Early Primary Glass Production in Southern Nigeria

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Abstract

*Fragmentary glass-working crucibles, drawn glass beads and ritual glass objects (*aje ileke*) from Ile-Ife, southwestern Nigeria, were analysed using scanning electron microscopy (SEM-EDS), electron probe microanalysis (EPMA) and X-ray fluorescence (XRF). The very unusual high-lime, high-alumina glass lining the crucibles matched the composition of the dark blue drawn beads and some of the blue and green glass fragments in the* aje ileke*. Similar crucible fragments, glass cullet and drawn glass beads were recovered during Frank Willett's excavations (1956-63) of two sites in Ile-Ife, and Claire Davison's unpublished chemical analyses from 1972 show the same high-lime, high-alumina glass from Ita Yemoo, with radiocarbon dates from the eleventh to thirteenth century CE, and Orun Oba Ado, with radiocarbon dates from the eighth to twelfth century. Such high-lime, high-alumina glass has been found only in West Africa, including Igbo-Ukwu in southern Nigeria, and is not known from Europe, the Middle East or Asia, ruling out the possibility that the glass was imported. We interpret these findings to propose the primary manufacture of high-lime, high-alumina glass in sub-Saharan Africa in the early second millennium CE, with production centred in southern Nigeria, and quite possibly in or near Ile-Ife. The results of our study, combined with those of Davison, provide the first strong evidence for early primary glass production in sub-Saharan Africa.*

Résumé

*Des fragments de creusets pour la fusion du verre, des perles étirées et des objets rituels de verre (*aje ileke*) provenant d'Ile-Ife dans le sud-ouest du Nigeria ont été analysés à l'aide d'un microscope électronique à balayage en mode EDS, d'une microsonde et de la fluorescence X. La composition du verre à l'intérieur des creusets, calcique et alumineuse, est assez peu commune. Elle est similaire à celle de perles étirées bleu foncé et de celle de certains fragments de verre bleus et verts du* aje ileke*. Des fragments de creusets, des blocs de verre et des perles étirées identiques ont été mis à jour lors des fouilles archéologiques (1956-63) de Frank Willett portant sur deux sites à Ile-Ife. Les analyses non-publiées de Claire Davison de 1972 montrent l'existence du même type de verre calcique et alumineux à Ita Yemoo et à Orun Oba Ado, sites respectivement datés par radiocarbone du XI^{e} au XIII^{e} siècles AD et du VIII^{e} au XII^{e} siècles AD. Ce verre calcique et alumineux a été trouvé seulement en Afrique de l'Ouest, y compris sur le site d'Igbo-Ukwu au sud du Nigeria. Il est totalement inconnu en Europe, au Moyen-Orient ou en Asie, ce qui élimine la possibilité que ce verre soit importé. Nous interprétons ces observations comme la preuve de l'existence d'une production de verre calcique et alumineux en Afrique sub-saharienne au début du second millénaire de notre ère, centrée dans le sud du Nigeria et assez probablement à Ile-Ife ou dans ses environs. Les résultats de notre étude, combinés avec ceux de Davison, fournissent la preuve d'une production primaire ancienne de verre en Afrique sub-saharienne.*

Keywords: West Africa, Nigeria, Yoruba, Ile-Ife, glass, primary glass production, chemical analysis

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Introduction

Yoruba oral traditions suggest the existence of an ancient glass beadmaking industry at Ile-Ife, with the first beadmaker being Olokun, the Yoruba divinity of the sea, of wealth and of beadmaking (Aremu 1999: 156). Many of the well known Ife terracotta and brass sculptures include depictions of ornaments suggesting both large and small beads. In some cases, these beads may be identified by shape and traces of applied paint as indicating the red stone beads, *iyun*, and the blue glass beads, *segi*, still precious to the Yoruba (Willett 1967: 105). In addition, small, dark blue, glass beads were found either attached to or inside a number of the Ife brass heads, based on notes on such beads now in the collection of the British Museum. There is abundant material evidence to support a claim of early glassworking and beadmaking in Ife, as suggested by Frobenius (1913), Willett (1977), Euba (1982), Connah (2001: 170) and Eluyemi (1986), whose excavations in the Olokun Grove, a ten-acre forested area sacred to Olokun on the outskirts of Ife, revealed beads and bead fragments, broken crucibles and the remains of furnaces thought to have been used for bead-melting, in addition to iron smelting pits, iron slag and pieces of tuyeres (Eluyemi 1986: 4). Eluyemi suggests that 'fusing' of glass was done on the pounded clay interior of bowl-like furnaces, and lists by size and shape most of the over 360 beads found in the excavation and on the surface.

On display at the National Museum, Ife, are glassworking crucibles, dark blue drawn glass beads and a hemispherical cake of fused dark blue glass beads known locally as *aje ileke,* meaning 'the most prized bead' or the wealth of Olokun. Although none have been found in dated contexts, an *aje ileke* bought by one of the Landers in the market at Old Oyo in 1830, and reported to have been dug from the ground in Ife, was the very first Ife antiquity to be purchased by a European (Willett 2004: Chapter I.2, p. 2). Frobenius may also have been referring to *aje ileke* when he mentions that the ceramic pots found 'about eighteen feet' below the surface of Olokun Grove may have 'at the bottom a mass of fused bits of glass from one-eighth to one quarter of an inch in depth' (Frobenius 1913: 309). Although the original function of the *aje ileke* was apparently already unknown by 1830, *aje ileke* have been used in more recent times as bridal gifts for high-status weddings (Eluyemi, *pers. comm.* 1998), and are placed on important Yoruba shrines, including that in the Olokun Grove.

Three Yoruba glass beadmaking traditions

In the collection of the British Museum are a number of objects acquired in Ife in the 1940s and 1950s, providing evidence for three separate glass beadmaking traditions. The first of these is the partial melting of finely powdered glass, usually in some sort of mould, to form the bead. Powder-glass beads were being made at Ife at least by 1946, the collection date of a sample of finely ground blue glass and a number of coral-red powder-glass beads, although the craft itself may be much older. Writing in 1986, Eluyemi lists four Ife families still making powder-glass beads, and indicates the steps involved in the beadmaking process (Eluyemi 1986: 27, 30).

Documented also in 1946, a second beadmaking industry employed the lapidary-working of glass, at least some of which was broken from dark green and brown glass bottles and jars. The British Museum collection includes evidence for most of the steps in a *chaine operatoire* for lapidary-glass beadmaking: unworked glass fragments; small, partially knapped, blocks; shaped but not drilled beads and drilled beads in various steps of grinding and polishing. Glass retrieved from Olokun Grove was used as well for the lapidary beads, and some of the British Museum glass blocklets (***Fig. 1***), light to dark blue with yellow-green or orange dichroism, may reflect the Olokun Grove's use as 'a mine for old glass, suitable pieces of which are now drilled in Ife to make beads' (Willett 2004: Chapter I.2, p. 23). Such mining for glass in Olokun Grove has a long history, and Frobenius describes 'trenches, from five to fifteen feet deep' within the Grove (Frobenius 1913: 93), as well as old excavation pits as deep as twenty-four feet (Frobenius 1913: 309).

Evidence for the third industry, from both 1946 and 1956, consists of a number of dark and medium blue drawn glass beads. These beads differ from the imported European drawn glass beads found at most sites in West Africa in their greater length, their very irregular surface and their method of production. Most European and South Asian drawn glass beads were cut from long, thin-walled, drawn glass tubes, then reheated to round-off the sharp edges. The resulting beads are usually small, with diameter less than 1 cm and length less than 2 cm, and the outer surface is smooth because the glass was either reheated or worked originally at a high temperature. Many of the Ife drawn glass beads examined at the British Museum are exceptionally long, up to 6 cm (***Fig. 2***), with others

Fig. 1. Four small blocks of dichroic glass from Ile-Ife, acquired in 1946 by the British Museum. BM291 was sampled for our study. Photograph by author JL, courtesy of the British Museum.

Fig. 2. Four drawn glass beads found in the Olokun Grove, Ile-Ife, acquired in 1956 by the British Museum. BM19a, BM19c and BM19d were sampled for our study. Photograph by author JL, courtesy of the British Museum.

almost 2 cm in diameter. The bead surfaces are irregular and marked by prominent striations, sometimes described as cords (Davison *et al.* 1971: 657, note 2), indicating that the glass was worked while still very viscous, possibly the result of a relatively low temperature. The manufacturing technique for the beads in the British Museum is not known, although prominent longitudinal fold marks on some of the larger beads suggests that a warm glass pad had been folded around a wire or mandrel, and then stretched into a tube, a method used for making drawn beads first described by Horace Beck for drawn beads from Amarna, dating to the fourteenth century BCE (Beck 1928: 60). Eluyemi documents a different procedure used in Ife in 1986, where small drawn beads were made starting from the powder-glass tradition (Eluyemi 1986: 32), and some of the British Museum beads without fold-lines might have been made in this or a related way. It is likely that over the long duration of drawn glass beadmaking at Ife, a number of techniques were used to produce drawn beads of several types. There is no indication in the British Museum notes if their drawn glass beads were thought to be old when obtained; these beads appear to have been restrung and are not heavily worn, although there are definite marks of string wear at the perforations.

During the course of our research, we became aware of two very significant contributions to the study of glass technology in Ile-Ife. The first of these is the recent publication by Frank Willett, the principal archaeological investigator of Ife from 1956 to 1963, of a CD-ROM, *The Art of Ife* (Willett 2004), with many details of both his and others' excavations, and with a number of photographs of excavated and casual finds related to glassworking. In Willett's synthesis, the area of Olokun Grove was the center of glassworking in Ife.

Olokun Grove was first excavated by Frobenius in 1910, who found large numbers of glass beads and crucible fragments with attached glass at least five metres below the surface, and additional glassworking crucibles buried in shafts up to seven metres deep (Willett 2004: Chapter I.2, pp. 8-9). In *The Art of Ife* Willett illustrates eight complete crucibles (***Fig. 3*** for an example found in Olokun Grove) with both an inner layer of glass showing scraping marks as the crucible had been emptied, and partial vitrification on the outer surface indicating that the crucibles themselves had been placed in a furnace structure, with the incidental external glass forming through the interaction of the hot ceramic with wood ash loose in the furnace. There are photographs as well of crucible fragments with a glass lining in dark blue, medium blue, blue-green, pale green, olive green, yellow, black and red (Willett 2004: T841).

The second significant contribution dates to 1972, the year Claire Davison completed her PhD dissertation on *Glass Beads in African Archaeology: Results of Neutron Activation Analysis, Supplemented by Results of X-ray Fluorescence Analysis* (Davison 1972). Although Davison published one paper on her work

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Fig. 3. Two views of a glass-working crucible 'dug up "almost 3 feet in the ground" in the Olokun Grove' in 1963 (WILLETT 2004: Notes on T831A and T831B). Height 31.6 cm. Photographs courtesy of Frank Willett.

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with African beads (DAVISON *et al.* 1971), detailing some of the XRF (X-ray fluorescence) results, the rest of the work was not published, and Davison apparently left archaeology a few years after receiving her PhD; unfortunately, we have not been able to find any further information. Davison worked closely with Willett, and also with Thurstan Shaw, the excavator at another important, and early, southern Nigerian site, Igbo-Ukwu. The dissertation research includes many glass samples from both Igbo-Ukwu and Ile-Ife. It is difficult to overestimate the importance of Davison's work. Not only was she among the first, if not the first, to apply modern analytical techniques to the study of glass in sub-Saharan Africa, but many of the excavated materials that she studied are no longer available. In the case of Ife, Davison concentrated on glass from two of Willett's excavations: beads from Orun Oba Ado, with radiocarbon dates from the eighth to twelfth centuries, and crucible fragments, glass cullet and beads from Ita Yemoo, dating from the eleventh to thirteenth centuries (WILLETT 2004: Chapter I.3, p. 14; *see below* for a more detailed discussion). The materials excavated by Willett kept in the University Museum, now the Natural History Museum, Obafemi Awolowo University, were apparently stolen some years ago (WILLETT 2004: Preface, p. 3), making Willett's photographs and descriptions, and Davison's analyses, now irreplaceable.

Research questions

When we began this work, we hoped to find evidence for the use of crucibles to colour glass at Ife, and for the production of drawn glass beads similar to those from the collection of the British Museum. By the time we became aware of Willett's recent review and Davison's analyses, we realized that we had a much more exciting story to tell, with broad implications for both Ile-Ife and sub-Saharan archaeology– the story of early primary glass production in southeastern Nigeria. We will return to a detailed consideration of crucible use and bead production in a future publication, but, for this study, our primary research questions were:

- What is the nature of the glass found in the crucibles, the drawn glass beads and the *aje ileke*? How do the glass compositions relate to one another and to the results reported by Davison?
- Were the Yoruba making glass, and, if so, how?

Materials

The artefacts examined are from four sources (***Tab. 1***). First are two fragments of glass-lined crucibles (***Fig. 4***) from the collection of the Natural History Museum, Obafemi Awolowo University, Ile-Ife, Nigeria. Although the surviving documentation is not entirely

Specimen type	Quantity	Glass composition type	Source	Origin	Associated date (Radiocarbon dates ± 2 stdev)	Glass colour
Present study materials						
Crucible fragments with attached glass	2	HLHA (high CaO, high Al_2O_3)	Natural History Museum, Obafemi Awolowo University	Olokun Grove, Willett excavation (?)		dark blue (1), light blue (1)
Drawn glass beads from *aje ileke* 1	4	HLHA (high CaO, high Al_2O_3)	Purchased 1998	Ile-Ife market		medium to dark blue
Drawn glass beads from British Museum	3	HLHA (high CaO, high Al_2O_3)	British Museum Af1956,07.19a,c,d	Olokun Grove 1956		medium to dark blue
Cullet fragments on *aje ileke* 1	13	HLHA (high CaO, high Al_2O_3)	Purchased 1998	Ile-Ife market		blue and green
Cullet fragment on *aje ileke* 2	1	HLHA (high CaO, high Al_2O_3)	as above	Ile-Ife market		dark blue
Cullet fragments on *aje ileke* 1	11	high CaO, lower Al_2O_3, Na_2O<10 wt%	as above	Ile-Ife market		pale green
Lapidary-worked bead (unfinished)	1	high CaO, lower Al_2O_3, Na_2O<10 wt%	British Museum Af1946,18.293	Ile-Ife 1946		dichroic blue/yellow
Partially worked blocklet	1	high CaO, lower Al_2O_3, Na_2O<10 wt%	British Museum Af1946,18.291	Ile-Ife 1946		dichroic blue/yellow
Cullet fragments on *aje ileke* 2	6	probable mixtures of HLHA glass with soda-lime glass	Purchased 1998	Ile-Ife market		green
Cullet fragments on *aje ileke* 3	1	soda glass with moderate CaO, lower Al_2O_3	as above	Ile-Ife market		olive green
Drawn glass beads from *aje ileke* 3	4	Mixed high CaO and soda-lime	as above	Ile-Ife market		green
Drawn glass bead from British Museum	1	soda-lime glass	British Museum Af1946,18.279	Ile-Ife 1946		medium blue
Powder-glass bead	1	soda-lime glass	Olokun Grove 1998		possibly made in 1960s	medium blue
Small dark blue bead attached to brass head	1	mixed alkali, high Al_2O_3, MnO, CoO	British Museum BM 17.2	originally attached to Ile-Ife brass head	possibly Wunmonije Compound 12th to 15th c. (TL dates)	dark blue
Selected Ife glasses in DAVISON 1972						
Crucible fragments with attached glass	8	HLHA (high CaO, high Al_2O_3)	Olokun Grove (2), Ita Yemoo (6)	Willett excavations	Ita Yemoo 11th-13th c.	blue-green (2), cobalt-blue (5), black (dark green) (1)
Cullet fragments	12	HLHA (high CaO, high Al_2O_3)	Olokun Grove (5), Ita Yemoo (7)	Willett excavations	Ita Yemoo 11th-13th c.	dichroic (1), blue-green (1), cobalt-blue (7), black (2), green (1)
Corded dark blue cane beads	12	HLHA (high CaO, high Al_2O_3)	Ita Yemoo (10), Orun Oba Ado (2)	Willett excavations	Orun Oba Ado 8th-12th c.	cobalt-blue
Dichroic cane beads	14	HLHA (high CaO, high Al_2O_3)	Ita Yemoo (11), Orun Oba Ado (3)	Willett excavations		dichroic blue/yellow
Blue-green beads Group I	5	HLHA (high CaO, high Al_2O_3)	Ita Yemoo (5), Willett excavations	Willett excavations		blue-green
Ile-Ife Dav ORU-82	1	HLHA (high CaO, high Al_2O_3)	Orun Oba Ado	Willett excavations	Orun Oba Ado 8th-12th c.	long cylindrical bead, cobalt-blue with 4 red stripes
Black barrel bead	1	HLHA (high CaO, high Al_2O_3)	Ita Yemoo Dav ITA-27U	Willett excavations	Ita Yemoo 11th-13th c.	black
Crucible fragments with attached glass	3	lower CaO, variably high Al_2O_3, Na_2O<10 wt%	Ita Yemoo (3)	Willett excavations	Ita Yemoo 11th-13th c.	blue-green (3)
Dichroic glass fragment	1	high CaO, lower Al_2O_3, Na_2O<10 wt%	British Museum, 'number 291'			dichroic blue/yellow
Small dark blue beads attached to brass heads	3	mixed alkali, high Al_2O_3, MnO, CoO (two beads XRF only)	Wunmonije brass head		Wunmonije 12th to 15th c. (TL dates)	dark cobalt-blue
Selected Igbo-Ukwu glasses in DAVISON 1972 (bead types as defined in SHAW 1970)						
Glass beads Type N3 (diam. variable)	4	HLHA (high CaO, high Al_2O_3) (1 out of 4)	Igbo Isaiah or Igbo Richard	Shaw excavations	8th-12th c. (wooden stool)	cobalt-blue
Glass beads Type S (diam. <3mm)	2	HLHA (high CaO, high Al_2O_3)	Igbo Richard	Shaw excavations	8th-12th c. (wooden stool)	green
Glass beads Type V (diam. <3mm)	3	HLHA (high CaO, high Al_2O_3) (colourless glass)	Igbo Richard	Shaw excavations	8th-12th c. (wooden stool)	colourless with red outer layer
Glass beads Type T (diam. <3mm)	3	Davison's Type II glass with high Al_2O_3	Igbo Richard	Shaw excavations	8th-12th c. (wooden stool)	grayish yellow
Glass beads Type X (cylindr., diam. ca 6mm)	1	mixed alkali, lower CaO, high Al_2O_3	Igbo Richard	Shaw excavations	8th-12th c. (wooden stool)	brownish red with four sets of stripes
Other West Africa glasses in DAVISON 1972						
Dichroic cane beads	5	HLHA (high CaO, high Al_2O_3)	Old Oyo (1), Ilesha excavation (1), Koumbi Saleh (1), Gao (1), Ossi River site (1),		mostly surface finds	dichroic

Tab. 1. Glass samples in present study plus selected glasses from DAVISON 1972 by type, quantity, composition, source, date (cal C14 unless indicated; all dates CE) and colour.

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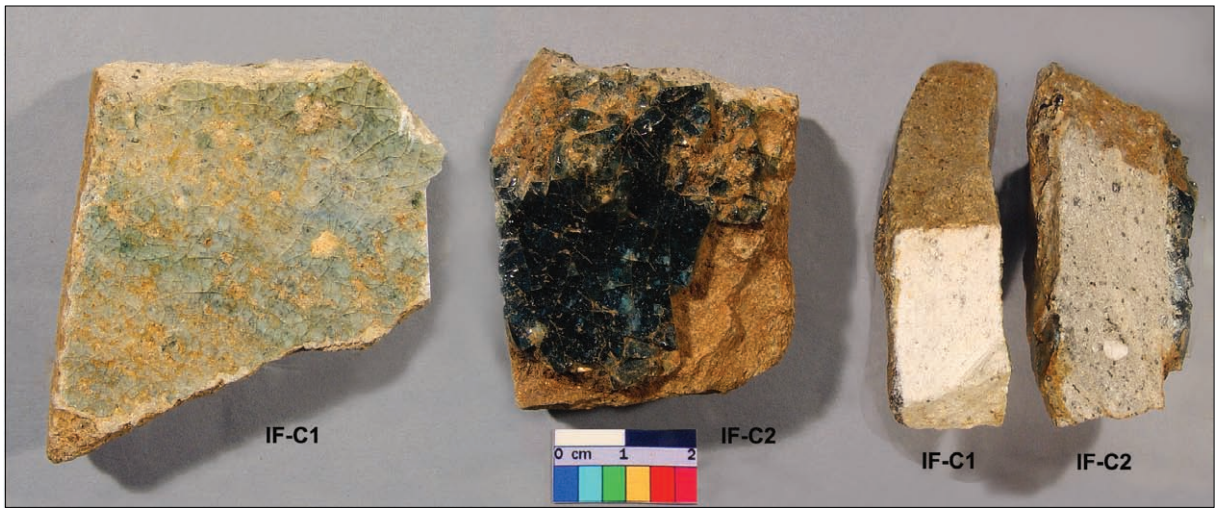

Fig. 4. Composite view of the two crucible fragments analyzed for this study, from the Natural History Museum, Obafemi Awolowo University, Ile-Ife. Photographs by author JL, all to same scale.

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clear, these objects were apparently recovered from a grave in the Olokun Grove. The fragments are relatively small, not exceeding six cm in maximum length, but they clearly originate from much larger vessels, as indicated by their curvature. Both pieces are from the lateral walls, with thicknesses varying from 14.8 to 18.1 mm, and are consistent with the crucibles illustrated by Willett. The ceramic body varies from near-white with few if any visible coarse grains, to greyish and coarser. Both fragments have a layer of glass on their inner surface, light blue and very thin (IF-C1), and dark blue (IF-C2) with a thickness of several mm. The outer surfaces of the crucible fragments show variable vitrification, with the glassy phase pale green to brown in colour.

Second are four *aje ileke*, purchased in the Ife market in 1998 (***Fig. 5***). *Aje ileke* 1, with the greatest number of dark blue drawn glass bead fragments (***Fig. 6a*** and cover photograph for a cross-section of *aje ileke* 1), was most extensively studied; samples from two others, *aje ileke* 2 and 3, were analyzed as well. *Aje ileke* 1 was selected because it appeared to be the oldest of the four, and most resembled the examples illustrated by Willett. All four of the *aje ileke* contain both cullet and beads, with a variable degree of fusion. The lateral and lower surfaces are smoother than the upper surfaces, and the lower surface is gently rounded, as shown in ***Figures 5*** and ***6***. Although the *aje ileke* were likely formed in some kind of mould or crucible, there must have been a parting layer of some sort to prevent the glass from adhering to the crucible or mould surface, since there is no ceramic or metal oxide layer, as seen most clearly in the cover photograph of a section through *aje ileke* 1. This absence of adherent ceramic indicates that the *aje ileke* may have been intentionally produced, rather than resulting from an interrupted step in the melting of glass scrap. In addition, for at least some of the *aje ileke* it appears that the basal cullet layer was melted for a longer period of time, so that the cullet fragments form smooth layers, while the surface beads and cullet were added later and only partially fused.

Third are dark blue and green drawn glass beads (***Fig. 5***, *aje ileke* 3, and ***Fig. 6a***), extracted from or sampled from the *aje ileke*. All of the drawn beads are short cylinders, possibly broken from longer examples, and most are marked by obvious longitudinal striations.

Fourth are various glass beads in the Ile-Ife collection at the British Museum (***Fig. 2*** for one group of these) along with a blue powder-glass bead from Olokun Grove, collected in 1998. We took micro-samples from five of the British Museum beads, four from the long, irregular beads described above and one from a small drawn bead that had been held in place by clay on Ife brass head number nine in the National Museum of Nigeria, as well as from the Olokun Grove powder-glass bead. In addition, we sampled a small block of blue dichroic glass (***Fig. 1***, BM291) shaped as a blank for the lapidary-working process, and a small, unfinished, dichroic lapidary glass bead.

The Ile-Ife glasses studied by Davison, primarily from Orun Oba Ado, Ita Yemoo and Olokun Grove, include similar types of materials although in larger num-

Fig. 5. Front and back views of the four *aje ileke* in this study. Photograph by author JL.

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Fig. 6. Detailed top and side views of *aje ileke* 1, with drawn glass beads and cullet on the surface (6a) and partially fused, layered cullet in cross-section (6b). Photographs by author JL.

bers, and are summarized in ***Table 1***, along with selected beads from Igbo-Ukwu. In particular, Davison emphasized two groups of beads found at Ile-Ife: 'corded' and dichroic. Both of these types were blue in reflected light, although the dichroic beads were yellowish green to orange in transmitted light. The one black and white illustration shows what appear to be similar-looking broken drawn tubular beads, 14 to 17 mm long and 5 to 6 mm in diameter (Davison 1972: 251). Davison's illustrated beads most closely resemble the broken beads on the surface of *aje ileke* 1, and are unlike the much larger Ife glass beads in the British Museum.

Methods

We performed microscopic and chemical analyses on the crucible fragments as well as on all of the glass samples listed above. The crucible fragments and the *aje ileke* 1 and 2 were sectioned with a diamond-coated cutting wheel, and the resulting crucible specimens and a group of beads and glass fragments removed from *aje ileke* 1 were set in epoxy resin and polished to a 1µm diamond paste finish. The cross-sectional fragments of *aje ileke* 1 and 2 were likewise polished, although without embedding because of their large size. The other glass specimens were sampled using a quasi-non-destructive diamond micro-sampling technique (Bronk & Freestone 2001: 518). Some of the samples were first analysed qualitatively using energy dispersive XRF (X-ray fluorescence) to determine the major and trace elements present, and all samples were carbon coated to prevent surface charging and distortion of the electron beam during analysis. All analyses were done in the Wolfson Archaeological Science Laboratories at the Institute of Archaeology, UCL, using a JEOL superprobe JXA 8600 for electron probe microanalysis (EPMA) of the embedded samples, and either a JEOL 35 or Hitachi S-570 scanning electron microscope equipped with energy-dispersive spectrometry (SEM-EDS) for the *aje ileke* cross sections and the micro-samples. EPMA operating conditions were set with an accelerating voltage of 15kV and a working current of 60 x 10^{-9} A, with scanning in a continuous raster pattern at 800x magnification, covering an area of approximately 280 µm^2, in order to avoid migration of sodium ions from the electron beam (Shugar & Rehren 2002: 147). For both techniques, the elemental concentrations of twenty major and minor elements in the glass were calculated using a ZAF program, with the oxides determined stoichiometrically. The precision and accuracy of both EPMA and SEM-EDS were checked using several glass standards, and, for SEM-EDS, were generally within 10 % for elements present in amounts greater than 1 %, and closer to 20 % for elements present at lower levels, in line with expectations as suggested by Freestone *et al.* (2000: 69). Precision, accuracy and detection limits were better by a factor of five to ten for EPMA. A recent blinded SEM-EDS analysis of standard glass Corning B flaked microsamples gave results somewhat better than expected, with all major oxides and even such minor components as MnO, CuO and P_2O_5 within 12 % of published values.

The analyses in Davison's 1972 dissertation of most interest to us were done by neutron activation analysis (NAA), an excellent technique for bulk analysis of glass samples, although less used today because of the need for a cyclotron to provide high energy neutrons to excite the samples. Gamma rays characteristic for the elements present in the excited material are measured by spectrometry, and converted to element concentrations. In Davison's technique, each sample received two neutron bombardments, the first brief and immediately followed by analysis for short-lived radioactive isotopes, and the second longer and

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a few days later, in order to measure the medium- and long-lived isotopes. Davison's methods were based on those reported by Perlman & Asaro (1969: 22), and are roughly comparable to NAA techniques used in more recent studies (Gratuze & Barrandon 1990: 156; Hancock *et al.* 1994: 256).

Although Davison does not give a detailed presentation of detection limits and accuracy for her method, she explains that standards were used to ensure accuracy. In presenting her results, Davison was careful to include only those elements that could be precisely determined, defining imprecise results as those where the 'counting error for a particular element is greater than 20 % of the concentration in one-third or more of the samples' (Davison 1972: 33). Thus, the actual elements listed vary from series to series, and, in many cases, the compositions of some of the common elements most useful for interpretation, such as silica, calcium, potassium and magnesium, are not given other than as broad ranges for the entire group of samples. Obviously, this lack of data for important elements would have made the archaeological interpretation of the results much more difficult.

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Results

Crucible ceramics

The investigation of the crucible fragments (***Fig. 4***) by light and electron microscopy revealed a uniform level of moderate vitrification of the ceramic paste throughout the samples and the presence of large amounts of fine quartz particles. These are typically shattered and ruptured as a result of the heating of the crucible; some begin to react chemically with the paste as part of the vitrification process. A few inclusions of iron and titanium oxides were found, likely residual ilmenite particles from the raw material. The porosity of the crucible fabrics is partly to fully rounded, in line with the observed level of vitrification of the ceramic paste; larger voids are typically elongated more-or-less parallel to the outer surfaces of the crucibles. These may represent evidence for organic material in the clay mixture, but it is unclear whether they are a natural component of the clay, or intentionally added temper. The quartz grains make up less than 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 were a natural sand component in the clay rather than added temper.

The chemical composition of the fabric is characterised by a 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% are potash, at around 3 to 3.5 wt%, and iron oxide, at 1.5 to under 2 wt%. Lime, soda, titania and magnesia are mostly present at levels of one third of one percent. Vitrified areas within the ceramic body are somewhat richer in soda, at just over 1 wt% and potash, 7 wt%. No other oxides were detected by SEM analyses, identifying this as a particularly refractory material, based on a very rich kaolinitic clay.

Crucible glass

The results of the SEM-EDS and EPMA analyses of the crucible glass and glass bead samples are summarized in ***Table 2***. The glasses adherent to the two crucible fragments have similar compositions. Both lime and alumina contents are remarkably high (referred to here as HLHA, or high-CaO, high-alumina), although the glass on crucible 1 (IF-C1), with a slightly paler colour, was lower in lime, and possibly higher in copper. We measured a number of different areas of glass on crucible 2 (IF-C2), finding significant variation in the levels of soda, potash, magnesia, copper and cobalt. In particular, there appear to be two subtypes of HLHA glass in crucible 2: sixteen areas had magnesia near or below the detection limits, while three of the measured areas had magnesia contents close to 2.5 wt%, with a corresponding decrease in soda and increase in potash compared to the rest of the crucible glass. In all cases the higher magnesia was accompanied by significantly higher phosphate. Although reaction with the crucible wall could cause regional compositional variation within the adherent glass, as noted by Verita *et al.* for the glass found in soapstone melting pots from Torcello (2002: 270), there was little visible evidence for such reaction in the Ife crucible fragments examined with the scanning electron microscope, and, in addition, the ceramic body of the crucibles was very low in magnesia. Additional explanations could be incomplete mixing within a particular batch of glass, or possibly the presence in the same crucible of glass from more than one original batch. The Ife glass itself is of good quality, with few bubbles or unreacted ingredients, although some of the cullet and bead fragments on *aje ileke* 1 contained numerous bubbles, as seen in the cover photograph, that may be the result of reworking.

No.	Sample	Source	Colour	Method	SiO_2	Na_2O	CaO	K_2O	MgO	Al_2O_3	Fe_2O_3	TiO_2	MnO	CuO	CoO	SnO_2	PbO	ZnO	P_2O_5	Cl	SO_3	Sb	BaO
Crucible fragments with attached glass, IF-C1 and IF-C2, by area																							
HLHA (high CaO, high Al_2O_3), variable MgO, K_2O and Na_2O																							
1	IF-C1	glass attached to crucible	light blue	SEM-EDS	61.3	1.4	12.3	8.1	nd	15.3	0.8	0.1	0.2	0.2	0.05?	nd	nd	nd	nd	0.02?	0.2	nd	nd
2	IF-C2 area 5	glass attached to crucible	dark blue	EPMA	52.3	0.6	20.2	7.2	3.0	13.9	1.5	0.3	0.6	nd	nd	nd	nd	nd	0.6	nd	nd	nd	nd
3	IF-C2 area 6	glass attached to crucible	dark blue	EPMA	52.5	0.7	18.8	8.1	2.6	14.1	1.3	0.3	0.5	nd	nd	nd	nd	0.1	0.6	nd	0.02?	nd	0.05?
4-15	IF-C2 mean of 12	glass attached to crucible	dark blue	EPMA	57.3	4.1	18.1	2.8	0.07?	15.2	1.1	0.07?	0.6	0.04?	0.1	0.02?	0.02?	0.2	0.01?	0.01?	0.01?	0.04?	0.01?
16	IF-C2 area 1	glass attached to crucible	dark blue	SEM-EDS	54.2	0.6	18.0	8.8	2.4	13.8	1.3	0.4	0.5	nd	nd	nd	nd	nd	0.7	nd	0.08?	nd	nd
17	IF-C2 area 2	glass attached to crucible	dark blue	SEM-EDS	60.3	3.0	18.1	4.6	0.10?	12.5	0.7	nd	0.6	nd	0.08?	nd	nd	nd	nd	nd	nd	nd	0.15?
18	IF-C2 area 3	glass attached to crucible	dark blue	SEM-EDS	58.7	3.7	18.8	2.8	nd	14.2	1.1	0.05?	0.7	0.05?	0.08?	nd	nd	nd	nd	nd	nd	nd	nd
19	IF-C2 area 4	glass attached to crucible	dark blue	SEM-EDS	58.4	3.9	17.1	2.8	nd	15.5	1.1	0.1	0.6	0.2	0.1	nd	nd	nd	nd	0.02?	0.1	nd	0.20?
Mean of 3 higher MgO HLHA					**53.0**	**0.6**	**19.0**	**8.0**	**2.7**	**13.9**	**1.4**	**0.4**	**0.5**	**nd**	**nd**	**nd**	**nd**	**nd**	**0.7**	**nd**	**nd**	**nd**	**nd**
Mean of 16 low MgO HLHA					**59.2**	**3.2**	**16.9**	**4.2**	**nd**	**14.5**	**0.9**	**0.1**	**0.6**	**0.2**	**0.1**	**nd**	**nd**	**nd**	**nd**	**nd**	**0.2?**	**nd**	**nd**
Standard deviation of 16 low MgO HLHA					**1.6**	**1.1**	**2.7**	**2.3**	**0.3**	**1.2**	**0.2**	**0.0**	**0.2**	**0.0**	**0.0**								
Drawn glass beads from *aje ileke* 1																							
HLHA (high CaO, high Al_2O_3), K_2O and Na_2O variable, MgO low																							
20	IF1B	drawn bead *aje ileke* 1	light blue	EPMA	57.8	6.3	15.5	3.4	0.02?	16.1	0.3	0.01?	0.4	0.02?	0.05?	0.01?	0.0	0.06?	0.0	0.01?	0.1	0.04?	0.0
21	IF1D1	drawn bead *aje ileke* 1, *in situ*	dark blue	SEM-EDS	51.8	5.4	21.9	3.8	nd	15.6	0.7	nd	0.7	0.2	0.10?	nd	nd	nd	nd	nd	nd	nd	0.2
22	IF1D3	drawn bead *aje ileke* 1, *in situ*	dark blue	SEM-EDS	53.6	6.4	17.5	3.3	nd	17.5	0.5	0.05?	0.4	0.3	0.07?	nd	nd	nd	nd	0.03?	0.2	nd	nd
23	IF1D2	drawn bead *aje ileke* 1, *in situ*	dark blue	SEM-EDS	54.8	6.8	16.8	2.6	nd	17.8	0.5	nd	0.5	0.2	0.06?	nd	nd	nd	nd	nd	0.1	nd	nd
Mean of 4 HLHA beads from *aje ileke* 1					**54.5**	**6.2**	**17.9**	**3.3**	**nd**	**16.8**	**0.5**	**nd**	**0.5**	**0.2**	**0.05**	**nd**	**nd**	**nd**	**nd**	**nd**	**0.1**	**nd**	**0.1**
Drawn glass beads from British Museum																							
HLHA (high CaO, high Al_2O_3), K_2O and Na_2O variable, MgO low																							
24	BM19a mean	large drawn bead, broken	dark blue	SEM-EDS	54.3	5.0	16.7	5.7	0.1	16.9	0.3	0.05?	0.3	0.2	0.03?	nd	nd	nd	nd	0.02?	0.2	0.10?	0.10?
25	BM19c mean	very long drawn bead	dark greenish blue	SEM-EDS	52.5	6.2	18.1	3.6	nd	16.9	0.7	0.02?	1.1	0.3	nd	nd	nd	nd	nd	nd	0.2	nd	0.5
26	BM19d mean	drawn bead, smaller diameter	medium blue	SEM-EDS	57.2	6.5	16.2	3.2	0.2	15.6	0.5	0.03?	0.4	0.2	0.1	nd	nd	nd	nd	0.04?	0.2	nd	nd
Mean of 3 HLHA beads from British Museum					**54.6**	**6.1**	**17.5**	**3.7**	**0.1**	**16.6**	**0.5**	**0.03?**	**0.5**	**0.2**	**0.05?**	**nd**	**nd**	**nd**	**nd**	**nd**	**0.2**	**nd**	**nd**
Cullet fragments from *aje ileke* 1 and 2, by glass type and area																							
HLHA (high CaO, high Al_2O_3), variable MgO, K_2O and Na_2O approximately equal																							
27	IF1.S	*aje ileke* 1	medium blue transp	SEM-EDS	56.0	4.6	17.9	4.7	0.12?	15.3	0.6	nd	0.6	0.06?	0.04?	nd	nd	nd	nd	nd	nd	nd	0.15?
28	IF1.K, darker area	*aje ileke* 1	dark blue transp	SEM-EDS	56.4	4.1	17.8	4.5	0.6	15.3	0.8	nd	0.5	0.10?	0.1	nd	nd	nd	nd	nd	nd	nd	nd
29	IF1.K, lighter area	*aje ileke* 1	dark blue transp	SEM-EDS	51.1	2.6	22.2	3.7	2.5	13.6	2.4	0.5	0.3	nd	nd	nd	nd	nd	1.1	nd	nd	nd	nd
30	IF1.M	*aje ileke* 1	pale blue	SEM-EDS	55.8	5.6	18.9	3.6	0.5	14.6	0.5	nd	0.4	nd	0.05?	nd	nd	nd	0.1	nd	nd	nd	0.2
31	IF1.T	*aje ileke* 1	dark blue transp	SEM-EDS	57.1	6.4	14.7	3.5	0.10?	17.2	0.4	nd	0.6	nd	0.05?	nd	nd	nd	nd	nd	nd	nd	0.15?
32	IF1.A	*aje ileke* 1	dark blue translucent	SEM-EDS	56.7	6.3	17.2	2.8	nd	15.8	0.5	0.1	0.6	nd	0.1	nd	nd	nd	nd	nd	0.1	nd	nd
33	IF1.P	*aje ileke* 1	pale blue	SEM-EDS	60.9	3.7	15.5	4.6	3.5	10.8	0.3	0.05?	0.4	nd	0.03?	nd	nd	nd	0.3	nd	nd	nd	nd
34	IF1.F	*aje ileke* 1	pale olive green	SEM-EDS	53.2	2.3	22.2	4.3	2.5	13.0	1.3	0.2	0.4	nd	nd	nd	nd	nd	0.6	nd	nd	nd	0.2
35	IF1.E	*aje ileke* 1	pale bluish green	SEM-EDS	58.5	4.6	16.1	5.4	0.3	14.8	0.5	nd	0.05?	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
36	IF1a large blue	*aje ileke* 1	dark blue dk	EPMA	58.0	6.7	14.8	2.8	0.0	15.8	0.3	0.02?	0.5		0.05?	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	IF1a small grayish blue	*aje ileke* 1	grayish blue	EPMA	52.0	6.0	20.2	3.9	0.0	16.3	0.5	0.03?	0.2	0.01?	0.01?	0.0	0.03?	0.0	0.05?	0.01?	0.0	nd	0.03?
38	If1a medium sized blue	*aje ileke* 1	dark blue	EPMA	53.9	6.1	19.3	3.7	0.0	15.7	0.4	0.0	0.4	0.0	0.03?	0.0	0.01?	0.0	0.1	0.01?	0.01?	0.0	0.0
39	IF1a small dk blue	*aje ileke* 1	dark blue	EPMA	54.1	6.8	15.5	3.2	0.0	16.8	0.5	0.0	0.7	0.0	0.08?	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
40	IF2.F	*aje ileke* 2	dark blue translucent	SEM-EDS	61.5	3.9	16.7	3.3	nd	13.4	0.5	nd	0.8	0.06?	0.1	nd	nd	nd	nd	nd	nd	nd	nd
Mean of 3 higher MgO HLHA cullet					**55.0**	**2.9**	**20.0**	**4.2**	**2.8**	**12.5**	**1.3**	**0.3**	**0.4**	**nd**	**nd**	**nd**	**nd**	**nd**	**0.7**	**nd**	**nd**	**nd**	**nd**
Mean of 11 low MgO HLHA cullet					**56.4**	**5.6**	**17.2**	**3.8**	**nd**	**15.5**	**0.5**	**nd**	**0.5**	**nd**	**0.05?**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**

Tab. 2 ***(continued on next page).*** Glass from Ile-Ife in present study by method of analysis and composition. Values listed are means of between 3 and 8 measurements. Values with question marks were within 2 (SEM-EDS) or 3 (EPMA) standard deviations of baseline. nd: not detected.

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No.	Sample	Source	Colour	Method	SiO_2	Na_2O	CaO	K_2O	MgO	Al_2O_3	Fe_2O_3	TiO_2	MnO	CuO	CoO	SnO_2	PbO	ZnO	P_2O_5	Cl	SO_3	Sb	BaO
Cullet fragments from *aje ileke* 1 and 2, by glass type and area (continued)																							
High CaO, low Al_2O_3, very low MgO, low K_2O, higher Na_2O cullet																							
41	IF1.B	*aje ileke* 1	pale yellowish green	SEM-EDS	70.9	7.8	17.6	0.3	nd	1.5	0.4	0.07?	0.9	nd	0.05?	nd	nd	nd	nd	nd	0.5	nd	nd
42	IF1.G	*aje ileke* 1	pale yellowish green	SEM-EDS	70.6	7.6	17.8	0.4	0.05?	1.6	0.4	0.04?	0.9	nd	nd	nd	nd	nd	nd	nd	0.5	nd	nd
43	IF1.H	*aje ileke* 1	pale yellowish green	SEM-EDS	74.7	7.9	14.0	0.6	0.2	1.8	0.5	0.1	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
44	IF1a small grayish green	*aje ileke* 1	grayish green	EPMA	72.5	8.9	12.9	0.7	0.2	1.8	0.4	0.1	0.04?	0.0	0.01?	0.0	0.0	0.0	0.03?	0.0	0.4	0.0	0.0
45	IF1.C	*aje ileke* 1	pale green transl	SEM-EDS	74.5	8.0	13.9	0.7	0.1	1.8	0.5	0.1	nd	nd	nd	nd	nd	nd	nd	nd	0.5	nd	nd
46	IF1.D	*aje ileke* 1	pale green transl	SEM-EDS	70.8	7.8	17.7	0.3	0.05?	1.5	0.4	0.1	0.9	nd	nd	nd	nd	nd	nd	nd	0.6	nd	nd
47	IF1.O	*aje ileke* 1	pale green	SEM-EDS	74.1	7.8	13.9	0.7	0.2	1.8	0.5	0.1	nd	nd	nd	nd	nd	nd	nd	nd	0.6	nd	nd
Mean of 7 high CaO, low Al_2O_3, very low MgO cullet from *aje ileke* 1					**72.6**	**8.0**	**15.4**	**0.5**	**0.2**	**1.7**	**0.4**	**0.1**	**0.9**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**nd**	**0.5**	**nd**	**nd**
High CaO, low Al_2O_3, low MgO cullet from *aje ileke* 1																							
48	IF1.L	*aje ileke* 1	pale green	SEM-EDS	70.0	8.9	13.6	1.0	0.8	2.7	1.0	0.2	1.2	nd	nd	nd	nd	nd	nd	0.1	0.5	nd	0.3
49	IF1.I	*aje ileke* 1	pale green	SEM-EDS	71.0	8.6	13.8	0.9	0.7	2.5	0.8	0.2	1.2	nd	nd	nd	nd	nd	nd	0.1	0.5		
High CaO, low Al_2O_3, moderate MgO cullet from *aje ileke* 1																							
50	IF1.R	*aje ileke* 1	green transp	SEM-EDS	65.7	5.4	20.4	1.0	2.2	2.3	1.4	0.05?	0.4	nd	nd	nd	nd	nd	nd	0.1	0.7	nd	0.15?
51	IF1a large green	*aje ileke* 1	green transl	EPMA	68.2	7.6	10.8	1.3	3.1	3.6	1.3	0.1	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Dichroic blocklet and beads from British Museum																							
High CaO, low Al_2O_3, moderate MgO, variable K_2O and Na_2O																							
52	BM293	unfinished cylindrical lapidary bead	light blue with green dichroism	SEM-EDS	64.2	5.2	20.7	0.6	2.7	3.7	1.2	0.2	0.1	0.2	0.02?	0.20?	nd	nd	nd	0.5	0.7	nd	nd
53	BM291	block of glass (bead roughout)	medium blue/ dichroic green and orange-amber	SEM-EDS	58.2	1.8	24.9	1.4	3.2	5.8	2.8	0.3	0.1	0.2	0.01?	nd	nd	nd	nd	0.4	0.6	nd	nd
Cullet fragments from *aje ileke* 2 and 3																							
Soda-lime glass, moderate CaO, low-to-moderate Al_2O_3, variable MgO, K_2O lower than Na_2O																							
54	IF2.D	*aje ileke* 2	dark green transp	SEM-EDS	63.4	10.3	13.6	2.3	0.2	7.0	1.7	0.2	1.1	nd	nd	nd	nd	nd	nd	0.02?	0.5	nd	nd
55	IF2.G	*aje ileke* 2	grayish green	SEM-EDS	64.4	10.9	11.8	2.6	0.3	6.7	1.8	0.2	1.2	nd	nd	nd	nd	nd	nd	nd	0.2	nd	0.13?
56	IF2.E	*aje ileke* 2	pale yellowish green	SEM-EDS	69.7	13.3	8.9	1.2	0.2	2.2	2.2	0.1	2.2	nd	nd	nd	nd	nd	nd	0.1	0.3	nd	nd
57	IF2.B	*aje ileke* 2	green transp	SEM-EDS	68.9	14.3	8.6	1.1	1.1	1.6	1.8	0.10?	2.0	nd	nd	nd	nd	nd	nd	0.03?	0.7	nd	nd
58	IF2.H	*aje ileke* 2	green transp	SEM-EDS	73.2	11.1	8.2	0.9	1.6	2.5	2.1	0.1	0.1	0.06?	nd	nd	nd	nd	nd	0.03?	0.2	nd	nd
59	IF2.C.1	*aje ileke* 2	dark green weathered	SEM-EDS	72.6	11.5	7.9	1.6	0.3	2.4	1.9	0.2	1.2	0.12?	nd	nd	nd	nd	nd	0.03?	0.2	nd	nd
60	IF3.5	*aje ileke* 3	olive green	SEM-EDS	66.2	15.5	5.9	0.9	0.2	2.0	2.7	0.1	2.7	0.2	nd	nd	nd	nd	nd	0.1	0.4	nd	nd
Drawn glass beads on *aje ileke* 3, *in situ*																							
Mixed high-CaO Ife and soda lime																							
61	IF3.1	*aje ileke* 3	yellowish green	SEM-EDS	73.4	16.5	5.7	0.8	0.7	1.0	1.0	0.1	0.1	0.2	nd	nd	0.8	nd	nd	0.1	0.3	nd	0.10?
62	IF3.2	*aje ileke* 3	medium green	SEM-EDS	64.1	12.0	9.5	2.7	1.0	7.1	1.6	0.3	1.1	0.2	nd	nd	nd	nd	0.04?	0.02?	0.3	nd	0.05?
63	IF3.3	*aje ileke* 3	pale green	SEM-EDS	48.7	12.5	12.5	1.6	0.4	2.5	1.5	0.2	1.2	0.1	nd	nd	nd	nd	0.05?	0.03?	0.4	nd	nd
64	IF3.4	*aje ileke* 3	pale green	SEM-EDS	67.3	17.0	7.1	1.8	0.4	2.8	1.3	0.1	1.1	0.12?	nd	nd	nd	nd	0.5	0.1	0.5	0.10?	nd
Soda-glass beads from British Museum and Olokun Grove																							
Soda-lime glass, moderate CaO, low Al_2O_3																							
65	BM279	long drawn bead with marked striations	medium blue transl	SEM-EDS	73.6	16.1	6.7	0.8	0.9	0.2	0.1	0.05?	0.03?	0.4	0.03?	0.2	1.0	nd	nd	0.1	0.7	nd	0.7
66	IFOG mean	powder glass tubular bead, Olokun Grove	medium blue	SEM-EDS	72.1	15.2	8.6	0.4	2.3	0.7	0.1	0.1	nd	0.2	nd	0.15?	nd	nd	nd	0.1	0.6	nd	nd
Small bead (one of eight attached by clay to brass head)																							
Mixed alkali glass, Al_2O_3>CaO, high MnO, high CoO																							
67	BM 17.2	small drawn (?) bead	dark blue opq	SEM-EDS	60.0	9.1	4.8	3.8	1.6	8.2	3.7	0.5	4.7	1.4	0.7	nd	nd	0.10?	0.2	0.6	0.3	nd	0.4

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Glass beads

The four dark blue beads removed from *aje ileke* 1 (***Fig. 6*** for these beads *in situ*) and the large, dark blue, drawn beads from the British Museum are all strikingly similar in composition, both to one another and to the low-magnesia, lower-potash HLHA glass from crucible 2, and, slightly less, to the HLHA glass from crucible 1. The crucible glass is somewhat lower in soda, possibly because of greater weathering on the thin layer of crucible glass.

Two of the blue beads, sample BM279 (not illustrated), a long drawn bead acquired in 1946, and the powder-glass bead collected in Olokun Grove in 1998, are soda glass with a similar composition, although differing in magnesia. Lime is moderate for both beads, ranging from 6.7 to 8.6 wt%, and alumina and iron are both very low.

The blue dichroic blocklet from the British Museum, BM291 (***Fig. 1***), and the unfinished dichroic bead also acquired in 1946 (BM293), have similar compositions. Both glasses have very high lime with moderate alumina and magnesia; soda and potash are relatively low, with combined levels between 3 and 6 wt%. The blue colour of these beads is probably due to light-scattering effects also linked to the dichroism, since both copper and cobalt levels are low. Among Davison's samples is one from the British Museum, numbered IFE 291. It is not clear which of the four blocks of group 291 was sampled, but the compositional result is similar to what we obtained.

The four green beads sampled from *aje ileke* 3 are soda glasses, with lime higher than alumina, although both oxides are variable.

The small, very dark blue, drawn bead in the British Museum, found attached by clay to an Ife brass head, is a mixed-alkali glass with alumina higher than lime. Cobalt is very high, 0.7 wt%, and is accompanied by elevated manganese. Davison analysed an apparently similar bead that was attached to one of the brass heads found in the Wunmonije compound in Ife. She reports very similar major oxide levels with the exception of lower lime, and high cobalt, 0.2 wt%, with a ratio of cobalt to manganese identical to that for the bead from the British Museum.

Glass cullet

The glass fragments analyzed from the cross-section of *aje ileke* 1 (***Fig. 6b***) fall into two distinct groups. All of the blue glass, and two of the green glasses, one olive green and the other pale bluish green, are very similar in compositions to the crucible glasses and the HLHA blue glass drawn beads. As with the glass adherent to crucible 2 (IF-C2), the *aje ileke* fragments show variability in magnesia, soda and phosphate, along with remarkable constancy in lime and alumina. Three of the fourteen cullet samples, coloured dark blue, pale blue and pale olive green, have the higher levels of magnesia and phosphate accompanied by lower soda seen in the three higher-magnesia crucible samples.

The other cullet fragments on *aje ileke* 1 are all pale green to pale yellowish green, and have variably high lime concentrations but much lower alumina, with the majority of the samples less than 2 wt%, and none higher than 3.6 wt%. Soda is less than 10 wt% and potash and magnesia are generally low, although two of the samples have magnesia values greater than 2 wt%. All of these fragments are very good quality glass, with few bubbles or inclusions, and they do not appear to have been remelted from beads or other finished objects, but rather to represent unworked glass. One remarkable physical difference between the two glass types is that all of the high-lime, low-alumina fragments have a rim of devitrification, visible as white outlines in ***Figure 6b*** and in the cover photograph of the cross-section of *aje ileke* 1, while none of the HLHA glasses are devitrified. The ability of alumina to diminish devitrification has been known since the nineteenth century (reported in Morey 1930: 718), and the *aje ileke* glasses provide an excellent illustration.

Lime and alumina

Figure 7, plotting lime versus alumina for the glass samples analysed in the present study along with some of those from Davison's dissertation, suggests three polar groups of glass, indicated by the three enclosed areas (these enclosures are for illustration only, and do not reflect statistical analyses of the glass samples). The first group contains the HLHA (high-lime, high-alumina) glasses, with both lime and alumina greater than 10 wt%, including crucible glass, dark blue drawn beads from our study and from both

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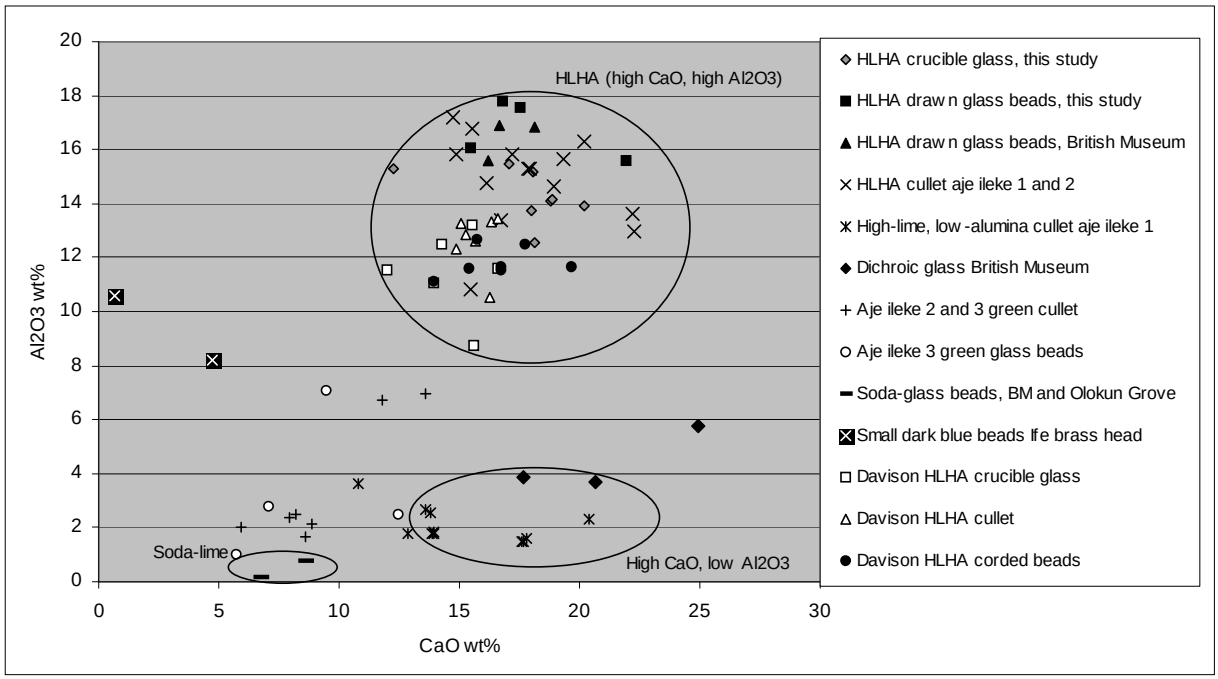

Fig. 7. CaO by Al_2O_3 Ile-Ife glass (enclosures for illustration only).

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of Willett's excavation sites in Ife, and a number of the fragments from *aje ileke* 1. The second polar group, with moderate lime and very low alumina, includes the two soda-lime beads in our study– the drawn bead acquired by the British Museum in 1946, and the powder-glass bead from Olokun Grove, said to be from the 1960s. The green high-lime glass from *aje ileke* 1, along with the dichroic blocklets and lapidary bead from the British Museum, make up the third polar group. The *aje ileke* 2 and 3 green glasses, along with the green drawn beads from *aje ileke* 3, generally fit between the HLHA glass and the soda-lime glasses.

Potash and soda

The plot of potash versus soda for Ife glass (***Fig. 8***) may be divided into the same three areas. The HLHA glass, with soda below 8.0 wt% and potash above 2.5 wt%, shows a negative correlation between potash and soda, with the trendlines for all of the HLHA groups having slopes between -0.9 and -1.7, with R^2 values as high as 0.9. Although the two small, high-cobalt, beads found with the brass heads have soda and potash levels below 10 and above 2.5 wt%, their relationship to this group is unclear. The two soda-lime beads are at the high-soda, low-potash end of the graph, while the third area of the graph, with soda less than 10 wt% and potash less than 2 wt%, again includes the dichroic glass from the British Museum and the *aje ileke* 1 green high-lime glasses. For these glasses, there is no apparent correlation between soda and potash. The green beads from *aje ileke* 3 and the *aje ileke* 2 and 3 glass fragments are generally intermediate, in absolute values, degree of correlation and trendline slope between the soda-lime glass and the HLHA glass.

Magnesia and phosphate

The phosphate and magnesia levels in the Ife glasses appear to divide the HLHA glass into two distinct groups: one with low levels of magnesia and phosphate and the other with distinctly higher levels (***Tab. 2***). For the six higher-magnesia HLHA glasses, higher magnesia correlates with lower soda and higher potash, particularly for the crucible glass. As mentioned above, all of the HLHA glass beads are low in both magnesia and phosphate. A plot of magnesia by phosphate levels for the higher-magnesia HLHA glass (not shown) does not reveal the positive correlation between magnesia and phosphate that might be expected if both magnesia and phosphate were introduced to the glass from the same source, for example, plant ash. Two factors may affect this result: 1. The magnesia values of the six glasses occupy a relatively

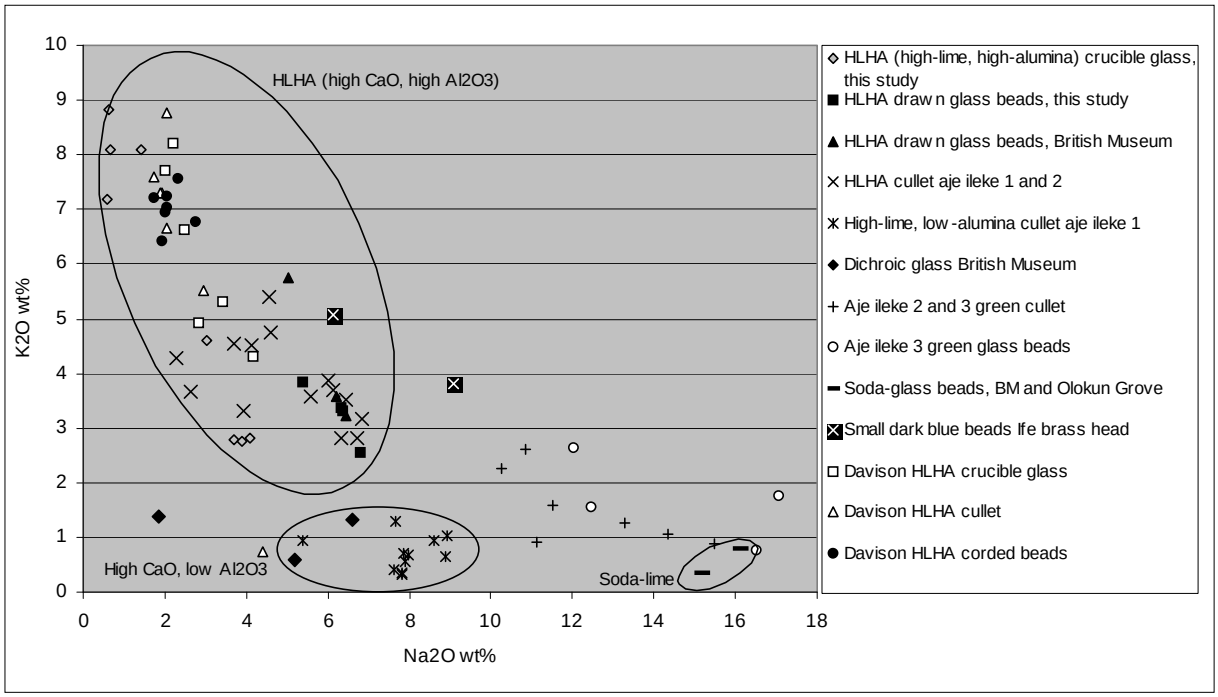

Fig. 8. Na_2O by K_2O Ile-Ife glass (enclosures for illustration only).

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narrow range, and 2. Although the SEM-EDS and EPMA determinations of phosphate are similar for these glasses, the SEM-EDS phosphate results may not be accurate enough to demonstrate correlation within this narrow range, particularly with so few samples. Unfortunately, magnesia and phosphate data are available from this study only, since Davison's results did not include either oxide.

Discussion: Three stories from Ile-Ife

Three stories emerge through the glass evidence from Ile-Ife. The first is told through the glass attached to crucible fragments found in various sites at Ife, the high-lime, high-alumina glass cullet analysed by Davison and found on *aje-ileke* 1, and the cobalt-blue drawn beads reported here, along with archaeological examples from Willett's excavations at Ita Yemoo and Orun Oba Ado, analysed by Davison. All of this glass has lime and alumina values high enough to be very unusual when found alone; found together, they are evidence for a glassmaking tradition unique to West Africa, and possibly unique to southern Nigeria and to the Yoruba culture.

The second story comes from the intact ceramic crucibles and hundreds of crucible fragments with attached glass found in and near Ife. The crucibles show a relatively uniform morphology quite unusual for glassworking crucibles, and were designed to be used, at least at times, with close-fitting ceramic lids (Willett 2004: Notes on T839). What were the functions of these crucibles, and is it possible that the glass itself was produced in them?

The third story is the actual technology used to make beads from the high-lime, high-alumina glass, as well as from the other glass types, some possibly local, found in the excavations of Shaw, at Igbo-Ukwu, and Willett, at Ile-Ife. While wound beads could be relatively easily produced in an incipient glass tradition, the production of small, drawn, beads is taken as the mark of a well-organized, sophisticated craft. The development of this craft in southern Nigeria is no less surprising than the development of advanced bronze or brass casting, such as from Igbo-Ukwu or Ile-Ife, and will, when more fully explored, provide fascinating insights into African technological traditions.

All three of these stories are long and incompletely understood. For this paper, we will concentrate on the first, and most astounding, story: the early primary production of glass in southern Nigeria.

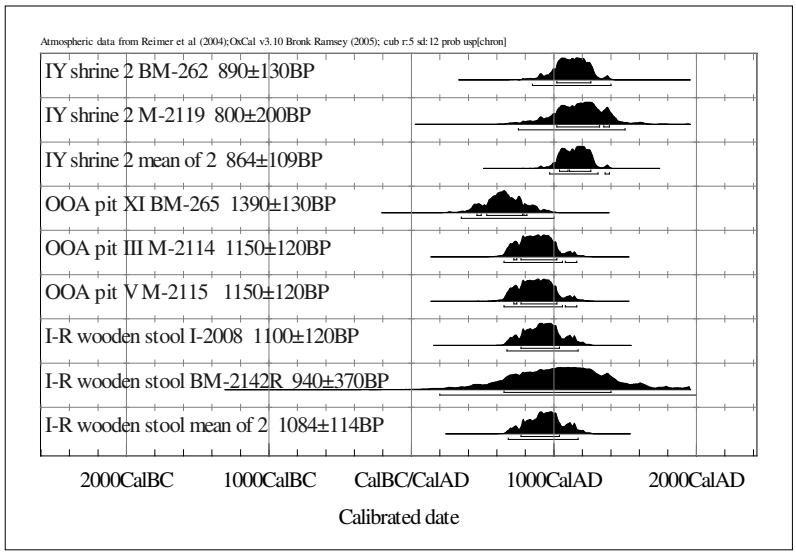

Fig. 9. Radiocarbon dates from archaeological contexts with evidence for high-lime, high-alumina glass. Radiocarbon dates in years BP (±1 standard deviation), along with the probability distributions of the calibrated dates from OxCal v3.10 with 2 standard deviation ranges. IY Ita Yemoo, OOA Orun Oba Ado, I-R Igbo-Richard. The dates for charcoal from Ita Yemoo shrine 2 and the Igbo-Richard wooden stool are also shown as weighted means (see text for discussion).

Primary glass production in southern Nigeria

When did this glassmaking tradition start and how long did it last? On what basis do we suggest 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 glass craftsmen?

Chronology

The HLHA (high-lime, high-alumina) Ife glasses analyzed by Davison include samples from two of Willett's excavation sites, both with radiocarbon dates. Although these dates have been discussed many times (most recently in WILLETT 2004: Chapter 1.3), those most associated with high-lime, high-alumina glass are reproduced in ***Figure 9***, along with the probability distributions of the calibrated dates, in order to illustrate the range and variability of the dating. Because all of the radiocarbon dates from both Ile-Ife and Igbo-Ukwu have high standard deviations, the probability distributions are rather wide. Where two radiocarbon results are known to be measurements of the same radiocarbon date, both accuracy and precision may be improved by combining the dates as a weighted mean (WARD & WILSON 1978), so that dates with lower standard deviations contribute more to the result. In ***Figure 9*** we show the individual dates as well as the weighted means for Willett's two charcoal samples from shrine 2 on pavement 7 at Ita Yemoo (WILLETT 2004: Chapter 1.3, p. 15), and for Shaw's two wood samples from the same wooden stool found in the grave at Igbo-Richard (SHAW 1995: 43). Whether or not combining these radiocarbon dates is justified will depend on such factors as the details of the sampling procedure and the species of tree (*e.g.* fast or slow growing), neither of which are known. For Ita Yemoo, the probability distribution for the combined date is restricted to the eleventh to thirteenth centuries (94.3 %, with an additional 1.1 % in the fourteenth century), while the individual dates extend from the tenth into the fourteenth or fifteenth centuries. For the wooden stool in Igbo-Richard, combining the dates makes less difference, since BM-2142R, with its high standard deviation, has little affect on the weighted mean.

Willett found terracotta sculpture, pottery, crucible fragments, cullet and glass beads at Ita Yemoo, and reports that the terracotta sculpture was found in shrine 2 on pavement 7 (WILLETT 2004: Chapter 1.3, p. 15). Although Willett does not specifically mention the beads or crucibles, Davison writes that the crucible fragments were found '*in situ*' at Ita Yemoo (DAVISON 1972: 267), most likely based on information from Willett. The shrine 2 radiocarbon date shown in ***Figure 9*** is thus our best candidate for a close relationship between the dated material and the excavated crucible fragments, and gives a date range from the eleventh to the thirteenth centuries if we accept the assumption that the two charcoal samples were either parts of the same bulk sample or were from wood of a similar age.

Willett's second excavation site, Orun Oba Ado, traditionally said to be the burial ground for the heads of the *obas* of Benin, was interpreted as being the earlier of his two excavation sites, based on the radiocarbon-

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dated charcoal samples included in ***Figure 9***. Six of the eleven 'burial pits' at the site were completely excavated (WILLETT 2004: Chapter 1.3, p. 14), and HLHA glass beads were found in at least three of these, along with a 'stone anvil,' of a type used in later times to drill glass beads, 'found 9 feet deep in Pit VIII' (WILLETT 1977: 22). Willett obtained five radiocarbon dates from Orun Oba Ado, all from charcoal fragments, and those from the three pits containing HLHA beads are included in ***Figure 9***, along with their two standard deviation ranges represented graphically. Neither Willett nor Davison mentions how many beads in total were found at Orun Oba Ado, but Davison analyzed one HLHA bead from Pit III, two from Pit V and one from Pit XI, with no indication for the source of the other two Orun Oba Ado HLHA samples. No cullet or crucible fragments were found at Orun Oba Ado. Although Willett suggests that the four later dates from Orun Oba Ado might be combined in order to decrease the variability, it is not clear from the dates themselves that they represent the same event, and Willett found no stratigraphic connection between the various pits (WILLETT 2004: Chapter 1.3, p. 14). Based on the dates shown here, we may conclude that the dated charcoal was very unlikely to post-date the twelfth century, and that a ninth to tenth century date was more likely. The charcoal from pit XI appears to be older. If these charcoals are representative of the entire fill materials, something that can now be neither proved nor disproved, the dates for the HLHA glass would be similar to those from Ita Yemoo, and possibly earlier.

The glass beads from Orun Oba Ado analysed by Davison fall into two groups: the first includes HLHA beads identical in composition to those found at Ita Yemoo. Most of these are cobalt-blue or dichroic drawn beads, although one is described as a cobalt-blue 'cane long cylinder, with four Indian red stripes' (DAVISON 1972: 273) but not illustrated. The second group of five beads is soda glass with alumina ranging from 3 to 7 wt%. The lime content was not precisely determined for these beads, but is given as a range from 8 to 14 wt%. Potash and magnesia levels were not measured, so it is difficult to be sure of the type of glass represented. The two main possibilities would be an Islamic-type soda-plant ash glass, particularly for the Orun Oba Ado bead with the lowest alumina, or a high-alumina, high-magnesia glass of the type reported by ROBERTSHAW *et al.* (2003: 144) as their Type B, found in southern Africa as early as the second quarter of the tenth century. Support for a South or Southeast Asian origin for this Type B glass comes from the high alumina levels, essentially unknown in European or Islamic glass, and the presence of similar glass at twelfth to fourteenth century Kota Cina, a harbour site on the North Sumatran coast (MCKINNON & BRILL 1987: 9). At any rate, the soda glass from Orun Oba Ado is almost certainly imported. In terms of dating the HLHA glass, the finds from Orun Oba Ado are only marginally helpful, both because of the unknown connection between the glass and the dated charcoals and because small numbers of beads may migrate from one stratigraphic level to another, something much less likely with crucible fragments. Perhaps our best conclusion would be that the evidence from Orun Oba Ado does not contradict that from Ita Yemoo, but neither does it lend strong support.

High-lime, high-alumina glass has been found at other sites in West Africa, including some with early radiocarbon dates. The most prominent of these is Igbo-Ukwu, 300 km southeast of Ife, excavated by Thurstan Shaw in 1959, 1960, and 1964. Shaw found over 165,000 beads, mostly glass, and divided them typologically into fifty different categories. DAVISON (1972: 305) and BRILL (1999, Vol. 2: 410-411) have analysed beads from a number of these types, finding high-lime, high-alumina glass in three of them: type N3, small, cobalt-blue, drawn beads; type S, small, translucent green beads; and type V, described by Shaw as 'beads of colourless glass with a thin covering on the longitudinal surface of a reddish brown colour, giving the appearance of beads of translucent violet brown' (SHAW 1970: 229), with a diameter of less than 3 mm. Type N3 beads are relatively common, with over 36,000 specimens from the Igbo-Richard grave site alone, but include several compositional groups, based on the differing analyses by Brill of Type N3 beads. Type S, with Brill's olive-green example described as wound, are rare, with fewer than 100 examples, all from Igbo- Richard. Type V beads, also found only in the Igbo-Richard burial, are more numerous, with 1083 examples.

The wooden stool in the burial chamber at Igbo-Richard was associated with a number of beads in the HLHA groups described above (SHAW 1970: Appendix IV), and samples of the wood gave two radiocarbon dates, shown combined in ***Figure 9***. The high standard deviation, even for the combined dates, results in a wide possible range from the eighth to twelfth century. Although Shaw suggests a narrower dating from 700 to 1020 CE for Igbo-Ukwu as a whole (SHAW 1977: 91), based on averaging all of the available dates, the actual date for the HLHA glass may be best represented by

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the wooden stool date in ***Figure 9***, since HLHA glass was not specifically associated with the other dated material, all of which was charcoal from the disposal pit at Igbo-Jonah, where few beads, and none from the HLHA groups, were found. At any rate, the eighth to twelfth century date for HLHA glass at Igbo-Ukwu supports the similar dates for HLHA glass from Ita Yemoo and Orun Oba Ado in Ile-Ife, and has the benefit of a more explicitly stated association of the dated material with the HLHA beads.

The three excavated areas from Igbo-Ukwu appear to have been in, or near, a center for high-technology bronze casting, producing bronze artefacts not found elsewhere. Because of the very limited nature of the excavations, and the type of contexts investigated, it is not surprising that no traces for bronze-casting technology were found. The same may be said for glass bead production, although the vast majority of Igbo-Ukwu glass beads are compatible with an origin in the Islamic or the South Asian world, based on the analyses by Brill and Davison. The relatively few beads with a high-lime, high-alumina composition may also be imports, although, in this case, imports from elsewhere in southern Nigeria. Alternatively, the HLHA beads themselves and even the glass could have been made locally, particularly since these specific bead types have not been reported from Ile-Ife.

In addition to those found at Igbo-Ukwu, high-lime, high-alumina glass beads with closely associated, early, radiocarbon dates have been reported from Gao, Mali (three examples, all cobalt-blue and dated by Insoll (Insoll 2000: 4) from the early to mid-eleventh to late fourteeth centuries (Robertshaw, *pers. comm. 2005*)); and Kissi, Burkina Faso (two examples, cobalt-blue, from Kissi cemeteries 13 and 14, where no graves post-date the eleventh century (Magnavita, *pers. comm. 2005*)). There are also examples found at Koumbi Saleh, Mauritania (one dichroic blue/yellow bead); Onikroga (one dichroic blue/yellow bead) and Ilesha (one dichroic blue/yellow bead), Nigeria and Elmina, Ghana (one dichroic blue/greenish bead) (data from Davison 1972: 272; Brill 1999, Vol. 2: 418). It seems reasonable to conclude from these isolated finds that high-lime, high-alumina glass was traded widely within West Africa beginning at an early date, although the character and extent of this trade are not known.

Other excavations at Ile-Ife have also revealed crucible fragments and glass beads, although none with chemical analysis of the glass. A possible glassworking and beadmaking site at Ayelabowo, one kilometre from Ita Yahoo, was explored by Adeduntan, and gave radiocarbon dates ranging from the eleventh to the fourteenth century (Adeduntan 1985: 165). Based on the published description, neither the type of beads being made nor the precise association of the dated material with the glass is clear, although Adeduntan mentions that half of the intact beads had no perforation (Adeduntan 1985: 165), which may indicate a lapidary rather than drawn-tube technique. Garlake's excavation at Woye Asiri in Ile-Ife uncovered a number of potsherd pavements and part of a broken glassworking crucible, along with seven other crucible fragments 'from five or six different crucibles to judge by the colour of the glass' (Garlake 1977: 89). Two of these sherds were actually incorporated into Pavement IX, and, while this particular pavement was not directly dated, Garlake suggests that the pavements were laid in the fourteenth century (Garlake 1977: 72). A crucible fragment from a secure seventeenth century context in the Yoruba town of Oshogbo (Ogundiran, *pers. comm.* 2005) may represent re-deposit of earlier material, but still suggests that such fragments were valued at that time; the association of an intact crucible with a shrine at Ita Yemoo (Willett 2004: Chapter II.29), although not found *in situ*, also reflects a high cultural value. Continued excavations in Ife, such as those by Eluyemi at Olokun Grove (Eluyemi 1986), will be very important in filling the gaps in the Ife glass tradition.

For the other end of the Yoruba glass tradition timeline we have the lapidary-worked glass beads, powder-glass beads and possibly the type of large drawn beads represented in the British Museum, acquired in the 1940s and 1950s. A limited production of powder-glass beads and some type of drawn glass beads continued until 1986, as described by Eluyemi (1986: 27), and it is possible that local workshops might open or close depending on the demand for new beads. The actual manufacture of glass from raw materials, and the melting and colouring of glass in crucibles, could have continued for several hundred years from its beginning, but was from a time beyond memory when Frobenius first excavated the mysterious glazed pots in Olokun Grove in 1910.

High-lime, high-alumina glass in context

How important was the HLHA glass at Ile-Ife? While we do not know what type of glass was uncovered in many of the above excavations, if we restrict discussion to the glass finds from this study and

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those from Ita Yemoo, it appears that a high proportion of the early Ile-Ife glass could have been HLHA. Davison analyzed a total of nine crucible fragments from Ita Yemoo; six of these (67 %) contained HLHA glass, while glass from the other three fell into Davison's heterogeneous Class II, a group with moderate alumina and lime, although individual lime values are not included. We do not know what proportion of excavated material, whether crucible fragments, cullet or beads, Davison was able to analyze, nor by what criteria, if any, the samples were chosen. The crucible glass colours represented are blue-green, cobalt-blue and very dark green (***Tab. 2***), in line also with the colours of our two HLHA crucible glass samples. These colours appear to have been those most commonly found, and we believe it is reasonable to suppose that a high proportion of Ife crucible glass, at least of these colours, would have been HLHA, since neither Davison nor ourselves had any reason to suspect that the glass composition might be unusual, and would not have known how to select only those glasses thought to be HLHA. The same may be said for the seven samples of Ita Yemoo glass cullet analyzed by Davison, all of which were HLHA. For the beads from Ita Yemoo, Davison appears to have been most interested in the blue corded and the dichroic beads, and may have selected these preferentially. In any case, 82 % of the thirty-three Ita Yemoo glass beads analyzed were HLHA, and not all of these were corded or dichroic. The picture emerging from Ita Yemoo is that there was an established glass industry in Ile-Ife, although probably not at Ita Yemoo itself, with crucibles, cullet and drawn glass beads, some of which may have been placed in a ritual context. Much or most of the glass was of a very unusual HLHA composition, and was contemporaneous with the potsherd layers dating from the eleventh to the thirteenth centuries. While the beads, cullet and crucibles are evidence for an active glassworking centre, the strong predominance of one type of glass– HLHA –further suggests that the glass being worked could have been made nearby. In addition, much of the non-HLHA glass at Ife is also quite unusual in composition, and, while not yet studied in detail, may have been made locally as well.

The much smaller proportion of HLHA glass beads, with no cullet or crucible fragments, from Igbo-Ukwu stands in contrast to these finds from Ile-Ife. At Igbo-Richard, the only one of Shaw's three excavations with bead types V and S, those most securely identified with HLHA glass, the likely portion of HLHA glass beads out of the total 98,654 reported was between 10 and 20 %, depending on how many of the N3 beads were HLHA (data from Shaw 1970: Appendix IV). Although Shaw's excavations certainly recovered far more beads than were found at Ile-Ife, the much lower proportion of HLHA glass at Igbo-Ukwu, coupled with the absence of cullet and glassworking crucibles, suggests that HLHA glass was relatively less important at Igbo-Ukwu than at Ile-Ife, and that the people active at Igbo-Ukwu were likely to have been consumers, rather than producers, for HLHA glass. Two *caveats* are important here: these figures from both Ile-Ife and Igbo-Ukwu are based on very limited excavations, dating to the middle of the last century, and the picture may change dramatically in the future; we are uncertain of the temporal relationship between the two sites. This second point has been much discussed and will not be resolved here, but, while Igbo-Richard is generally thought to be earlier than Ile-Ife, particularly Ita Yemoo, the actual calibrated radiocarbon dates given in ***Figure 9*** suggest that there could have been considerable overlap.

If not there, where?

In this paper we suggest that high-lime, high-alumina glass represents a distinct West African tradition, with much of the evidence pointing toward southern Nigeria. How can we be so sure, particularly when the physical evidence for early primary glass production has not been identified in the published archaeological reports? In fact, this lack of archaeological evidence is part of the larger issue that primary glass production may leave few traces in the archaeological record. Although glass was certainly made in a number of places, based on the large numbers of glass artefacts at many archaeological sites, finding the evidence, particularly for relatively small scale production, has been difficult. In contrast to metallurgy, which leaves large amounts of slag, glass producers could recycle almost all of their waste with the next batch of glass. In addition, the furnaces used for glass production would not necessarily leave a distinguishable imprint. Often, we are left only with the compositional evidence, and, while glass compositional evidence, by itself, can seldom prove primary glass production, in favourable cases it can help establish centres for glass manufacturing, and tell us a surprising amount about the technologies involved (Lankton *et al.* 2006).

Such a favoured case is that for Ile-Ife and southern Nigeria. Here, the very unusual nature of the high-lime, high-alumina glass is key. Although Shaw (1977: 85), Willett (2004: notes on *aje ileke* T611) and

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DAVISON (1972: 259) all concluded that the beads found at Igbo-Ukwu and Ile-Ife, including the high-lime, high-alumina glass, were made either in Europe or the Middle East and then brought by trade to West Africa, there are simply no other known sources for this unusual glass, neither in the tenth century nor at any other time. Such high alumina, in particular, is unusual, so that BRILL, writing in 1986 and discussing alumina (Al_2O_3) data from 243 individual glass analyses performed to that time, concluded that 'it seems reasonable to set a level of approximately 3.5-4.0 % Al_2O_3 and define glasses with Al_2O_3 contents greater than that as being significantly different from the vast majority of European and Middle Eastern glasses' (BRILL 1987: 4). Twenty years later, with thousands of glass analyses available from many parts of the world, there is little reason to revise this opinion.

In ninth and tenth century Europe, glass production was beginning to split between a soda-lime or soda-ash glass south of the Alps, and medieval potash glass north of the Alps. Southern glass, particularly as found in Italy, had moderate lime, usually below 10 wt%, and low-to-moderate alumina, generally below 4 wt%. Potash and magnesia were variable, depending on whether a mineral soda, such as natron or trona, or plant ash were used as the alkali source (VERITA *et al.* 2002: Table 3). North of the Alps, early wood ash glass begins in the late eighth century, and continues in one form or another into the sixteenth century (WEDEPOHL 2000: 255). Wood ash glass was characterized by very high lime levels, often above 20 wt%, and variable potash, below 10 wt% for the ninth and tenth centuries, and closer to 20 wt% from the eleventh century. To this extent, Willett and Davison were correct in assuming that the Ife high-lime, high-alumina glass could have a European origin. They may not have been aware that European wood ash-glass alumina concentrations are quite low, usually below 2 wt%, ruling out a European origin for high-lime, high-alumina glass on compositional grounds alone.

Middle Eastern glass in the ninth and tenth centuries was also at a transition point. By the late eighth century, the natron-based soda glass that had been produced for over 1500 years was giving way to plant ash glass, produced from ground quartz pebbles or very pure sand mixed with the ashes of desert or coastal halophytic plants. The changes are well-documented for Egypt (GRATUZE & BARRANDON 1990: 162) and Syria (HENDERSON *et al.* 2004: 439-468), and were nearly complete by the tenth century. While lime levels for all of these Middle Eastern glasses are variable, they seldom exceed 10 wt%; alumina is similarly variable, but almost never above 5 wt% (see BRILL 2001: 43 for an unusually high-alumina glass with mean concentration of 4.2 wt%, from Qasr al-Saghir, a fortress in Morocco). Like Europe, the Middle East can be ruled out on compositional grounds as a source for the Ife high-lime, high-alumina glass.

How about Asia? When Brill suggested alumina limits for European and Middle Eastern glass, he also noted that Indian-made glasses seldom had lime levels above 4.5 to 5.0 wt%, although the distinction was not as strict as for alumina (Brill 1987: 5). In Dussubieux's study of over 500 glasses from South and Southeast Asia, she did find glass with lime as high as 10 wt%, and glass with alumina up to 16 wt%, but no glass with both high lime (above 9 wt%) and high alumina (above 6 wt%) (DUSSUBIEUX 2001: Annex 5). Two further examples of high-alumina glass (alumina 18 wt%) with a probable South or Southeast Asian origin, excavated from the seventh-century Nongningsi Temple site in Luoyang, China, both had lime levels below 3 wt% (AN JIAYAO 2000: 83).

Chinese glass from the Tang through Yuan periods (seventh to fourteenth centuries), some of it likely imported, may have rather high lime levels, up to 19 wt%, but these glasses have alumina levels no higher than 5 wt%; later Chinese glasses are generally even lower in alumina, with exceptional examples as high as 4 wt% (AN JIAYAO 1991: 18; BRILL *et al.* 1991: 54, 55).

Brill's recent review of glasses from several Central Asian sites dating from the Sasanian and Early Islamic periods (fourth to ninth centuries) suggests some specific Central Asian glass types, plant-ash soda-lime glasses with variably high potash. One group of vessel fragments found near Kashgar, Xinjiang, with lime concentrations between 7 and 8 wt%, has alumina values up to, but not exceeding, 10 wt% (BRILL 1999, Vol. 2: 345; BRILL 2005).

Korea is the only place outside West Africa from where glass samples with a high-lime, high-alumina composition have been reported. Four very small, green, high-lime, high-alumina glass fragments, but no high-lime, high-alumina glass beads, were recovered by flotation from the Poongnab castle site in Seoul, dating to the second to fourth century CE. The compositions are quite close to those of the Ife higher-magnesia glass, with lime 25 wt%, alumina 10 wt%,

soda and potash both below 3 wt%, and magnesia around 3 wt% (Yu & Kang 2003: 22). In addition, a chunk of glass described as cullet or waste, found at a sixth-century kiln site near Wolsung, South Korea, had a composition of 24% lime and 13.5% alumina (Brill 1999, Vol. 2: 373), within the Ife high-lime, high-alumina compositional range, as shown in ***Figure 7***. Did Korean craftsmen make the Ife glass? Not very likely, but the idea of a parallel technology may not be so far-fetched.

Two models for primary glass manufacture

We asked earlier how the HLHA glass was made, and there are two basic models describing the interaction of the introduced batch materials and the furnace temperature. Each of these models has certain implications for the type of residual material, and these implications may be helpful in the future in determining the circumstances of early glass production in Ile-Ife.

Partial batch melting model

The remarkable compositional consistency, over many years, of both plant-ash Bronze Age glass from Mesopotamia and Egypt, and Roman-period natron glass led Rehren to suggest that such uniform compositions might result from the actual melting behaviour within the glass furnaces, rather than from meticulous control over the proportions and compositions of the raw materials (Rehren 2000: 1225). With the supporting evidence of quantities of partially melted glass from a few ancient primary production sites and the preliminary results from experimental glass melts (Rehren *et al.* 2005; Rehren & Pusch 2005), along with the ethnographic data that tank furnaces in northern India, using traditional techniques, resulted in only about 50 % usable glass, the remainder to be recycled in the next melt (Sode & Kock 2001: 165), Rehren has proposed that the glass from many pre-industrial glass furnaces, where the temperature achieved was just adequate to produce glass, formed co-existing with a 'buffer of surplus crystalline material' (Rehren 2000: 1227). The transparent, good quality, glass formed in the melt could be manually separated from the remaining, partially reacted, buffer material, a process known as beneficiation, and either used as it was, or remelted to form a uniform, high quality glass free of residual batch material. The incompletely reacted buffer material from the primary melt could be added to the next firing of the furnace, as is done in India today, leaving behind little waste to serve as evidence for future investigators. However, any primary manufacture furnace chambers or crucibles that do remain should show evidence for this buffer layer.

The result is that the final glass composition will depend on the temperature within the furnace, provided the raw materials are present in more-or-less the proper proportions to supply adequate ingredients to the developing glass. The glass formed will have a composition determined by the eutectic, or easily melted, portions of the appropriate compositional system. In the case of Late Bronze Age glass, the soda-lime-silicate system, with the addition of about 5 wt% magnesia, has a series of eutectic points depending on temperature, forming a eutectic trough or cotectic, closely corresponding to the observed glass compositions.

Complete batch melting model

If the temperature within the furnace is high enough and the ingredients chosen carefully, all of the added ingredients will melt completely to form a glass whose composition depends on the proportion and composition of the original ingredients. Such a situation is found today with industrial glass, and appears to apply to medieval wood ash glass production. In this case, we would expect greater variability in batch chemistry, and glass manufacturing units (for medieval wood ash glass, large ceramic crucibles) containing fully melted glass.

Ternary diagrams

Diagrams illustrating the relative compositions of the three most important ingredients within a glass melt, ternary diagrams, may be combined with experimental data on the melting behaviour at each point. In order to illustrate in two dimensions the interaction of changing oxide levels with melting temperature, the oxides other than those chosen for the diagram must be either ignored, if their levels are sufficiently low, or mathematically transposed to one of the oxides included in the diagram. This process requires a number of assumptions that become less and less reasonable with increasing levels of the oxides to be transposed. However, the resulting graphic representation may allow insight into the melting behaviour of the glasses in question that would otherwise be difficult to recognize, although any conclusions derived must be qualitative rather than quantitative.

For the high-lime, high-alumina glasses from Ife, both those analyzed for this study and those analyzed by Davison, the remarkable constancy of the lime and

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No.	Sample	*Reduced compositions (7 major oxides normalized to 100%) SiO_2*	Na_2O*	CaO*	K_2O*	MgO*	Al_2O_3*	Fe_2O_3*	**Converted, normalized SiO_2**	CaO**	Al_2O_3**
Eutectic mixtures (TAUBER & WATTS 1952)											
CAS (calcia-alumina-silica)		63.2		23.3			13.7		63.1	23.3	13.7
CAMS (calcia-alumina-magnesia-silica)		63.0		20.9		2.1	14.0		62.5	23.6	13.9
Glass attached to crucibles											
1	IF-C1	61.8	1.4	12.4	8.2	nd	15.4	0.8	64.6	19.3	16.0
2	IF-C2 mean of 2 high K_2O	53.3	0.7	19.8	7.8	2.8	14.3	1.4	55.4	29.9	14.7
3	IF-C2 mean of 12	58.1	4.2	18.3	2.9	0.1	15.4	1.1	59.8	24.4	15.8
4	IF-C2 area 1	54.7	0.7	18.1	8.9	2.4	13.9	1.4	57.2	28.4	14.4
5	IF-C2 area 2	60.7	3.0	18.2	4.6	0.1	12.6	0.7	62.5	24.5	12.9
6	IF-C2 area 3	59.1	3.7	19.0	2.8	nd	14.3	1.1	60.8	24.6	14.6
7	IF-C2 area 4	59.2	3.9	17.3	2.8	nd	15.7	1.1	60.9	23.1	16.0
Glass beads from *aje ileke* 1											
8	IF1B	58.1	6.4	15.6	3.4	nd	16.2	0.3	59.5	23.9	16.6
9	IF1D1	52.2	5.4	22.1	3.9	nd	15.7	0.7	53.8	30.1	16.1
10	IF1D3	54.2	6.5	17.7	3.4	nd	17.8	0.5	55.7	26.2	18.2
11	IF1D2	55.2	6.9	16.9	2.6	nd	17.9	0.5	56.5	25.2	18.3
Glass beads from British Museum											
12	BM19a mean	54.8	5.1	16.8	5.8	0.1	17.1	0.3	56.6	25.8	17.6
13	BM19c mean	53.6	6.3	18.5	3.6	nd	17.2	0.7	55.3	27.1	17.6
14	BM19d mean	57.6	6.5	16.3	3.3	0.2	15.7	0.5	59.0	24.9	16.1
Cullet fragments from aje ileke 1 and 2											
15	IF1.S	56.4	4.7	18.0	4.8	0.1	15.4	0.6	58.2	26.0	15.8
16	IF1.K, darker area	56.6	4.1	17.9	4.5	0.6	15.4	0.8	58.4	25.9	15.8
17	IF1.K, lighter area	52.1	2.7	22.6	3.7	2.5	13.9	2.5	54.3	31.5	14.2
18	IF1.M	56.1	5.6	19.0	3.6	0.5	14.7	0.5	57.5	27.5	15.0
19	IF1.T	57.4	6.5	14.8	3.5	0.1	17.3	0.4	58.9	23.4	17.7
20	IF1.A	57.0	6.4	17.3	2.8	nd	15.9	0.5	58.4	25.3	16.3
21	IF1.P	61.3	3.7	15.6	4.6	3.5	10.9	0.3	62.1	26.9	11.0
22	IF1.F	53.9	2.3	22.5	4.3	2.5	13.2	1.3	55.3	31.3	13.4
23	IF1.E	58.4	4.6	16.1	5.4	0.3	14.7	0.5	60.3	24.6	15.2
24	IF1a large blue	58.8	6.8	15.1	2.9	nd	16.1	0.4	60.2	23.4	16.4
25	IF1a small grayish blue	52.6	6.1	20.4	3.9	nd	16.5	0.5	54.1	29.0	16.9
26	If1a medium sized blue	54.4	6.2	19.5	3.7	nd	15.8	0.4	55.8	28.0	16.2
27	IF1a small dk blue	55.8	7.0	16.0	3.3	nd	17.3	0.5	57.3	25.0	17.7
28	IF2.F	61.9	4.0	16.8	3.3	nd	13.4	0.5	63.4	22.9	13.7
High CaO, high Al_2O_3 glass from Ile-Ife, DAVISON 1972. SiO_2 estimated by subtraction from 100%: nr not reported.											
A	Davison crucible glass mean of 8	63.6	3.2	14.4	6.0	nr	11.7	1.2	65.3	22.6	12.1
B	Davison cullet mean of 11	62.2	3.1	15.1	5.3	nr	12.6	1.7	64.2	22.8	13.0
C	Davison corded beads mean of 13	62.8	2.6	16.1	6.2	nr	11.8	0.4	64.0	23.8	12.2
D	Davison dichroic beads mean of 21	62.4	2.1	15.3	7.4	nr	12.3	0.4	63.7	23.4	12.9
E	Davison other Ife beads mean of 7	61.8	3.0	14.2	6.2	nr	12.9	2.0	65.0	21.5	13.5

Tab. 3. Ile-Ife glass with high CaO, high Al_2O_3, variable MgO, K_2O and Na_2O, for ternary diagram. Data shown as reduced compositions* (BRILL 1999, Vol. 2: 9) and as converted, normalized oxides** to fit ternary diagram. Conversion factors, based on the molecular weights of the oxides, as follows: Na_2O to CaO (0.91), K_2O to CaO (0.60), MgO to CaO (1.39), Fe_2O_3 to SiO_2 (0.38). nr: not reported.

alumina values suggests that the partial batch melting model may be applicable here as well, since it is unlikely that such close control over the raw materials would have been possible over the wide temporal range that these glasses may represent. In addition, the levels of lime, alumina and silica are very near those of the CAS (calcia (lime)-alumina-silica) eutectic mixture: lime 23.3 wt%, alumina 13.7 wt% and silica 63.2 wt%, with a melting temperature of 1200° C, or 1172° C for prefused ingredients (TAUBER & WATTS 1952: 459). Although Ife glass is entirely different in composition from Bronze Age and Roman-period glass, it seems possible that the principle that the final glass composition is determined by melting behaviour within the furnace remains the same.

The issue becomes how to demonstrate this graphically. Two possible ternary or quasi-ternary phase diagrams might be appropriate: lime-alumina-silica (LEVIN *et al.* 1974: Fig. 630) and soda-lime-silica with alumina standardized to 5, 10 or 15 wt% (MOIR & GLASSER 1976: 50). For the Ife high-lime, high-alumina

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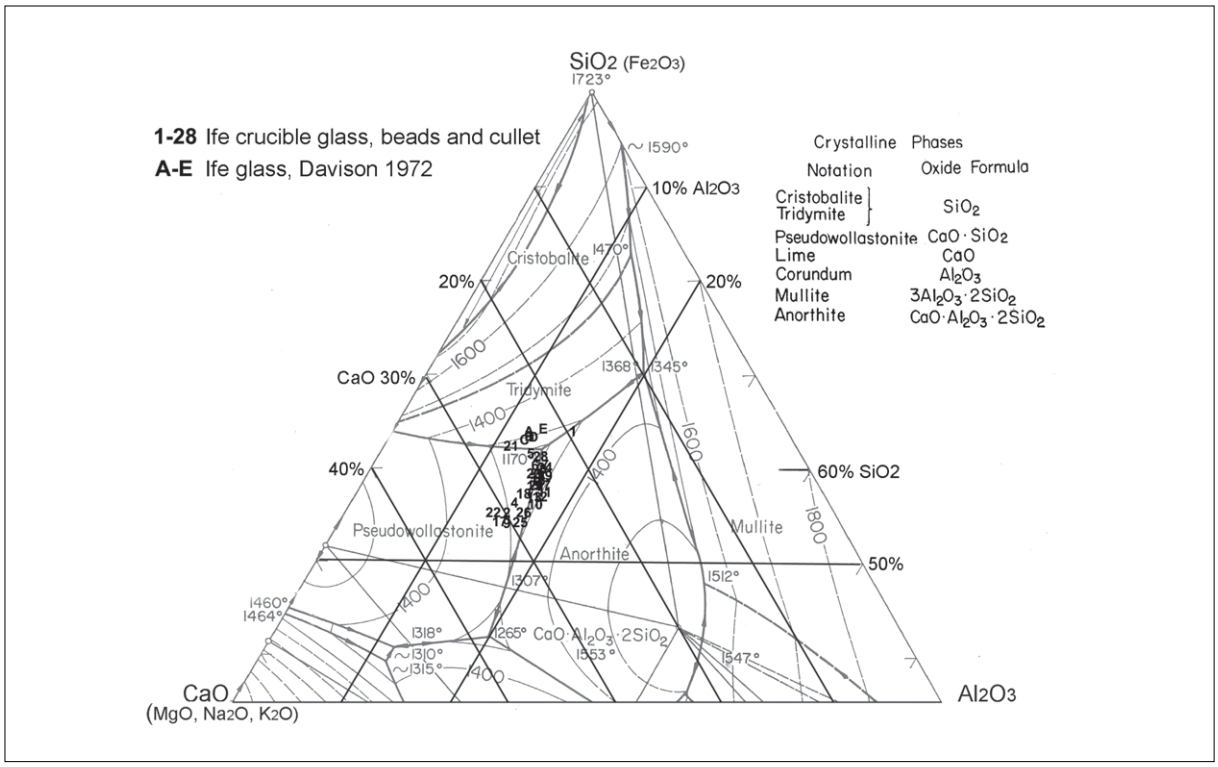

Fig. 10. Ternary diagram showing the converted, normalized** (*see* ***Table 3*** and text for explanation) compositions of the high-lime, high-alumina glass from this study (samples 1 to 28) and from DAVISON 1972 (samples A to E) superimposed on the phase diagram of the CAS (calcia (lime)-alumina-silica) system (adapted from LEVIN *et al.* 1974: Fig. 630). The eutectic trough extends between the points marked 1170° and 1265°.

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glass, because iron oxide levels are quite low, we can reasonably follow the lead of REHREN 2000 and convert the iron oxide to silica by multiplying the wt% concentration of iron oxide by the ratio of the molecular weight of silica to that of iron oxide, since an equivalent molar amount of silica will weigh less than the same number of moles of iron oxide. The other two oxides present in significant amounts are soda and potash, with a combined level equivalent to 6 to 8 wt% soda. If we believe that lime and alumina are the most significant variables, we could choose the lime-alumina-silica ternary diagram, but must first convert the soda and potash to something else, for example, lime, as shown in ***Table 3*** and ***Figure 10***. The resulting ternary diagram shows a remarkably close association of the transposed compositions with the lime-alumina-silica cotectic, supporting the model of partial batch melting along the cotectic trough. However, we must keep in mind that the actual melting behaviour of the system could be affected in complex ways by all of the oxides present, and particularly by the significant fluxing action of both soda and potash. For this particular case, lime may also act as a flux, lowering the melting temperature as lime increases from 10 to 25 wt%.

On the other hand, if we believe that the observed levels of soda and potash had a greater effect than the variability in alumina, we could use a quasi-ternary soda-lime-silica diagram with alumina adjusted to 15 wt% (not shown but available in MOIR & GLASSER 1976: 50). The important assumptions here would be that potash can be converted to soda, using a formula analogous to that given for iron oxide above, and that alumina may be adjusted to 15 wt% by borrowing from some other oxide- in this case, silica may be the most appropriate, since we are more interested in the effects of independent changes in lime and soda concentrations. When the data are transposed in this way the resulting compositions fall near the 1250° C melting curve, although not as neatly as in ***Figure 10***, and not in the eutectic region of the phase diagram, which is in the temperature range of 1100° C, with lime levels of 5 wt%. In this case, we would say that the Ife high-lime, high-alumina glasses do not fit the eutectic mixture determined by alumina 15 %, lime, soda and silica, and we would expect fully melted glass with varying levels of lime depending on the furnace temperature. The rather consistent lime levels in our results and in those of Davison would in this case be explained by

close temperature control, within a range of 50° C or so, an event that may be unlikely in the context of early second millennium technology. Clearly, none of the phase diagrams available consider all of the oxides important in the Ife glass, and the interactions of these oxides introduce complexities well beyond the scope of this paper. We like the CAS phase diagram because it appears to fit the available data and illustrates a plausible mechanism for rather precise control of lime and alumina levels. On the other hand, there are as yet no reported archaeological remains from Ife that might be interpreted as evidence for primary glass manufacture incorporating a buffer zone of unreacted ingredients, while, to the contrary, there is an abundance of ceramic crucibles, all with an inner layer of fully melted glass, such as might have been used for primary glass manufacture with complete batch melting. Further study of the crucibles and their contained glass, combined with experimental melts of ingredients similar to those that might have been used at Ile-Ife, with all variables controlled, will be very helpful in choosing between the two glassmaking models.

While there has been no work on the calcia (lime)-alumina-silica (CAS) eutectic system for glass compositions, at least in part because glasses with this composition have not been recognized as a distinct category, the CAS and CAMS (including also magnesia) eutectic melting systems have been studied in relation to wood ash glaze on Chinese stoneware dating from the first to the eleventh centuries (Wood *in press*: Table I; Kerr & Wood 2004: Table 84), and apply as well to the glazes on Korean celadon and whiteware ceramics from the ninth to tenth centuries (Koh Choo *et al.* 2004: Table 3). For the CAMS system, the eutectic composition of the four components, melting at 1185° C with a drop to 1145° C if the ingredients have been prefused, is lime 20.9 wt%, alumina 14.0 wt%, magnesia 2.1 wt% and silica 63.0 wt% (Tauber & Watts 1952: 459). This composition is very close to the glaze compositions, and close as well to the compositions of the higher-magnesia glass from Ile-Ife, as shown in ***Table 2***, if we neglect for the moment the higher soda and potash content of the Ife glass. For the stoneware glazes, the presence of magnesia, along with mean phosphate levels of 1.2 wt%, reflects the use of wood ash as the source of alkali. In contrast, later Chinese glazes were made with limestone, rather than wood ash, as the source of lime, with consequently lower magnesia and negligible phosphate concentrations. In addition, lime levels are lower as well. When the compositions of these glazes (Kerr & Wood 2004: Tables 95-99) are plotted on the CAS phase diagram, they do not follow the eutectic trough, suggesting that by this time glaze compositions more closely reflect the original ingredients, and that firing temperatures were adjusted to obtain optimal melting.

We mentioned above that Korean high-lime, high-alumina glass might be connected to Ile-Ife, and we can now see that the connection is technological rather than historical. Korean craftsmen, possibly experimenting with early glazes, produced small amounts of glass with the CAMS eutectic composition. This glass was not further developed in Korea, where the demands for glass ornaments were met by imports from South and Southeast Asia (Lankton & Lee 2006), or by the local production of lead-silica glass beginning in the seventh century. On the other hand, in or near Ile-Ife the ready availability of local raw materials, the tradition of high-temperature technology in the form of copper alloy or iron working and local and regional demand for glass beads combined to stimulate primary and secondary glass technologies that would continue for many centuries.

Making the Ife glass

We do not know how the high-lime, high-alumina glass found at Ile-Ife was made. There is no direct evidence for stores of glassmaking raw materials, and no artefacts, with the possible exception of some of the surviving crucibles and crucible fragments, that can be directly linked to primary glass production. As a result, how we reconstruct the glassmaking processes may depend as much on our theoretical framework for the spread of glassmaking technology as on the compositional evidence itself.

Support for glassmaking as a transferred technology begins with the early centuries of glass production, with the possibility that glass was 'invented' in Mesopotamia and the technology then transferred to such important glassmaking cultures as New Kingdom Egypt, most likely by the actual movement of Levantine glass craftsmen.

Such a scenario may account for the spread of glassmaking in Europe, as well as in South and Southeast Asia, where methods similar to those developed in established glassmaking centres were adapted to local ingredients in new areas. Important here is the notion that glassmaking itself is not an obvious or easy technology, and was ordinarily learned through a lengthy apprenticeship.

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An alternative theoretical approach to the spread of new technology is that craft workers could re-invent the steps used to produce a certain desired object or commodity. In this case, the new process may be based on technology already existing in the culture, but the resulting *chaine operatoire* will differ in both approach and raw materials from that used to produce the original, emulated, material. Actual examples for this second scenario, particularly in terms of glass technology, are difficult to find, although one can imagine that craft workers such as those at Ile-Ife, familiar with the look and feel of imported glass, might have recognized either metallurgical slag or the waste material from lime kilns as being in some way related, and then, through trial and error, have produced the high-lime, high-alumina glass by combining these two pre-existing technologies. In this same volume of the *Journal of African Archaeology*, Ian Freestone suggests a very original reconstruction of Ife glassmaking technology consistent with this second theoretical framework.

If we pursue the first theoretical framework, that glassmaking should be a transferred technology, we would expect traditional glassmaking methods to be adapted to the raw materials available near Ile-Ife. We saw above that CAMS-eutectic glazes formed on Chinese and Korean ceramics from the combination of high-lime wood ash (lime content 30 to 40 wt% for ash from Fujian Province) (Wood *in press*: Table 3) with aluminous, siliceous, clay, probably added to the wood ash as a slip. For the Chinese ceramics, neither the ash nor the stoneware ceramic body has alumina compositions above 10 wt%, and the high alumina content of the glaze results from the preferential uptake of alumina into the developing glaze melt to satisfy eutectic demands. For the Ife high-lime, high-alumina glass, we would expect the raw materials to include sand (or ground quartz) and a source of alkali, either plant (or wood) ash or mineral soda, ingredients analogous to those used in the manufacture of seventh to tenth century glass elsewhere. While there is no evidence for mineral alkali deposits near Ife, and, in addition, the total soda and potash in the glasses is quite low for this approach, both sand and wood ash would have been readily available around Ife, as discussed below. The resulting glass would reflect the eutectic melt, in this case the CAMS eutectic, with wood ash providing most of the lime, soda, potash, magnesia and phosphate, and the sand providing silica, alumina and iron. The higher levels of soda and potash in the Ife glass compared to the Chinese glazes do not present a problem, since both soda and potash would have been removed by washing the ash used in China for glazing.

What is a problem is that only six of the Ife samples actually contain both magnesia and phosphate. Conventional wisdom would indicate that these are wood-ash glasses, supported as well by the negative correlation between magnesia and soda levels, since wood ash is generally lower in soda than in potash. Were these glasses made from wood ash while the other samples were not? This seems unlikely, and would be contrary to most known glassmaking traditions, where one method was used to produce one type of glass over long periods of time. Is it possible that the ash used at Ife was ordinarily treated in some way to remove preferentially both magnesia and phosphate? Neither washing, which removes the soluble alkali like soda and potash, nor leaching, where the soluble alkali are concentrated or recrystallized from solution, would appear to do this.

Following the second theoretical framework, we could suppose that the Ife high-lime, high-alumina glass was made using some entirely different approach not involving plant ash, such as the hypothesis suggested by Freestone in this volume, and that the few magnesia-containing glasses were either contaminated by plant residue containing magnesia and phosphate, or that the magnesia and phosphate were introduced in some other way. Of course, it is possible that both techniques were used to make glass in Ife, perhaps in different time periods. The only glass in our report that we know for certain is very early is that excavated by Willett, and for these samples we have neither magnesia nor phosphate levels. Later glass, possibly reflected in the materials we have analyzed here, could have been made using different raw materials, analogous to the 10th century change from wood ash to limestone as the alkali source for Chinese glazes. Reuse of old crucibles could result in two distinct types of glass in the same crucible, as our compositional results indicate for Crucible 2. Further investigation and sampling of raw materials near Ile-Ife may help explain the seeming paradox of both plant-ash and non-plant-ash glass in the same crucibles, but, for now, what is most certain is that we still have a lot to learn.

In terms of locally-available raw materials, the forests near Ife could have provided the large amounts of wood necessary for the preparation of wood ash (see Jackson & Smedley 2004: 39 for an estimate of the amount of wood needed to produce ash used for glazing or glassmaking). In addition, the geology of the Ile-Ife area provides sand deposits of varied compositions that could have been exploited by ancient Ife

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glassmakers. Ife lies in a valley surrounded by voluminous granitic rocks forming prominent hills and inselbergs on the northern and southeastern flanks of the city and rocks of basic and ultrabasic composition on the eastern flank. The granitic rocks have been sources of several white sand deposits which are still being mined and used as the main building raw materials for cement blocks and mortar. Mafic to ultramafic rocks are abundant in Ife and the surrounding areas, with secondary enrichment of the overlying lateritic profiles with cobalt, copper and vanadium (Emofurieta *et al.* 1995: 42), as well as with manganese (Ige *et al.* 2005: 17). High-alumina sand would come from the low-lying, almost completely decomposed, metamorphosed sediments such as sillimanite-rich quartzites and mica schists. The high-alumina, kaolinitic clay used for the Ife glass crucibles provides further evidence for sources of high-alumina deposits near Ife.

Other glass compositions in Ife

We divided ***Figures 7*** and ***8*** into three areas. The high-lime, high-alumina glasses form one distinct area. The two soda-lime glass beads, at least one of which, the powder-glass bead, was made locally but from imported, possibly European, glass, occupy another distinct polar position. On both charts, the green glass from *aje ileke* 2 and 3 and the green beads found on *aje ileke* 3 are intermediate in composition between the soda-lime glass and the high-lime, high-alumina glasses. The most likely explanation for this would be that these green glasses were made by mixing soda-lime glass with high-lime, high-alumina glass, perhaps recycled from the glass 'mine' at Olokun Grove. When this might have been done is not known, although it was probably after the period of use of Orun Oba Ado and Ita Yemoo, since these showed no very low-alumina soda-lime glass in the ninth to twelfth centuries. Soda-lime glasses made from such pure ingredients, with alumina and iron both below 1 wt%, are more characteristic of the past 200 years, and may not predate the nineteenth century.

The high-lime, low-alumina glasses on *aje ileke* 1 form their own group, but are associated with the dichroic high-lime glass from the British Museum. The high-lime, low-alumina green glasses, like the high-lime, high-alumina glasses, have variable magnesia levels, but, in this case, there is no apparent correlation with phosphate, suggesting that plant ash, or at least the same sort of plant ash, may not have been the source of the alkali. The lime levels are high enough to be unusual, and the alkali content lower than for most European glass, while the low alumina makes an Asian origin unlikely. Is the high-lime, low-alumina glass another local product? It is difficult to say with our very limited numbers of analyses, but the unusual composition raises the possibility that these glasses were also locally produced. The period of production would most likely have begun after the twelfth century, the ending date for Ita Yemoo.

Cobalt sources near Ife

Much of the high-lime, high-alumina glass from Ile-Ife is coloured medium to dark blue by the presence of varying concentrations of cobalt. Davison demonstrates that cobalt levels correlate with the manganese content of the high-lime, high-alumina glass (Davison 1972: 256), and suggests that a manganese ore rich in cobalt, such as asbolite, could have been used as the glass colorant (1972: 258). The manganese to cobalt ratios in her data are rather consistent at about nine to one. We mentioned above that both manganese and cobalt are present in the Ife area, although exact sources for cobalt-rich manganese ore are not yet known. An ancient gold-mining area located five km from Ife is apparently associated with cobalt as well (Ajayi & Suh 1999: 106), although we do not know whether this cobalt source was exploited in antiquity. Another possibility would be that the cobalt used to colour the Ife glass was imported, possibly from South Asia, along with the glass beads with a likely South Asian origin found at both Ile-Ife and Igbo-Ukwu (see Francis 2002: 38 for a discussion of Indian high-manganese cobalt sources and the possible export of cobalt colorant). Further investigation and characterization of cobalt sources, both in Africa and in South Asia, will be essential for a full understanding of glass colouring in Ile-Ife.

Conclusion: Early glass technology in sub-Saharan Africa

Based on the compositional analyses reported here, particularly when combined with earlier work by Willett and Davison, we can now place the manufacture of glass from its raw materials– primary glass production–with the other great sub-Saharan traditional industries, including bronze and iron manufacture, brass casting as at Ile-Ife, innovative textile and ceramic technologies and the working of stone and wood. The antecedents of this glass production are not known,

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but, reasoning from the predominance of indigenous high-lime, high-alumina glass at the earliest sites in Ile-Ife, along with extensive archaeological evidence for the technical ceramics important in glassworking, especially when coupled with strong oral traditions for ancient glassworking at Ife, and nowhere else, we believe that the centre of the developing technology was in or near Ile-Ife, and certainly within southern Nigeria, with early glass evidence from Igbo-Ukwu as well.

This southern Nigerian glass was not the first in West Africa, but followed almost 1000 years of trade in glass beads. Such glass finds as those from Kissi, Burkina Faso, with glass beads from graves dated to the first to third centuries CE (Magnavita 2003: 133), provide evidence for very early trans-African trade. Most, if not all, of the earliest glass beads in Africa have the form, and, as far as we know, the composition, of the small, drawn beads referred to as Indo-Pacific by Peter Francis Jr (2002: 19, for a detailed exposition) that were made in South or Southeast Asia at least as early as the fourth century BCE. As international trade increased during the later first millennium CE, so too did the sources of the glass beads. What is new at the beginning of the second millennium is the presence of locally manufactured glass; glass itself would have long been a familiar, albeit precious, material.

We are aware that this developing picture is still incomplete, with missing chronological details and material evidence that can only be provided by further field archaeology, but the strong compositional evidence presented here demands attention. We believe that the most reasonable interpretation of all of the available data is that primary glass production was well under way in southern Nigeria in the early centuries of the second millennium CE, and may have started even earlier. Further archaeological and analytical work designed to better characterize early West African glass traditions will be important for a full understanding of the glass production, particularly in terms of the raw materials used and how the resulting glass compositions were determined.

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