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ANALYTICAL RESULTS OF PROTON-INDUCED X-RAY EMISSION (PIXE) PROBE OF YORUBA POTTERY OBJECTS

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Abstract

Two hundred and sixteen (216) Yoruba ceramic (pottery) objects in Ita Yemoo Museum collection, Ile-Ife, Nigeria were examined; a sample size of twenty–four (24) pottery objects, ten per cent (10%) of the pottery selected using systematic random sampling to determine their material contents ('chemical fingerprints'). Qualitative, descriptive and evaluative data were collected for analysis. Material compositional information was assessed with the use of Proton-induced X-Ray Emission (PIXE) technique; PIXE result returned twenty-three (23) elements that are used as chemical fingerprints for the selected pottery objects. Major, minor and trace elements discovered were expressed in parts per million (ppm). The study concluded that the data similarities, differences, and correlation provided enhanced provenance data generation useful in taxonomic and provenance determination of potteries with the possibility of generating a database to identify Yoruba ceramic objects generally.

Keywords: *Yoruba; pottery; material composition; provenance; pixe analysis; database.*

Introduction

Describing physically Yoruba ceramics alone is therefore not enough; establishing their medium and their material compositional information will go a long way to help in their studies over cursory inspection alone. There have been several studies on Yoruba ceramics which have focused mainly on types, forms, functions, themes, contextual and stylistic issues. There is a dearth of information on material compositional information related to Yoruba pottery. This discourse is germane to providing in-depth knowledge on material content information of Yoruba pottery productions. However, the significance of this exercise is seen much from the perspectives of policy formulation for the stakeholders in the areas of African pottery and art historical studies; museum management practices; and the gaps it fills in literature.

This study is considered useful to African art researchers as enlightenment to current research interests in art studies which is scientific. The establishment of 'chemical fingerprint' for every work of art and all museum objects enhances the determination of their provenance should extreme conditions such as war, conflicts and illegal operations arise during their period of their storage, exhibition, and management. The material compositional data of the Yoruba ceramic collections need to be carried out and stored in a database under modern cataloguing system. The importance of a generated data cannot be overemphasized; the information from this exercise is of special interest to

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scholars and museum practitioners. The scope of this discourse is limited to Yoruba pottery objects in the collection in Ita Yemoo museum, Ile-Ife, Nigeria which number over two hundred (200) pots of ceramic origin (terracotta) with no glazes for generation of ceramic data using of Proton-induced X-ray Emission (PIXE) facility at the Center for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria.

Ita Yemoo Pottery Museum is an annexe of the Ife National Museum, Ile-Ife which was opened to the public on 11th February 1973, it covers a large number of Yoruba potteries collected by Ulli and Georgina Beier between the 1960s and early 1970s [1]. Other pottery objects of contemporary times from Yorubaland were added at a later period to the collection in the Ita Yemoo museum [2]. Ita Yemoo in Ile-Ife attracted prominence because of the oral, artistic, and archaeological pieces of evidence attached to Ita Yemoo Grove as a historic, religious-shrine complex in Ile-Ife. This site (Yemoo Grove) had since been acquired by the Federal Government of Nigeria to become an archaeological reserved area under the authority of the Department of Antiquities now renamed The National Commission for Museums and Monuments (NCMM) of Nigeria. The site is now a large compound encapsulating the Ita Yemoo (Yoruba) Pottery Museum and the ancient embankment system of the early Ife city wall [3,4,5,6,7,8].

When pottery object(s) in a collection remain anonymous, without their proper identity and field notes, there is a need for examination, identification, investigation, classification and description. Apart from the traditional formal, thematic and stylistic study of art objects, today, the most appropriate form of study perhaps is the analytical means of pottery studies. Samples used for such queries require procurement of geologic/geochemical data of clays sourced for pottery making in restricted geographic locations. Therefore, generating potential sources for such pottery objects will require the use of spectrometers like XRF, XRD, INAA, ICP-MS etc. and discriminant analytical procedures such as Principal Component Analysis (PCA), Bivariate plots of elements (BV), Phenogram and Clustering of elements to resolve potential pottery provenance queries with the use of multivariate statistical data. This study ‘eagerly’ generates Yoruba pottery (ceramics) data using the PIXE technique.

Literature abounds on Yoruba arts, pottery, museum antiquities, and archaeological findings in Nigeria with various analytical results. Considering the complexity Yoruba cosmology, pantheon and their impressive arts, the Yoruba are much compared with the ancient Greeks [9]. Yoruba art productions are very outstanding: their unique artistic traditions include wood carving, metal sculpture, metal works, textiles, beadwork, pottery, and so on [10]. Today, the Yoruba still make some of the world's greatest works of art and they are one of the most prolific arts producing people in Africa reason they have been the focus of many ethnographic surveys.

Various scholars have worked on Yoruba Pottery [13-27] and these Yoruba pottery studies have mainly focused on types, forms, functions, themes, contextual and stylistic issues. The traditional Yoruba pottery wares in the collection of Ita Yemoo Museum are much used in religious observances of the Yoruba [11, 12]. There is a dearth of information on material compositional information and ceramic database of Yoruba pottery; therefore, this discourse is very germane to presenting an in-depth knowledge of information about the material content of selected Yoruba pottery collection. The significance of this exercise as stated earlier is seen from the perspectives of policy formulation for the stakeholders in the areas of African art studies; museum management practices; and the gaps it fills in literature of Yoruba pottery authentication theory and practices.

Experimental

The material compositional information of African works of art had remained questionable and under-explored for centuries. Identities of objects must be ascertained analytically and be recorded in a retrievable database. This study made use of primary and secondary data. The primary data was obtained by taking clay core samples (powders) from the pottery objects for their material study. The museum ledger at Ita Yemoo Museum (a data source) was examined to confirm the inventory of the pottery objects. Linear measurements of the pottery objects were done (Table 1) and digital photographs of the pottery objects were captured (Fig. 1).

Fig. 1. Images of the selected pottery objects (Picture credit: Olufemi Olaleye-Otunla, 2016)

The PIXE information (chemical fingerprints) of the pottery objects were accessed at the Tandem laboratory of the Center for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria. The interpretation of the chemical fingerprints of the pottery objects show the presence of elements; with the differences and similarities among the element of content analysed for each of the pottery objects (Appendix A & B). Secondary data were obtained from existing analytical and empirical literature on pottery, material compositional analysis, and provenance studies of works of art and artifacts.

The study population consists of all the two hundred and sixteen (216) pottery objects in the Ita Yemoo Pottery Museum collection because they are a homogenous collection. A sample size of twenty-four (24) pottery objects (about 10%) systematically and randomly selected. Fig.1.shows images of the selected pottery objects. This selection is based on the object's occurrence at every tenth count on the museum inventory. Pottery types, shape, size, surface treatments, decorative techniques as well as function are not material content determinants and so were ignored. The clay core (powder) was sampled from the pottery objects surfaces that were of little or no significance.

The selected twenty-four (24) pottery objects were examined with PIXE technique of analysis for it has been widely used in material compositional studies of artifacts by material scientists [28, 29]. The sampling technique was guided by the Quantitative analytical method [30]. The clay core samples, (powder) obtained from the pottery objects were prepared according to laboratory specifications and standards, pressed into small disks suitable for examination in the Tandem laboratory of CERD, O.A.U., Ile-Ife; PIXE instrument was used to obtain the spectrum of elements of interest (major, minor, trace and rare earth elements) in parts per million (ppm).

Tiny fragments or powders were carefully taken in the least damaging way from parts of the selected pottery objects that are of little relevance to their shape and decoration. After the procedure described by Sleetenfreund and Ballong [31], the spots where samples were collected were cleaned with swabs of cotton wool soaked with ethanol and distilled water. Tiny scrapes and powders were removed from spots with the least impact on the shape or ornamentations of the pottery objects. Sleetenfreud and Bollong observed that when artifacts are analysed with extraneous surface materials produced results are widely different from expected results.

Fragments or powders of about 200-300mg were removed from each pottery object using a high-speed twist drill of tungsten carbide burr to obtain clay core samples from the objects; the burr was cleaned at the end of each scrape or drill with distilled water and ethanol to avoid contamination of samples. A Model Flight Accessories (MFA) Komo Power Drill 399D with a high-speed twist drill of 2mm bit at 200 revolution/min was used to get the powders, scraped or drilled into white filter papers (Whatman No.1 Qualitative, Filter Paper) of 11cm diameter before being transferred into 5ml sterile non-vacuum vials manufacture by GD Medical Factory for E.c. Becton Inc. Ltd., Idumota, Lagos, Nigeria; adequate care was taken to avoid contamination as much as possible by putting on a pair of rubber gloves.

The samples were given analytical identification file names of OLA-XX.PIX; numbers ranged in the order of the count of tens sequentially e.g. OLA-1.PIX; OLA-10.PIX; OLA-20. PIX (Table 1; Appendix A & B). To identify the samples to be analysed, a particular vial is marked with an identification name (OLA-XX.PIX), referencing the pottery objects' museum accession number (e.g. 73.1.47) for each pottery object under examination to avoid misidentification of and mixing-up of samples. These identification numbers were used for every basic observation, inference and discussion made for the pottery objects examined. Samples were subjected to PIXE spectroscopy for elemental values of the major, minor and trace earth elements in parts per million (ppm). PIXE is a non-contaminant, fast, reliable, and inexpensive tool for determining the compositional profile of a range of organic compounds [28, 29]. Test results for each pottery object displayed elements present in each sample which is herein referred to as the chemical fingerprints. The analyses were conducted ex-situ at the CERD Tandem laboratory following procedural standards used in that laboratory for sample preparation, reference, and quality–control.

The selected pottery objects' physical characteristics were recorded by measuring each pottery object's mouth, neck, rim, height, maximum diameters with a tape measure, a straight-edge and Vernier calliper calibrated in centimetres (*cm*) – Table 1; the physical appearance with emphasis on pottery object's characteristics and surface decorations were recorded with the digital camera. The dried clay core samples were ground in an agate mortar, and mixed with 100% ultrapure carbon prepared into thick pellets of 13 mm diameter without binder. The Proton-induced X-ray Emission (PIXE) experiments were performed using a 2.5 MeV proton beam obtained from the Center for Energy Research and Development (CERD) Ion Beam Analysis (IBA) facility in O. A. U., Ile-Ife.

The measurements were carried out with a beam spot of 4 mm in diameter and a low beam current of 3-6 nA. The irradiation was for about 10-20 minutes. A Canberra Si(Li) detector Model ESLX 30-150, beryllium thickness of 25 µm, with a full width half maximum (FWHM)of 150 eV at 5.9 keV, with the associated pulse processing electronics, and a Canberra Genie 2000 (3.1) MCA card interfaced to a personal computer (PC) were used for the X-rays data acquisition. Concerning the beam director, the sample's normal was located at 0º and the Si (Li) detector at 45º. The PIXE set-up was calibrated using some pure element standards and NIST geological standard, NBS278. The computer code GUPIXWIN [4] was used for the analysis of the PIXE data. This provides a non-linear least-square fitting of the spectrum, together with subsequent conversion of the fitted X-ray peak intensities into elemental concentrations, utilizing the fundamental parameter method for quantitative analysis.

Results

The PIXE analysis returned the presence of twenty-three (23) elements in form of values in parts per million (ppm) for each of the 24 samples. The found elements were listed according to the standard periodic table of elements with their elemental abbreviations (Appendix A & B). The peculiarity of each pottery object's chemical fingerprint was defined using Appendix A & B; the value of the elements returned per sample is expressed in parts per million (ppm), and the concentration of each element was expressed with four nominal values. The value scales were arrived at by grouping the returned values relatively in each column into four sets high, medium, low, very low, and no values nominally. Column-by-column appraisals returned elemental values across the twenty-four pottery objects; while row-by-row appraisals returned the values of the elements present per pottery object in ppm (Appendix A & B). Data were recorded in terms of the quantitative analysis of samples taken from the twenty-four (24) pottery objects. The results of elemental occurrences from the PIXE analysis returned the presence of twenty-three (23) elements across all the samples in parts per million (ppm).

The following twenty-three (23) elements were returned with their abbreviations in parentheses. The relative values of the amount of the elements present per sample in parts per million (ppm) amounted to the chemical fingerprint returned for the twenty-four samples. Sodium (Na); Magnessium (Mg); Aluminium (Al); Silicon (Si); Phosphorus (P); Sulphur (S); Chlorine (Cl); Potassium (K); Calcium (Ca); Titanium (Ti); Vanadium (V); Chromium (Cr); Manganese (Mn); Iron (Fe); Nickel (Ni); Zinc (Zn); Asbestos (As); Rubidium (Rb); Strontium (Sr); Zirconium (Zr); Barium (Ba); Cerium (Ce); and Lead (Pb). The values of the relative presence of the elements in each of the samples are recorded in tabular form (Table 3). The elemental abbreviations are interpreted with a standard Periodic Table of Elements. The highest and lowest relative values of each element per sample were recorded for the PIXE analysis of samples (Appendix B).

Table 1. Linear measurements of the 24 selected pottery objects with the corresponding laboratory tags and Museum Accession numbers.

Ser no	File name	Museum accession no	Height (cm)	Circumference (cm)	Neck height (cm)	Neck circumference (cm)	Rim/mouth circumference (cm)	Rim thickness (mm)	Orifice diameter (cm)
1	OLA-1.PIX	73.1.59	60	128	2	92	94	20	24/29
2	OLA-10.PIX	73.1.35	5	49	1	10.5	*N/A	10	*N/A
3	OLA-20.PIX	xxvii	49.5	123	4	66	67	15	17/21
4	OLA-30.PIX	72.1.23	10.55	57.5	2	52	36.5	7	12/12.5
5	OLA-40.PIX	66.1.8	26	71	4	45	71	8	22/23
6	OLA-50.PIX	51.1.99	42.5	103	16	76	122	17	36/38
7	OLA-60.PIX	72.3.111	5	80	*N/A	*N/A	*N/A	9.5	23/25
8	OLA-70.PIX	72.3.125	3	74.5	*N/A	*N/A	*N/A	8	20.5/24
9	OLA-80.PIX	72.3.86	15	85	2	69	86	11	20/27
10	OLA-89.PIX	72.3.15	87	102	2.5	81	53	9.5	17/18.5
11	OLA-100.PIX	72.1.7A	26.5	110	5	96.5	100	10	3.5/14
12	OLA-110.PIX	72.3.8	13	43	2.5	26	34.5	8	5.5/11
13	OLA-120.PIX	66.1.17	36	112.5	3	52	53	11	13.5/16
14	OLA-130.PIX	73.1.44	39.5	84	24/3.5	44.5/42	59	11	17.5/19
15	OLA-140.PIX	72.1.93	39.5	118	3	62	64	8	18.5/20
16	OLA-150.PIX	73.1.9	23	90	2	76	82	14	21.5/25
17	OLA-160.PIX	72.1.48	17.5	59	2.5	34	43	9	12/13.5
18	OLA-170.PIX	73.1.37	24	81	5	49	69.5	8	20.5/22
19	OLA-180.PIX	73.1.87	16	59	2	36	42	9	11.5/13
20	OLA-190.PIX	72.3.71	33	91.5	6	18	20	9	4.5/6
21	OLA-200.PIX	X^4	46.5	125	2	106	113	16	31/35
22	OLA-206.PIX	X^7	71	126	2	101	105	10	28/33
23	OLA-210.PIX	73.1.57	61.5	125	2	89	93	20	24/30
24	OLA-213.PIX	72.1.46	76	176	19	77	115.5	20	32/35

***N/A- Not Applicable**

The PIXE values of elements recorded in parts per million (ppm) – [Appendix A & B]

OLA-1.PIX: Na = 2520; Mg = 4390; Al = 113891; Si = 291968; P = 1180; S = 206.5; Cl = 352.9; K = 20392; Ca = 8794; Ti = 9594; V = 50.37; Cr = 72.84; Mn = 568.9; Fe = 64538; Ni = 0; Zn = 711.2; As = 0; Rb = 14.04; Sr = 242.2; Zr = 1555; Ba = 0; Ce = 1606; Pb = 3188.

OLA-10.PIX: Na = 3393; Mg = 6010; Al = 147108; Si = 268738; P = 620.5; S = 1722; Cl = 658.8; K = 14379; Ca = 12173; Ti = 5148; V = 62.73; Cr = 135.9; Mn = 403; Fe = 63205; Ni = 0; Zn = 512.9; As = 0; Rb = 11.9; Sr = 396.8; Zr = 172.4; Ba = 0; Ce = 0; Pb = 0.

OLA-20.PIX: Na = 2626; Mg = 10129; Al = 123861; Si = 233640; P = 2736; S = 509.9; Cl = 645.6; K = 225286; Ca = 8990; Ti = 14766; V = 132.8; Cr = 0; Mn = 1004; Fe = 103397; Ni = 0; Zn = 12646; As = 0; Rb = 25.76; Sr = 649.3; Zr = 309.9; Ba = 0; Ce = 15925; Pb = 0.

OLA-30.PIX: Na = 4800; Mg = 5237; Al = 114024; Si = 288898; P = 0; S = 384.2; Cl = 1777; K = 14748; Ca = 9781; Ti = 6069; V = 57.77; Cr = 148.4; Mn = 1523; Fe = 70644; Ni = 0; Zn = 565.3; As = 6.012; Rb = 0; Sr = 355.7; Zr = 80.74; Ba = 4949; Ce = 6137; Pb = 0.

OLA-40.PIX: Na = 5234; Mg = 9897; Al = 129627; Si = 280129; P = 0 ; S = 770.9; Cl = 728.5; K = 12362; Ca = 9551; Ti = 6434; V = 79.26; Cr = 188.6; Mn = 905.9; Fe = 64844; Ni = 0; Zn = 1039; As = 5.776; Rb = 15.87; Sr = 262.6; Zr = 493.3; Ba = 0; Ce = 30.74; Pb = 0.

OLA-50.PIX: Na = 5214; Mg = 12952; Al = 111265; Si = 278463; P = 1053; S = 1281; Cl = 456.5; K = 5838; Ca = 16581; Ti = 6948; V = 126.3; Cr = 310.1; Mn = 1554; Fe = 67030; Ni = 0; Zn = 15850; As = 0; Rb = 0; Sr = 283; Zr = 1058; Ba = 0; Ce = 6370; Pb = 0.

OLA-60.PIX: Na = 3793; Mg = 11763; Al = 148311; Si = 251446; P = 0; S = 278.9; Cl = 1527; K = 11414; Ca = 12130; Ti = 7441; V = 184.2; Cr = 239.1; Mn = 406.9; Fe = 85078; Ni = 0; Zn = 633.3; As = 6.651; Rb = 10.91; Sr = 299.6; Zr = 223.8; Ba = 0; Ce = 0; Pb = 0.

OLA-70.PIX: Na = 764.9; Mg = 21273; Al = 101938; Si = 287255; P = 836; S = 740.2; Cl = 612.7; K = 16997; Ca = 8091; Ti = 7927; V = 72.7; Cr = 892.7; Mn = 815.4; Fe = 68167; Ni = 419.9; Zn = 292.7; As = 0; Rb = 38.55; Sr =93.06; Zr = 290; Ba = 0; Ce = 13377; Pb = 0.

OLA-80.PIX: Na = 1004; Mg = 5619; Al = 108171; Si = 303589; P = 0; S = 236.6; Cl = 371; K = 9621; Ca = 7101; Ti = 5149; V = 108.6; Cr = 239.1; Mn = 1035; Fe = 63119; Ni = 0; Zn = 198; As = 0; Rb = 14.92; Sr = 280.5; Zr = 68.55; Ba = 0; Ce = 17833; Pb = 0.

OLA-89.PIX: Na = 514.9; Mg = 5175; Al = 120130; Si = 292762; P = 0; S = 353; Cl = 342.7; K = 19921; Ca = 3958; Ti = 5899; V = 107.4; Cr = 167.2; Mn = 559; Fe = 54877; Ni = 0; Zn = 126.8; As = 8.941; Rb = 19.91; Sr = 51.91; Zr = 239.7; Ba = 0; Ce = 20599; Pb = 0.

OLA-100.PIX: Na = 987.4; Mg = 3743; Al = 299117; Si = 172480; P = 0; S = 212.8; Cl = 346.8; K = 3261; Ca = 8611; Ti = 1893; V = 0; Cr = 90.5; Mn = 175.6; Fe = 17206; Ni = 0; Zn = 49.06; As = 0; Rb = 0; Sr = 364.1; Zr = 0; Ba = 15319; Ce = 0; Pb = 0.

OLA-110.PIX: Na = 431.8; Mg = 698.9; Al = 464703; Si = 42822; P = 0; S = 138.1; Cl = 0; K = 1479; Ca = 711.4; Ti = 1172; V = 41.71; Cr = 29.65; Mn = 133.5; Fe = 11653; Ni = 0; Zn = 20.99; As = 0; Rb = 5.664; Sr = 0; Zr = 0; Ba = 0; Ce = 0; Pb = 7802.

OLA-120.PIX: Na = 1050; Mg = 10216; Al = 157305; Si = 236582; P = 838.7; S = 1988; Cl = 2009; K = 8349; Ca = 11727; Ti = 9075; V = 222; Cr = 200; Mn = 1573; Fe = 96807; Ni = 0; Zn = 324.7; As = 0; Rb = 44.17; Sr = 285.5; Zr = 0; Ba = 0; Ce = 0; Pb = 0.

OLA-130.PIX: Na = 911.9; Mg = 7544; Al = 148488; Si = 235420; P = 203.7; S = 1286; Cl = 536.1; K = 16602; Ca = 9142; Ti = 5588; V = 63.64; Cr = 291.8; Mn = 293.3; Fe = 55445; Ni = 8.181; Zn = 68.54; As = 0; Rb = 0; Sr = 425.1; Zr = 164.9; Ba = 0; Ce = 54503; Pb = 17694.

OLA-140.PIX: Na = 1685; Mg = 4237; Al = 154898; Si = 253585; P = 1119; S = 756.9; Cl = 316.7; K = 29625; Ca = 5061; Ti = 7620; V = 106.3; Cr = 103.2; Mn = 642.3; Fe = 68767; Ni = 0; Zn = 2308; As = 0; Rb = 15.31; Sr = 282.3; Zr = 437.8; Ba = 0; Ce = 1876; Pb = 0.

OLA-150.PIX: Na = 3299; Mg = 9753; Al = 137511; Si = 249653; P = 2320; S = 1047; Cl = 4278; K = 21240; Ca = 11993; Ti = 10179; V = 230.7; Cr = 237.3; Mn = 691.4; Fe = 86277; Ni = 0; Zn = 283; As = 24.22; Rb = 7.208; Sr = 359.1; Zr = 462.9; Ba = 0; Ce = 0; Pb = 0.

OLA-160.PIX: Na = 3588; Mg = 5495; Al = 119168; Si = 296551; P = 0; S = 379.2; Cl = 457; K = 15791; Ca = 9334; Ti = 6531; V = 123.2; Cr = 167.9; Mn = 1171; Fe = 65711; Ni = 0; Zn = 322.5; As = 0; Rb = 0; Sr = 369.3; Zr = 802.6; Ba = 0; Ce = 879; Pb = 0.

OLA-170.PIX: Na = 1721; Mg = 5817; Al = 135606; Si = 273142; P = 716; S = 868.9; Cl = 432.3; K = 21264; Ca = 7341; Ti = 7231; V = 95.98; Cr = 327.7; Mn = 240.8; Fe = 70178; Ni = 0; Zn = 318.8; As = 44.56; Rb = 8.803; Sr = 0; Zr = 249.7; Ba = 0; Ce = 2423; Pb = 488.2.

OLA-180.PIX: Na = 4288; Mg = 5912; Al = 123631; Si = 291444; P = 0; S = 717.9; Cl = 545.6; K = 16054; Ca = 9778; Ti = 5881; V = 104.4; Cr = 250.7; Mn = 682.1; Fe = 61055; Ni = 0; Zn = 305.3; As = 0; Rb = 11.14; Sr = 209.2; Zr = 258.3; Ba = 0; Ce = 1220; Pb = 0.

OLA-190.PIX: Na = 1701; Mg = 7515; Al = 143952; Si = 262974; P = 595.6; S = 401.2; Cl = 292.7; K = 27916; Ca = 4969; Ti = 5773; V = 100.1; Cr = 158.2; Mn = 595.4; Fe = 70128; Ni = 0; Zn = 268.7; As = 0; Rb = 6.737; Sr = 176.4; Zr = 306.9; Ba = 3734; Ce = 1284; Pb = 0.

OLA-200.PIX: Na = 4108; Mg = 5113; Al = 130550; Si = 286612; P = 2563; S = 2022; Cl = 824.6; K = 10858; Ca = 7496; Ti = 6272; V = 64.49; Cr = 139; Mn = 641; Fe = 59835; Ni = 0; Zn = 490.3; As = 0; Rb = 5.907; Sr = 45.55; Zr = 32.52; Ba = 0; Ce = 1496; Pb = 0.

OLA-206.PIX: Na = 2292; Mg = 5762; Al = 170914; Si = 254967; P = 773.6; S = 710.9; Cl = 193.3; K = 6567; Ca = 5407; Ti = 5828; V = 45.49; Cr = 112.5; Mn = 682.5; Fe = 68292; Ni = 0; Zn = 365.6; As = 297; Rb = 13.83; Sr = 21.64; Zr = 234.2; Ba = 0; Ce = 0; Pb = 0.

OLA-210.PIX: Na = 2305; Mg = 3301; Al = 226367; Si = 227450; P = 0; S = 391.9; Cl = 1580; K = 7537; Ca = 3204; Ti = 3404; V = 61.13; Cr = 301.2; Mn = 231.1; Fe = 42209; Ni = 0; Zn = 186.6; As = 0; Rb = 3.33; Sr = 9.196; Zr = 0; Ba = 0; Ce = 0; Pb = 158.9.

OLA-213.PIX: Na = 5859; Mg = 2578; Al = 193954; Si = 244457; P = 0; S = 468.9; Cl = 124; K = 4192; Ca = 15410; Ti = 5694; V = 3.875; Cr = 280.1; Mn = 793.9; Fe = 37537; Ni = 0; Zn = 739.1; As = 243.1; Rb = 4.067; Sr = 50.21; Zr = 241.4; Ba = 7897; Ce = 828.1; Pb = 0.

Discussions

The twenty-four (24) pottery objects returned the presence of Sodium (Na); pottery objects serial numbers 4; 5; 6; 19; 21 and 24 returned high concentration of sodium; objects serial numbers 1; 2; 3; 7; 16; 17; 22 and 23 returned medium concentration of sodium. Objects serial numbers 8; 9; 10; 11; 13;14; 15; 18; and 20 recorded low concentration of sodium, while object serial number 12 returned very low concentration of sodium.

Magnesium (Mg) was returned by all the twenty-four (24) pottery objects; only pottery object serial number 8 returned high concentration of magnesium; objects serial numbers 3; 6; 7 and 13 returned medium concentration of magnesium. Objects serial numbers 1; 4; 5; 9; 10; 11; 14; 15; 16; 17; 18; 19; 20; 21; 22; 23 and 24 returned low concentration of magnesium. However, only pottery object serial number 12 returned very low concentration of magnesium.

All the twenty-four (24) pottery objects returned the presence of Aluminium (Al); only pottery object serial number 12 returned high concentration of aluminium; objects serial numbers 11 and 23 returned medium concentration of aluminium, while objects serial numbers 1; 2; 3; 4; 5; 6; 7; 10; 13; 14; 15; 16; 17; 18; 19; 20; 21; 22 and 24 returned low concentration of aluminium; object serial numbers 8 and 9 recorded very low concentration of aluminium.

All the twenty-four (24) pottery objects returned the presence of Silicon (Si); Only pottery object serial number 9 returned high concentration of silicon; while pottery objects serial numbers 1; 2; 4; 5; 6; 7; 8; 10; 15; 16; 17; 18; 19; 20; 21; and 22 returned medium concentration of Silicon. Pottery objects serial numbers 3; 11; 13; 14; 16; 23 and 24 returned low concentration of silicon. Pottery object serial number 12 returned very low concentration of silicon.

Thirteen (13) of the pottery objects returned the presence of Phosphorus (P); pottery objects serial numbers 3; 16 and 21 returned high concentrations of phosphorus; pottery objects serial numbers 1; 6 and 15 returned medium concentrations of phosphorus, while pottery object serial numbers 2; 8; 13; 18; 20 and 23 returned low concentration of phosphorus; and pottery object serial number 14 returned very low concentration of phosphorus. Pottery objects serial numbers 4; 5; 7; 9; 10; 11;12; 17; 19; 23 and 24 returned the absence of phosphorus.

The twenty-four (24) pottery objects returned the presence of Sulphur (S); only pottery object serial number 21 returned high concentration of sulphur; pottery objects serial numbers 2; 6; 13; 14 and 16 returned medium concentration of sulphur, while pottery object serial numbers 1; 3; 4; 5; 7; 8; 9; 10; 11; 15; 17; 18; 19; 20; 22; 23 and 24 returned low concentration of sulphur; while pottery object serial number 12 recorded very low concentration of sulphur.

Twenty-three (23) pottery objects returned the presence of Chlorine (Cl); only pottery object serial number 16 returned high concentration of chlorine; pottery objects serial numbers 4; 7; 13 and 23 returned medium concentration of chlorine, while pottery objects serial numbers 1; 2; 3; 5; 6; 8; 9; 10; 11; 14; 15; 17; 18; 19; 20 and 21 returned low concentration of chlorine; pottery objects serial numbers 22 and 24 returned very low concentration of chlorine; while only pottery object 12 returned the absence of chlorine.

All the twenty-four (24) pottery objects returned the presence of Potassium (K); pottery objects serial numbers 1; 3; 15; 16; 18 and 20 returned high concentration of potassium; while pottery objects serial numbers 8; 10; 14; 17 and 19 recorded medium concentration of potassium; while pottery objects serial numbers 2; 4; 5; 6; 7; 9; 13; 21; 22 and 23 returned low concentration of potassium; pottery objects serial numbers 11; 12 and 24 recorded very low concentration of potassium.

All the twenty-four (24) pottery objects returned the presence of calcium (Ca); only pottery object serial numbers 6 and 24 returned high concentration of calcium; pottery objects serial numbers 2; 7; 13 and 16 returned medium concentration of calcium, while pottery objects serial numbers 1; 3; 4; 5; 8; 9; 10; 11; 14; 15; 17; 18; 19; 20; 21; 22 and 23 returned low concentration of calcium; and only pottery object 12 returned very low concentration of calcium.

All the twenty-four (24) pottery objects returned the presence of Titanium (Ti); only pottery objects serial numbers 3 and 16 returned high concentration of titanium; pottery objects serial numbers 1; 2; 3; 4; 5; 6; 7; 8; 9; 10; 13; 14; 15;17; 18;19; 20; 21; 22 and 24 returned medium concentration of titanium, while only pottery object serial number 23 returned low concentration of titanium and the pottery objects 11 and 12 returned very low concentration of titanium.

Twenty-three (23) pottery objects returned the presence of Vanadium (V); only pottery object 11 returned no concentration of vanadium; pottery objects serial numbers 13 and 16 returned high concentration of vanadium, while pottery objects serial numbers 3; 6; 7; 9; 10; 15; 17; 19 and 20 returned medium concentration of vanadium; pottery objects serial numbers 1; 2; 4; 5; 8; 9; 12; 14; 18; 21; 22 and 24 returned very low concentration of vanadium.

Twenty-three (23) pottery objects returned the presence of Chromium (Cr); only pottery object serial number 3 returned absence of chromium; and only pottery object serial number 8 returned high concentration of chromium, while pottery objects serial numbers 2; 4; 5; 6; 7; 9; 10; 13; 14; 15; 16; 17; 18; 19; 20; 21; 22; 23 and 24 returned low concentration of chromium; pottery objects serial numbers 1; 11 and 12 returned very low concentration of chromium.

All the twenty-four (24) pottery objects returned the presence of Iron (Fe); only pottery object serial number 3 returned high concentration of iron; pottery object serial number 13 returned medium concentration of iron, while pottery objects serial numbers 1; 2; 4; 5; 6; 7; 8; 9; 10; 14; 15; 16; 17; 18; 19; 20; 21; 22; 23 and 24 returned low concentration of iron; only pottery objects serial numbers 11 and 12 returned very low concentration of iron.

Only two (2) of the pottery objects returned the presence of Nickel (Ni); pottery object serial number 8 returned a high concentration of nickel, and pottery object serial number 14 returned low concentration of nickel; while no other pottery object returned the presence of nickel.

All the twenty-four (24) pottery objects returned the presence of Zinc (Zn); only pottery objects serial number 3 and 6 returned high concentration of zinc; pottery objects serial numbers 5 and 15 returned medium concentration of zinc, while pottery object serial numbers 1; 2; 4; 7; 8; 9; 10; 13; 16; 17; 18; 19; 20; 21; 22; 23 and 24 returned low concentration of zinc; pottery object serial numbers 11; 12 and 14 returned very low concentration of zinc, none of the pottery objects recorded the absence of zinc.

Two (2) pottery objects returned the presence of Asbestos (As); only pottery objects serial numbers 22 and 24 returned high concentration of asbestos; pottery object serial number 18 returned medium concentration of asbestos, while pottery object serial number 16 returned low concentration of asbestos; pottery objects serial numbers 4; 5; 7 and 10 returned very low concentration of asbestos, none of the other pottery objects recorded the presence of asbestos.

Nineteen (19) pottery objects returned the presence of Rubidium (Rb); only pottery objects serial numbers 8 and 13 returned high concentration of rubidium; pottery objects serial numbers 3; 5; 10 and 15 returned medium concentration of rubidium, while pottery objects serial numbers 1; 2; 7; 9; 19 and 22 returned low concentration of rubidium; pottery objects serial numbers 12; 16; 18; 20; 21; 23 and 24 returned very low concentration of rubidium, pottery objects serial numbers 4; 6; 11; 14 and 17 recorded the absence of rubidium.

Twenty-two (22) pottery objects returned the presence of Strontium (Sr); only pottery object serial number 3 returned high concentration of strontium; pottery objects serial numbers 1; 2; 4; 5; 6; 7; 9; 11; 13; 14; 15; 16; 17 and 19 returned medium concentration of strontium, while pottery objects serial numbers 8; 10; 20; 21; 22 and 24 returned low concentration of strontium; while pottery object serial number 23 returned very low concentration of strontium, pottery object serial numbers 12 and 18 recorded absence of strontium.

Twenty (20) pottery objects returned the presence of Zirconium (Zr); only pottery object serial number 1 returned high concentration of Sulphur. Pottery object serial number 6 returned medium concentration of zirconium, while pottery objects serial number 2; 3; 5; 7; 8; 10; 14; 15; 16; 17; 18; 19; 20; 22; 23 and 24 returned low concentration of zirconium; pottery objects serial numbers 4; 9 and 21 returned very low concentration of zirconium, while pottery objects serial numbers 11; 12; 13 and 23 recorded absence of zirconium.

Four (4) pottery objects returned the presence of Barium (Ba); only pottery object serial number 11 returned high concentration of barium; pottery object serial number 24 returned medium concentration of barium, while pottery objects serial numbers 4 and 20 returned low concentration of barium.

Sixteen (16) pottery objects returned the presence of Cerium (Ce); only pottery object serial number 14 returned high concentration of cerium; pottery objects serial numbers 3; 8; 9; 10 returned medium concentration of cerium, while pottery objects serial numbers 1; 4; 5; 6; 8; 15; 18; 19; 20 and 21 returned low concentration of cerium; pottery objects serial numbers 17 and 24 returned very low concentration of cerium, and pottery objects serial numbers 2; 7; 11; 12; 13; 16; 22 and 23 recorded absence of cerium.

Five (5) pottery objects returned the presence of Lead (Pb); only pottery object serial number 14 returned high concentration of lead; pottery object serial number 12 returned medium concentration of lead, while pottery object serial number 18 returned low concentration of lead; pottery object serial number 23 returned very low concentration of lead, none of the other pottery objects recorded the presence of lead.

Specific value scale of elements returned for each pottery object is expressed as follows: High Concentration (HC); Medium Concentration (MC); Low Concentration (LC); Very Low Concentration (VLC) and Nil / Zero Concentration (NC). See Appendix A & B for table format.

OLA-1.PIX
HC = K, Zr, Pb
MC = Na, Si, P, Ti, Sr
LC = Mg, Al, S, Cl, V, Mn, Fe, Zn, Rb, Ce
VLC= Cr
NC = Ni, As, Ba

OLA-10.PIX
HC = no high concentration recorded
MC = Na, Si, S, Ca, Ti, Sr
LC = Mg, Al, P, Cl, K, V, Cr, Mn, Fe, Zn, Rb, Zr
VLC= no very low concentration recorded
NC = Ni, As, Ba, Ce, Pb

OLA-20.PIX
HC = P, K, Ti, Fe, Zn, Sr
MC = Na, Mg, V, Mn, Rb, Ce
LC = Al, Si, S, Cl, Ca, Zr
VLC= no very low concentration recorded
NC = Cr, Ni, As. Ba, Pb

OLA-30.PIX
HC = Na, Mn
MC = Si, Cl, Ti, Sr
LC = Mg, Al, S, K, Ca, V, Cr, Fe, Zn, Ba, Ce
VLC= As, Zr
NC = Pb, Ni, Rb, Pb

OLA-40.PIX
HC = Na
MC = Si, Ti, Zn, Rb, Sr
LC = Mg, Al, S, Cl, K, Ca, V, Cr, Mn, Fe, Zn, Ce
VLC= As
NC = P, Ni, Ba, Pb

OLA-50.PIX
HC = Na, Ca, Mn, Zn
MC = Mg, Si, P, S, Ti, V, Sr, Zr
LC = Al, Cl, K, Cr, Fe, Ce
VLC= no very low concentration recorded
NC = Ni, As, Rb, Ba, Pb

OLA-60.PIX
HC = no high concentration recorded
MC = Na, Mg, Si, Cl, Ca, Ti, V, Sr
LC = Al, S, K, Cr, Mn, Fe, Zn, Rb, Zr
VLC= As
NC = P, Ni, Ba, Ce, Rb

OLA-70.PIX
HC = Mg, Cr, Ni, Rb
MC = Si, K, Ti, Ce
LC = Na, P, S, Cl, Ca, V, Mn, Fe, Zn, Sr, Zr
VLC= Al
NC = As, Ba, Pb

OLA-80.PIX
HC = Si
MC = Ti, V, Mn, Sr, Ce
LC = Na, Mg, S, Cl, K, Ca, Cr, Fe, Zn, Rb
VLC= Al, Zr
NC = P, Ni, As, Ba, Pb

OLA-89.PIX

HC = no high concentration recorded
MC = Si, K, Ti, V, Rb, Ce
LC = Na, Mg, Al, S, Cl, Ca, Cr, Mn, Fe, Zn, Sr, Zr
VLC= no very low concentration recorded
NC = Ni, As, Ba, Ce, Pb
OLA-100.PIX
HC = Ba
MC = Al, Sr
LC = Na, Mg, Si, S, Cl, Ca
VLC= K, Ti, Cr, Mn, Fe, Zn
NC = P, V, Ni, As, Rb, Zr, Ce, Pb
OLA-110.PIX
HC = Al
MC = Pb
LC = V
VLC= Na, Mg, Si, S, K, Ca, Ti, Cr, Mn, Fe, Zn, Rb
NC = P, Cl, Ni, As, Sr, Zr, Ba, Ce
OLA-120.PIX
HC = V, Mn, Rb
MC = Mg, S, Cl, Ca, Ti, Fe, Sr
LC = Na, Al, Si, P, K, Cr, Zn
VLC= no very low concentration recorded
NC = Ni, As, Zr, Ba, Ce, Pb
OLA-130.PIX
HC = Ce, Pb
MC = S, K, Ti, Sr
LC = Na, Mg, Al, Si, Cl, Ca, V, Cr, Mn, Fe, Zr
VLC= P, Ni, Zn
NC = As, Rb, Ba
OLA-140.PIX
HC = K
MC = Si, P, Ti, V, Zn, Rb, Sr
LC = Mg, Al, P, Cl, K, V, Cr, Mn, Fe, Zn, Rb, Zr
VLC= no very low concentration recorded
NC = Ni, As, Ba, Pb
OLA-150.PIX
HC = P, Cl, K, Ti, V
MC = Na, S, Ca, Sr
LC = Mg, Al, Si, Cr, Mn, Fe, Zn, As, Zr
VLC= Rb
NC = Ni, Ba, Ce, Pb
OLA-160.PIX
HC = no high concentration recorded
MC = Na, Si, K, Ti, V, Mn, Sr
LC = Mg, Al, S, Cl, Ca, Cr, Mn, Fe, Zn, Zr
VLC= Ce
NC = P, Ni, As, Rb, Ba, Pb
OLA-170.PIX
HC = K
MC = Si, Ti, As
LC = Na, Mg, Al, P, S, Cl, Ca, V, Cr, Mn, Fe, Zn, Zr, Ce, Pb
VLC= Rb
NC = Sr, Ba
OLA-180.PIX
HC = Na
MC = Si, K, Ti, V, Sr
LC = Mg, Al, S, Cl, Ca, Cr, Mn, Fe, Zn, Rb, Zr, Ce
VLC= no very low concentration recorded
NC = P, Ni, As, Ba, Pb
OLA-190.PIX
HC = K
MC = Si, Ti, V
LC = Na, Mg, Al, P, S, Cl, Ca, Cr, Mn, Fe, Zn, Sr, Zr, Ba, Ce
VLC= Rb
NC = Ni, As, Pb
OLA-200.PIX
HC = Na, P, S
MC = Si, Ti
LC = Mg, Al, Cl, K, Ca, V, Cr, Mn, Fe, Zn, Sr, Ce
VLC= Rb, Zr
NC = Ni, As, Ba, Pb
OLA-206.PIX
HC = As
MC = Na, Si, Ti
LC = Mg, Al, P, S, K, Ca, V, Cr, Mn, Fe, Zn, Rb, Sr, Zr
VLC= Cl
NC = Ni, Ba, Ce, Pb
OLA-210.PIX
HC = no high concentration recorded
MC = Na, Al, Cl
LC = Mg, Al, Si, S, K, Ca, Ti, V, Cr, Mn, Fe, Zn
VLC= Rb, Sr, Pb
NC = P, Ni, As, Zr, Ba, Ce,
OLA-213.PIX
HC = Na, Ca, As
MC = Ti, Ba
LC = Mg, Al, Si, S, Cr, Mn, Fe, Zn, Sr, Zr
VLC= Cl, K, V, Rb, Ce
NC = P, Ni, Pb

Laboratory analysis also facilitated comparison of data similarities and differences; correlation of such data allowed inferences to be drawn for provenance postulation. A critical study of Table 3 along the rows showed that from all the twenty-four (24) samples analysed; no two pottery objects returned the same values for all the elements identified. In cases where samples returned the presence of the same elements, their relative values are different. However, the values returned along the columns revealed marked commonalities and differences, especially for the elements Phosphorus (P); Nickel (Ni); Asbestos (As); Rubidium (Rb); Zirconium (Zr); Barium (Ba); Cerium (Ce); and Lead (Pb).

Pottery object OLA-1.PIX is made with clay sample that has no inclusion of nickel, asbestos and barium as elements. Thus the fingerprint returned affinity with pottery objects serial numbers 2; 3; 4; 5; 6; 7; 9; 10; 11; 12; 13; 15; 16; 17; 18; 19; 20; 21; 22; 23 and 24. However, this fingerprint exhibited the highest value of zirconium even though, the presence of zirconium was virtually returned for all the pottery objects except pottery objects 11; 12; 13 and 23 which returned absence of zirconium. With particularity, there is also the presence of cerium and lead in the clay sample used for pottery object OLA-1.PIX. Pottery objects OLA-10.PIX is made with clay sample that has no inclusion of nickel, asbestos, barium, cerium and lead as elements; the fingerprint has affinity with pottery objects serial numbers 3; 6; 7; 12; 13 and 23. However, with particularity, the fingerprint returned does not exhibit high value for all the elements returned. The elements' concentration returned between medium and low ppm values.

Pottery object OLA-20.PIX is made with clay sample that has no inclusion of chromium, nickel, asbestos, barium and lead as elements; the fingerprint has affinity with pottery objects serial numbers 9; 13; 15; 17; 19; 21 and 23. However, with particularity, the fingerprint returned absence of chromium and it is the only pottery object that returned highest concentration of phosphorus, potassium, titanium, iron, zinc and strontium. Pottery object OLA-30.PIX is made with clay sample that has no inclusion of phosphorus, nickel, rubidium, and lead as elements; the fingerprint has affinity with pottery objects serial numbers 5; 7; 9; 10; 17 and 19. This fingerprint returned high concentration of sodium, very low concentration of asbestos, and low concentration of barium which made it distinct from other pottery objects. Pottery object OLA-40.PIX is made with clay sample that has no inclusion of phosphorus, nickel, rubidium, and lead as elements; the fingerprint displayed affinity with pottery object serial number 4. The fingerprint returned has a slight difference from pottery object serial number 4 in that it returned medium concentration of rubidium. Pottery object OLA-50.PIX is made with clay sample that has no inclusion of nickel, asbestos, rubidium, and lead as elements; the fingerprint displayed affinity with pottery object serial number 4. However, this fingerprint returned has affinity with pottery objects serial numbers 9; 15; 17; 19; 21 and 23. It is slightly different from other pottery objects because of high concentrations of sodium, calcium, manganese and zinc.

Pottery object OLA-60.PIX is made with clay sample that has no inclusion of phosphorus, nickel, barium, cerium and lead as elements; the fingerprint displayed affinity with pottery object serial number 23 but with a difference because it has very low concentration of lead as inclusion; with peculiarity it returned no high concentrations of the twenty-three (23) elements. The fingerprint also returned medium concentrations of sodium, magnesium, silicon, chlorine, calcium, titanium, vanadium and strontium. Pottery object OLA-70.PIX is made with clay sample that has no inclusion of barium, asbestos, and lead as elements; the fingerprint returned has affinity with pottery objects serial numbers 13; 15; 17; 19 and 21. It is the only pottery object with high concentration of nickel and high concentrations of magnesium, chromium, nickel and rubidium.

Pottery object OLA-80.PIX is made with clay sample that has no inclusion of phosphorus, nickel, barium, asbestos, and lead as elements; the fingerprint returned has affinity with pottery objects serial numbers 10; 17; 19 and 23. It is the only pottery object with high concentration of silicon. Pottery object OLA-89.PIX is made with clay sample that has no inclusion of phosphorus, nickel, barium, and lead as elements; the fingerprint has affinity with pottery objects serial numbers 5; 7; 9; 17; 19 and 23.

Pottery object OLA-100.PIX is made with clay sample that has no inclusion of phosphorus, vanadium, nickel, asbestos, rubidium, zirconium, cerium, and lead as elements; the fingerprint has affinity with pottery object serial number 23 only. The pottery object that returned absence of vanadium and high concentration of barium. Pottery object OLA-110.PIX is made with clay sample that has no inclusion of phosphorus, chlorine, nickel, asbestos, strontium, barium, and cerium as elements; the fingerprint returned affinity with pottery object serial number 23. It is the only pottery object that recorded no absence of chlorine but returned high concentrations of aluminium and medium concentration of lead.

Pottery object OLA-120.PIX is made with clay sample that has no inclusion of nickel, asbestos, strontium, barium, cerium and lead as elements; the fingerprint returned affinity with pottery objects serial numbers 2; 16 and 23. It returned high concentrations of vanadium, manganese and rubidium. Pottery object OLA-130.PIX is made with clay sample that has no inclusion of asbestos, rubidium, and barium as elements; the fingerprint returned affinity with pottery object serial number 6 though with a particularity of the absence of cerium and lead. Pottery object OLA-140.PIX is made with clay sample that has no inclusion of nickel, asbestos, barium, and lead as elements; the fingerprint returned affinity with pottery objects serial numbers 2; 3; 6; 9; 13; 16; 17; 19 and 21. It returned a high concentration of potassium.

Pottery object OLA-150.PIX is made with clay sample that has no inclusion of nickel, barium, cerium and lead as elements; the fingerprint returned affinity with pottery object serial number 22. It also returned high concentrations of phosphorus, chlorine, potassium, titanium and vanadium. Pottery object OLA-160.PIX is made with clay sample that has no inclusion of phosphorus, nickel, asbestos, rubidium, barium, and lead as elements; the fingerprint returned affinity with pottery object serial number 6. Pottery object OLA-170.PIX is made with clay sample that has no inclusion of nickel, strontium and barium as elements; the fingerprint returned affinity with pottery object serial number 12. It also returned high concentration of potassium.

Pottery object OLA-180.PIX is made with clay sample that has no inclusion of phosphorus, nickel, asbestos, barium, and lead as elements; the fingerprint returned affinity with pottery objects serial numbers 5; 6; 7; 9; 10; 17; 18 and 23. It returned high concentration of sodium only. Pottery object OLA-190.PIX is made with clay sample that has no inclusion of nickel, asbestos and lead as elements; the fingerprint returned affinity with pottery objects serial numbers 2; 3; 5; 6; 9; 11; 13; 15; 17; 19 and 21. It returned high concentration of potassium.

Pottery object OLA-200.PIX is made with clay sample that has no inclusion of nickel, asbestos, barium, and lead as elements; the fingerprint displayed affinity with pottery objects serial numbers 2; 3; 6; 9; 13; 15; 17 and19 with high concentrations of sodium, phosphorus and the only pottery object with high concentration of sulphur. Pottery object OLA-206.PIX is made with clay sample that has no inclusion of nickel, barium, cerium and lead as elements; the fingerprint returned has affinity with pottery objects serial numbers 2; 7; 13; and 16 with high concentration of asbestos.

Pottery object OLA-210.PIX is made with clay sample that has no inclusion of phosphorus, nickel, asbestos, zirconium, barium, and cerium as elements; the fingerprint returned affinity with pottery objects serial numbers 12 and 13 with no high concentration of all the twenty-three elements. Pottery object OLA-213.PIX is made with clay sample that has no inclusion of phosphorus, nickel and lead as elements; the fingerprint returned affinity with pottery objects serial numbers 2; 3; 4; 5; 6; 7; 8; 9; 10; 11; 13;15; 16; 17; 19; 20; 21 and 22 with high concentrations of sodium, calcium and asbestos.

Conclusion

This research proved further that technical information can motivate the need for scholarly analyses and generate scientific databases for understanding material constituents of artifacts. Their chemical description, provenance and provenience will be a springboard for scholarly works of literature on the examination of material constituents of art objects in Nigeria and elsewhere using the probe technologies of the physical sciences. Many Yoruba ceramic/pottery objects in many museums have remained anonymous without proper identity and field notes, hence, the need for their examination, identification, investigation, classification and description which are not processed.

The returned values for samples in this study had proved further the postulate which stated that differences between distinct sources of raw materials can be recognised analytically, and those compositional variations will be greater between sources than within sources [32]. Relating the individual object to its specific origin is one of the most difficult tasks of studying ancient relics; researchers today are forced to agree with field and laboratory investigations [33]. To trace each pottery object from its origin and its source of manufacture, provenance researchers assumed that compositional analysis (fingerprint) of materials facilitates manufactured things (pottery inclusive) to their corresponding material dictates [34,35]. From Tables 2 & 3, elements such as Sodium (Na); Magnesium (Mg); Aluminium (Al); Silicon (Si) are prominent in many clay samples analysed and they returned different values for all the pottery objects, that is, to prove that all the pottery objects examined are quite distinct from each other and that they are from different sources, though not too far from each other as some of the values returned has proved.

It will constitute a bad science and art to assume that clayey materials that looked alike in colour and texture are likely to be the same. The use of PXRF analysis to solving such in-situ museum and archaeological investigations has been reported [36, 37]. In support of all the above, scholars opine that part of art history dictate is to solve the problem of authenticity, origin, and the period of production of any art piece; identify the creator-artist, what manner of fabrication and style displayed; the contextual meanings attached to any art piece and under what socio-cultural context does the piece thrived; further, to examine the idiosyncrasies displayed by the piece in comparison to others, looking at both the internal and external conditions and quality of its creation [38].

In the attribution of a particular character to a particular object, the nature of the material in an object is exclusively responsible for the work of creativity; therefore, the source of the material is as important as its final destination. It is intellectual dishonesty to misattribute the source of a material to another place; a kind of material fraud which glorifies that which should not, an error that is not pardonable; an injustice, and material plagiarism. Therefore, the position of this research is that in African art studies (especially ceramics/pottery with a particularity) without material compositional studies there is a constitution of a rupture in the genetic relationship between that object and the material used for it; this relationship can only be detected with analytical tools for a holistic investigation. The material content of any object must not be ignored, the presence of various elements in each sample taken and analysed must have come a long way towards influencing a particular work of creativity; materials react differently to experimental procedures because of the presence or absence of particular elements.

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APPENDIX A.

The results of PIXE analysis of elements for each of the 24 samples in parts per million (ppm).

ITYM	File Name	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Zn	As	Rb	Sr	Zr	Ba	Ce	Pb
1.	OLA-1.PIX	2520	4390	113891	291968	1180	206.5	352.9	20392	8794	9594	50.37	72.84	568.9	64538	0	711.2	0	14.04	242.2	1555	0	1606	3188
2.	OLA-10.PIX	3393	6010	147108	268738	620.5	1722	658.8	14379	12173	5148	62.73	135.9	403	63205	0	512.9	0	11.9	396.8	172.4	0	0	0
3.	OLA-20.PIX	2626	10129	123861	233640	2736	509.9	645.6	25286	8990	14766	132.8	0	1004	103397	0	12646	0	25.76	649.3	309.9	0	15925	0
4.	OLA-30.PIX	4800	5327	114024	288898	0	384.2	1777	14748	9781	6069	57.77	148.4	1523	70644	0	565.3	6.012	0	355.7	80.74	4949	6137	0
5.	OLA-40.PIX	5234	9897	129627	280129	0	770.9	728.5	12362	9551	6434	79.26	188.6	905.9	64844	0	1039	5.776	15.87	262.6	493.3	0	3074	0
6.	OLA-50.PIX	5214	12952	111265	278463	1053	1281	456.5	5838	16581	6948	126.3	310.1	1554	67030	0	15850	0	0	283	1058	0	6370	0
7.	OLA-60.PIX	3793	11763	148311	251446	0	278.9	1527	11414	12130	7441	184.2	239.1	406.9	85078	0	633.3	6.651	10.91	299.6	223.8	0	0	0
8.	OLA-70.PIX	764.9	21273	101938	287255	836	740.2	612.7	16997	8091	7927	72.7	892.7	815.4	68167	419.9	292.7	0	38.55	93.06	290	0	13377	0
9.	OLA-80.PIX	1004	5619	108171	303589	0	236.6	371	9621	7101	5149	108.6	239.1	1035	63119	0	198	0	14.92	280.5	68.55	0	17833	0
10	OLA-89.PIX	514.9	5175	120130	292762	0	353	342.7	19921	3958	5899	107.4	167.2	559	54877	0	126.8	8.941	19.91	51.91	239.7	0	20599	0
11.	OLA-100.PIX	987.4	2743	299117	172480	0	212.8	346.8	3261	8611	1893	0	90.5	175.6	17206	0	49.06	0	0	364.1	0	15319	0	0
12.	OLA-110.PIX	431.8	698.9	464703	42822	0	138.1	0	1479	711.4	1172	41.71	29.65	133.5	11653	0	20.99	0	5.664	0	0	0	0	7802
13.	OLA-120.PIX	1050	10216	157305	236582	838.7	1988	2009	8349	11727	9075	222	200	1573	96807	0	324.7	0	44.17	285.5	0	0	0	0
14.	OLA-130.PIX	911.9	7544	148488	235420	203.7	1286	536.1	16602	9142	5588	63.64	291.8	293.3	55445	8.181	68.54	0	0	425.1	164.9	0	54503	17694
15.	OLA-140.PIX	1685	4237	154898	253585	1119	756.9	316.7	29625	5061	7620	106.3	103.2	642.3	68767	0	2308	0	15.31	282.3	437.8	0	1876	0
16.	OLA-150.PIX	3299	9753	137511	249653	2320	1047	4278	21240	11993	10179	230.7	237.3	691.4	86277	0	283	24.22	7.208	359.1	462.9	0	0	0
17.	OLA-160.PIX	3588	5495	119168	296551	0	379.2	457	15791	9334	6531	123.2	167.9	1171	65711	0	322.5	0	0	369.3	802.6	0	879	0
18.	OLA-170.PIX	1721	5817	135606	273142	716	868.9	432.3	21264	7341	7231	95.98	327.7	240.8	70178	0	318.8	44.56	8.803	0	249.7	0	2423	488.2
19.	OLA-180.PIX	4288	5912	123631	291444	0	717.9	545.6	16054	9778	5881	104.4	250.7	682.1	61055	0	305.3	0	11.14	209.2	258.3	0	1220	0
20.	OLA-190.PIX	1701	7515	143952	262974	595.6	401.2	292.7	27916	4969	5773	100.1	158.2	595.4	70128	0	268.7	0	6.737	176.4	306.9	3734	1284	0
21.	OLA-200.PIX	4108	5113	130550	286612	2563	2022	824.6	10858	7496	6272	64.49	139	641	59835	0	490.3	0	5.907	45.55	32.52	0	1496	0
22.	OLA-206.PIX	2292	5762	170914	254967	773.6	710.9	193.3	6567	5407	5828	45.49	112.5	682.5	68292	0	365.6	297	13.83	21.64	234.2	0	0	0
23.	OLA-210.PIX	2305	3301	226367	227450	0	391.9	1580	7537	3204	3408	61.13	301.2	231.1	42209	0	186.6	0	3.33	9.196	0	0	0	158.9
24.	OLA-213.PIX	5859	2578	193954	244457	0	468.9	124	4192	15410	5694	3.875	280.1	793.9	37537	0	739.1	243.1	4.067	50.21	241.4	7897	828.1	0

APPENDIX B. The relative occurrence of elements returned from PIXE analyses of the 24 samples

ITM	File Name	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Zn	As	Rb	Sr	Zr	Ba	Ce	Pb
1.	OLA-1.PIX	2520	4390	113891	291968	1180	206.5	352.9	20392	8794	9594	50.37	72.84	568.9	64538	0	711.2	0	14.04	242.2	1555	0	1606	3188
2.	OLA-10.PIX	3393	6010	147108	268738	620.5	1722	658.8	14379	12173	5148	62.73	135.9	403	63205	0	512.9	0	11.9	396.8	172.4	0	0	0
3.	OLA-20.PIX	2626	10129	123861	233640	2736	509.9	645.6	25286	8990	14766	132.8	0	1004	103397	0	12646	0	25.76	649.3	309.9	0	15925	0
4.	OLA-30.PIX	4800	5327	114024	288898	0	384.2	1777	14748	9781	6069	57.77	148.4	1523	70644	0	565.3	6.012	0	355.7	80.74	4949	6137	0
5.	OLA-40.PIX	5234	9897	129627	280129	0	770.9	728.5	12362	9551	6434	79.26	188.6	905.9	64844	0	1039	5.776	15.87	262.6	493.3	0	3074	0
6.	OLA-50.PIX	5214	12952	111265	278463	1053	1281	456.5	5838	16581	6948	126.3	310.1	1554	67030	0	15850	0	0	283	1058	0	6370	0
7.	OLA-60.PIX	3793	11763	148311	251446	0	278.9	1527	11414	12130	7441	184.2	239.1	406.9	85078	0	633.3	6.651	10.91	299.6	223.8	0	0	0
8.	OLA-70.PIX	764.9	21273	101938	287255	836	740.2	612.7	16997	8091	7927	72.7	892.7	815.4	68167	419.9	292.7	0	38.55	93.06	290	0	13377	0
9.	OLA-80.PIX	1004	5619	108171	303589	0	236.6	371	9621	7101	5149	108.6	239.1	1035	63119	0	198	0	14.92	280.5	68.55	0	17833	0
10	OLA-89.PIX	514.9	5175	120130	292762	0	353	342.7	19921	3958	5899	107.4	167.2	559	54877	0	126.8	8.941	19.91	51.91	239.7	0	20599	0
11.	OLA-100.PIX	987.4	2743	299117	172480	0	212.8	346.8	3261	8611	1893	0	90.5	175.6	17206	0	49.06	0	0	364.1	0	15319	0	0
12.	OLA-110.PIX	431.8	698.9	464703	42822	0	138.1	0	1479	711.4	1172	41.71	29.65	133.5	11653	0	20.99	0	5.664	0	0	0	0	7802
13.	OLA-120.PIX	1050	10216	157305	236582	838.7	1988	2009	8349	11727	9075	222	200	1573	96807	0	324.7	0	44.17	285.5	0	0	0	0
14.	OLA-130.PIX	911.9	7544	148488	235420	203.7	1286	536.1	16602	9142	5588	63.64	291.8	293.3	55445	8.181	68.54	0	0	425.1	164.9	0	54503	17694
15.	OLA-140.PIX	1685	4237	154898	253585	1119	756.9	316.7	29625	5061	7620	106.3	103.2	642.3	68767	0	2308	0	15.31	282.3	437.8	0	1876	0
16.	OLA-150.PIX	3299	9753	137511	249653	2320	1047	4278	21240	11993	10179	230.7	237.3	691.4	86277	0	283	24.22	7.208	359.1	462.9	0	0	0
17.	OLA-160.PIX	3588	5495	119168	296551	0	379.2	457	15791	9334	6531	123.2	167.9	1171	65711	0	322.5	0	0	369.3	802.6	0	879	0
18.	OLA-170.PIX	1721	5817	135606	273142	716	868.9	432.3	21264	7341	7231	95.98	327.7	240.8	70178	0	318.8	44.56	8.803	0	249.7	0	2423	488.2
19.	OLA-180.PIX	4288	5912	123631	291444	0	717.9	545.6	16054	9778	5881	104.4	250.7	682.1	61055	0	305.3	0	11.14	209.2	258.3	0	1220	0
20.	OLA-190.PIX	1701	7515	143952	262974	595.6	401.2	292.7	27916	4969	5773	100.1	158.2	595.4	70128	0	268.7	0	6.737	176.4	306.9	3734	1284	0
21.	OLA-200.PIX	4108	5113	130550	286612	2563	2022	824.6	10858	7496	6272	64.49	139	641	59835	0	490.3	0	5.907	45.55	32.52	0	1496	0
22.	OLA-206.PIX	2292	5762	170914	254967	773.6	710.9	193.3	6567	5407	5828	45.49	112.5	682.5	68292	0	365.6	297	13.83	21.64	234.2	0	0	0
23.	OLA-210.PIX	2305	3301	226367	227450	0	391.9	1580	7537	3204	3408	61.13	301.2	231.1	42209	0	186.6	0	3.33	9.196	0	0	0	158.9
24.	OLA-213.PIX	5859	2578	193954	244457	0	468.9	124	4192	15410	5694	3.875	280.1	793.9	37537	0	739.1	243.1	4.067	50.21	241.4	7897	828.1	0

Values in ppm

- High
- Medium
- Low
- Verv low
- No value

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