiles, a conclusion could be made that the clays are suitable for the production of ceramic building materials, especially fired bricks. For manufacture of ceramic wares, these clays need further processing through addition of grog and other additives to improve it firing characteristic. The texture, structure, consistence and color of the clay samples collected were dependent on the depth of the “B” horizon.

Base on the characteristics of these clays, the local ceramic industries/potters are better guarded as to which depth they should collect clays and how they could make maximum use of it during processing, forming/molding and eventually firing to required temperatures.

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