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THE SCIENCE BEHIND THE STORIES: The Adventure of a Museum Geologist

By

Olugbenga Akinlolu Ige
Professor of Geology and Materials Research

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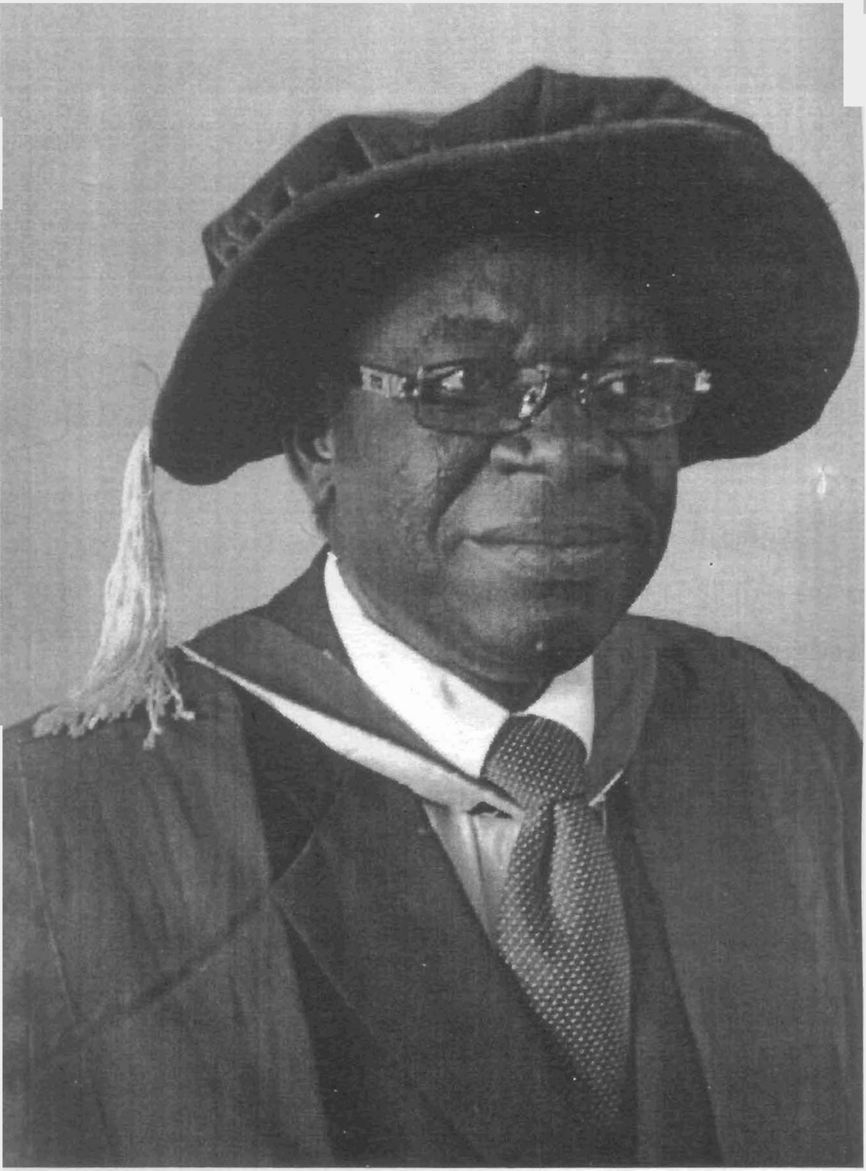

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An Inaugural Lecture Delivered at Oduduwa Hall
Obafemi Awolowo University, Ile-Ife, Nigeria
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THE SCIENCE BEHIND THE STORIES:
The Adventure of a Museum Geologist

Mr Vice- Chancellor, distinguished colleagues, ladies and gentlemen, I stand here today, with humility, through the grace of God, to deliver this 236th inaugural lecture, which is the second from the Natural History Museum. The Fellow who stands before you walked as a primary school boy, through this 'territory' of the Obafemi Awolowo University, (then called University of Ife) when the roads were dusty and the first building the Faculty of Agriculture, was being erected. I could recollect that we were required to carry a 'pass' to be able to cross this territory to our village near the Shasha River. At that time, I had wished and prayed that I will be a member of this university, to partake of the sumptuous meals being served in the students' Canteen. Afterwards, I worked here as a Library Assistant, and further, observed the polished faces of the students and the chubby, robust appearances of the Catering Staff. I thank God today that I am not just a member of staff but a Senate member of this great university.

The beginning my Adventure

I was employed as a Junior Research Fellow in the Natural History Museum in April 1983, in order to add another research area in the Earth Sciences Unit, with the late Professor (Mrs) A.B. Durotoye and Mr P.O. Awojide who specialized in Quaternary Geology and Palaeontology respectively. The Natural History Museum as an institute was established in 1971, as a subunit under the then Department of Biological Sciences. In the 1990/91 academic session, the Department of Archaeology in the University was merged with the Museum, thus expanding the scope of activities to include Archaeology and Cultural Anthropology; Subsequently, it was upgraded to the present status of an autonomous Institute. Apart from the Institut Fundamental Afrique Noir in Dakar, Senegal, this Museum is the only Natural History Museum in West Africa. The Museum was established with the following objectives:

a. To conduct research into the vast natural and cultural history of Nigeria.

b. To serve as a repository of natural and cultural objects in Nigeria.

c. To create scientific awareness on natural and cultural resources of Nigeria through annotated exhibitions for public enlightenment in display galleries.

d. To prepare data bases on natural history and cultural resources of Nigeria, and thus facilitate an information-retrieval system on them for use by the public and the scientific community as a basis for sustainable development.

e. To provide identification services on natural history and cultural objects to user groups especially pest control workers in Agriculture, Veterinary and Human Medicine.

Currently, the Museum is organized into six scientific sections, namely: Botany, Entomology, Zoology, Earth Sciences, Palaeontology and Archaeology/Anthropology. There is, in addition, a services section comprising Illustration, Graphic, Taxidermy and Publications.

I was appointed Acting Director in March 2006 and then a substantive Director in October 2007. The directors before me are Professors A. O. Segun, Late Professor (Mrs) A.B Durotoye, Professor B. A. Lasebikan, Late Dr O. Olatunji, Professor A. E. Akingbohungbe, and Professor M.A Isawumi. These great men and woman invested their energy to put the Museum on proper footing.

MY STORY, MY SCIENCE

I was originally trained as a mineralogist specializing in materials research, under Professor M. A. Olade of the University of Ibadan. There, I was trained to look at each mineral, its geologic setting, chemical composition and industrial application. I worked on two versatile industrial minerals-talc and residual clays that have applications as pharmaceutical excipients, fillers in paints, and as raw materials for the ceramic and paper industries. I carried this trait into Ife and when a controversy about my Ph.D topic threatened to delay my work, I fell back on my beautiful orientation at Ibadan and expanded my earlier work to include the petrology, geochemistry and industrial applications of the vast talc deposits present within the Schist Belt of Southwestern Nigeria.

My PhD was supervised by Professor A. A. Kayode of blessed memory. This great man took me through classical mineralogy and gave me sufficient determinative tools, which enabled me unravel the petrogenesis and metamorphic evolution of the talc bearing basic ultrabasic rocks and the associated metapelites (Ige et al, 1998; Ige and Holness, 2002; Ige, 2002; Ige and Okrusch, 2005; Ige et al, 2005). After completing the PhD programme, I went further to evaluate the industrial potentials of the major talc deposits in Nigeria, from Ife to Kaduna (Ige, 1985, Durotoye and Ige 1991) and was nicknamed 'a talc man'.

Talc is best known as a personal care product. It is a functional mineral with many natural properties such as water repellency, heat resistance and biological inertness that makes it an important ingredient in the manufacture of paper, paints, plastics and ceramics. In the coatings industry, talc is used to improve the flow of paint and in decorative coatings, it enhances coverage, allowing for savings in the use of titanium dioxide pigment. In anti-corrosion systems, talc improves water-resistance and adhesion. In pulp and paper manufacturing and recycling, talc absorbs the microscopic droplets of resin that form deposits which hamper production, whilst helping the machines to run smoothly and reduce pollution in the water circuit. Talc also improves paper's mechanical handling properties for the printer, it provides a smoother finish and improved readability. Because each talc ore body differs according to its genesis, every talc bearing rock is different and can be applied in different functions according to a customer's needs. The finest quality talcs give plastics the right balance of rigidity and impact strength, making the material suitable for applications as dashboards and bumpers. High purity talc also provides long term thermal stability ideal for use in packaging, including odour-sensitive food wrap. Talc's contribution to the performance of ceramics stems from its chemical composition, from the variety of ore combinations, found in different deposits. Associated with silica, talc reinforces ovenware. Such is the versatility of the mineral talc. Talc bearing rocks occur in several locations along North to South trending Schist belt of Nigeria.

Mr Vice- Chancellor Sir, it appears that my academic destiny was tied to these rocks and majority of my outstanding research works have centred on them. I have found these enigmatic rocks useful like the palm tree. From the least to the highest grades, they have contributed to modern and ancient industrial evolution. I started my research career by studying the nearly monomineralic cryptocrystalline variety of talc, (Ige 1985) in Apomu and have found out that these thick deposits can provide pharmaceutical grade talc, for tablet formulation. These varieties are found in several localities within the Schist Belts of Nigeria associated with other less pure varieties. I then went on to study the amphibole-rich variety referred to as talc schist or amphibole rocks, which are potential hosts to base metals such as nickel, chromium and gold mineralization (Ige and Asubiojo, 1991; Asubiojo and Ige, 1992). Some varieties of these rocks are also weathered to form titanium - rich sands, which had been used in ancient metallurgical operation (Ige and Rehren, 2003, Ige et al, 2005). They were also used as carving stones by the ancient Yoruba technicians (Ige and Swanson, 2008).

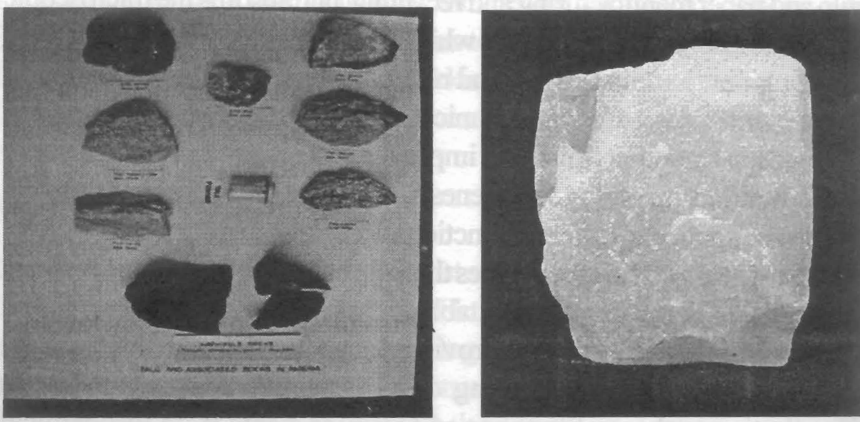


Fig 1 Picture of varieties of talc bearing rocks

In my research, I was able to use the extensive determinative tools available in our Geology Departments at that time, before moving over to the Universities of Munich and Wurzburg, in Germany. It might be a pleasant surprise to many people seated here that our Geology Department used to be home to very sophisticated petrologic tools, such as advanced optical microscopes, X-ray Fluorescence Spectrometer, Atomic Absorption Spectrophotometer, Franz Isodynamic Separator, X-ray Diffractometer and an ultramodern Thin and polished Section laboratory that were the envy of many Geology Departments in the country, although things have dramatically changed. I took advantage of these instruments to isolate, characterize and document all minerals associated with talc bearing rocks found within the Schist belts of Nigeria. The samples of high grade talcs and amphiboles isolated in those days, have been subjects of further collaborative research with colleagues in the Faculty of Pharmacy, for tablet formulation (Afolabi and Ige 1993) and in the determination of chemical species and levels of safety of the samples, with colleagues from the center for Energy Research and Development (Olabanji et al, 2005). Apart from my research work on talc- bearing rocks, I have collaborated with Professor Olabanji and others in the chemical characterization and industrial evaluation of other industrial minerals such as topaz, tourmaline and high grade muscovite from several localities in Nigeria (Olabanji et al, 2005a; and b, Ige et al, 2006; Ige et al, 2007).

Mr Vice-Chancellor Sir, by far my greatest contribution to science has been in the field of Archaeometry from which the title of my inaugural lecture has been derived: "The Science behind the Stories."

This is the story: I was to work with a visiting German Professor, Tietz to study the mineralogical and geochemical evolution of laterites, from two contrasting geological terrains in Nigeria: the amphibolites complex of southwestern Nigeria and the Younger Granite of Jos area. However, in view of subterranean circumstances and politics in the department at that time, I had to abandon that project because someone complained that I was 'crossing scientific boundaries'. But that was after I had gone on field work and collected many samples of lateritic soils overlying many rock types in southwestern Nigeria. Among the samples collected is what I initially referred to as lateritic duricrust, locally called *idaro*, not knowing that it will soon become a subject of great scientific stories. I kept those samples for several years in the Museum until I was given a Postdoctoral Fellowship at the University of Cambridge, United Kingdom. There, I discovered that the samples were actually slags, from ancient metallurgical operation. Examining these samples in computer assisted optical microscopes and advanced instruments, like the electron microprobe, I discovered the co-existing minerals had such levels of titanium, and alumina unknown then in scientific literature (Ige and Rehren, 2003). This work launched me into international limelight in the Archaeometry world. It is been like the discovery of gold mines at my backyard!

Geology applied to Archaeology: Archaeometry

Archaeology as a discipline deals with Man's past through the study of material remains that have been left behind. The archaeologist is thus concerned with a wide range of naturally occurring and synthetic materials in the form of artefacts. With the information obtained from these materials, he faces the task of reconstructing economic and social events and establishing the historical sequence of past civilizations. By tradition, archaeologists are mainly interested in the shape of material remains. Employing art history techniques, they search for significant typological elements to determine the evolution of artefacts and their mutual relationships.

Geologists, on the other hand are more interested in the composition and physical properties of artefacts, since materials carry a wealth of information, recorded within their structure, that can be elucidated by scientific methods. The structural characteristics of matter, its composition and its thermal history are some of the properties that can provide criteria for dating, identifying or collating archaeological materials, establishing ancient manufacturing techniques and determining geographical origin.

For over two centuries, scientists have been interested in the information revealed by physical studies, about the history and ways of life of the ancients, and the materials and processes that they used. In the last 20 years, the rapid development of scientific instrumentation and the application of radioanalytical and nuclear techniques, have brought about a revolution in archaeological research and which has led to the emergence of a new field of study, known today as archaeometry. Archaeometry studies are concerned with one of the following:

i. Prospecting for hidden objects and structures by geochemical or geophysical methods.

ii. Determination of the age of materials or the time of events within a chronologically absolute world-wide reference system.

iii. Identification of materials used in the past and

iv. Determination of the provenance (source), authenticity and technology of artefact production. Sourcing or chemical fingerprinting of archaeological materials is becoming increasingly important in our understanding of prehistory, especially in helping to reconstruct past mobility and exchange systems. This is a sub discipline called Forensic Archaeology. The establishment of the provenance of stone, for example, can be of great help in the study of ancient trade patterns and of cultural relations between distant communities. For example, the morphology and petrography of marbles have, at times, provided useful information. Petrographic analysis of samples from Greek quarries has shown that most marbles had distinctive petrographic fabric patterns which made it possible to determine their provenance. However elaborate the processes of cutting, sizing, shaping and polishing that may have been used, the basic physical and chemical properties of the stone remain unchanged and may be used to characterize the material. If some physical property or the distribution of elements throughout a rock deposit is uniform, it is reasonable to expect that geological 'fingerprinting' will make it possible to trace the provenance of the stone from which an implement was made.

Mr Vice-Chancellor, several stories have emerged from my use of geological tools to confirm or explain oral tradition, ethnographic and archaeological data especially in southwestern Nigeria. By the grace of God, I have been privileged to pioneer the study of several ancient great industries using the most advanced methods, from the best laboratories in the world. For the purpose of this Inaugural Lecture, I will elaborate on five outstanding scientific stories. I will specially concentrate on my discovery of industrial complexes in Pre-colonial Yoruba. The results of these research on ancient metallurgical, ceramic and glassmaking industries have now won international acclaim.

THE ANCIENT CERAMIC INDUSTRY IN SOUTHWESTERN NIGERIA

The first industry I investigated produced high grade mullite (Al_2SiO_3) furnaces that were capable of producing steady and concentrated heat for the melting of silica, and other refractory materials. This great ceramic industry among the Yoruba still exists today, although on a small scale, in several towns for example, Ipetumodu in Osun State. My research has shown that this industry produced several sophisticated technical vessels, especially the furnaces used in steel production and glass making. (Fig. 2). The unique feature of this industry is that the ancient Yoruba ceramists took advantage of the geologic setting of the area and discriminated and blended pure kaolinite with lateritic clays, to make different vessels. In the furnaces for iron smelting and glass making, I found that the kaolinite-rich walls were reinforced with sillimanite quartz schists that are abundant in the area. Incidentally, sillimanite is a mineral used in modern day industrial operations involving high temperature. The Yoruba craftsmen have used this rock, to construct furnaces that were capable of melting materials at very high temperature without breaking down.

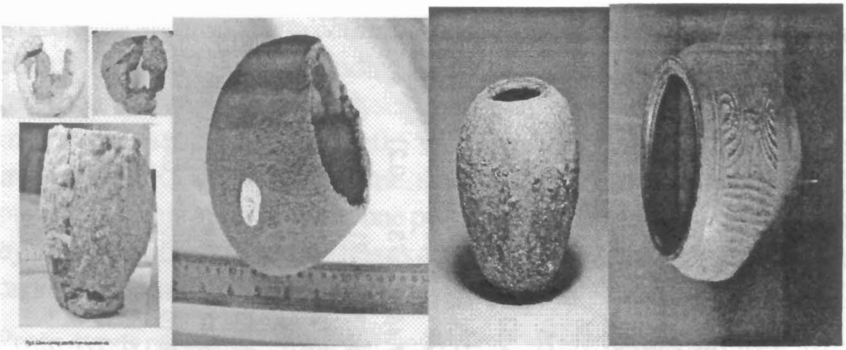


Fig 2. Ancient Glass making and iron making crucibles.

My studies (Ige, 2003; Ige; 2009, Ige and Adesina 2007) of the crucibles, by light and electron microscopy revealed a continuous level of vitrification of the ceramic paste throughout the vessels studied and the presence of large amounts of fine quartz particles. These were typically shattered and ruptured as a result of the heating of the crucible; with some reacting chemically with the paste as part of the vitrification process. Traces of iron and titanium oxides were found, as residual ilmenite particles from the raw material. The porosity of the crucible fabrics was partly to fully rounded, in line with the observed level of vitrification of the ceramic paste; larger voids were typically elongated more-or-less parallel to the outer surfaces of the crucibles. These may represent evidence for the presence of organic material in the clay mixture, but it is unclear whether they are natural component of the clay, or intentionally added temper. The quartz grains were about one third by volume of the ceramic body, and appear rounded and well sorted with a typical grain size below 0.2 mm, as if they are a natural sand component in the clay rather than added temper.

Table 1. Chemical composition of crucibles (EPMA+SEM-EDX)

Number	Form	SiO_2	Na_2O	CaO	K_2O	MgO	Al_2O3	Fe_2O_3	TiO_2
If-c2.30	Fragment with glass	68.26	0.41	0.26	3.32	0.29	26.28	1.71	0.27
If-c2-31	Fragment with glass	72.82	0.42	0.19	2.97	0.01	22.56	1.43	0.20
If-c2-32	Quartz inclusion	100.00	0.05	0.06	0.02	0.09	0.05	0.00	0.02
If-c2-33	Fragment with glass	57.10	0.33	0.08	3.82	0.27	36.83	1.97	0.19
If-c2-35	Cr-Ni-inclusion	4.44	0.17	0.03	0.00	0.10	0.14	69.85	0.04?
If-c2-36	Pb-inclusion	1.71	0.10?	0.15	0.01	0.05?	1.48	0.30	0.03
If-c2-37	Fragment with glass	65.58	0.41	0.21	3.83	0.14	27.46	1.73	0.21
If-c2-38	Fragment with glass	64.98	0.45	0.26	3.70	0.20	28.53	1.91	0.29
If-c2-39	Ti-Fe-rich inclusion	0.88	0.00	0.00	0.09	0.62	23.78	27.56	49.99
If-c2-40	Fragment with glass	74.47	7.86	13.81	0.66	0.06	1.83	0.49	0.09
If-c2-c1	Fragment with glass	53.30	0.35	0.17	3.69	0.16	25.73	1.40	0.18
If-c2-c2	Fragment with glass	45.86	0.37	0.22	3.42	0.26	27.44	1.54	0.16
If-c2-c3	Fragment with glass	55.90	0.38	0.26	3.18	0.13	23.10	1.20	0.16
If-c2-c4	Fragment with glass	47.99	0.39	0.22	3.07	0.10	25.10	1.40	0.18

The chemical composition of the fabric (Table 1) showed very high alumina content (around 25 wt%, including the natural quartz particles), and reaches more than 35 wt% in spot analyses in the pure ceramic material. The only minor oxides present above ca 0.5 wt% were potash (3 to 3.5 wt %,) and iron oxide, (1.5 to 2 wt %.). Lime, soda, titania and magnesia are mostly present at levels of one third of one percent. No other oxides were detected by SEM analyses, identifying this as a particularly refractory material, based on very rich kaolinitic clay.

Proto-types of some of these advanced vessel are being designed in our laboratory (Ige and Akinwumi 2010) based on the chemistry of these ancient furnaces. Because the raw materials are locally abundant, this product, when fully developed, could form the basis of several industries. Several aspects of these products are still being worked out and will warrant funding and the protection of the formulation.

YORUBA IRON METALLURGICAL ADVANCES

My second story is the story of ancient Yoruba metallurgical industries. Generations of the Yoruba have smelted iron and the skill has been taught from one generation to another. In all metallurgical operations that led to the fashioning of weapons and utensils from iron, the Yoruba have followed routines and rituals. Although the ancient Yoruba did not understand the chemistry of burning, and the physics of incandescence of molecules, they perfected elaborate rituals through which they controlled the carbon content and the temperature to which the finished sword had to be reheated and the rate at which it was cooled, during the quenching process.

In my research on ancient iron metallurgy, I discovered widespread occurrence of technical ceramics, as well as copious amount of slags, suggesting that there were hundreds of smelters , producing weapon-grade steel in several Yoruba towns, most of whose names derived from the possession of iron technology e.g. Akarabata, Isundunrin, Oko, Iponrin-Oyo, Ilorin etc. From ethnographic data, it is clear that there was a chief smelter in each community who usually directed the smelting process. These master smelters not only presided over the magic and ritual, but also organized the long months of intensive labour necessary to bring smelting to fruition. They are known to have imposed on the workers certain prohibitions from ordinary activities such as sexual contact, in order to "frame" the metallurgical operation as a unique event. They also knew and led invocations, dances, songs, praises, exhortations, and other esoteric activities necessary to make the entire process a success. For example, before a family went out in search of ironstones and during the smelting process, they were expected to make peace with themselves and neighbours and seek forgiveness for offences. The location of raw materials, mine and furnace designs, mode of dressing and the enforcement of discipline on the guild, were directed by the oracles. The smelting was usually done by men, and carried out near river banks. First, the furnaces were constructed by the sides of the river, on hillsides and across the paths of the wind. Next, the iron ore was pounded to dust and then placed in successive layers of charcoal. The furnace was then fired from beneath and a forced draught was created by using tuyeres. This they considered as the 'fanning hands of the gods'. The heating of the furnaces by the continuous blast takes days (two to three) would eventually make the iron stone to glow red hot which is an indication that the ironstone had been properly smelted. The smelted iron was then removed from the furnace, placed on a large stone and thoroughly beaten with a hammer, until the components amalgamated into a solid black lump of iron. This was then put in a clay ball wrapped in leaves. By this process the ancients did not know that they actually designed and built wind-powered furnaces which produced steel rather than soft iron.

Just like in smelting, the blacksmith routinely hammered out a piece of iron, until it became flat and then worked the iron into a lump again, thereby driving out a lot of the slag and other impurities in the bloom iron. The process was repeated enough times, such that he could hammer extra carbon and be left with a softer, more malleable iron. Sometime the tools came out too soft to hold a sharp edge for any period of use. When the instrument came out right, it was hard and tough, kept a good edge, and withstood the rigours of use. Some swords, produced by powerful blacksmiths, were thought to have magical or spiritual powers and were handed down from one generation of warrior to the next. Thus, mysticism grew around certain weapons that withstood the rigors of battle as they are believed to confer blessings and protection on the warriors who used them. As a result of successful metallurgical processes, slag dumps occur at several historical sites in southwestern Nigeria, especially around Ife, Ibadan, and Oyo. These areas were identified and characterized by their immense slag deposits.

The geologists study metallurgical processes by conducting mineralogical analyses of slags and ores from iron smelting sites. The precise mineralogical composition of the individual slag sample reflects the bulk chemical composition, that in turn depends upon the materials used (ore, furnace lining, charcoal, fluxes) as well as upon the physicochemical conditions under which the slag had formed.

In my research, I was able to locate the ores used for ancient metallurgical works among the Yoruba and went further to experimentally re-enact the process, leading to the formation of iron blooms and residual slags. The extensive work (Ige and Rehren, 2003, Rehren et al, 2005; Ige, 2009) show that the raw materials for smelting consisted of weathering products of assorted basic igneous rocks, which produced different iron ores such as goethite (iron hydroxide), siderite (iron carbonate) and ilmenite rich sands.

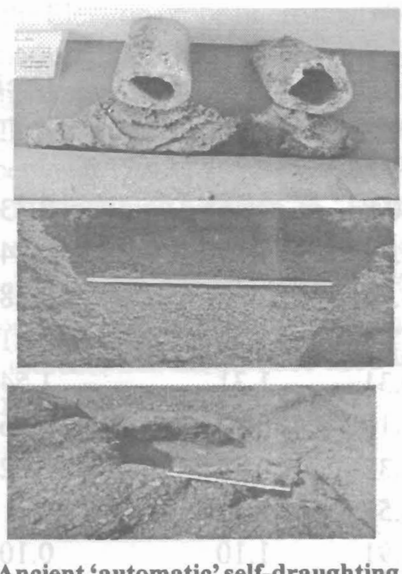


Fig. 3. Remnants of Ancient 'automatic' self-draughting furnaces (below) with Tuyeres and slags (top)

The unique feature of this ancient technology is that these raw materials were blended with ilmenite rich sand, produced naturally from the weathering of certain Titanium-rich amphibole rocks, thus taking advantage of the geology of the area. This technical skill amongst Yoruba is an index of the existence of an advanced civilization.

In modern technology, titanium is classified as a strategic metal since much of it is consumed in the manufacture of high-performance jet aircraft, turbine engines, guided missile assemblies, spacecraft, nuclear power plants, and other ferroalloy products. Because titania is as strong as steel and 45% lighter, it is especially suitable for use in aviation and astronautics. About 50% of titanium production is used for jet engine components (rotors, fins and compressor parts). A Titanium alloy with the composition Ti + 2.5% tin + 5% aluminium is used when high strength at high temperatures is required. The Yoruba smelters have used these materials over 700years ago. The routine blending of the lateritic ores with titanium and ilmenite rich sand points to sound scientific sense.

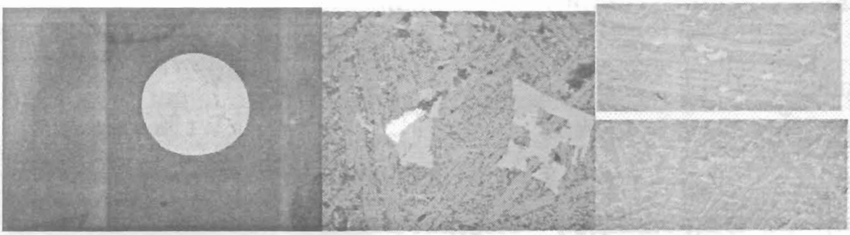
Table -2 Chemical composition of parent rocks and ironstone from smelting sites

	Fresh basic rock	IlmeniteSand	Ore1	Ore 2
SiO_2	40.81	36.66	2.33	5.23
TiO_2	4.74	10.77	0.84	1.88
Al_2O_3	4.74	10.13	4.28	1.44
Fe_2O_3	17.439	46.41	81.12	73.01
Cr_2O_3	0.31	1.31	1.54	1.56
NiO	0.10	0.22	0.66	0.61
MnO	0.32	0.57	0.52	0.10
MgO	6.57	2.12	0.11	0.11
CaO	8.91	1.10	0.10	0.10
K_2O	0.51	0.01	0.00	0.00

Table 3 Chemical composition of slags

Oxides	I	II	III	IV	V
	Wt %	Wt %	Wt %	Wt %	Wt %
$Fe0$	59.42	65.17	61.29	65.35	63.05
Al_20_3	9.48	7.04	6.7	5.31	5.94
$Mg0$	0.31	0.5	0.3	0.39	0.32
$Si0_2$	20.93	20.08	17.54	20.01	21.65
$Ti0_2$	6.3	6.6	11.12	7.72	7.73
$Mn0$	0.11	0.18	0.06	0.31	0.24
P_20_5	1.32	0.95	0.34	0.63	0.65
$Ca0$	1.41	0.11	1.54	0.17	0.7
K_20	0.78	0.04	0.68	0.18	0.02

In my research work, I studied over 320 samples of slags from Ife to Oyo and Ekiti areas using optical (OM and SEM-EDS), X-ray diffractometer and the Electron probe micro analyser. The results show that the slags contained unusual levels of TiO_2 leading to the formation of a series of Al, Ti spinels essentially spinifex textured fayalite and glass. Two types of optically homogeneous spinel were observed: a light, Al_2O_3 – rich containing between 12.43 to 49.86% Al_2O_3 and 2.3 to 13.12% TiO_2 a darker variety containing between 25.56 and 32% TiO_2 and 5.3 to 7.2% Al_2O_3 There is a third type that contains a hercynite core with a rim rich in ulvospinel. Zoning trends are from high TiO_2 to high Al_2O_3 and no signs of exsolution were seen. There is conspicuous absence of wüstite in the slags which indicate that the furnace used were very efficient, producing steel rather than soft iron.



4a 4b 4c

Fig 4a Iron droplets signifying extreme reducing condition. Fig 4 b and c =Al, Ti spinel minerals set in glassy matrix of fayalite suggestive of fast quenching typical of bloomery iron smelting

In spite of these distinctive achievements and this level of technical sophistication, the industry gradually declined at different rates in different areas in the face of cheap imported iron from the blast furnaces of Europe. This occurred mostly around the turn of the century, when European colonizers prohibited local African industries like iron-smelting in order to decrease African self sufficiency (Schmidt 1996). The older technology, ideology, magic, and social organization of ironworking became obsolete in most parts of Yoruba land. The Yoruba blacksmiths adapted by transforming the scrap iron into many useful utensils and weapons. The various disciplinary measures imposed on miners and smelters (e.g. sexual abstinence) were not mere rituals but are in conformity with the law of conservation of energy- a requirement for such daring and dangerous operations! My work on the metallurgical operation is a reference material in the scientific archaeological world.

APPLICATION OF GEOLOGY TO PROVENANCE OF SOAP STONE ARTIFACTS

My next story is about the archaeometric studies on a collection of soapstone statues in Esie, a town located about 150 Kilometers northwest of Ife. The inhabitants of Esie are the Igbomina sub-grouping of the Yoruba ethnic group and they appeared to have settled in their present homeland some 300 years ago. The sculptures, numbering about 1000 were found in quiet groves and they are reputed to be the largest collection of sculptures found anywhere south of the Sahara desert. The sculptures represent men, women and children in different human activities (Fig 5).

Fig. 5 Esie soapstone statues, the largest collection in sub Saharan Africa

The figurines are depicted playing musical instruments, holding machetes, or with their hands on their knees. The diversities in these accoutrements attest to a highly developed and complex civilization.

For a long time, the origin of these stone sculptures was enigmatic and mysterious. From oral tradition, the stones were actually human beings who turned into stones to avoid being captured by invaders. The community believes the images have supernatural powers to do evil, but if appeased could be turned to good. A yearly worship which takes place between March and April is in the form of a hunting ceremony (*Odun Ere*) centered around the images. The festival is to appreciate the images for their protection during the past year and to pray for posterity in the coming year. Although the statues were known to the indigenous people for a long time, it was brought to public attention by a Christian Missionary (Hambolu, 1987). Archaeological evidence later revealed that the stone sculptures fragment found in situ were dated between 16th and 17th Century AD (Andah, 1982; Hambolu, 1987; Onabajo and Ige, 2005). The present Esie community claim to have met these images when they migrated to the area during the reign of Alafin Abiodun from Old Oyo, thus constraining the date to more than 300 years ago. A shelter was built at the groove to protect the images from further deterioration, in 1937 this was renovated into Nigeria's first National Museum in 1945.

Previous workers had propounded various theories on the origin of the statues. There is the group that believed in the mythical creation of the objects (Obayemi, 1970). This group claimed that the objects were white traders, turned into stone images, as a punitive measure for invading Esie community: this tradition conforms to age-long attempts by different societies at explaining or rationalizing mysterious phenomena around them (Andah, 1982).

Another group believed the images must have been brought from elsewhere. Two sources were proposed, either Old Oyo (Stevens, 1978) or the Ife area. This association was based on the fact that soapstone figures are also known at Ife, and a tradition has been recorded, that a monarch from the nearby town of Ikole Ekiti, removed some of the images from Ife, as a sign of divine connection to his ancestral home in Ile-Ife.

A third group believes that the origin of the object must be within the immediate environment. The earliest reference to a local origin was by Frobenius (1913). This idea was further supported by Stevens (1978) who observed mining sites within the Esie ultramafic rocks. These facts may suggest that the sculptures are the work of indigenous artists, who lived in and around present day Esie before the emergence of the present population. Attempts have been made to date the Esie objects, results have not been satisfactory. The Thermoluminescence dating of fragments of associated terracotta yielded approximately 1100 A.D (Stevens, 1978) which correlates with the time of mass movement from Ile-Ife. In the most recent archaeological investigation, similar soapstone figurines were discovered near Esie, which prompted the author to suggest that the raw materials were probably located within the area (Usman, 2005).

There has been some scientific evaluation of source areas for the raw material for these stones. A mineralogical study of soapstones was cited by Stevens (1978), but the work was flawed because the co-existing minerals were misidentified (sillimanite rather than cummingtonite, kyanite rather than tremolite, garnet rather than chromite). This work however showed the potential of using soapstone mineralogy, as a way to identify the source of the stone used to make the images. A more recent work by Olabanji et al (1990) presented compositional data on some of the statues collected by the PIXE technique which conclude that the images had a local source.

When I began my investigation on Esie figurines, I hoped to provide answers to some of the following questions.

- What is the source of these objects and who made them?
- Of what type of stone were they made and what is the source of the raw material?
- What do these lithic figures symbolize? Do they exemplify a social assembly or a political organization?

- What is the relationship of these objects to the Ife and the terracotta industries, and other ancient Yoruba industries?

My study drew on my experience and data base of samples of mafic ultarmafic rocks, collected along the 800km Schist belts of Nigeria (Ige 1982, Ige, 1988; Ige and Asubiojo, 1991; Ige et al., 1998), and thus appear to have a tremendous advantage over the early studies. I employed the petrographic microscope and the Electron probe microanalyser (Ige and Swanson 2007) to create a typology based on chemical fingerprints of co-existing minerals.

In order to locate the sources of rocks for these artefacts, I discovered several variables such as:

- the correct identification of the trade and migration routes of the Yorubas;
- the identification of areas of obvious ancient mining of soapstone along these routes;
- the development of mineralogical models that will differentiate between thousands of outcrops of talc bearing rocks;
- and use of mineral chemistry in an attempt to identify the source of the soapstone used for the images.

In my work, I focused on deposits of talc bearing rocks found within a radius of 160 km to the Esie Museum that were extensive enough for the production of many of the statues. The sites fall along the trade and migration route of the early Yoruba from Ile-Ife. Four potential sources areas for soapstone were located (relative to Esie) 30 km SE (Agbonda), 65 km NW (Odogbe), 125 km SW (Asegbo), and 160 km SW (Obaluru). Samples were selected from areas with obvious evidence of ancient soapstone mining. Three types of mafic ultramafic rocks are present in each site: dark-colored amphibole-epidote rocks, three- amphibole rock, and talc-rich rocks (soapstone). The rock outcrops were examined and areas with rough textures (indicating abundant amphiboles), unsuitable for carving, were not sampled. Sampling of the smooth, talc-rich areas yielded approximately three hundred and fifty samples and these were stored in the Natural History Museum. Only samples with abundant talc that resembled the soapstone of the images were prepared for further petrographic work, resulting in a total of 78 samples. Representative samples of broken Esie soapstone sculptures from the different strata of the society depicted – kings, commoners, professional- were also sampled.

Samples of some broken artefacts were also studied in thin section and using the electronprobe. It was discovered that three important minerals were associated and useful as mineralogical screens- talc, cummingtonite and chromite. Whilst talc is common in all samples, cummingtonite and chromite are rare. Cummingtonite is an amphibole that behaves like talc in carving, whilst chromite is a mineral highly sought by petrologists, for petrogenitic interpretation of mafic- ultramafic assemblages. In the electron probe work, I looked for uncommon minerals which are common to both soapstones and statues.

POSSIBLE SOURCE ROCKS FOR ESIE STATUES

Two types of ultramafic rocks bodies are found in the Schist Belt of southwestern Nigeria. The bodies are elongate, parallel to the regional foliations and are enclosed in metasedimentary schists and quartzites. The bodies are composed of black amphibolite or chlorite-bearing talc schists. Soapstones are found in the chlorite-talc schist bodies.

Table 4. Modal composition of samples from statues and source rocks

Sample	Talc	Chlorite	Tremolite	Cummingtonite	Chromite rim	Chromite rim	Chromite rim	Ilmenite/ Rutile
					low Al	Magnetite	Chlorite	
					Chromite		Corona	
Statue 1	M	M	R	M	No	X	No	
Statue 2	M	M	No	M	No	X	No	X
Statue 3	M	M	No	M	X	No	No	X

Modal composition of Proposed source area samples

1a	M	M	No	M	No	X	No	X
1b	M	M	No	M	No	X	No	X
2a	M	M	M	M	No	No	X	X
2b	M	M	M	M	No	No	No	X
3a	M	M	M	M	No	No	X	X
3b	M	M	M	M	No	No	X	X
4a	M	M	No	M	No	X	No	X
4b	M	M	M	M	No	No	X	X

M = major phase; m = minor phase; R = rare phase; x = present; no = not observed

Amphibolites

Amphibolites consist wholly of the amphibole minerals, hornblende and cummingtonite with lesser amounts of plagioclase and clinozoisite. They appear to be the most abundant ultramafic rock type in the Yoruba area of southwestern Nigeria. They consist almost exclusively of long-prismatic amphiboles, which usually are randomly intergrown and show a preferred orientation only in distinct zones of channelized high strain. Two types of amphibole can be distinguished. A pale-green hornblende is the most abundant and is overgrown by second generation, colorless cummingtonite. The oblique extinction and the frequent polysynthetic twinning distinguish the cummingtonite. The only accessory mineral occurring in the amphibole rock is ilmenite (about 3-5 vol. %). These rocks were rejected by sculptors. A comprehensive description of these rocks, with trace element data, is found in Ige et al. (1998).

Chlorite-bearing Talc Schists

The chlorite-bearing talc schists consist mostly talc and chlorite but also contain amphiboles. The nearly monomineralic variety, are highly sought by sculptors, is technically called soapstones by the archaeologists. Talc-chlorite soapstone contains the most talc along with colorless tremolite and cummingtonite arranged in a randomly oriented metamorphic texture. Chromite is found in some of the soapstones. Accessory grains of rutile are intergrown with or surrounded by xenoblasts of ilmenite. No hornblende is found in this rock. This is the preferred rock for carving and it was selectively removed during mining.

A relatively high amount of xenoblastic olivine characterizes the other type of soapstone. The olivine grains are usually pierced by slender prisms of colorless tremolite and cummingtonite. Minor chlorite, talc, and a magnesite are interstitial aggregates or seem to replace amphiboles.

Proposed Source Area 1

The soapstone outcrops are found in ancient mining sites in Agbonda, about 30km southeast of Esie. The mine consists of series of open pits, hand dug wells and some short tunnels. It appears most of the talc-rich soapstone was removed during mining leaving behind the coarser-grained, more amphibole-rich rock. The geometry of the mines and the remaining outcrops suggests the soapstone formed lenses and sometime massive bodies along the 1.5 km of outcrop. There is an extensive deposit of iron slag, terracotta pieces and furnaces associated with iron smelting which may point to the existence of a centre of early civilization, similar in some respect to the one at Ile-Ife one (Clark, 1938; Stevens, 1978). In hand specimen, the rocks are greyish to white on fresh surfaces, but weather brown with green patches. The rock was medium-grained, massive and dense, with a soapy feel. Soapstone near the amphibolite body has a gritty feel, probably related to the abundance of amphibole in the soapstone. Minerals identifiable in hand specimens include talc, chlorite and needles of brownish amphibole (anthophyllite).

In thin section, the soapstone is composed of talc (65%), cummingtonite (20%), chlorite (13%) and iron oxide (2%). Talc and cummingtonite form a dense network of intergrown crystals with chlorite in the interstices. Iron oxide occurs as disseminated minute crystals and tends to form clusters and streaks in the samples. Cummingtonite is partially altered to talc at crystal margins.

Proposed Source Area 2

Asegbo is a village about 145 kilometers from Esie. The soapstone outcrops occur as lense- shaped discontinuous sequences on a hilltop. The boulders could be traced for about 700 metres along strike in a NNE direction with a width of 480 meters and are intimately associated with a massive, medium grained amphibolite. Active mining activities have obliterated any trace of ancient mining activities.

The soapstone samples are so similar in very many respects that they will be described as one. In hand specimen, the rocks are greenish grey with dark patches made up of aggregates of amphibole crystals. They are medium grained, massive, and show prominent elongated amphibole crystals and reflective grains of chlorite. Scattered green prisms of amphiboles are distinguishable in hand specimens. In thin sections the rock is made up of tremolite (35%), talc (30%), cummingtonite (20%), chlorite (14%) and iron oxide (1 %) in that order of abundance. Some of the amphiboles form radial patterns while some occur in bundles of crystals. Talc and chlorite occur as finely divided flakes filling interstices between amphibole grains. Small amount of FeTi oxide occur as dust-like grains.

Proposed Source Area 3

Odogbe is about 45 km NW of Esie at the boundary between the Yoruba and Nupe tribes of Nigeria. In this place, the interaction between the Yoruba culture and the Nupes is obvious. However, the images at Esie are distinctly Yoruba in origin and style.

The soapstone here occurs as an extensive deposit of talc-rich rocks which can be traced for at least 2 km and are the subject of extensive exploration and mining activities in recent years (Durotoye and Ige 1991). In hand specimen, the rock was fine-grained, somewhat schistose, and grey-white in color. In thin section, the samples contain about 80% talc, 20% pale-green chlorite, and traces of colourless prisms of amphibole. An interesting feature is the occurrence of veins of amphibole cutting across entire thin sections.

Proposed Source Area 4

Obaluru is a locality 15 km east of the archaeologically famous Ile-Ife. This area contains one of the most extensive deposits of soapstone and amphibolite in the Schist Belt. These rocks are the subject of extensive research because of associated gold mineralization (e.g. Klemm et al., 1983, Elueze (2000), Ige et al., 1998). Two samples of fine-grained, chlorite- and amphibole-bearing talc schist from this area were selected for electron microprobe analysis. The rock is brownish in color due to disseminated very-fined grained rutile. Lighter-colored recrystallized zones (veins) cut this brown fabric and contain the largest grains of talc and chlorite. Talc is the most abundant mineral, but chlorite and amphibole are also major phases in the rock.

The talc is generally fine-grained (0.02-0.05 mm), but some areas of coarser-grained talc (0.9-1.5 mm) are also found in both samples.

Fine-grained (0.02 - 0.0.05 mm) chlorite is interstitial to fine-grained talc and coarser-grained 0.2-0.4 mm) chlorite occurs with the coarser-grained talc. Acicular grains of cummingtonite 0.2 to 0.4 mm long are scattered through the rock. Sample 4b contains some tremolite overgrown by cummingtonite. Chromite in sample 4a is rimmed by chromian magnetite. Coronas (1-2 mm diameter) of talc + chlorite surround very-fined grained chromian magnetite grains in sample 4b. The coronas represent replacement of an earlier generation of chromite. Very fine grained ilmenite with overgrowths of rutile is found within the rocks. Individual grains of coarser-grained rutile (to 0.2 mm) are found in the rock that lacks chromite.

PETROGRAPHIC DESCRIPTION OF THE SOAPSTONE SCULPTURES:

Samples of the soapstone statues were taken from the broken pieces in view of our commitment to conservation standards and non-destructive policy of the Museum. Samples were taken to represent the major strata of the society represented by the images- kings, commoners and traders.

Thin sections from the soapstone images contain talc, pale green chlorite, and cummingtonite, tremolite, and CrFeTi oxides. The talc forms flakes up to 1mm long and is intergrown with amphibole and chlorite, forming a randomly orientated metamorphic texture. The chlorites are colorless to light green, optically positive or (rarely) negative with anomalous interference colours, and conform to clinochlore-penninite. Amphibole is mostly cummingtonite. Cummingtonite occurs as elongate porphyroblasts (0.5 - 2mm) and, when abundant, they form poikiloblastic networks that show nearly simultaneous extinction over large areas of thin section. Accessory minerals include chromite, ilmenite, and rutile (sometimes as overgrowths on ilmenite).

Statue 1

This statue is of the king and the sample analysed was taken from the trunk of the figure. It is composed of fine-grained, chlorite and amphibole-bearing talc schist. The rock is brownish in color due to oxidation of chlorite, especially along some fractures. Lighter-colored recrystallized zones (veins) cut this brown fabric and contain the largest grains of talc and chlorite. Talc is the most abundant mineral, but cummingtonite is also abundant. Lesser amounts of chlorite and chromite are also found in the rock.

The talc is generally fine-grained (about 0.1 mm), but some areas of coarser-grained talc (0.4-1.6 mm) are also found. Chlorite (0.01 to 0.4 mm) is concentrated along some fractures. Acicular grains of cummingtonite (0.2 to 1.5 mm long) are scattered through the rock. Rare grains of tremolite have an overgrowth of cummingtonite. Subhedral grains of chromite, 0.04 to 0.3 mm, often have a bright rim in reflected light of chromian magnetite.

Statue 2

This statue is composed of brownish, fine-grained, chlorite and amphibole-bearing talc schist carved in the form of a drummer. The sample was taken from a broken leg fragment. Lighter-colored recrystallized zones (veins) cut this brown fabric and contain the largest grains of talc and chlorite. The transition between the finer- and coarser-grained fabric is marked by a zone rich in chlorite and amphibole. Talc is the most abundant mineral, lesser amounts of chlorite and cummingtonite are also found in the rock.

The talc is generally fine-grained (about 0.05 mm), but some areas of coarser-grained talc (0.6-2.8 mm) are also found. Chlorite (0.1 to 0.6 mm) is intergrown with the coarser-grained talc. Acicular grains of cummingtonite 0.1 to 2.2 mm long are scattered through the rock. Subhedral grains of chromite (0.04 to 0.3 mm) with rims of chromian magnetite is the most abundant oxide mineral. Very fine-grained rutile surrounds some small ilmenite grains

Statue 3

This statue of a weaver is composed of fine-grained, chlorite-cummingtonite-talc schist. The sample was taken from the broken head. Oxidation of ilmenite/rutile gives the rock a brownish color. Recrystallization of the talc produces lighter-colored zones. That cut the brown fabric.

Talc is the most abundant mineral, but acicular grains of cummingtonite are also very abundant (Table 3). Lesser amounts of chlorite, chromite, and ilmenite with overgrowths of rutile are also found in the rock.

The talc is generally fine-grained (0.05- 0.25 mm), but some areas of coarser-grained talc (0.3 - 0.6 mm) are also found. Chlorite (0.1 to 0.3 mm) is intergrown with the talc. Acicular grains of cummingtonite (0.2 to 0.9 mm long are scattered through the rock. Subhedral grains of chromite (0.02 to 0.1 mm) appear homogeneous in reflected light. Fine-grained (about 0.01 mm) ilmenite surrounded by very fine-grained rutile is more common than chromite.

Geochemistry

Compositions of soapstone from the statues and proposed source areas presented in Table 5 have been plotted in Fig.6c. It should be emphasized that the data are averages of a number of individual analyses. Individual analyses of soapstone show more scatter than the pattern defined by the depicted in. Figure 7 shows the average compositions from Table 5 together with individual unpublished soapstone analyses from the four proposed source areas. The scatter of the individual analyses is apparent and is related to variation in the abundance of the various minerals in the individual samples. Olabanji et al (1990) also report considerable scatter in their analyses of Esie statues. Given the scatter of the soapstone bulk compositions it seems that the statues could be derived from any of the proposed source areas, but the clustering of the statues with proposed source areas 1, 2, and 4 makes these more likely candidates. It is with this background that we examined mineral compositions in an attempt to identify source areas for the statues.

Mineral Compositions

Silicate minerals in the rocks of the statues and proposed source areas lack detectable compositional zoning. This homogeneity facilitated the use of mineral compositions to characterize the different rocks. Chromite is zoned in some samples and here care taken to assure that the same levels/positions of zoning are compared between samples.

Major element composition of samples of statues and source rocks

	Statues			Proposed source area			
Statue or area	1	2	3	1	2	3	4
Number of analyses (*N*)	2	3	3	5	9	21	12
SiO_2	50.49	50.83	50.63	51.05	49.64	54.55	51.13
TiO_2	0.45	0.23	0.42	0.44	0.03	0.14	0.59
Al_2O_3	7.18	6.79	6.01	6.87	7.94	3.37	6.49
Cr_2O_3	0.24	0.26	0.07	0.01	0.01	0.11	0.04
FeOt	8.96	8.86	8.76	9.88	8.88	7.13	8.64
MnO	0.24	0.22	0.30	0.31	0.34	0.34	0.15
MgO	30.25	30.96	31.82	29.96	31.18	20.04	27.50
CaO	0.49	0.08	0.66	0.01	0.02	9.87	2.79
Na_2O	0.07	0.54	0.03	0.07	0.04	0.54	0.12
K_2O	0.06	0.06	0.01	0.02	0.02	0.03	0.03
Total	98.43	98.78	98.71	98.62	98.10	96.12	97.56

Table 5a Major element composition of talc rocks.

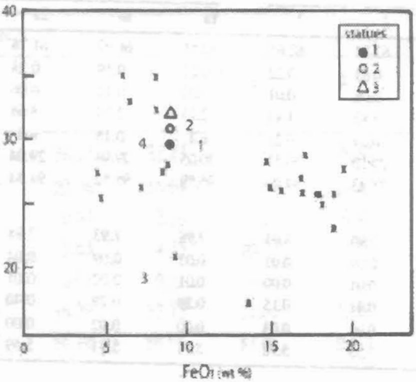


Fig 6a. Plots of the chemical composition

Silicate minerals are Mg-rich, reflecting the ultramafic character of the rocks. The minerals talc, tremolite, cummingtonite, and chlorite are (or are near) Mg-end member compositions of their respective solid solution series. This lack of major element chemical variability presents some challenges for distinguishing between various samples. In this study the emphasis is on those chemical traits that exhibit some level of variability and thus offer potential for matching statues to proposed source rocks.

Talc is the most common mineral in all of the samples; statues and proposed source area rocks. Talc is rich in Mg, magnesium numbers (mg# = (Mg/Mg + Fe) x 100) range from 93 to 99 and contains a few weight percent Fe. A few tenths of a weight percent of aluminium are found in the talc. Al is the only trace element measured in talc above background levels. There is no difference in major element composition between talc in various textural settings (relict, vein, or corona on chromite).

Compositional ranges defined by talc from the four proposed source areas all overlap making it impossible to distinguish between individual areas. Talc from statues 1 and 2 plots with the fields of the four proposed source areas but talc from statue 3 is higher in Mg and plots outside these fields.

Selected microprobe analyses of talc

Sample type	Statues			Proposed source areas				
Sample number	1	2	3	1a	1b	2a	2b	3a
SiO_2	62.30	62.11	62.65	62.55	61.97	61.78	61.75	62.60
Al_2O_3	0.25	0.63	0.22	0.22	0.59	0.28	0.14	0.07
Cr_2O_3	0.03	0.08	0.01	0.04	0.11	0.06	0.00	0.02
FeO^*	2.88	3.82	1.43	2.73	2.73	3.68	3.16	3.77
NiO	0.12	0.09	0.21	n.d.	0.18	n.d.	0.04	n.d.
MgO	29.94	29.10	30.31	30.05	29.94	29.04	29.95	29.32
Total	95.52	95.83	94.83	95.59	95.52	94.84	95.04	95.78
Formula based on 22 O								
Si	7.97	7.95	8.01	7.98	7.93	7.98	7.94	8.00
Al	0.04	0.09	0.03	0.03	0.09	0.04	0.02	0.01
Cr	0.01	0.01	0.00	0.01	0.02	0.01	0.00	0.00
Fe	0.31	0.41	0.15	0.29	0.29	0.40	0.34	0.40
Ni	0.02	0.01	0.03	0.00	0.02	0.00	0.01	0.00
Mg	5.71	5.55	5.78	5.71	5.71	5.59	5.74	5.58

FeO^*, total Fe as FeO.

Table 5b. Selected microprobe analyses of talcs in source rocks and staues.

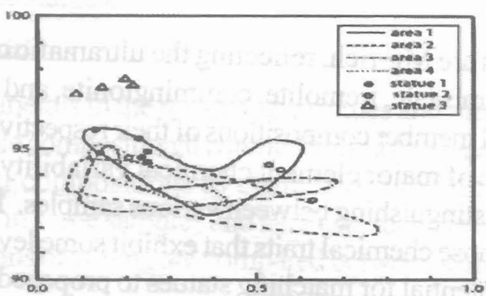


Fig 6b. Plots of chemical composition in source rocks and statues of talcs

Chlorite

Chlorite in the soapstones is chromian clinochlore with Cr contents on the order of one weight percent The chlorite contains 4 to 17 weight percent Fe (mg # = 80 to 93) and the Fe gives the chlorite a light green color in plane light.

Chlorite from the proposed source areas define relatively small compositional fields that overlap. Chlorite from area 1 is different from chlorite in area 2, but area 3 chlorites overlap area 2 and area 4 chlorites overlap all of the other proposed areas. Chlorite from the statues shows a greater range of compositions. There is some overlap of chlorites from statues 1 and 2 with areas 1 and 4, but several statue 1 and 2 chlorites have higher ratio of Al to Al+Cr. Chlorite from statue 3 is considerably higher in Mg (mg # = 93) than any of the other statue chlorites or the chlorites from proposed source rocks.

Sample type	Statues			Proposed source areas				
Sample number	1	2	3	1a	1b	2a	2b	3a
SiO_2	31.58	36.72	31.47	28.95	28.50	32.51	30.73	33.50
Al_2O_3	22.80	22.36	16.04	19.08	19.15	16.34	15.58	16.39
Cr_2O_3	0.78	0.63	2.16	1.10	0.90	0.89	1.16	0.91
FeO^+	9.34	9.63	4.35	10.23	9.80	8.44	9.08	8.79
NiO	0.09	0.01	0.21	n.d.	0.07	n.d.	0.21	n.d.
MgO	20.74	16.79	32.72	27.67	27.88	28.60	29.34	27.69
Total	85.33	86.14	86.95	87.03	86.30	86.78	86.10	87.28
Formula based on 22 O								
Si	6.22	7.04	6.13	5.73	5.68	6.34	6.13	6.49
Al	5.29	5.05	3.68	4.45	4.49	3.76	3.67	3.74
Cr	0.18	0.14	0.49	0.25	0.21	0.20	0.27	0.20
Fe	1.54	1.54	0.71	1.69	1.63	1.38	1.51	1.42
Ni	0.02	0.00	0.04	0.00	0.01	0.00	0.04	n.d.
Mg	6.09	4.80	9.50	8.17	8.28	8.31	8.72	7.99

Table 5c. Selected microprobe analyses of talcs in source rocks and statues.

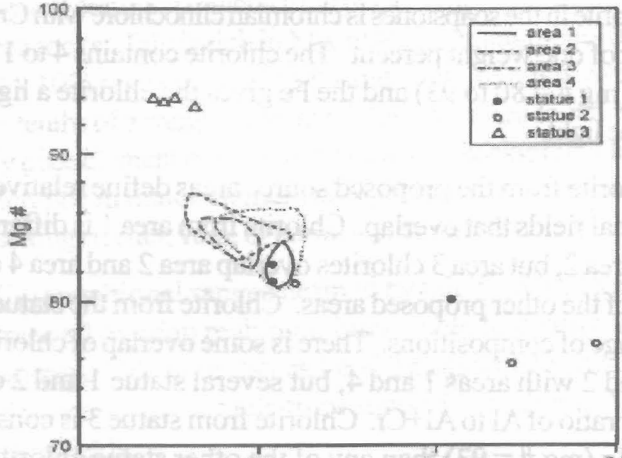


Fig 5c. Plots of chemical composition of chlorites in source rocks and statues

Amphibole

Amphiboles- cummingtonite and/or tremolite, is found in all of the source area and statue samples. Cummingtonite forms acicular grains with a small inclined extinction. Tremolite grains are more tabular and have a larger extinction angle. Cummingtonite forms discrete grains and as overgrowths on tremolite. The tremolite is a relict phase, associated with an the older, more chlorite- and amphibole-rich fabric. Tremolite is not found in samples from source area 1 or in statues 2 or 3

All of the amphiboles are Mg-rich (cummingtonite mg # = 68 to 85; tremolite 78 to 96; Amphibole (both tremolite and cummingtonite) grains in some samples show a variation of several weight percent Fe-Mg in adjacent zones. Cummingtonite typically overgrows tremolite. The amphiboles are mostly Fe-Mg$\pm$Ca silicates with low concentrations of Ti, Cr, and Na; and these trace elements are not included in the summary data.

Amphibole from the proposed source areas define relatively small compositional fields that overlap. Tremolite grains from areas 2, 3 and

4and statue 1 have similar major element compositions, but show some variation in trace amounts of Mn. Tremolite in statue 1 and source areas 2, 3 and 4 are identical in terms of Ca-Fe-Mg, but the Mn content of statue 1 tremolite is most similar to samples from source area 1. Cummingtonite grains from statues 1 and 2 are similar to those from source areas 1 and 4), but some of the cummingtonites from statue are more Fe-rich than any analyses from the source area samples. There is considerable scatter in the Mn contents of cummingtonites. Statue 1 and 2 cummingtonites are generally coincident with source areas 1 and 4 cummingtonites in terms of Mn contents, but the statue cummingtonites are more variable. Cummingtonite from statue 3 is more Mg-rich than any other low-Ca amphiboles, either from other statues or from any of the proposed source areas.

Selected microprobe analyses of amphiboles

Sample type	Statues				Proposed source areas							
Sample # mineral[a]	1 Cumm	1 Trem	2 Cumm	3 Cumm	1a Cumm	1b Cumm	2a Trem	2b Trem	3a Trem	3b Trem	4a Cumm	4b Trem
SiO_2	56.39	57.82	56.42	57.85	56.09	57.08	57.32	57.82	58.36	58.10	56.46	57.41
Al_2O_3	0.18	0.36	0.24	0.02	0.19	0.23	0.41	0.10	0.13	0.04	0.18	0.75
FeO^+	15.59	4.04	15.37	10.56	16.70	15.24	5.81	4.13	4.93	3.64	15.04	4.56
MnO	0.60	0.08	0.64	0.22	0.90	0.68	0.37	0.26	0.22	0.18	1.48	0.21
MgO	23.44	22.99	23.86	27.72	22.38	23.68	22.31	22.91	22.77	23.21	23.05	22.32
CaO	0.80	12.87	0.52	0.48	0.76	0.64	11.56	12.98	12.69	12.97	0.63	13.09
Total	97.00	98.16	96.81	96.85	97.02	97.55	97.78	98.20	99.10	98.14	96.84	98.34
Formula based on 23 O												
Si	7.98	7.91	7.97	7.98	7.99	8.00	7.92	7.93	7.94	7.95	8.00	7.89
Al	0.03	0.06	0.04	0.00	0.03	0.04	0.07	0.02	0.02	0.01	0.03	0.12
Fe	1.85	0.46	1.82	1.22	1.99	1.79	0.67	0.47	0.56	0.42	1.78	0.52
Mn	0.07	0.01	0.08	0.03	0.11	0.11	0.04	0.03	0.03	0.02	0.18	0.02
Mg	4.94	4.69	5.02	5.70	4.75	4.95	4.60	4.68	4.62	4.74	4.87	4.57
Ca	0.12	1.89	0.08	0.07	0.12	0.10	1.71	1.91	1.85	1.90	0.10	1.89

FeO^+, total Fe as FeO.

Cumm, cummingtonite; trem, tremolite.

[a] Mineralogy of amphibole.

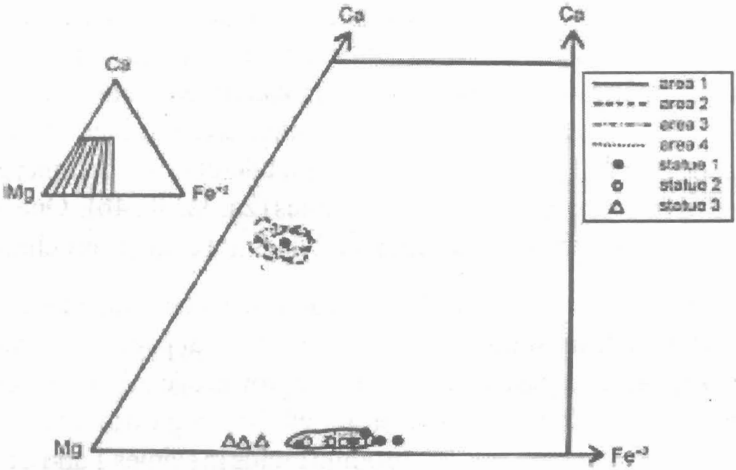


Table 5d Amphibole composition from statutes compared to sources.

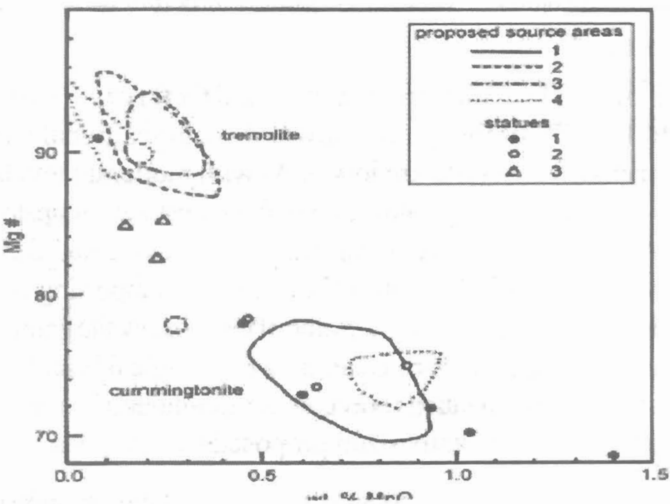


Fig.6e Mn in of amphiboles of statue and source rocks

CrFeTi Oxides

All of the samples contain oxide minerals. Chromite is the most common, but ilmenite overgrown with rutile is found in all of the samples except for statue 1. Chromite occurs as isolated subhedral grains in six samples (all three statues and proposed source area samples 1a, 1b, and 4a) and as anhedral grains surrounded by a talc-chlorite corona in four samples from proposed source area samples (2a, 3a, 3b, 4b). One of the samples (2b) from proposed source area 2 does not contain any chromite.

Chromite is Cr- and and Fe-rich and Al contents are moderate to low. Chromite from statue 2 illustrates the general pattern of lower Al contents in grain rims and the occasional overgrowth of chromian magnetite (shown by the low-Cr rim composition,). Cellular overgrowths of chromian magnetite forms a bright rim on chromite grains in statues 1 and 2 and in proposed source area samples 1a, 1b, and 4a. Textural considerations of oxide minerals further distinguish statues and proposed source areas. None of the statues contain chlorite-talc coronas around chromite grains. All of the samples except statue 1 contain fine-grained ilmenite with overgrowths of rutile.

All of the chromites are rich in Fe and Cr (cry# = (Cr/Coral) x 100 = 71 to 100; Chromite grains show little compositional variation. Magnetite rims on chromite are low in Al with moderate levels of Cr. These rims form during recrystallization of the soapstone. Soapstone with chromian magnetite rims on chromite also has small isolated grains of chromian magnetite included within the talc fabric supporting growth of the magnetite during metamorphism. Some of these magnetite grains include talc showing the magnetite formed along with the talc fabric. Given the variability of overgrowth relations only core compositions of chromite grains were compared between statues and proposed source areas.

Chromite core compositions show relatively little variation in terms of Cr- Fe-Al contents.

SOURCE OF ESIE SOAPSTONE SCUPLTURE:

Mineral chemistry was used to define the source rocks of the statutes. Mineral composition of talc, chlorites, cummingtonite and chromites found within the samples of statues and rocks were plotted in the discriminant diagrams as shown in Fig 6 a, b, c and d .

Consideration of the basic mineralogy of the samples from proposed source areas and the statues restrains the proposed source areas for statues to Agbonda (25Km to Esie). The mineralogical screens were applied as follows:

- Several of the chlorite analyses from statues 1 and 2 plot within or near the proposed source area 1 chlorite, but several chlorite analyses from these statues had higher Al contents and plot outside the ranges of any of the proposed source areas.
- Compositions of cummingtonite from statues 1 and 2 plot within or near the field defined by source area 1, but a few of the statue 1 samples have higher Mn content.
- The lack of chlorite-talc coronas on any of the chromite grains from the statues and the occurrence of these coronas in source areas 2, 3 and 4 precludes these as possible source areas.
- Source area 1 lacks chlorite-talc coronas and had some chromian magnetite rims on chromite grains.
- The statues contained mostly low-Ca amphibole (cummingtonite), but statue 1 contains traces of tremolite.
- Source areas 2, 3 and 4 contained abundant tremolite and cummingtonite. Fine-grained ilmenite with overgrowths of rutile was found in all the samples except statue 1.

Mineral assemblage data suggested that the statues are derived from proposed source area 1

Talc compositions from statues 1 and 2 were near or within the range reported for source area 1. Moreover Area 1 showed extensive evidence of mining and much of the soapstone was apparently removed. It is possible the removal of better quality soapstone resulted in some minor differences in statues and the soapstone remaining in the outcrops that was sampled in this study.

The results of this work showed that mineral compositions furnished a check on the provenance of the soapstone. Talc from statue 3 is lower in Fe than any of the other samples resulting in higher mg #s for statue 3. Statue 3 chlorite has higher Mg contents than any of the other samples and plots outside the range of any other sample. Cummingtonite from statue 3 is unlike any of the other low-Ca amphiboles. Chromite core compositions show little overall variation between source areas and statues Statue 1 and proposed source area sample 1a show overgrowths of a chromian magnetite rims on the chromite. Statue 2 has some chromian magnetite rims on chromite, but most of the chromite only shows a modest loss of Al from the core to the rim, source area sample 1b shows a similar pattern. Statue 3 chromite shows loss of Al from core to rim, but does not have any rims of chromian magnetite. Mineral composition data suggested proposed source area 1 is a possible source for the soapstone in statues 1 and 2, but statue 3 did not appear to be represented by any of the proposed source area samples.

Table 5e. Selected microprobe analyses of chromites from source rocks and statues

Selected microprobe analyses of chromite

Sample type	Statues				Proposed source areas						
Sample number	1		2	3	1a	1b	2a	3a	3b	4a	4b
Texture	Core	Rim	Core	Core	Core	Core	Core	Core	Core	Core	Core
Cr_2O_3	43.17	12.32	44.46	45.95	38.36	44.29	44.38	45.64	45.79	42.21	45.09
Al_2O_3	8.40	0.25	7.99	6.45	9.63	8.44	5.88	5.68	6.26	9.31	5.29
Fe_2O_3	11.92	54.04	12.73	9.90	15.38	12.35	12.07	11.23	10.98	13.49	10.75
MgO	0.60	0.06	0.64	1.98	0.33	0.73	0.34	0.33	0.39	0.63	0.33
FeO	29.67	30.15	30.58	28.12	30.21	30.21	29.39	29.51	30.46	30.49	29.02
MnO	1.35	0.33	1.19	0.35	1.47	1.28	1.37	1.30	1.13	1.26	1.47
TiO_2	0.18	0.11	0.27	0.42	0.21	0.15	0.41	0.40	0.61	0.16	0.36
Total	95.29	97.26	97.86	93.17	95.59	97.45	93.84	94.09	95.62	97.55	92.31
Cations normalized to 3											
Cr	1.28	0.38	1.29	1.39	1.13	1.28	1.35	1.39	1.37	1.22	1.40
Al	0.37	0.01	0.35	0.29	0.42	0.37	0.27	0.26	0.28	0.40	0.25
Fe^{+3}	0.34	1.60	0.35	0.28	0.43	0.34	0.35	0.33	0.31	0.37	0.32
Mg	0.03	0.00	0.04	0.11	0.02	0.04	0.02	0.02	0.02	0.03	0.02
Fe^{+2}	0.93	0.99	0.94	0.90	0.94	0.93	0.95	0.95	0.96	0.93	0.95
Mn	0.04	0.01	0.04	0.01	0.05	0.04	0.05	0.04	0.04	0.04	0.05
Ti	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.02	0.00	0.01

FeO^+, total Fe as FeO.

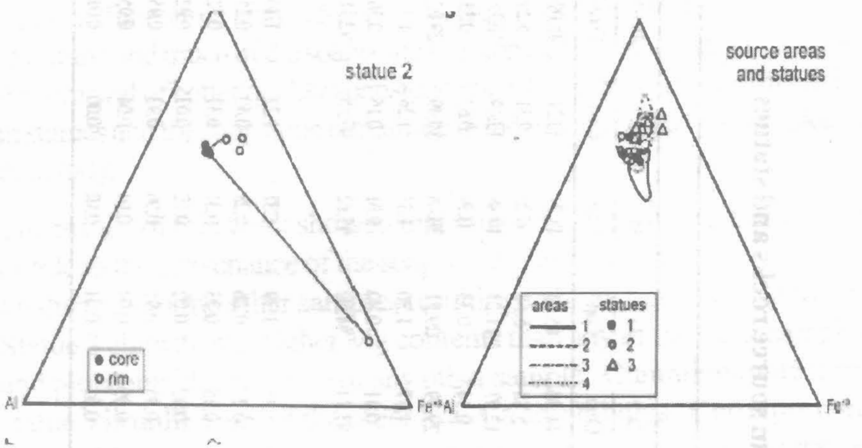


Fig.6f and g. Composition of CrFe oxides from statues (1-3) compared to the field defined by the source areas

Comparison of mineral assemblages and compositions suggests a likely source for two of the statues within the Agbonda area. The occurrence of extensive deposit of iron slag, terracotta pieces and furnaces associated with iron smelting which may point to the existence of a center of early civilization, similar in some respect to the Ile-Ife (Clark, 1938; Stevens, 1978). This work shows the potential of mineral assemblages and compositions in the sourcing of soapstone artifacts. Minerals from a given soapstone outcrop area tend to be homogeneous (unlike bulk compositions that vary with mineral abundance), but variable between outcrops. Mineral assemblages and compositions thus provide a way to identify source areas for soapstone.

THE SCIENCE OF ANCIENT GLASS MAKING IN SOUTHWESTERN NIGERIA

The third story is the story of glass making among the Yoruba.

Glass is a non-crystalline material that is, in essence, a super cooled liquid rather than a solid. The production of glass requires several pre-requisite factors: a pneumatically drafted furnace with the ability to produce concentrated heat of between 900 - 1000 degrees centigrade; the temperature reduced inside the furnace to that required for vitrification by means of the introduction of an alkaline flux; "a first firing of the mixture of granulated silicate and raw materials resulting in the production of a frit at a temperature of about 750 [degrees centigrade;] a second firing at a higher temperature of about 1000 [degrees centigrade]. This firing requires sustained temperatures over lengthy periods of time and complete vitrification can take many days to achieve. In order to speed up the vitrification process, cullet is added to the batch to act as a catalyst in the process of liquefaction into a homogeneous mass. Possession of glass technology is regarded as the climax of creativity and a symbol of an advanced civilization.

The chemical composition of glass

The primary constituent making up the chemical composition of glass is silica (silicon dioxide), which is the most common component of the earth's crust and accounts for 50-70% of the weight of ancient glass. Silica for ancient glassmaking was extracted from raw materials as freely available as quartz sand, white quartz pebbles and flint.

Soda (Na_2O, $NaHCO_3$, and Na_2CO_3) is one of the prominent ingredients of glass because it acts as a flux to lower the temperature of melting of sand. Some soda glasses have been found to contain as much as 23% Na_2O, but high sodium content makes glass vulnerable to deterioration through weathering. Potassium oxide (K_2O) can replace sodium oxide as the flux in glass, resulting in a greater level of brilliance as well as a superior colour. The resultant glass possesses a higher melting point; it is solid and is more enduring. The necessary potassium compounds are extracted from plant and wood ashes.

Calcium (lime - CaO) acts as a stabiliser to glass, allowing glass to harden more rapidly during the cooling process. Calcium derivatives commonly occur in nature as calcium oxide or lime. Calcium carbonate (CaCO3), for example, is present in sea shells, limestone and chalk. Usually the main source of CaO is limestone which also contains variable amounts of MgO.

As MgO is a common constituent of Egyptian glasses, it has been hypothesised that the composition of the sand may be responsible for its presence in the glass.

The predominant types of early glasses were soda-lime-silica and potash-lime-silica glasses. In ancient glassmaking the raw materials utilised were first put through cleansing processes prior to use. These processes included screening, washing and burning for extraneous coarse particles, organic matter and other impurities to be expunged (Saitowitz 1996).

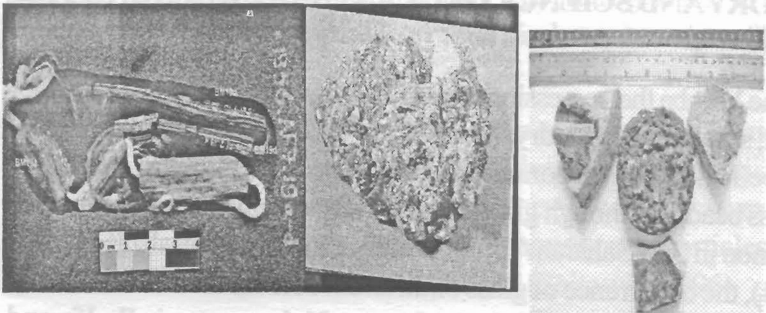
From the beginning of the Roman period, starting around the Seventh century BC in Italy, a new kind of glass began spreading throughout the Mediterranean world. This glass was termed "low-magnesia glass", because its percentage of magnesia and potassium oxide components was less than 1% (Freestone 1991). The higher counts of magnesia and potassium oxide in the glasses from the previous millennia were the result of utilisation of plant ash in the manufacturing process. Plant ash is not composed of pure soda. However, Roman glass-makers achieved a result of low impurities through the application of high-quality soda or natron.

In ancient Egypt, the dark amethyst-coloured glass of the Eighteenth (1550 - 1069 BC) and Twentieth dynasties (1186 - 1069 BC) owed their colour to a manganese compound, of which 0.5 - 0.7% has been calculated as oxide (Lucas & Harris 1962. The colouring of the Ancient Egyptian black glass was caused by three compounds varying in proportion to each other and thereby in visual effect: copper, manganese, and iron (Lucas & Harris 1962). Although black glass was certainly manufactured in Egypt at a later date, the early black glass (which, amongst others, was used to manufacture beads) was due to the use of impure materials that contained, for instance, a large proportion of iron compounds. In modern Egypt, a cobalt compound is used for colouring blue glass while many of the blue glass specimens from the Eighteenth and Twentieth dynasties owed their colouring to a copper compound. The green glass derives its colour either from compounds of copper or of iron. The colouration of the modern green bottle-glass is, for example, produced by the latter method.

THE STORY AND SCIENCE OF GLASSMAKING AMONG THE YORUBA

Among the Yoruba the possession of glass objects was considered a symbol of wealth, status and wizardry. Many Yoruba sacred and secular objects were embellished with elaborate images and symbolic designs, created by small glass beads. Although glass making was not considered a registered phenomenon in Sub-Saharan Africa (Willett, 1967; Eluyemi, 1986; Willett et al 2004), the occurrence of glass of different colours on crucible lining, together with long drawn beads in the famous Olokun grove in Ile-Ife, and some 'sightings' in nearby Yoruba towns suggests the existence of a primary or secondary glass technology among the Yoruba. Ethnographic and historical data showed that the glass was regularly being produced in southwestern Nigeria by around 1200 AD. These glass objects were common enough to figure prominently in Sixteenth century West African trade prior to the coming of the Europeans. This is evidenced by the fact that there were documented occurrences of similar glass beads in Igbo-Ukwu, (southern Nigeria) Gao, Mali and; Kissi, Burkina Faso and at Koumbi Saleh, Mauritania (Shaw 1970, Davison 1972 Davison et al 1971, Robertshaw et al 2003) attesting to its being transported over large distances in different forms.

The glass objects were said to be worth their weight in gold and so were highly valued. Glass object were and still used for different ceremonial as well as spiritual purposes. They were prestige products, almost always strongly coloured, and was used for the production of beads and gift objects. Some glass chunks (Aje-Ileke) are sought among the Yoruba today as gifts for high status brides. These ritual items are believed to enhance fertility and wealth and to help barren women become pregnant. The glass objects and beads are still being mined today attesting to the fact that Ile-Ife and adjoining towns appear to represent the remains of both a prosperous glass working center and religious sanctuary.



a=Drawn aborigine glass beads **b= Glass chunks (Aje-ileke)** **c=Glass of different colors on crucibles**

d=Drawn glass **e= Lapidary Glass.** **f=Powdered glass**

Fig. 7 a, b, c, d, e, f. Different species of ancient glass object.

PREVIOUS WORKS

The German archaeologist, Frobenius, (1913), was the first to give an account of a possible glass making factory around Ile-Ife, when he excavated the famous Ori Olokun. He also found numerous glass beads, crucible fragments, as well as the remnants of a special domed furnace, along with decomposed feldspar and some smelting slag. He also reported excavating shafts extending some seven meters below ground level. Willett and other archaeologists also discovered many fragments of glass bead crucible in many places in Ile-Ife such as Ita-Yemoo, and Olokun Grove while Ogundiran (2007) reports some sightings in Osogbo and Ilesa areas, confirming that there were many centres of glass and bead industry among the Yoruba.

Experts, who have studied this glass, (Davison, et al, 1971) and Willett, et. al, (2004), have suggested that the Yoruba reworked imported glasses exclusively.

However in our recent investigations (Lankton et al (2006), Ige 2009, Ige 2010), we pointed to a possible indigenous glass of unique chemistry. In these land mark papers we employed geochemical evidence to prove that glass was produced in or around Ile-Ife about 800 years ago. Along with Freestone (2006) we argued that two types of glass found at Ife- the cobalt blue and blue-green segi glass types- that have a high lime and very high alumina chemical composition are unique in the 10,000 entry database of world glass, meaning that they representing a unique (independent) Yoruba glass invention. This is because they contain unusual levels of CaO and Al_2O_3 such that they fall into a different nomenclature of glass and therefore warranting a new system of classification. In my papers I suggested that high-lime, high-alumina glass represents a distinct West African tradition, with much of the evidence pointing toward southern Nigeria.

Table 6 Electronprobe analysis of glass, glass beads and glass working crucibles

Number	Form	SiO_2	Na_2O	CaO	K_2O	MgO	Al_2O_3	Fe_2O_3	TiO_2	MnO	CuO	CoO	PbO	P2O5	BaO
If1a	glass fragment	54.07	6.11	19.46	3.67	0.00	15.91	0.37	0.03	0.38	0.00	0.01	0.02	0.06	0.00
If1a-2	glass fragment	54.43	6.72	16.66	3.04	0.05	17.48	0.47	0.02	0.68	0.01	0.08	0.03	0.09	0.06
If1a-3	glass fragment	53.90	7.06	17.36	3.04	0.03	17.54	0.50	0.00	0.71	0.01	0.07	0.03	0.00	0.05
If1a-4	glass fragment	53.50	6.73	18.45	2.97	0.01	17.62	0.49	0.00	0.71	0.00	0.10	0.02	0.08	0.05
If1a-5	glass fragment	57.97	6.48	15.16	3.19	0.00	16.72	0.39	0.02	0.50	0.06	0.06	0.06	0.00	0.01
If1a-6	glass fragment	57.44	6.93	15.00	2.75	0.00	16.45	0.36	0.00	0.51	0.05	0.08	0.00	0.06	0.00
If1a-7	glass fragment	57.73	7.03	15.00	2.48	0.03	16.55	0.31	0.03	0.47	0.04	0.06	0.00	0.04	0.04
If1b-1	drawn bead 1	57.75	6.29	15.90	3.35	0.02	16.20	0.34	0.00	0.38	0.05	0.06	0.00	0.07	0.04
If1b-2	drawn bead 1	57.11	6.34	15.95	3.33	0.01	16.02	0.32	0.02	0.36	0.03	0.04	0.02	0.03	0.03
If1b-3	drawn bead 1	57.70	6.40	15.93	3.33	0.00	16.34	0.33	0.00	0.41	0.02	0.07	0.04	0.06	0.08
If-c2-1	Crucible	56.80	4.21	18.13	2.89	0.04	15.42	1.03	0.08	0.79	0.06	0.11	0.00	0.51	0.00
If-c2-2	Crucible	57.86	4.15	17.21	2.97	0.05	15.51	1.10	0.06	0.69	0.04	0.08	0.03	0.12	0.02

In the course of my research, some questions came to me as a scientist.

- How could we be so sure the glass discovered were produced by the Yoruba, particularly when the physical evidence for early primary glass production has not been identified in the published archaeological reports?
- What was the extent of glass production?
- Was there evolution in materials through times?
- When did this glassmaking tradition start and how long did it last?
- On what basis can we be so sure that the high-lime, high-alumina Ife glass represents a distinct tradition, rather than the reworking of glass imported from elsewhere?
- How was the glass made, and what can we say about the technological choices of the craftsmen?

EXPERIMENTAL MELTING OF LOCAL RAW MATERIALS

Following our observation, I set out to search for possible raw materials that will give the unique chemical compositions of the ancient Yoruba glass found in Ile-Ife. Geologically, Ile-Ife is situated within the so- called Basement Complex comprising granite gneisses, quartzite and quartz mica schists. Weathering and decomposition of these rocks have produced a very thick regolith cover in several areas of Ife especially along the *Okun* (locally called 'sea') river flood plains. Thus, in terms of raw materials for creating glass, Ife, like many Yoruba cities had an ample supply of high-alumina sand deposits from decomposed metasediment rich in mica schist and quartzite which could have been exploited by the ancient glass makers. In addition the forest in Ile-Ife could have provided the large amounts of wood necessary for the preparation of wood ash.

For this investigation, several recipes which I assumed could probably represent raw materials for an ancient glass factory, were selected for analysis and subsequent glass making. By varying the proportions of quartz, feldspar and mica, different raw material mixtures were obtained. The approximate mineralogical compositions of raw materials are as follows.

1½ g quartz + 3g oligoclase + ½ g biotite..recipe 1

1½g quartz + 2g oligoclase + 1g microcline ½ g biotite ½ g muscovite.....recipe 2

2g quartz + 2g oligoclase + 1g microcline ½ g biotite ½ g muscovite....recipe 3

2 g quartz + 2g oligoclase + ½g biotite...recipe 4

In collaboration with Professor E. A. Ajayi of the Department of Physics, powdered samples of the recipes were melted in silica crucibles placed in a Wildbar Furnace at a temperature of 1050-1150 °C for 15 to 48 hours. Sometimes the samples were first sintered and crushed. After cooling, the frit was thoroughly ground and homogenized in a boron carbide pistil mill in order to get rid of gas bubbles. Some of our recipes produced moderate amounts of glass. Experiments with recipes rich in white mica tend to yield a nearly colourless glass, while recipes rich in feldspar and biotite yield an olive green glass similar to ancient glasses. The glasses produced were analysed using the Electron probe facility at the University of Georgia Athens, USA. Compared to the excavated glass the experimentally produced glasses were broadly similar in silica, and magnesia, were generally higher in alumina and much lower in lime than those of the ancient glass (Table 7). Thus, the experimental glasses can be classified as low magnesium, moderate calcium, high alumna glass which shows that the experimentally produced glasses were broadly similar in composition with the ancient glass in terms of Al, Si and Na (Table 7) but lack the distinctively high Ca.

Further ethnographic and archaeological works suggested that snail shells, a recurrent find in the excavation sites, were used in the making of the glass. According to informants, snail shells were used to blend the sand from Olokun streams and were formulated according to the cultural uses and societal stratification. Thus the glass makers made one recipe for priests with abundant snail shells, in order to ensure maximum divinity. A different recipe was made for kings and chiefs with moderate calcium, whilst glass with the lowest amount of calcium was for the commoners. Snail is regarded as a sacred animal with spiritual versatility. In Yoruba pharmacopeia, snail is used as divine shield against the fiery spiritual darts from the enemy and increases potency of most local pharmaceutical excipients.

In my experiments, when powdered snail shells were added to the recipes the resulting experiments show that not only was the temperature of melting lowered to about 700°C, there was significant elevation in the calcium contents of the produced glass which then matched virtually the composition of the ancient glass.

Table 7: Chemical analyses of ancient glasses and experimentally produced glasses

X-Ray Fluorescence analysis of recipes

	SiO_2	TiO_2	Al_2O_3	MgO	FeO	MnO	CaO	K_2O	Na_2O	BaO
Sample 1	54.07	0.74	18.86	1.89	3.58	0.04	5.05	9.88	5.58	0.18
Sample 2	53.12	0.55	20.33	1.58	0.44	0.16	6.03	11.86	5.31	0.13
Sample 3	50.77	0.55	19.77	1.65	1.51	0.14	3.55	14.18	7.66	0.14
Sample 4	55.06	0.32	16.87	0.91	1.95	0.11	7.09	10.98	6.45	0.14

EPMA data on experimentally produced glass samples(wt%)

Experimental melts	SiO_2	TiO_2	Al_2O_3	MgO	FeO	MnO	CaO	K_2O	Na_2O	BaO
Average Melt 1	60.02	0.04	23.30	0.02	0.11	0.00	4.85	8.19	2.81	0.07
Average Melt 2	62.25	0.11	19.96	0.06	0.78	0.10	2.06	10.32	2.57	0.21
Average Melt3	66.42	0.02	21.17	0.02	0.27	0.05	2.26	3.35	6.55	0.03
Ancient glasses										
Mean of low MgO HLHA	59.20	0.11	14.50	0.12	0.91	0.61	16.90	4.21	3.21	0.01
Mean of low MgO HLHA	53.00	0.41	13.90	2.71	1.41	0.51	19.01	8.01	0.61	0.02

The addition of snail shells to a glass recipe is actually scientifically sound, because CaO is a stabilizer that prevents glass from breaking down during chemical attacks by acid-laden rains. This composition has preserved the Yoruba glass for more than seven hundred years in archaeological records. This research will definitely help ailing glass factories in Nigeria. We have now designed and fabricated a furnace capable of producing glass on a small scale which can be used by local artisans. I have just applied to UNESCO to give a grant to execute a programme of training artisans and school leavers in making special ancient glasses. If successful, the grant will allow us retrain local artisans who will produce glass as collector items, thus boosting the local economy and attracting foreign tourists to Ile-Ife.

THE STORY AND SCIENCE OF ROYAL CERAMIC PAVEMENT MAKING:

Potsherd pavements, a unique aspect of Ife culture is widespread in Ile-Ife and other ancient Yoruba cities in southwestern Nigeria. These ceramics are special royal pavement invented by the only female *Ooni* that reigned in Ile-Ife. The potsherd pavements were made of pottery sherds in a special architectural design. From different oral and written documents (Akinjogbin and Ayandele, 1985, Eluyemi 1986), this female king (with the name Luwo) invented this special ceramic pavement, in order to force an environmental code on the Ife people and the 'colonies'. Like her bead making counterpart, she was outstandingly ingenious. The consequence of her technical expertise is the widespread occurrence of potsherd pavements in several Yoruba towns and also as far as Togo and Benin Republics, thus becoming a West African cultural phenomenon. Historical data show these potsherd pavements are found in several places, as a symbol of divine connection amongst the Yoruba.

Several historical and archaeological works exist on potsherd pavement of southwestern Nigeria. These mainly dealt with the attributes and cosmology of the ceramic objects (e.g Ogunfolakan 2001, Agbaje-Williams 2001, and Ogundiran 2002). While methods such as attribute analysis are important, the conclusions drawn from their results cannot be complete, unless otherwise complemented with other methods. Despite success in many areas worldwide with sourcing pottery (Bishop et al. 1988; Lynott 2000), this avenue of research has been virtually ignored by Nigerian archaeologists. As a whole, chemical analyses of ceramic in the Nigeria lag far behind the analysis of other artefact categories.

When we started this work, we hoped to find scientific evidence to connect some of the ancient Yoruba history, depicting migration patterns between Ile-Ife and other important Yoruba royal towns. Using geochemical evidence we aimed to fingerprint the different artefacts and determine whether the objects were transported from Ife or they were geologically controlled. In this work we have employed petrographic method for mineral identification and Inductively Coupled Plasma-MS technique to obtain major, trace and rare earth element data to complement large scale historical and archaeological information. In this work we tried to use geochemical methods to answer the following questions.

- What compositional groups are represented in ceramics from different archaeological sites and how do they differ from each other?
- Were there differences in manufacturing techniques?
- Is migration a factor in technological evolution of the ceramics?
- Are the chemical compositions of sherds a reflection of the local geology?

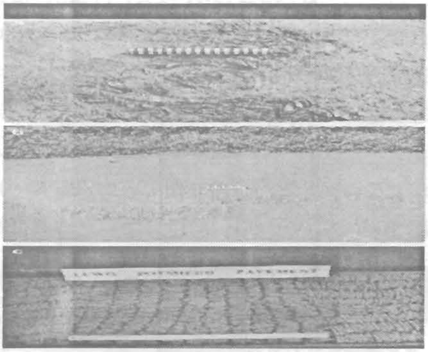
Several samples of potsherd pavement were recovered during excavation and archaeological reconnaissance of six sites, along the trade and migration route of the Yoruba of southwestern Nigeria. Microscopic analysis of samples shows the presence of high proportions of non-plastic grains, mainly quartz, micas, minor plagioclases, and traces of ferruginous grains, tourmaline and amphibole, interpreted as low temperature firing. The chemistry of the potsherd samples are generally similar to clay derived from granitic rocks, which are abundant in the area. Principal component analysis (PCA) was used to reduce the number of variables and model-based cluster analysis was used to find clusters in the PCA scores. Model-based clustering found one major cluster in the data set, which corresponds to the local weathered granitic/pegmatitic raw materials near the sites. Our work shows that the technology for the manufacture of these special royal pavements might have originated from a centralized production site but it also reflected the geology of the area.

A large variety of elemental scattergram plots, utilizing the major elements, trace elements and the combination of both has been used. Most of these plots provide clear delineation of the raw materials and form a chemically large homogeneous group. In particular the REE, Th and Sc which are considered to be the most confident elements for provenance studies of ancient ceramics were used in the delineation. This is because they are considered insoluble and the effects of metamorphism, weathering and diagenesis upon them are minor. The multi element variation diagrams (spidergrams) of trace and some major elements are shown in Fig 8b.

From the plots, the lines joining the data points of the analyses for each of the sherds and the raw materials have patterns showing a striking resemblance to each other. Despite the differentiations due to some variation in element concentrations, most of the analyzed potsherd and raw material

Table 8: Chondrite normalised rare earth compositions of potsherds and granite regoliths from SW Nigeria

Sample	La/N	Ce/N	Pr/N	Nd/N	Sm/N	Eu/N	Gd/N	Tb/N	Dy/N	Ho/N	Er/N	Tm/N	Yb/N	Lu/N
IRC-1	63.2	62.0	56.3	43.0	30.0	30.5	19.2	12.3	13.6	7.8	9.8	6.3	8.5	4.7
IRC-2	146.5	107.7	110.0	87.0	50.1	12.3	30.7	19.4	18.8	10.8	13.0	8.4	10.4	6.5
IRC-3	76.3	86.9	54.6	41.3	21.9	15.8	13.2	8.9	10.7	6.5	9.4	5.9	9.4	5.9
IPC 1-1	212.0	172.0	140.2	100.5	53.4	14.9	34.5	23.0	23.0	14.5	18.1	13.1	16.0	12.6
IPC 3-2	175.0	141.0	117.9	85.2	47.6	30.0	29.7	20.0	21.1	11.9	15.3	10.6	13.6	9.7
IPC 3-7	104.0	75.0	72.1	59.2	29.1	14.2	17.1	8.5	9.6	5.5	7.5	4.1	6.9	4.4
IPC 5-4	153.5	124.8	100.5	74.4	40.6	24.0	27.0	19.4	23.0	15.8	20.2	15.3	17.5	13.8
MIFE 1	88.5	65.7	75.0	64.1	38.2	53.2	23.9	13.4	14.4	8.1	9.6	5.0	7.2	3.5
MIFE 3	331.0	170.0	232.5	169.7	90.5	6.6	56.7	34.9	32.4	19.0	21.5	15.3	16.4	12.4
KP 3	37.6	30.5	28.3	21.6	13.8	6.2	9.1	5.1	7.2	4.0	5.9	3.1	5.8	2.1
KPC 1	35.8	27.4	27.9	21.9	13.3	7.5	9.5	6.4	8.9	5.4	7.7	3.4	6.3	2.9
KPC 2	39.2	35.7	30.3	24.5	14.6	19.7	9.9	6.0	7.6	4.5	6.8	3.4	6.1	2.9
KM 1	126.5	99.5	87.3	64.2	37.9	21.9	25.4	17.7	19.1	11.8	16.5	10.6	13.2	9.1
KM3	115.6	86.5	87.9	66.1	40.5	20.5	26.8	19.4	22.0	13.7	18.6	13.1	17.4	12.6
KM 4	86.5	73.7	70.6	54.4	36.1	32.2	27.5	21.7	25.5	18.3	25.2	17.5	20.6	16.2
IC 1	227.6	134.5	149.9	105.0	51.6	17.4	29.6	16.6	16.4	9.0	11.6	6.3	9.4	4.4
IC 2	175.0	119.0	110.5	78.8	47.6	12.1	32.4	23.4	25.4	15.5	21.4	14.4	17.7	12.4
IC 3	156.7	92.3	91.6	60.3	28.5	12.7	16.6	8.1	9.3	5.3	7.6	3.1	6.2	2.1
IC 4	422.0	383.0	305.3	204.7	116.5	15.6	69.8	46.2	43.4	26.5	33.5	22.8	25.3	18.5
IFE RAW1	70.8	54.5	50.8	37.0	24.3	26.7	16.7	10.6	14.3	8.6	13.2	8.1	12.5	7.9
IFE 1	112.0	78.5	86.6	67.8	39.6	24.8	26.8	16.4	18.4	11.3	14.9	9.4	12.2	7.6
IFE 2	110.0	81.5	89.0	71.3	42.6	24.1	25.2	14.9	16.8	9.1	13.1	7.2	11.3	5.6
IFE 3	87.0	75.2	61.7	48.9	27.7	20.3	17.3	8.7	11.1	6.5	9.8	5.3	9.6	5.6
IFE FUV1	127.0	79.5	88.7	63.8	37.5	20.5	24.8	16.6	18.7	10.5	13.8	8.1	11.2	6.2
IFE FUV2	129.0	84.0	89.8	64.2	38.0	0.0	24.5	16.2	18.1	10.5	14.0	7.5	11.6	5.9



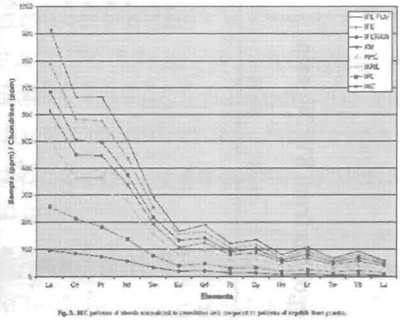


Fig. 8 a=Ancient Potsherd pavement with it superior architecture Fig.8b= REE pattern of samples from different sites

present chemical similarities, pointing to the use of the same kind of raw materials. We therefore concluded that pre-historic peoples collected the raw materials around the area, close to the sites. To improve the plasticity properties of this matrix, the Yoruba intentionally added other materials quartz, sand or crushed rocks and feldspars, which has led to SiO_2 enrichment.

Although the problem of the origin of the present Yoruba population is still a subject of deliberations, the identification and chemical characterization of potsherd pavement, in majority of the towns in the study areas, will open up more lines of discussion on the relationship of Ile-Ife, with other Yoruba towns and cities.

THE STORY OF THE NATURAL HISTORY MUSEUM BUILDING.

My greatest story is about the completion of the Natural History Museum Building. This building designed by James Cubitt Adenuga and Co was to cost a sum of 2million naira, but it stood there abandoned for 26 years, inspite of the good efforts of past directors. When I became the Director, the Museum building had almost become an albatross! The Museum as an academic department had also become a dead end to the staff, or at best a transit point to better, greener pastures. There were even stupid moments when some eminent colleagues suggested the closing down of the Museum and annexation to some departments. The first problem was that many people do not understand the importance of a Natural History Museum. Some of my eminent colleagues asked amazing questions such as 'what do you really do in that place? Or, 'What are you a geologist, doing in a museum? Such was the misunderstanding of the role of a natural history museum in national development, that both the university and government did not put the building on a priority list, either for capital or staff development.

When I became an Acting Director in 2006, Professor A. A. Adediran was the Deputy Vice-Chancellor and then acting Vice Chancellor, who gave museum so much support in releasing vehicle and funds for my many travels, in search of funds to complete this building. Meanwhile I offered two prayers to the God of heaven and earth who owns all silver and gold and who has power to succeed.

- "You O God have always helped me to turn a wilderness to a highway and a desert to a watered land, in my Christian adventures. Help me this time again Lord".
- "You O God have said ' In all labour, there is profit'. Do not let me labour in vain or bring forth for trouble in this matter of the museum."

I then went ahead to search for money for the building. I, with my colleagues in the Museum visited the National assembly, Federal Ministries and government parastatals and non governmental agencies such as the National Conservation Foundation, carrying with us the architectural design of this building. And in my desperation, we visited even the British American Tobacco company! In most of these places, we got more than our fair share of negative accolades. In the midst our distress and desperation, a light appeared at end of the tunnel, when someone gave me an idea that the A.G Leventis Foundation may be willing to help.

Also, at that stage came on the scene, this rare gem of a vice-chancellor, Professor Michael Faborode, who thereafter became a notable benefactor, in the story of the Natural History Museum. I could recollect that, on his first outing as a Vice-Chancellor to All Soul's Chapel, I, (arrayed in my priestly robe) called him aside and stuck my hands to him and said. 'This building must be completed during your tenure'. And he said. 'Amen provided we can get the funds'. To me, that brief conversation was a 'covenant', a legal document between the two of us, in the presence of God and His hosts. That officio-spiritual backing was all I needed to break the logjam, to crack the evil code, and dislodge and flush out the rogue 'gene' causing the stalemate, on the museum. With that commitment legally extracted from the vice-chancellor, I went ahead to deploy the forces of heaven for assistance in the building project. (The story of this profound intervention by the A.G Leventis Foundation, and the various contributions of members of this administration- the Deputy Vice-Chancellors, Registrar etc- is being packaged and is reserved for the day of commissioning of the Museum building). Thus Natural History Museum has prospered under the current management such that it is now in a moderate position to attract some international funding and collaboration. However, there is still a lot to be done, to make this Museum a world class conservation facility, which will compare with its peers all over the world. For example, when I came to this University, the Museum had a brand new Jeep which was constantly used for field work, to build up our collection base, but things have changed dramatically.

What lessons we can learn from my adventures? The 'gods' who invented Yoruba metallurgy, glass making technology, royal pavement and forced environmental code on the Yoruba, among others, were actually men and women who were deified, as a result of the spirit of excellence found in them and their pristine scientific breakthroughs. They were like Daniel in the Bible, who had this commentary sticking out of his ministry. 'There is a man in thy kingdom, in whom is the spirit of the holy gods; and in the days of thy father light and understanding and wisdom, like the wisdom of the gods, was found in him;.... Daniel 5: 10-11 (Holy Bible KJV).

Whilst I was a Royal Society Fellow at the University College London, I noticed that each of the Departments and Institutes were actually built on rooms, where some great scientist or philosopher had lived -perhaps to breathe scientific inspiration into the staff and students. This gave me an inspiration to create an amazing scientific story that goes forth: There might have been a senate of a pristine Yoruba University. The senate members must have included all the inventors in the fields of metallurgy, pharmaceutics and geology and who perhaps won the equivalents of Nobel Prizes, who have been referred to in this lecture. These 'professors' were men of like passions like us but they excelled in doing certain things and together, they turned Yoruba land to a sprawling industrial centre, comparable to many advanced civilizations in the world. They invented steel and brass making by lost wax method – a method still used today to make aircraft engines. They invented glass making which has survived about 800 years of tropical weathering and created wind-powered self draughting furnaces capable of melting ironstones and quartzites.

My feeling is that the spirits of such ancestors rested on Obafemi Awolowo University Council, who prompted the architects to design the building of an architectural masterpiece, which now houses the Natural History Museum. They designed and formulated a museum which they said will be in the mould of the Smithsonian Institution, in the United States or the Natural History Museum in London, Britain. This museum is the only one of its kind in West Africa and is an emerging centre of excellence that must be supported.

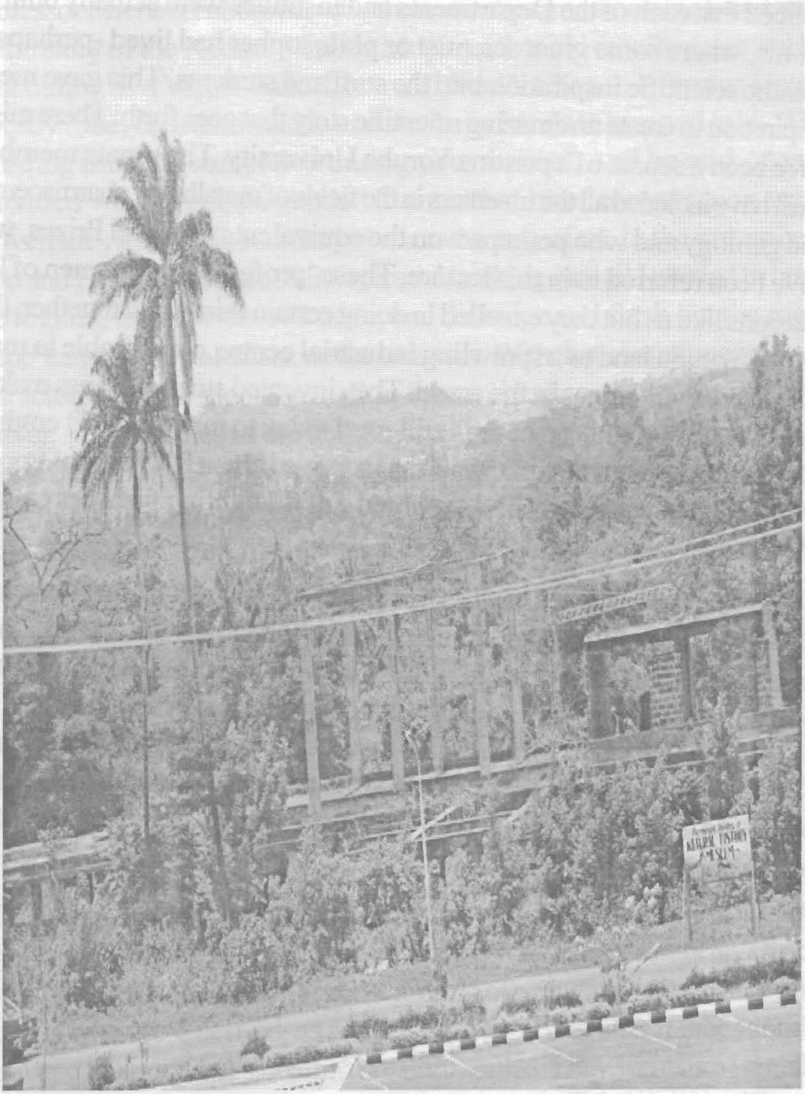


Fig. 9a- The uncompleted Natural History Museum Building (2006)

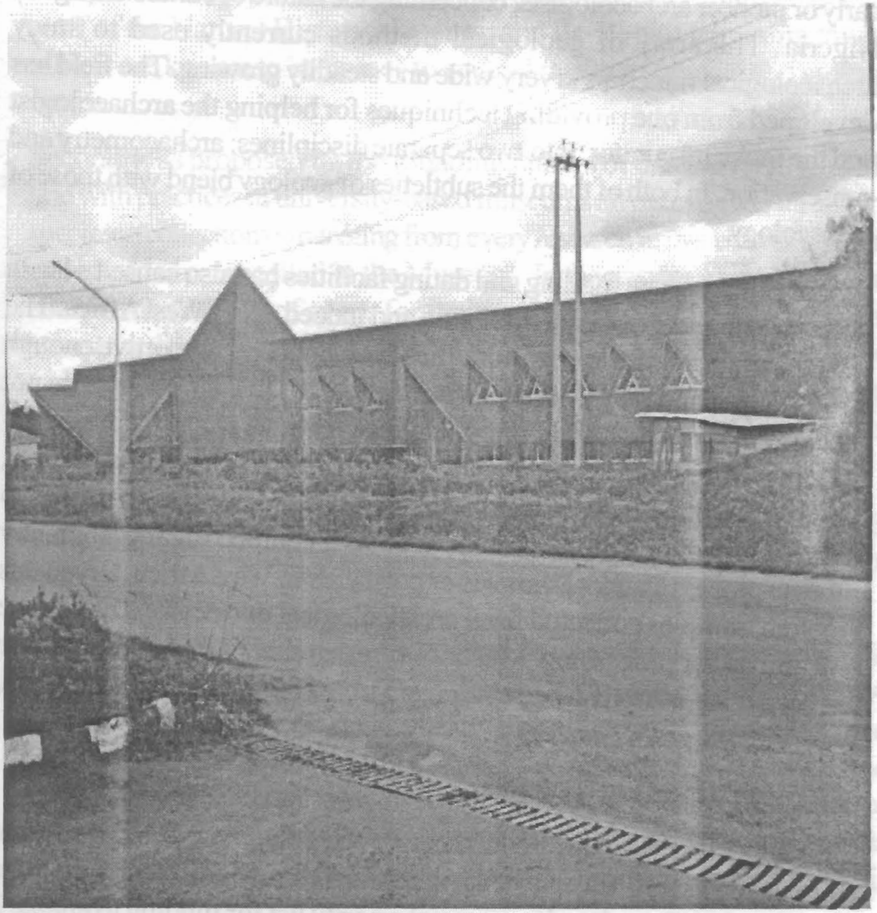


Fig. 9b. The Natural History Museum Building Now

RECOMMENDATIONS

Mr Vice- Chancellor Sir, the contribution of geology to archaeology has been greatly expanded in the last few decades, although in developing countries like Nigeria, research in this area, is very low. This lack and in places, paucity of geological data in archaeological work, has tended to encourage unrestrained speculation and taboos which in fact largely accounted for some insupportable hypotheses, being put forward by many early or pioneer archaeologists, concerning the nature of culture change in Nigeria. The array of geological methods currently used to study archaeological materials is very wide and steadily growing. The field has developed from one providing techniques for helping the archaeologist and the museum curator, into two separate disciplines: archaeometry and conservation. In both of them the subtleties of geology blend with those of archaeology.

The lack of adequate funding and dating facilities has also caused a lag in geoarchaeological research in Nigeria and indeed, all of West Africa. The governments of West African countries have not been supportive enough of museum work, partly because both the leaders and the peoples do not recognize the role a sound knowledge of the past can play in nation-building. Many sites threatened by construction work such as bridges, roads, houses and dams are not normally rescued because there are no sources of funding. There is up to now, no well-equipped dating laboratory either to process charcoal samples or potsherds in West Africa. Given this problem, samples collected from archaeological excavations have to be sent abroad for processing. Most of the research reported in this lecture has been done with advanced equipment from laboratories outside Africa. Where do we go from here?

My suggestions are as follows:

First, this university has a comparative advantage in having this great Museum on its soil. The university must immediately see it as an important asset and therefore place it on special priority list for funding to enable it build up its collection base, so it can attract international collaboration and thus become a world class conservation facility, to serve the West African Sub region. Fortunately for us, most of the facilities required to blaze the trail are now in place: a new building with space for staff, and guest researchers and with support from a world class sponsor of conservation studies, the A.G Leventis Foundation; an array of equipment now available in the University Central Laboratory and the Accelerator- based analytical equipment at the Centre for Energy Research and Development, which can be standardised to do non-destructive analyses of museum specimens;

a crop of museum professionals, and scientists who are within or associate staff of the Natural History Museum; and Ile-Ife and adjoining towns, which are known to be homes to several museum objects and cultural outfits.

Secondly, as proposed by the founding fathers of this university, and in line with practices in university-based museums all over the world, all type specimen collections emanating from every research in this University were expected to be deposited in the Museum. In the past, our colleagues had complained of lack of space for their precious specimens, but that has been solved through the landmark donation of this architectural masterpiece. I am now using this medium to appeal to my eminent colleagues to donate their scientific specimens and collection of art works to the Museum for proper preservation.

Thirdly, at the National level, funds should be made available to train museum professionals in scientific characterisation and prospecting of artefacts.

Fourthly I wish to appeal to our government to shield special scientific centres such as the Natural History Museum from political manoeuvres. A great idea has come out of Great Ife. Where ever such great ideas and initiatives are found, they must be supported without consideration of the usual political, leprous legacy of federal character, north- south divide or zoning. The government of this country must now provide funding for this museum and other centres of excellence, without consideration of their location.

Finally a law should be promulgated that no excavation works on roads, houses etc, should be embarked without inspection by competent Museum staff, to allow for urgent rescue excavation.

CONCLUSION

Mr Vice-Chancellor Sir, this is not a valedictory lecture because the journey has just begun. However, I must submit with humility and gratitude to God, that I have had a distinguished career as a Museum Geologist. My works on provenance studies and reconstruction of ancient technologies, using technical finds from archaeological excavation, have received international acclaim. My work on scientific reconstruction and corroboration of ancient story is unprecedented in Nigeria. I have applied the powerful geological tool to turn historical taboos and ethnographic data into scientific sense. In recognition of my research work, I was one of the privileged scientists asked to address conservators and scientists at the British Museum, during the just concluded exhibition titled Ife Kingdom Arts. I was the only African invited to address the meeting of the exclusive European Association on the History of Glass in Thessaloniki, Greece and the International Council on Museums which held recently at the only glass museum in the world- the Corning Glass Museum in New York. I had visited and lectured in more than twelve world class museums- from New Delhi to New York, from Beijing to Birmingham, from Lagos to London, from Abuja to Athens. As a museum geologist, I had become an octopus in solving scientific problems related to cultural and natural history. The beauty and blessings of my adventures is the deployment of the concept of collaborative research. I have conducted researches and have written papers with colleagues in the fields of chemistry, pharmaceutics, physics, archaeology, history, botany and entomology (e.g Ayansola et al 2003), deploying the subtlety of geology. I have rubbed shoulders with the most distinguished scholars in my field and I am able to hold my head high in any gathering of scholars anywhere in the world- as a proud alumnus of great Ife, and a representative of Nigeria. And in several nations and continents of the world, I have marketed Museum and the Leventis Foundation with my usual evangelical zeal. My scientific adventure has led to my appointment and election into the scientific committees of several international associations and committees.

I have been trying to replicate myself first by training four established museum personnel at master's level in our Master programme in conservation science. And in our efforts to popularize conservation practices, we have also started to train established museum professionals, as well as new entrants, in our newly approved Diploma programme in Conservation Science and Tourism. We are also collaborating with the National Commission for Museums and Monuments and the Conservator-Generals Office to train museum staff and conservators.

In all these adventures, I have prospered because the spirit of the holy God is within me; because the Holy Ghost wands are in my hands and because I am backed by the forces of heaven. Therefore I wish to sing.

'Who is like unto you O God, Amongst the gods, who is like you?

Glorious in holiness and fearful in praises, doing wonders Hallelujah'

Also, I acknowledge those who have encouraged me in the story of the Natural History Museum , especially the Executive Director of the A.G Leventis Foundation, Dr Abimbola Adewumi, who has become like an elder brother and a great benefactor; my great, powerful, colleagues at the Natural History Museum, who have laboured and supported this story especially with prayer and fasting on our Thursdays 'Happy Hours'.

I am especially indebted to my family, particularly my wife- a serene, cautious and quiet woman- who married a positively furious person, an incurable optimist and an adventurous man; who gives me stress- bursting treatments, each time I arrive home exhausted from my many adventures!

I THANK YOU ALL FOR YOUR ATTENTION

References

Adediran B. 1992, "The Early Beginnings of the Ife State", The Cradle of a Race (Ife from the Beginning to 1980), Akinjogbin I.A. (ed.) Sunray Publications Lagos, pp. 77-95

Adeniji D. (1977) Iron mining and smelting in Yoruba land. Inst. African Studies Occasional publication No 31.

Adesina, M.O. (1985) Reconnaissance survey of pre-colonial iron working sites in central part Oyo state: Iponrin via Ajase as a case study. M.Sc Thesis University of Ibadan 115p

Agbaje-Williams, B., 2001. Potsherd pavements and early urban sites in Yorubaland, Nigeria – an interim report. Nigerian Field 66, 93–104.

Akinjogbin, I.A., Ayandele, E.A., 1985. Yoruba up to 1800 A.D.. In: Ife: the Genesis of the Yoruba Race. Ikeja Publishers, Nigeria.

Afolabi M. and Ige, O.A. 1993 Analytical studies on some locally available talc samples. African Journal of Pharmacy. 23 :37-46.

Asubiojo O. I. and Ige ,O. A. 1992 Rare earth element patterns in ultramafic rocks of the Schist of belt of Southwestern Nigeria by Instrumental Neutron Activation Analysis. Journal of Radioanalytical Chemistry .158:193-200.

Ayansola A; Ige, O.A. and Adeyemi C. C. 2003. Mosquitoes associated with rock holes in the Okeiho-Iseyin area of southwestern Nigeria. *The Nigerian Field* 68: 3-17.

Bishop, R.L., Canouts, V., De Atley, S.P., Qoyawayma, J., Aikins, C.W., 1988. The formation of ceramic analytical groups: Hopi pottery production and exchange, D.C.1300–1600. Journal of Field Archaeology 15, 317–337.

Brill, R.H. 1999. Chemical Analyses of Early Glasses, Volume 1 and 2. Corning Museum of Glass, Corning.

Bronk, H. and Freestone, I. 2001. A quasi non-destructive microsampling technique for the analysis of intact glass objects by SEM/EDXA. Archaeometry 43, 517-527.

Davison, C., Giauque, R. and Clark, J.D. 1971. Two chemical groups of dichroic glass beads from West Africa. *Man*, New Series, 6 (4), 645-659.

Davison, C. 1972. *Glass Beads in African Archaeology: Results of Neutron Activation Analysis,Supplemented by Results of X-ray Fluorescence Analysis.* Unpublished PhD dissertation, University of California, Berkeley.

Durand, S.R., Shelley, R., Antweieler, R.C., Taylor, H.E., 1999. Trees, chemistry, and prehistory in the American southwest. Journal of Archaeological Science 26,185–203.

Durotoye, Bisi; Ige, O.A. and Awojide P. 1988. Small-scale mining of a clay deposit at Ipetumodu near Ile-Ife, Oyo state of Nigeria . Journal Mining and Geology. 27 :65-69.

Durotoye B. and Ige, O.A 1991 An inventory of talc deposits in Nigeria and its industrial potentials. Journal of Mining and Geology. 27:27-31.

Eluyemi, O 1986 .The living arts and crafts of Ile-Ife. Adesanmi Press, Ile-Ife Nigeria

Freestone, I. 1991. Looking into Glass. In, Bowman, S. (ed.), Science and the Past. London: British Museum Press [back]

Freestone I. 2006. An indigenous technology? A commentary on Lankton et al. Early primary glass production in Southern Nigeria Journal of African Archaeology 4:139-142

Frobenius, Leo 1913 The Voice of Africa , Volume 2. London : Hutchinson & Co. (2 vols.)

Hambolu, M. (1987) Esie soapstone images in new perspectives. 6th Annual Conference of the Archaeological Association of Nigeria, Ife, Nigeria.

Ige, O.A. 1985 Mineralogical and industrial properties of some Wonu Apomu talcs S.W. Nigerian Journal of Science 19 :121-130.

Ige, O.A and Asubiojo, O. 1991. Trace element geochemistry and petrogenesis of some metaultramafites in the Apomu and Ife-Ilesa areas. Chemical Geology, 91:19-32.

Ige, O.A., Okrusch, M; Schussler U; Schmadicke E, and Cook, N. J 1998. The metamorphic mafic-ultramafic rocks of Ife-Ilesa Schist Belt, SW Nigeria .. African Journal of Geology. 26: 593-618.

Ige O.A, 2000 Mineral chemistry of the mafic-ultramafic rocks of Mokuro-Ilesa area southwestern. Nigerian Journal of Science 35: 395-403.

Ige, O.A. & Ogunfolakan, B. 2001 Archaeological prospection using hosting rock characteristics: an example from archaeological sites in Igbajo SW Nigeria. ODU: A Journal of West African Studies 41, 23-31.

Ige, O. A, and Holness M.B.2002 Paragenesis, conditions and timing of the metamorphism of the metapelitic rocks in the Ilesha Schist Belt, Southwestern Nigeria . Journal of Mining and Geology 38:71-79.

Ige, O.A, 2002 Calculating temperature and pressure of metamorphism using the software Thermocalc: examples from metapelites of the Aiyetoro-Iseyin Schist belt, southwestern Nigeria . Nigerian Journal of Science 36 :187-196

Ige, O.A. & Rehren, Th 2002 The Yoruba ancient metallurgical advances,: Routine or Ritual ? ODU: A Journal of West African Studies 43:21-37

Ige, O.A. & Rehren, Th. 2003 Black sand and ironstone: iron smelting in Modakeke, Ife, Southwestern Nigeria . A Journal of the Institute of Archaeo-Metallurgical Studies, London 23:15-20 .

Ige O.A. 2003. The reconstruction of ancient smelting techniques among the Yorubas. Journal of Cultural Studies 5: 343-356.

Ige O.A., Durotoye B, and Oluyemi E.A 2005. Mineralogy and geochemistry of lateritic profiles on ultramafic rock bodies around Mokuro in Ile-Ife, southwestern Nigeria . Journal of Mining and Geology 41 : 11-18

Ige O.A. and Okrusch M. 2005. Distribution of Fe and Mg between coexisting garnet and biotite in interpreting P-T conditions of metamorphism of pelitic rocks in Ilesha area, southwestern Nigeria . Journal of Mining and Geology 41:151-161

Ige O.A; Olabanji S.O and Ceccato 2006. PIXE analysis of muscovites from tourmaline bearingpegmatites in southwestern Nigeria . Journal of Radioanalytical and Nuclear Chemistry, 268 : 47-51

Ige O.A., Tubosun I.A., Ogundare F.O. and Balogun F.A. 2006. TL Response of Muscovite Samples from granite pegmatite of Ile-Ife and Ijero-Ekiti, Southwestern Nigeria . Journal of Radiation Measurement. 41:967-970

Ige O. A. and Swanson S. E.2008 Provenance studies of Esie sculptural soapstone from southwestern Nigeria . Journal of Archaeological science vol. 35, no6, pp. 1553-1565

Ige, O.A ; Ogunfolakan BA; & EOB Ajayi 2009; Chemical characterization of some potsherd pavements from parts of Yorubaland in southwestern Nigeria In: Journal of Archaeological Science. - 36:1. - 90-99.

Ige, O. A. Rehren Th. Lankton J. W. 2009 Chemical characterization of archaeological glass beads from Ile-Ife, southwestern Nigeria .ISA

2008 International Symposium in Archaeometry. Sienna Italy p342-243

Ige, O. A. 2009. Yoruba Iron Metallurgy: Raw materials, routines and rituals World Iron Congress, London Archetype Publishers WIC2009.

Ige, O. A. 2009. Glassmaking in southwestern Nigeria. In European Conference on the History of Glass. Thessaloniki 2009

Ige O. A. and Adesina M. O 2009. Petrographic studies of archaeological ceramics from southwestern Nigeria . West African Journal Archaeology (in press)

Ige, O. A. 2010. Classification and preservation of glass beads from Ile-Ife, southwestern Nigeria. In: Glass and Ceramics Conservation 2010. Proceedings of the ICOM-CC Glass and Ceramics Interim Meeting. Corning Museum of Glass pp 63-74

Jackson , C.M. and Smedley, J.W. 2004. Medieval and post-medieval glass technology: melting characteristics of some glasses melted from vegetable and sand mixtures. Glass Technology 45, 36-42.

Jones, G.T., Bailey D. G and Beck, C. 1997. Source provenance of andesite artefacts using non destructive analysis. Journal of Archaeological Science 24:929-943

Lankton W. J., Ige O. A. and Rehren Th 2006. Early primary glass production in southern Nigeria Journal of African Archaeology, 4: 111-138

Lynott, M.J., Neff, H., Price, J.E., Cogswell, J.W., Glascock, M.D., 2000. Inferences about prehistoric ceramics and people in southeast Missouri: results of ceramic compositional analysis. American Antiquity 65 (1), 103–126.

Magnavita, S. 2003. The beads of Kissi, Burkina Faso. *Journal of African Archaeology* 1, 127-138.

Ogundiran, O.A., 2002. Archaeology and history in Ilare District (Central Yorubaland, Nigeria), 1200–1900 A.D.. In: BAR International Series 1090, Cambridge

Ogunfolakan, A., 2001. Luwo potsherd pavement: a unique aspect of Ife culture. Journal of Arts and Ideas 3, 88–97.

Olabanji S. O., Ige , O. A, Mazzoli, C, Ceccato, D, Ajayi E. O. B, Buoso, M, De Poli M, Moschini, G. 2005. Accelerator-based analytical technique in the evaluation of some Nigeria's natural minerals: Fluorite, tourmaline and topaz .Nuclear Instruments and Methods in Physics Research B .240: 350-355.

Olabanji S. O., Ige O. A, Mazzoli, C, Ceccato, D, Akintunde J, Buoso, M, De Poli M), Moschini, G. 2005. Quantitative elemental analysis of an industrial mineral talc, using accelerator-based analytical technique Nuclear Instruments and Methods in Physics Research B, 240: 327-332.

Olabanji, S.O., Olarewaju, V.O.,& Onabajo, O. O. (1990), PIXE analysis of museum soapstone sculptures from Esie, southwest Nigeria . Nuclear Instruments and Methods in Physics Research, B47, 415-420.

Ogunfolakan, Adisa (1987): Luwo Potsherd Pavement in Ile-Ife: 30 years of Nigeria Independence Moscow Academy of Science.

Onabajo, O. and Ige, O. A. 2005. Mineralogy and raw material characterization of Esie stone sculptures. Ife Journal of Science 7:113-118.

Rahaman, M.A., Ajayi,, T.R., Oshin, I.O., & Asubiojo, F.O.I. (1988) Trace-element geochemistry and geotectonic setting of Ile-Ife Schist Belt. In: Olujide et al (ed), Precambrian Geology of Nigeria (pp.241-256). Geological Survey of Nigeria .

Rehren, Th., Charlton, M., Chrikure, Sh., Hamphris, J., Ige, O. A. and Veldhuijzen, A.H. (2007): Decisions set in slag—the human factor in African iron smelting. In: S. LaNiece, D. Hook and P. Craddock (eds), Metals and Mines – Studies in Archaeometallurgy. Archetype, London , 211-218.

Robertshaw, P., Glascock,M., Wood, M. and Popelka, R. 2003. Chemical analysis of ancient African glass beads: A very preliminary report. Journal of African Archaeology 1, 139-146.

Schmidt, P (1996.) (ed). The Culture and Technology of African Iron Production. University Press of Florida.

Steponaitis VP, Blackman MJ, Neff H. 1996. Large scale patterns in the chemical composition of Mississippian pottery. Am Antiquity 61(3): 555- 572.

Tylecote, R.F.; J.N. Austin; and A.E. Wraith.1971 "The Mechanism of the Bloomery Process in Shaft Furnaces," Journal of the Iron and Steel Institute 204(1971): 342-363.

Usman, A.A., Speakman, R.J., Glascock, M.D., 2005. An initial assessment of prehistoric ceramic production and exchange in northern Yoruba, North Central Nigeria. Results of ceramic compositional analysis. African Archaeological Review 22 (3), 141–168.

Willett, F., with Blackmun, B. and Lister, E. 2004. The Art of Ife. A Descriptive Catalogue and Database (CD-ROM). University of Glasgow, Glasgow.