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ORIGINAL PAPER

Zanzibar and Indian Ocean trade in the first millennium CE: the glass bead evidence

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Abstract Recent archaeological excavations at the seventh- to tenth-century CE sites of Unguja Ukuu and Fukuchani on Zanzibar Island have produced large numbers of glass beads that shed new light on the island's early interactions with the wider Indian Ocean world. A selected sample of the beads recovered was analyzed by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) to determine the origins of the glass used to make the beads and potential trade relationships are considered. The data show that two major glass types can be identified: mineral-soda glass, m-Na-Al, produced in Sri Lanka (and possibly South India) and plant ash soda glass. The latter comprises three subtypes: two with low alumina concentrations and different quantities of lime (here designated v-Na-Ca subtypes A and B) and one with high alumina (designated v-Na-Al). The v-Na-Ca subtype A beads are chemically similar to Sasanian type 1 glass as well as Zhizo beads found in southern Africa, while v-Na-Ca subtype B compares reasonably well with glasses from Syria and

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the Levant. While the mineral-soda beads were made in South Asia, it appears likely that at least some of the plant ash beads were made in South or Southeast Asia from imported raw and/or scrap Middle Eastern glass. In contrast, during this period, all beads imported into southern Africa were made of Middle Eastern glass from east of the Euphrates (v-Na-Ca subtype A) and appear to have arrived on ships from Oman and the Persian Gulf. These data suggest that the two sections of the African coast were engaged in different Indian Ocean trade circuits.

Keywords LA-ICP-MS · Archaeological science · Eastern Africa · Middle East · South Asia · Southeast Asia

Introduction

In 2011 and 2012, the Sealinks Project (www.sealinksproject.com/) undertook excavations at two archaeological sites on Zanzibar that possess evidence for trade contacts with the wider Indian Ocean world in the second half of the first millennium CE. The small site of Fukuchani lies on the northwest coast of the island, and Unguja Ukuu, which was a significant port town, lies on the southwest coast more or less opposite present-day Dar es Salaam (see Figs. 1 and 2 for maps of the Indian Ocean and Zanzibar). Earlier excavations at the two sites (Horton and Clark 1985; Horton and Middleton 2000; Horton 2015; Juma 2004) provided evidence of Indian Ocean trade, but the Sealinks Project excavations were undertaken with the aim of further refining the chronological parameters for the two sites. Renewed excavation at the two sites was also undertaken as part of a systematic study by the Sealinks Project into the trans-oceanic biological exchange that brought a variety of Asian plants and animals to the East African coast in the premodern period (Boivin et al. 2013, 2014; Crowther et al. 2014, 2015; Helm et al. 2012). This paper addresses the glass component of the bead assemblages recovered from Fukuchani and Unguja Ukuu in the 2011 field season.

The rich glass bead assemblage from Zanzibar, the result of more intensive recovery methods than in previous excavations on the island, provides an exceptional opportunity to explore Zanzibar's connections to the broader Indian Ocean world. Most of the beads recovered are not morphologically distinct; they are small and monochrome and are often types that were made over the span of several thousand years. Here we attempt to explore the beads' origins through geochemical and technological analyses that provide insights into their production. We perform elemental analyses to trace the origins of the different glasses used to produce the beads. Since glass was widely traded in antiquity, however, we also examine the method by which the beads were made. We draw on these datasets to begin to reconstruct the trade routes that brought the beads to the African shore. We also compare the Zanzibar bead assemblages and the trade connections they inform with those in southern Africa during the same period to attempt to discern whether or not the two ends of the eastern African coast were involved in overlapping trade circuits.

Material and methods

Sites and samples

Unguja Ukuu is located on a narrow coral-rag peninsula between a resource-rich bay and a small, shallow inlet. The archaeological site extends over some 17 ha and contains settlement remains and deep midden deposits rich in animal bone, shell, iron slag, daub, glass fragments and beads, shell beads, bead grinders, and pottery. Fukuchani is situated on a long beach protected by the island of Tumbatu, which sits directly opposite the bay. When first recorded by Horton and Clark in 1985, the site comprised a series of midden mounds that ran for 1 km along the beach, though on returning in 2011, the Sealinks Project found that these had been largely destroyed by the construction of a local school on the site. Our excavations targeted areas where subsurface deposits appeared intact.

The artifacts analyzed in this study derive from four trenches at Unguja Ukuu (trenches 10–13) and three at Fukuchani (trenches 10–12). All trenches were between 1 × 2 m and 2 × 2 m in area and were 0.7–1.75 m deep when sterile deposits were reached, though trench 11 at Unguja Ukuu reached a maximum depth of 2.92 m. The glass beads were found throughout the full depositional sequence at both sites in association with quantities of other imported goods, including Chinese and Near Eastern ceramics (e.g., Changsha painted stoneware, Yue Green ware, and Dusun stoneware from China; and turquoise-glazed and white-glazed wares from Iraq and/or Iran) and glass vessel fragments. They also co-occur with local Early Tana Tradition/Triangular Incised Ware (ETT/TIW) pottery that dates regionally to the seventh–tenth centuries CE (Fleisher and Wynne-Jones 2011). A suite of radiocarbon dates obtained from both sites support this chronology (Crowther et al. in preparation). Post-1000 AD ceramics found in the upper levels of trench 13 at Unguja Ukuu, including imported sgraffito ceramics, suggest that occupation of some of the excavated areas extended into the eleventh century CE or so. Trench 11 at Fukuchani primarily contained a human burial.

All deposits at both sites were sieved with 3 mm or smaller mesh resulting in excellent retrieval rates: 863 glass beads and one presumed weight came from Unguja Ukuu and 30 beads came from Fukuchani (see Online Resource 1 for a full description of the samples and the contexts[1] from which they

[1] The context of an archaeological object describes where in the excavation it was found—including the trench, the section in the trench, and the depth. This stratigraphic information can help date objects.

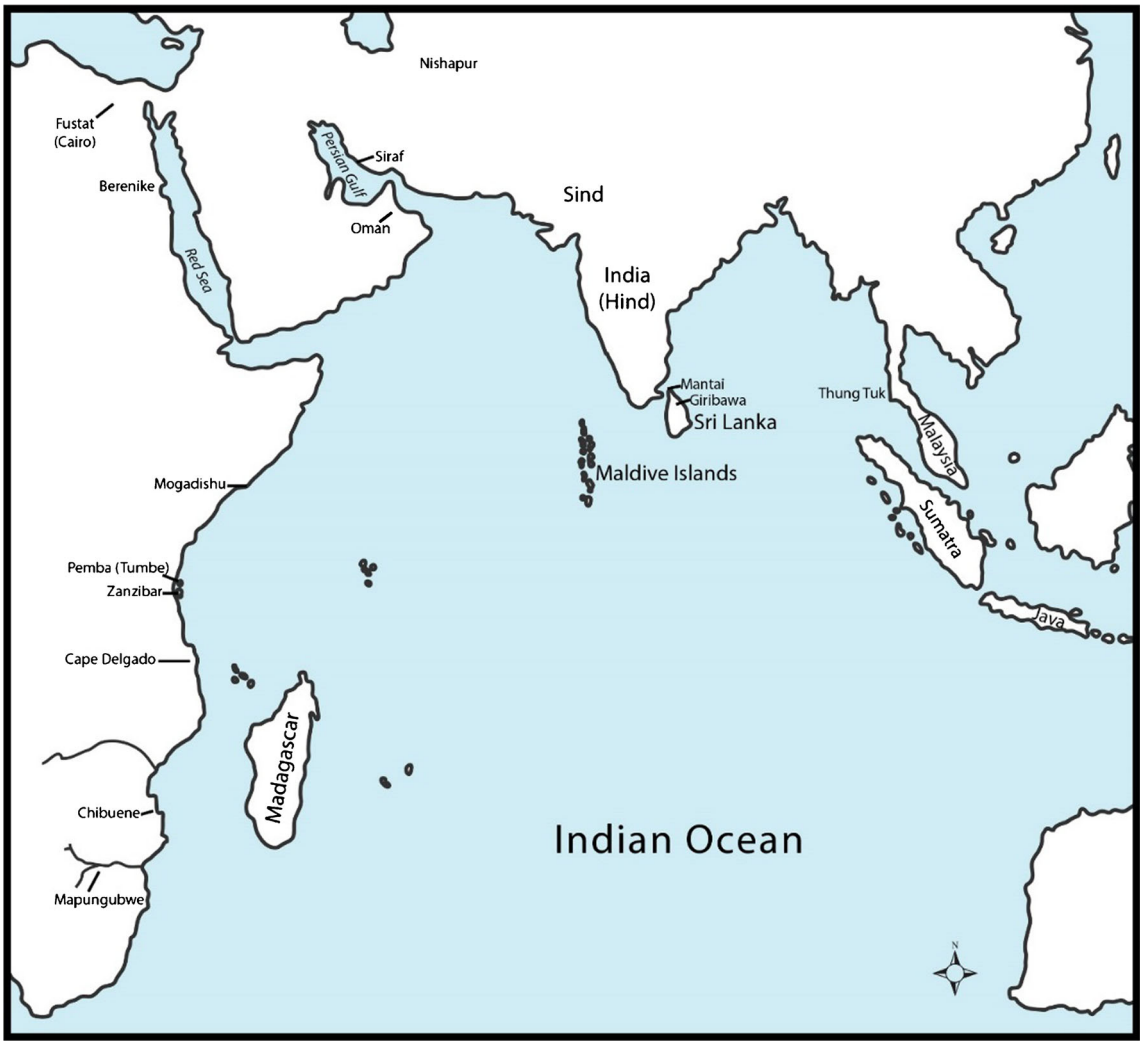

Fig. 1 Indian Ocean map with places mentioned in the text

came). The selection of the beads for chemical analysis was not random but rather a range of each type and color was chosen to try to include all possible glass types present. Thus, 68 beads from Unguja Ukuu and 11 beads from Fukuchani were chosen for analysis. A small blue cuboidal glass object from Unguja Ukuu (UU174) measuring $5.5 \times 5.5 \times 3$ mm and decorated on one side with nine small indented circles, thought to be a weight for precious metals such as silver or gold, was also included in the analysis for comparison.

Instrumentation

Elemental analysis was performed through laser drilling via laser ablation on a spot on the glass surface (LA system: New Wave Research UP 213, Fremont, USA) followed by online inductively coupled plasma-mass spectrometry (ICP-MS) (quadrupole Agilent 7500ce, Palo Alto, USA). The laser ablation device contained a frequency quintupled Nd:YAG laser (wavelength 213 nm and pulse width 4 ns) with a motorized stage. Tuning of the LA-ICP-MS system and optimization of the sensitivity was carried out using the standard glass NIST 612. Sampling of the glass artifacts was conducted using the spot mode with a laser beam diameter of 100 μm and a repetition rate of 10 Hz, yielding a penetration rate of ca. 1.1 μm s^{-1}. The mass spectrometer was set up in time-resolved analysis mode, measuring one point per isotopic mass and acquiring 53 masses values (Table 1 gives the operational conditions). In order to establish a blank signal for all masses, laser ablation started 10 s after the gas blank measurement (He/Ar mixture). A more detailed description of the LA-ICP-MS system used in this work is given in van Elteren et al. (2009).

Five hundred shots were fired per spot. The raw ICP-MS data acquired (in counts per second) during the last 100 shots were averaged for each of the 53 isotopes. Subsequently, the raw ICP-MS data were subjected to quantification with the so-called sum normalization

Fig. 2 Map of Zanzibar, showing the location of Fukuchani and Unguja Ukuu

calibration method previously described (van Elteren et al. 2009) based on summation of the oxides to 100 % and using Si as an internal standard to correct for ablation differences between different glass matrices. Four different series of standard reference materials were used to determine the concentration of major, minor, and trace elements: NIST SRM 610 and 612 (National Institute of Standards and Technology); SGT 2, 3, 4, and 5 (Society of Glass Technology); CMG B, C, and D (Corning Museum of Glass); and DLH 6, 7, and 8 (P&H Developments Ltd.).

Glass standards from the Corning Museum of Glass (CMG), which mimic ancient compositions, are the most suitable for accurate quantification of ancient glasses, especially for elements not present at trace levels, such as in lead glasses. CMG A (no longer available) and B match the composition of SLS Egyptian, Mesopotamian, Roman, Byzantine, and Islamic glasses. CMG C is a lead-barium glass similar to those found in East Asia, and CMG D is a high-Mg, high-Ca potash glass with typical medieval composition (Brill 1999). Since ancient glass samples often show signs of surface degradation, the laser was used in drilling mode to enable the measurement of the actual elemental bulk composition underlying any degraded layer. Most of the samples presented leached and corroded surfaces with an enrichment of magnesia, potash, lime, or alumina compared to the pristine glass, due to the precipitation of mineral phases from the soil onto the glass surface.

Table 1 LA-ICP-MS operating conditions for LA spot analysis drilling procedure

Laser (NWR UP213)	
Beam diameter	100 μm
Fluence	7 J/cm^{-2}
Repetition rate	10 Hz
Penetration rate	ca. 1.1 μm s^{-1}
Dwell time	50 s
ICP-MS (Agilent 7500cs)	
Number of measured elements	53 (^{9}Be, ^{11}B, ^{23}Na, ^{24}Mg, ^{27}Al, ^{29}Si, ^{31}P, ^{39}K, ^{43}Ca, ^{45}Sc, ^{47}Ti, ^{51}V, ^{53}Cr, ^{55}Mn, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{63}Cu, ^{66}Zn, ^{69}Ga, ^{75}As, ^{82}Se, ^{85}Rb, ^{88}Sr, ^{89}Y, ^{90}Zr, ^{93}Nb, ^{95}Mo, ^{107}Ag, ^{111}Cd, ^{115}In, ^{118}Sn, ^{121}Sb, ^{137}Ba, ^{139}La, ^{140}Ce, ^{141}Pr, ^{146}Nd, ^{147}Sm, ^{153}Eu, ^{157}Gd, ^{159}Tb, ^{163}Dy, ^{165}Ho, ^{166}Er, ^{169}Tm, ^{172}Yb, ^{175}Lu, ^{197}Au, ^{208}Pb, ^{209}Bi, ^{232}Th, ^{238}U)
Total acquisition time (per element)	0.64 s (10 ms per element)

Results

Online Resource 2 presents all the data from the analysis of 80 artifacts (but including 84 analyses since several beads are multicolored and each color was tested) comprising the contents of 52 elemental oxides. Online Resource 3 presents reduced compositions of all samples based on the method of Brill (1999, pp. 8–11) [in tables and graphs reduced compositions are indicated with *]. Online Resource 4 presents mean concentrations and standard deviations of all oxides by glass type and color, and Online Resource 1 provides morphological characteristics of all samples, their site contexts, and glass type.

Three basic types of soda-silica glass are represented in the assemblages, one in which the flux used in primary glass manufacture was derived from mineral soda (m-Na-Al) and the other two where the flux was a halophytic plant ash (v-Na-Ca and v-Na-Al) [the v stands for *végétale*, French for plant]. Magnesia concentrations are useful in separating these glass types: mineral soda glasses are normally characterized by MgO levels below 1.5 wt%, while plant ash glasses normally contain levels greater than 2.5 wt%. In addition, the m-Na-Al glass from these Zanzibar sites also contains higher concentrations of alumina than the plant ash glasses. Both m-Na-Al and v-Na-Ca glass types were found at Unguja Ukuu and Fukuchani but v-Na-Al occurred only at Unguja Ukuu. Figure 3 clearly shows the separation between these glass types based on their lime and alumina concentrations.

Discussion of the glass types and the beads produced

Mineral-soda-alumina (m-Na-Al) glass

Fifty-four (68.4 %) of the 79 tested Zanzibar beads are made of mineral-soda-alumina glass (Online Resources 1 and 4). Dussubieux et al. (2010) have identified five different subtypes of m-Na-Al glass in samples dating from about the fifth century BCE to the nineteenth century CE. Two of these (m Na-Al 1 and m-Na-Al 2) are found at sites in Africa, though

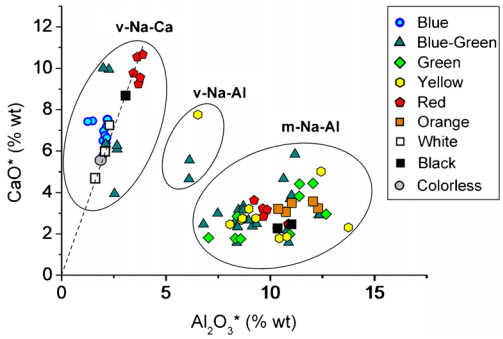

Fig. 3 Plot of lime vs alumina for all analyzed Zanzibar beads (reduced compositions calculated using the method of Panighello et al. (2012)

the time span during which this glass occurred at sites sampled to date within Africa is more restricted. One of these glass subtypes, m-Na-Al 1, is present in the Zanzibar beads along with a few outliers that do not comfortably fit any known subtype. The m-Na-Al 1 glass was formerly known as low uranium-high barium (or lU-hBa) glass. At first, we thought it possible that some of the outliers belonged to the m-Na-Al 2 subtype, a high uranium-low barium glass formerly known as hU-lBa (Dussubieux et al. 2008), but that attribution may be questionable as will be shown.

Dussubieux et al. (2010) differentiated the m-Na-Al 1 and 2 subtypes on the basis of the concentrations of four characterizing elements: Sr, Zr, Ba, and U. These four elements were probably chosen because they were the only elements which presented an acceptable separation between the concentration ranges in m-Na-Al 1 and 2 glasses, even though the first three of these elements partially overlap. An analysis of the whole dataset, however, indicates that alumina may also be useful in separating the two subtypes, so here we include it and thus employ five elements—Sr, Zr, Ba, U, and Al—to characterize and compare the m-Na-Al Zanzibar beads.

In comparing the Zanzibar m-Na-Al glasses to the compositions of Dussubieux et al. (2010) m-Na-Al 1 and 2 subtypes, we used compositional data, kindly provided by Dussubieux. This included beads from South and West India as well as Kenya. Our Sri Lankan data came from Dussubieux (2001). The source of the South Indian data included two archaeological sites that appear to predate the current era. The West Indian data is from samples ranging in date from the ninth to nineteenth centuries CE obtained at Chaul, a port site south of present-day Mumbai. The African samples are from four sites in Kenya. One of these has dates that span from the tenth to eighteenth centuries CE, and the others postdate the tenth century and cluster between the thirteenth and sixteenth centuries. The Sri Lankan data is from Giribawa, a third-century BCE to second-century CE glass- and beadmaking center.

When subjected to principal component analysis (PCA), the compositions of these beads (expressed in ppm of the elements and then standardized) formed two clusters representative of the compositional features of most of the samples of each m-Na-Al subtype (see blue and pink ovals of Fig. 4). The majority of the Zanzibari, Sri Lankan, and South Indian beads form a fairly compact group that suggests they are closely related, but the numerous outliers from this core suggest that there may be other subtypes that have not yet been identified. The overlapping between the two subtypes is a consequence of samples that lie between the concentration ranges as reported by Dussubieux et al. (2010).

The PCA extracted five principal components, of which only the first two (PC1 and PC2) were considered significant on the basis of the scree plot. These explain about 70 % of the variance. Most of the Zanzibar beads (red points of Fig. 4) form a compact cluster within the area of Dussubieux et al.'s

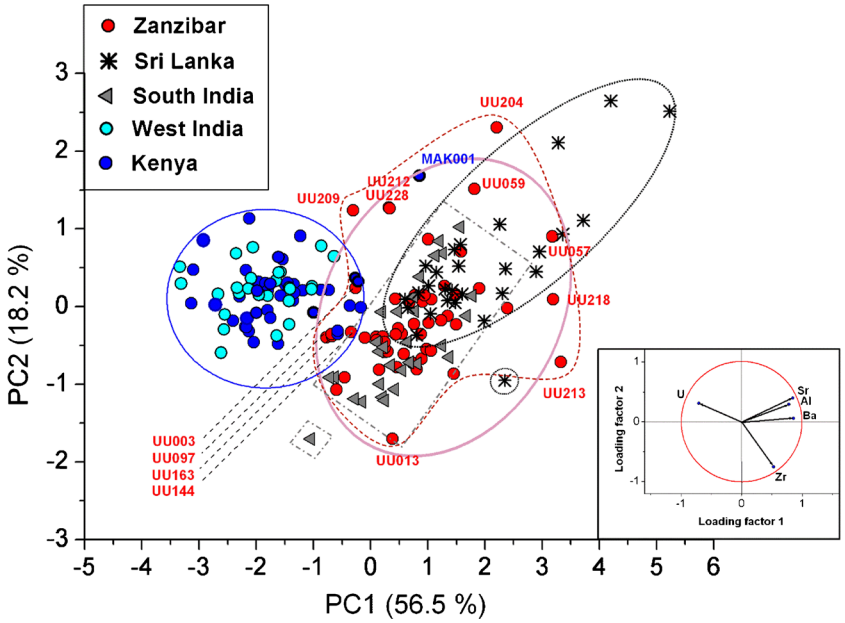

Fig. 4 PCA of m-Na-Al samples based on U, Ba, Zr, Sr, and Al levels. The Zanzibar beads are compared to others from Sri Lanka (Dussubieux 2001) and South India, West India, and Kenya (data courtesy of Dussubieux; see also Dussubieux et al. 2008, 2010). The *black oval* delineates samples from Sri Lanka, while the *gray dashed-dotted rectangle* outlines the South Indian ones. The *red dashed line* includes all of the Zanzibar samples. The *blue circle* delineates the Dussubieux et al. (2010) m-Na-Al 2 group parameters, and the pink oval the parameters of their M-Na-Al 1 group. Individual Zanzibar beads that do not fall comfortably within the parameters of either m-Na-Al 1 or 2 are identified by ID number and their relevant element concentrations and affinities are listed in Table 2

m-Na-Al 1 subtype, while the samples reported in Table 2 appear external to or borderline to this group. In particular, samples UU003, UU097, UU144, and UU163 fall in the area of overlap between the two subtypes. The analysis of variable loading (Fig. 4 inset) shows that along PC1 uranium and the other four elements as a group are inversely correlated: the former (with highly negative loading) essentially favors the m-Na-Al 2 cluster, while the latter load on the m-Na-Al 1 side. The variable loadings of the second PCA component show that the positions of the single samples reported in Table 2 (except UU003, 097, 144, and 163) are due mainly to the loading of the Al, Sr, and U variables.

The blue and pink ovals of Fig. 4 statistically circumscribe about 70 % of the m-Na-Al 1 and m-Na-Al 2 samples on the basis of the Dussubieux data. Therefore, the borderline samples (UU013, 057, 059, 212, 218, and 228) and those just outside the border (UU204, 209, and 213) may be part of the m-Na-Al 1 subtype. As Table 2 illustrates, none of the beads in the area of overlap between the two subtypes fit unequivocally into the m-Na-Al 2 category. Finally, although the PCA analysis represents a statistical synthesis of the concentration distributions of five elements, a detailed analysis of the data for the samples individually reported in Table 2 (and illustrated in Fig. 4) indicates the contradictory or uncertain assignments of these samples when the data for each element are considered separately. This underscores the limits of the Dussubieux et al. (2010) criteria when attempting to determine to which subtype some individual samples belong. In concurrence with this observation, new research by Dussubieux on other Zanzibar beads has confirmed the difficulty of assigning beads of m-Na-Al glass from the East African coastal region to only subtypes 1 and 2 (2015, personal communication).

Unfortunately, due to their similarity, beads of the two m-Na-Al subtypes cannot be separated based on morphology. It is interesting, however, that the majority of the chemically unusual beads that do not fit comfortably in either category come from disturbed contexts. As Table 3 shows, 8 of the 13 beads were found in trench 10 contexts 005, 006, and 009—all of these are from the fill of a pit dug into the trench.

m-Na-Al 1

Glass of the m-Na-Al 1 subtype is known from Sri Lankan, South Indian, and Southeast Asian sites dating between about the fifth century BCE and the tenth century CE (Dussubieux et al. 2009, p. 159, 2010; Dussubieux 2001; Dussubieux and Gratuze 2013). Archaeological and associated chemical evidence indicates that one manufacturing center for this glass was located at Giribawa in Sri Lanka (Bopearachchi 1999, 2002; Dussubieux 2001), but that site is dated between the third century BCE and the second century CE and is thus too early to have been the source of the Zanzibar glass. No other sites manufacturing this glass type have been located, but there likely were other such glassmaking centers in Sri Lanka; for example, Francis (2013) concluded that Mantai

Table 2 Average concentrations and standard deviations in parts per million or weight percentage of elements/oxides important for separating m-Na-Al 1 from m-Na-Al 2 glass (data from Dussubieux et al. 2010), followed by data for questionable samples from Unguja Ukuu with suggestions of possible subtype attribution based on each element/oxide

		Sr (ppm)	Zr (ppm)	Ba (ppm)	U (ppm)	Al_2O_3 (wt%)
m-Na-Al 1	Dussubieux et al. (2010)	373 ± 145	561 ± 420	931 ± 432	11 ± 10	9.8 ± 2.1
m-Na-Al 1	Our data	345 ± 58	538 ± 133	826 ± 210	15 ± 18	9.3 ± 1.4
m-Na-Al 2	Dussubieux et al. (2010)	213 ± 70	168 ± 91	357 ± 114	105 ± 66	7.5 ± 1.6
m-Na-Al ?						
UU003		235 ± 16	540 ± 42	872 ± 46	121 ± 9	10.8 ± 0.2
	Related to subtype:	2	1	1	2	1
UU013		273 ± 4.3	922 ± 16	985 ± 15	7 ± 2	6.6 ± 0.1
	Related to subtype:	2(?)	?	1	2	2
UU097		215 ± 6	293 ± 8	438 ± 12	24 ± 1	8.5 ± 0.1
	Related to subtype:	2	1	2	1	1 or 2
UU144		233 ± 4	315 ± 7	483 ± 15	29 ± 1	8.4 ± 0.1
	Related to subtype:	2	1	2	1	1 or 2
UU163		232 ± 3	321 ± 6	480 ± 10	27 ± 1	8.4 ± 0.1
	Related to subtype:	2	1 or 2	2	1	1 or 2
UU213		567 ± 6	1400 ± 45	1218 ± 13	20 ± 1	12.1 ± 0.1
	Related to subtype:	?	?	1	1	1
UU218		589 ± 20	1021 ± 58	1260 ± 25	19 ± 1	12.1 ± 0.1
	Related to subtype:	?	?	1	1	1
UU057		589 ± 6	674 ± 7	1263 ± 35	18 ± 1	13.1 ± 0.3
	Related to subtype:	?	1	1	1	?
UU212		460 ± 4	277 ± 3	587 ± 6	94 ± 2	10.8 ± 0.1
	Related to subtype:	1	1 or 2	1	2	1
UU228		459 ± 14	277 ± 10	572 ± 20	95 ± 3	10.8 ± 0.1
	Related to subtype:	1	1 or 2	1	2	1
UU059		626 ± 19	331 ± 17	633 ± 37	36 ± 2	11.8 ± 0.2
	Related to subtype:	?	1	1	1(?)	1
UU204		720 ± 20	204 ± 5	806 ± 15	59 ± 2	12.2 ± 0.1
	Related to subtype:	?	1 or 2	1	2	1
UU209		368 ± 25	133 ± 8	344 ± 17	88 ± 3	11.3 ± 0.1
	Related to subtype:	1	2	2	2	1

was both a glassmaking and beadmaking center. However, as Dussubieux and Gratuze (2013, p. 404) note, South India may have produced m-Na-Al 1 glass as well. The orange beads made of this glass (a rather bright pumpkin orange [Munsell 5YR 5/10]) are potentially significant markers in that this is the first time they have been recorded in eastern Africa, although they do occur in the late occupation phase (fourth to sixth centuries CE) at Berenike, a Red Sea port in Egypt (Francis 2002, p. 228, note 21). They were common at Mantai where Francis (2002) proposed they were made. It is noteworthy that this is the first time m-Na-Al 1 glass has been recorded in eastern or southern Africa, apart from two morphologically unusual beads: one from Ungwana on the Kenyan coast (Dussubieux et al. 2008, p. 814) and the other from Mahilaka in northwest Madagascar (Robertshaw et al. 2006).

Table 3 Trench and context of beads whose subtype designation is uncertain

Bead ID	Trench	Context
UU209	10	009
UU097	10	005
UU163	10	006
UU144	10	006
UU213	10	009
UU218	10	009
UU204	10	009
UU212	10	009
UU228	13	006
UU057	11	017
UU059	11	017
UU013	11	005
UU003	11	002

m-Na-Al 2

Glass of the m-Na-Al 2 subtype is widely distributed in eastern and southern African sites, as well as at sites in

Madagascar and India and beyond, dating from about the mid-tenth to seventeenth centuries CE (Dussubieux et al. 2008; 2010; Robertshaw et al. 2003, 2006, 2010b). In East Africa, some reports indicate that this glass type appears in sites that have date ranges that include the ninth century (Dussubieux and Gratuze 2013, p. 404) but no details of the contexts in which the beads were found are provided. In addition, the earlier East African dating evidence is probably less secure than that for southern Africa. All available evidence indicates that m-Na-Al 2 glass was probably manufactured at a number of locations in India widely distributed from the Uttar Pradesh region southwards from a mineral soda known, at least in recent times, as *reh* (Brill 2001a, b; Kanungo 2004; Sode and Kock 2001). It appears unlikely that any of the Zanzibar beads were made from this glass type. As Table 2 and Fig. 4 demonstrate, none of the beads fit unequivocally into that type's parameters. In addition, the AMS dates for the trenches in which potential examples were recovered predate the tenth century, whereas this glass type has not been recorded earlier than the tenth century.

The most important conclusion that can be drawn from the analysis of the m-Na-Al beads found in Zanzibar is the pronounced contrast between the prevalence of subtype 1 and probable absence of subtype 2 of this glass in the assemblage and the fact that virtually all the m-Na-Al glass from southern Africa belongs to subtype 2 (Robertshaw et al. 2010b). These differences can be explained by temporal parameters: subtype 1 glass, as has been mentioned, was produced up to but not beyond the tenth century CE (Dussubieux et al. 2009, p. 159, 2010; Dussubieux 2001; Dussubieux and Gratuze 2013), while in southern Africa, no m-Na-Al glass beads have been recorded that predate the tenth century (Robertshaw et al. 2010b; Wood 2011).

Plant ash soda glasses

Two distinct types of glass were identified among the 26 samples fluxed with plant ash. The first type (v-Na-Ca) comprises 23 samples (including the presumed glass weight) that can be tentatively divided into two subtypes and two outliers, while the second (v-Na-Al), which contains elevated levels of alumina, is represented by only three beads; these will be discussed separately.

v-Na-Ca

All of the 23 v-Na-Ca samples have relatively small quantities of alumina. Twelve of the beads, along with the blue and white glasses of the eye bead (UU225), and the glass weight, form a subtype, here designated A, characterized by medium concentrations of lime, while subtype B, characterized by higher concentrations of lime, is represented by seven beads plus the black base glass of the eye bead (UU225). Two outliers, UU091 and UU173 with their higher soda concentrations and mostly lower concentrations of other major oxides (as well as trace element concentration differences), do not fit any of the identified groups; these are discussed in the section "The outliers" below.

The distinction between the proposed subtypes is tentative. Lime and phosphorus pentoxide contents show quite good separation between the subtypes (Fig. 5), but samples cannot be easily assigned to a subtype based on the quantities of numerous other elements, though some elements, such as chromium and boron, appear more promising as discriminants (e.g., Fig. 6).

v-Na-Ca subtype A Subtype A includes 12 beads, the blue and white glasses of the eye bead (UU225) and the glass weight but produced 17 analyses because three beads are multicolored and each color was tested; the multicolored beads are discussed more fully below. Colors that are found in subtype A beads include cobalt blue, blue-green colored with copper, white colored with tin and one colorless sample (UU114) with a notable, if predictable, absence of any coloring agent. Four of the seven cobalt blue beads, including the two striped beads, have been reheated on a flat surface (see "Bead types in the overall 2011 Zanzibar assemblages" for a description and Online Resource 1 for details). Among the blue-green beads, UU090 was pinched from a large tube with a large perforation and then reheated on a flat surface. FK017 is similar and may have been produced in the same manner. The remaining two, UU112 and UU235, are smaller but still have large perforations. Their walls are very thin so the ends have deteriorated making it impossible to determine whether they were reheated at all. The colorless bead (UU114) is uniformly

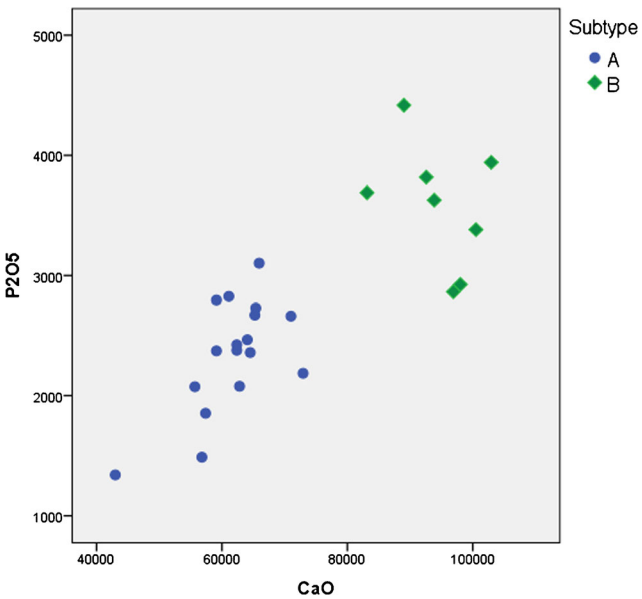

Fig. 5 Plot of lime vs phosphorus pentoxide for the v-Na-Ca A and B samples. Measurements in parts per million

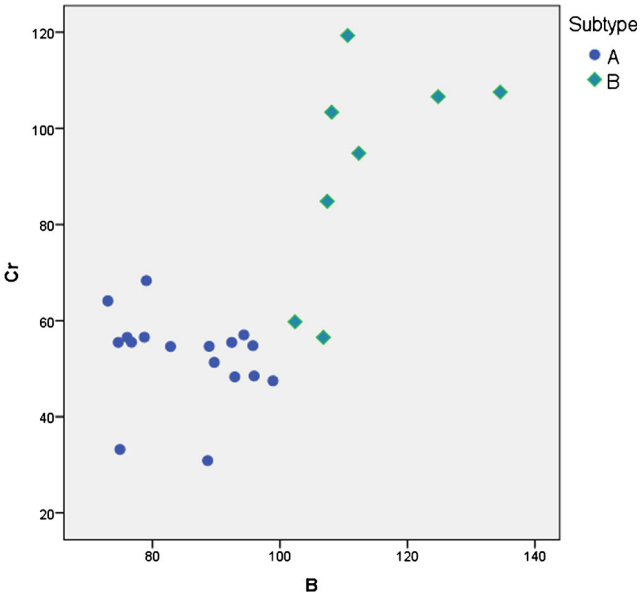

Fig. 6 Plot of chromium vs boron for the v-Na-Ca A and B samples. Measurements in parts per million

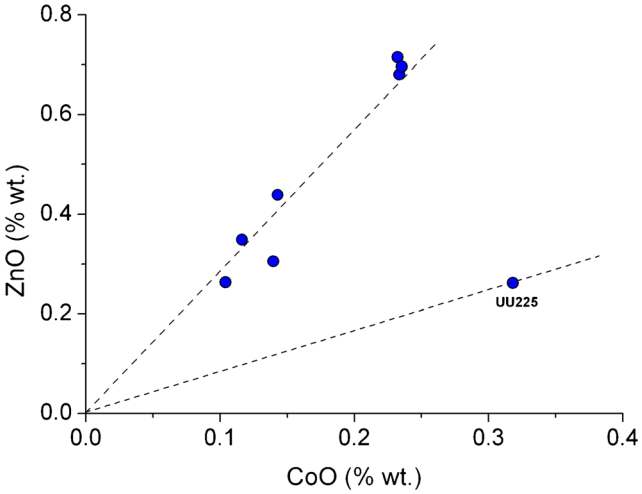

Fig. 7 Correlation between zinc and cobalt in the blue Zanzibar beads

rounded on both ends. The remaining v-Na-Ca subtype A samples are the white and blue "eyes" within the eye bead which is the only wound bead in the Zanzibar assemblages; it is described in the following section.

In the Zanzibar assemblages, cobalt blue glass is found only in beads (and the weight) made of v-Na-Ca glass and specifically only within subtype A; those with cobalt concentrations of over 1000 ppm ($n = 9$) will be discussed here. Cobalt in glass is often associated with various elements incorporated in the raw cobalt-bearing materials. Gratuze et al. (1992) note that cobalt can come from cobaltite (CoAsS), skutterudite (Co,Ni) As3-x, or trieuite ($2Co_2O{\cdot}CuO{\cdot}6H_2O$), or it can be associated with Fe, Ni, and As or Pb, Zn, In, etc. One of the three main cobalt mineral groups identified by Gratuze et al. is cobalt-zinc, in which these two elements are correlated with lead and indium. The cobalt in the Zanzibar beads is correlated with zinc and copper but not with other elements; they do include variable amounts of lead (0.1 to 5 wt%) and iron (0.9 to 2.1 wt%) but these are not correlated with the cobalt, and our indium levels are unfortunately not reliable due to the interferences between 118Sn and 115In isotopes in the ICP-MS system. Figure 7 shows that there is a strong Co-Zn linear correlation for all of our blue samples except UU225 (the eye bead), which has a Co/Zn ratio of 0.8 compared to the other samples with a ratio of 3. This different glass is the blue "pupil" of the eye bead, and given that the morphology and construction technology of this bead is so different from all the others, it might not be surprising that a glass colored with cobalt from a different source was used in its manufacture. Unfortunately, there is a dearth of information on the chemistry of cobalt sources in the Middle East during the early Islamic period.

Unguja Ukuu produced three multicolored beads, all from trench 10 below the rubbish pit mentioned earlier (section "m-Na-Al 2"). Two of these beads are made of v-Na-Ca subtype A glass, while the third (UU225) consists of a base glass assigned here to v-Na-Ca subtype B glass and eyes of blue and white glass that appear to be of subtype A. The fact that both v-Na-Ca subtypes appear to have been used in the manufacture of a single bead highlights the tentative nature of the identification of two subtypes; however, it has been shown that glass workshops in the early Islamic period sometimes used raw glass from different primary sources (Freestone et al. 2002, p. 270; Robertshaw et al. 2010b: Table 7), so it is well within the bounds of possibility that two different (sub)types of glass could have been used in the manufacture of a single multicolored bead.

Studies of these multicolored beads and others like them from sites in Sri Lanka, Thailand, and Scandinavia have enabled their manufacture to be placed in a time frame roughly between the late eighth and mid-ninth centuries (Wood, unpublished data). Two of these (UU231 and UU232) are cobalt blue with white stripes that run parallel to the perforation. The third bead (UU225) is known as a stratified eye bead (see Fig. 17 for images). It is wound (all others in the entire Zanzibar assemblage are drawn) with a black body and eyes made of a circle of white glass topped by a smaller one of cobalt blue. Eye beads are fairly common with a very long history, but the type discussed here is specific enough to have been named the "Takua Pa eye bead" after an eighth- to eleventh-century archaeological site (sometimes called Takua Pa but actually named Thung Tuk) on the Andaman coast of peninsular Thailand (Chaisuwan 2011) where a large number were found and where Francis (2002, p. 97) proposed they may have been made. We compared the chemistry of UU225 with three other "Takua Pa" eye beads from Thung Tuk (data courtesy of Jim Lankton), an eye bead from al-Basra in Morocco (PR1019FM; Robertshaw et al. 2010a) and two

eye beads from Chibuene in Mozambique (CHB0045 and CHB0047; Wood et al. 2012). All of these sites have eighth- to ninth-century components.

The al-Basra and Chibuene eye beads are morphologically unlike the "Takua Pa" eye beads but all are made of v-Na-Ca glasses, as is UU225. As Fig. 8 demonstrates, UU225 is very similar in terms of its major oxide concentrations and ratios to the Thung Tuk beads, being characterized by a high combined concentration of magnesia and potash and a low alumina to lime ratio. By contrast, the Chibuene eye beads differ in their alumina to lime ratios, while the al-Basra bead has less magnesia and potash than the Zanzibar and Thung Tuk specimens. The distinction between the Zanzibar eye bead and those from Thung Tuk on the one hand and the al-Basra eye bead on the other seems to be borne out by examination of the apparent coloring agents in the white glasses of these beads as well as of the blue and white striped beads from Unguja Ukuu and Tumbe, discussed next. The al-Basra white glasses, but not the others, are notable for their relatively high concentrations of lead and arsenic, as well as tin (Table 4), suggesting that the white color in the al-Basra glass might derive from a mixture of cassiterite and lead arsenate, whereas the others, including the Chibuene eye beads, seem to have been colored primarily with cassiterite. It is perhaps worth noting that the lead/arsenic ratios of the al-Basra white glasses are very different from those of the other white glasses discussed here. Moreover, with the exception of al-Basra, the quantities of arsenic, tin, and lead in the white glasses from the other sites are not correlated.

The two striped beads from Unguja Ukuu (UU231 and UU232) are morphologically very similar to one (PR788) from the site of Tumbe on the north end of Pemba Island in Tanzania (Fleisher and LaViolette 2013). Similar beads are also present at Thung Tuk. All these beads are also chemically very similar, with the exception of the blue glass of the Tumbe bead (Table 5 and Fig. 9), but this particular glass is clearly corroded, as is evident from both its high silica and low soda levels. In all the beads, the blue color can be ascribed to additive levels of both copper and cobalt, while the white glass exhibits high levels of tin, corresponding to tin oxide used as a white opacifier. The ratios of lead and tin to arsenic are strikingly similar in the white glasses of UU232 and the Tumbe bead (Table 4). Although all of these sites have eighth- to ninth-century components, this type of striped bead may also be present outside this time frame.

v-Na-Ca subtype B Of the eight subtype B beads, five are an opaque brick-red glass that is filled with bubbles, giving the ends a sponge-like appearance (see Fig. 17 FK019a and b): the three from Fukuchani (FK019a, b, and c) are medium sized (5.5 to 6 mm diameter), while the two from Unguja Ukuu (UU007 and UU115) are large (9.6 diameter) and appear to have been pinched from a glass tube rather than cut from tubes like the smaller beads. All were reheated on a flat surface to slightly round the cut ends which is an unusual treatment (see section "Bead types in the overall 2011 Zanzibar assemblages"). Two subtype B beads are translucent blue-green and large (the more complete one measures 11 mm in diameter), and they were made by a process known as segmenting. Both the brick-red and blue-green subtype B beads were colored with high concentrations of copper. The

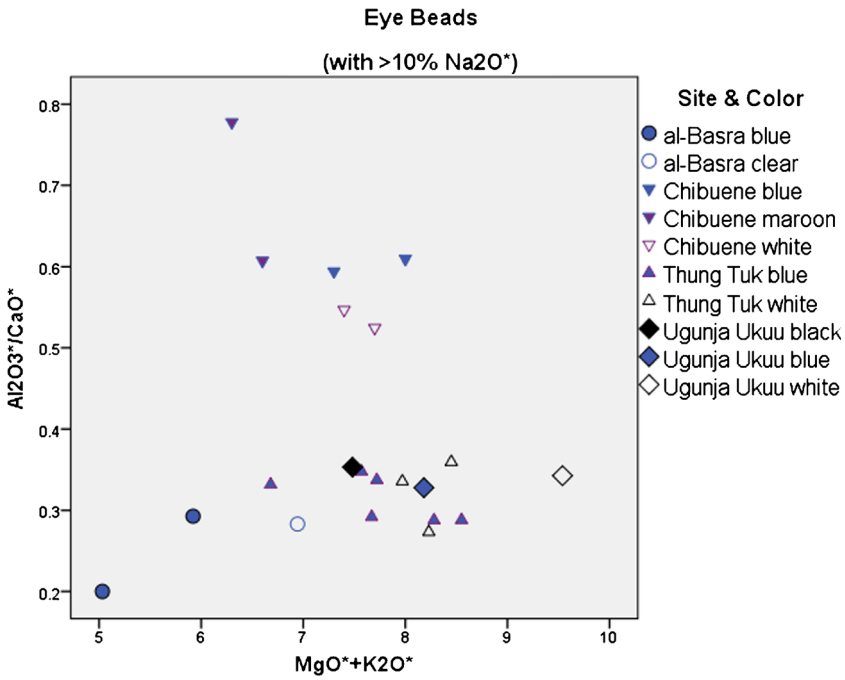

Fig. 8 Reduced alumina (Al_2O_3) and magnesia (MgO) compositions (wt%) of UU225 compared with those of other eye beads. The three data points for UU225 represent the three different colored glasses that were analyzed on this bead. The other beads in the figure also have multiple data points, each based on the analysis of a differently colored glass

Table 4 Concentrations (in ppm or weight percentage as shown) and ratios of the coloring agents in the white glasses of the eye and striped beads

ANID	Site	As_2O_3	SnO_2 (%)	PbO (%)	PbO/As_2O_3	SnO_2/As_2O_3
PR1019FM	al-Basra	0.14 %	16.89	10.28	72	118
PR1019FM-2	al-Basra	0.12 %	26.85	11.78	95	217
UU225	Unguja Ukuu	88.58	3.07	2.27	297	346
KKK TT 041	Thung Tuk	10.55	7.44	1.22	1161	7047
KKK TT 040	Thung Tuk	9.93	5.54	0.95	957	5581
KKK TT 058	Thung Tuk	12.90	7.85	0.51	398	6086
CHB0045	Chibuene	0.00	2.43	2.92	–	–
CHB0047	Chibuene	76.46	3.09	1.99	197	405
UU231	Unguja Ukuu	36.71	2.63	0.15	41	717
UU232	Unguja Ukuu	49.30	6.15	1.40	285	1247
KKK TT 044	Thung Tuk	12.41	4.33	0.91	732	3487
KKK TT 036	Thung Tuk	119.94	7.40	2.31	193	617
PR788	Tumbe	34.08	3.56	0.88	259	1043

final bead of this subtype comprises the black glass that forms the base of the eye bead (UU225) discussed above.

The origins of the increased concentrations of CaO in the subtype B glass are not entirely clear. Henderson (2013, p. 284) reports that most lime in plant ash glass comes from the ash itself. However, the lime content of some halophytic plants was insufficient to make Islamic glass, so a third primary raw material, such as feldspar which is rich in both calcium and alumina, could have been added along with the sand which, especially with desert and stream sands, is often low in calcium (Duckworth et al. 2015). Unfortunately, our data cannot differentiate between potential calcium sources. The mean ratios between the lime, alumina, and phosphorus oxide contents in subtypes A and B are similar, but other oxides that characterize the ashes, such as sodium, potassium, and magnesium, are rather different. In the end, these differences cannot account for the differences in lime levels between the two subtypes, thus suggesting at the very least the use of ashes from different plants.

Comparison of v-Na-Ca subtypes to related datasets

African comparisons: There are two datasets comprising chemical compositions of beads of plant ash glass from the late first millennium CE that are appropriate for comparison with the Zanzibar v-Na-Ca subtypes. The first comprises the plant ash glass beads from the port of Chibuene in Mozambique where three subtypes of plant ash glass were identified (Wood et al. 2012). The first of these, Chibuene "v-Na 1" glass, is represented by beads, vessel shards, blobs, and cullet, with the beads identified as belonging to the Zhizo series (Wood 2011). Chibuene "v-Na 2" glass, with relatively high concentrations of chromium, nickel, and zirconium, consists of green vessel shards, cullet, and blobs but no beads, while Chibuene "v-Na 3" glass is represented only by beads which were assigned to a new morphological type, the Chibuene series (Wood et al. 2012). The second comparative African dataset used here comprises the results of chemical analysis of 16 beads of the Zhizo series from various southern African sites

Table 5 Reduced compositions (weight percentage) of the striped beads. Reduced compositions are calculated following the method described by Brill (1999, pp. 8–11)

Bead ID	Site	Color	Na_2O*	MgO*	Al_2O_3*	SiO_2*	K_2O*	CaO*	Fe_2O_3*
KKK TT 044	Thung Tuk	Blue	15.2	4.1	1.7	68.9	3.2	5.4	1.5
KKK TT 044	Thung Tuk	White	15.4	4.7	2.2	67.0	3.1	6.4	1.1
KKK TT 036	Thung Tuk	Blue	15.0	4.3	2.0	68.4	3.2	5.9	1.2
KKK TT 036	Thung Tuk	White	15.4	5.2	2.3	66.4	2.9	7.1	0.8
UU231	Unguja Ukuu	Blue	15.2	4.7	2.0	67.2	3.5	5.8	1.6
UU231	Unguja Ukuu	White	14.3	4.4	2.1	69.4	3.0	6.0	0.8
UU232	Unguja Ukuu	Blue	14.6	4.5	2.2	66.5	3.3	7.4	1.5
UU232	Unguja Ukuu	White	15.4	4.8	2.3	65.7	3.6	7.3	1.0
PR788	Tumbe	Blue	6.9	3.2	6.4	75.3	1.5	4.6	2.0
PR788	Tumbe	White	13.0	3.9	3.5	72.2	2.6	4.3	0.5

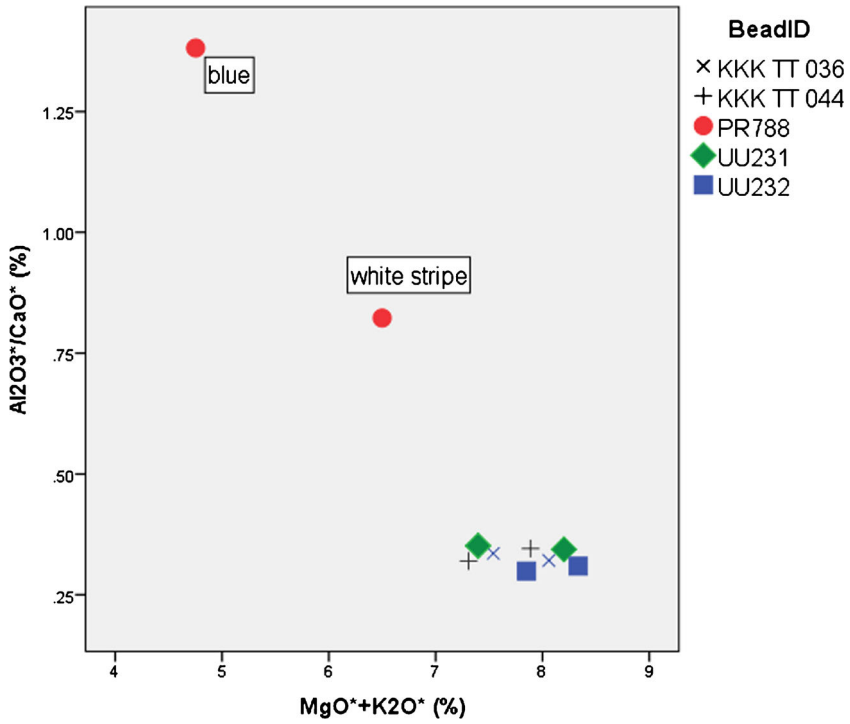

Fig. 9 Reduced compositions (wt%) of the striped beads from Unguja Ukuu (Zanzibar), Tumbe (Tanzania), and Thung Tuk (Thailand)

(Robertshaw et al. 2010b). These Zhizo series beads are chemically very similar to those of the Chibuene v-Na 1 series. It may be noted that glass beads with chemistries very similar to the Chibuene v-Na 1 and Zhizo series beads have also been recovered from several West African sites, including Igbo-Ukwu in Nigeria (Robertshaw, unpublished data), Gao in Mali (Cissé 2011; Cissé et al. 2013), and Kissi in Burkina Faso (Robertshaw et al. 2009).

Table 6 presents the mean compositions of the major oxides and selected trace elements for the Zanzibar plant ash subtypes and the African comparative dataset. Perusal of this table and Fig. 10 confirms the distinctively different composition of the Chibuene v-Na 3 glass (Chibuene bead series), as reflected, for example, in the quantities of lime, potash, magnesia, chromium, rubidium, barium, and uranium. The second most distinctive glass is the Zanzibar subtype B glass with its high lime levels, as well as somewhat elevated levels of soda and chromium, though, as noted above, lime aside, it shows considerable compositional similarities to Zanzibar subtype A, as well as to the Chibuene v-Na 1 and Zhizo glasses. Chibuene v-Na 2 glass is also not entirely dissimilar to the other types, at least when the quantities of individual oxides are compared, though it has notably higher amounts of chromium, nickel, and zirconium and less rubidium. Chromium and nickel levels in the Chibuene v-Na 2 glass are highly correlated (Wood et al. 2012, p. 64), as they are as well in Zanzibar subtype B glass ($r = 0.855$, $p = 0.007$) but not in Zanzibar subtype A ($r = 0.324$, $p = 0.204$), though the overall quantities of these elements are generally higher in the Chibuene v-Na 2 glass.

Middle Eastern comparisons: Plant ash glasses found in eastern and southern Africa that are dated to the late first millennium AD and contain less than about 4 % alumina are widely considered to have been manufactured in the Middle East (Robertshaw et al. 2010b; Wood et al. 2012), though the beads found on Zanzibar that were made of Middle Eastern glass may well have been manufactured outside the Middle East (see discussion in section "East Africa"). The question here is whether we can source either of the Zanzibar plant ash glass subtypes to any particular region within the Middle East. Henderson (2013, pp. 290–300) has investigated the complex variation in glass compositions across the Middle East, noting the inevitable complexities that result where raw materials, as well as raw and scrap glass were widely traded, as was the case here, but nevertheless noting some potential avenues of inquiry.

Al-Raqqa in Syria is the only primary plant ash glass manufacturing site of the late first millennium AD that has been thoroughly investigated and for which considerable compositional data are available (Henderson et al. 2004). Henderson and colleagues identified three plant ash glass types (types 1, 2, and 4) at al-Raqqa, with type 4 glasses varying considerably in composition because they were perhaps the products of experiments in the production process. Figures 11 and 12 compare some of the major oxide compositions of the Zanzibar plant ash subtypes with the al-Raqqa types. The Zanzibar plant ash glasses fall within the broad compositional range of al-Raqqa type 4 glasses based on their alumina and magnesia compositions (Fig. 11), but their potash and lime concentrations tell a different story, with the Zanzibar

Table 6 Major oxide and selected element compositions (mean and standard deviations) of late first millennium eastern and southern African plant ash glass types

		Glass type					
		Zanzibar A	Zanzibar B	Chibuene v-Na 1	Chibuene v-Na 2	Chibuene v-Na 3	Zhizo series
n		17	8	52	13	11	15
SiO_2 (%)	Mean	65.12	59.70	66.31	67.39	66.37	67.42
	SD	2.83	2.50	3.88	1.33	2.01	3.64
Na_2O (%)	Mean	14.53	15.79	13.87	14.13	15.10	12.66
	SD	2.13	0.38	1.01	0.81	0.76	1.81
CaO (%)	Mean	6.17	9.46	5.62	5.47	3.68	5.45
	SD	0.67	0.64	1.10	0.95	0.33	1.38
K_2O (%)	Mean	3.03	2.65	3.20	2.97	4.87	3.05
	SD	0.35	0.26	0.54	0.36	0.29	0.62
MgO (%)	Mean	4.03	3.86	3.75	4.53	2.34	4.20
	SD	0.83	0.32	0.49	0.64	0.17	1.37
Al_2O_3 (%)	Mean	2.00	3.10	3.09	2.02	3.86	3.13
	SD	0.32	0.69	0.72	0.59	0.38	0.58
Cr (ppm)	Mean	53	92	47	191	20	42
	SD	9	23	10	56	3	15
Ni (ppm)	Mean	30	49	41	115	18	39
	SD	9	12	41	44	5	33
Rb (ppm)	Mean	15	16	20	10	52	26
	SD	2	2	3	2	7	14
Zr (ppm)	Mean	135	83	74	288	78	88
	SD	45	28	44	130	12	40
Ba (ppm)	Mean	148	209	244	170	705	275
	SD	74	109	68	57	160	99
La (ppm)	Mean	8	8	6	4	16	7
	SD	2	1	1	1	2	1
Nd (ppm)	Mean	7	7	5	3	13	6
	SD	1	1	1	1	2	1
U (ppm)	Mean	0.7	0.9	0.8	1.0	3.0	0.7
	SD	0.1	0.1	0.2	0.3	1.0	0.3

subtype A glasses aligning with al-Raqqa type 1, rather than type 4, because of their high lime concentrations, though subtype A still broadly matches al-Raqqa type 4 (Fig. 12). Furthermore, a plot of lime and alumina concentrations in raw furnace glass from al-Raqqa (Henderson 2013, p. 285) shows that this glass is characterized by >6 % lime and <2 % alumina, which makes it a poor match for the Zanzibar plant ash glasses.

Looking further afield in the Middle East than al-Raqqa, Henderson (2013, pp. 294–295) has drawn attention to possible broader geographical patterns in the major oxide compositions of Islamic glass across the Middle East. Given that high lime concentrations are what defines our Zanzibar subtype B glass, it is noteworthy that comparable high lime glasses include the raw glass from the eleventh-century Serçe Limani shipwreck (Brill 2009), eighth–eleventh-century glass from Ramla in Israel (Freestone et al. 2000), glass from furnaces on the island of Tyre (Freestone et al. 2002), and glass from Fustat in Egypt (Brill 1999). Henderson (2013, p. 294) argues that the high lime concentrations in these glasses derive from shell fragments in beach sands, with the Levantine coast being the most likely source. This encourages us to suggest that the Zanzibar plant ash subtype B glasses most likely derive from the same Levantine region, though it is important to note that the Zanzibar subtype B glasses generally possess more alumina than do their Levantine counterparts, suggesting the use of sand rather than quartz as the silica source. We should also remember that the Levantine samples derive from raw glass and vessel glass rather than colored beads.

It is tempting to look eastwards, to Iraq and Iran, for an origin for the Zanzibar subtype A glass. Figures 13 and 14

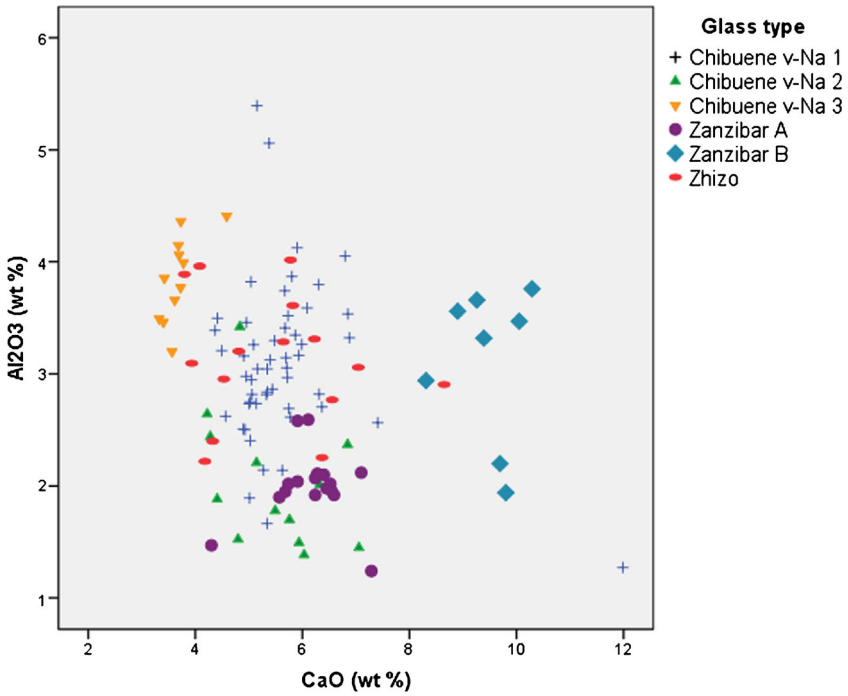

Fig. 10 Biplot of weight % alumina vs lime in the Zanzibar and other eastern and southern African plant ash glasses of the late first millennium AD

compare the Zanzibar plant ash subtypes with a variety of Iranian and Iraqi glasses of similar age or, in the case of the Sasanian glass, earlier. While the high lime and alumina concentrations of most of the Zanzibar subtype B glasses show that they are not a good match with these eastern Middle Eastern glasses, those of Zanzibar subtype A are a better fit, particularly perhaps with the Sasanian type 1 glasses. Freestone (2006) noted that glasses found to the east of the Euphrates have higher potash and magnesia concentrations than those to the west (see also Rehren and Freestone 2015: Fig. 5), providing further support for an eastern origin for the Zanzibar subtype A glasses.

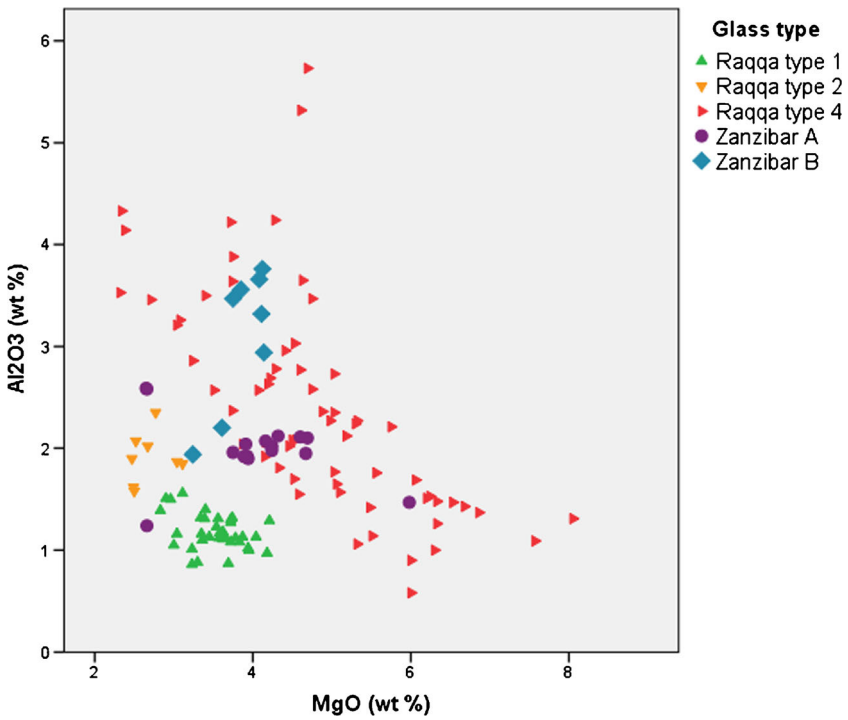

Fig. 11 Biplot of weight % alumina vs magnesia in the Zanzibar and al-Raqqa plant ash glasses (data from Henderson et al. 2004)

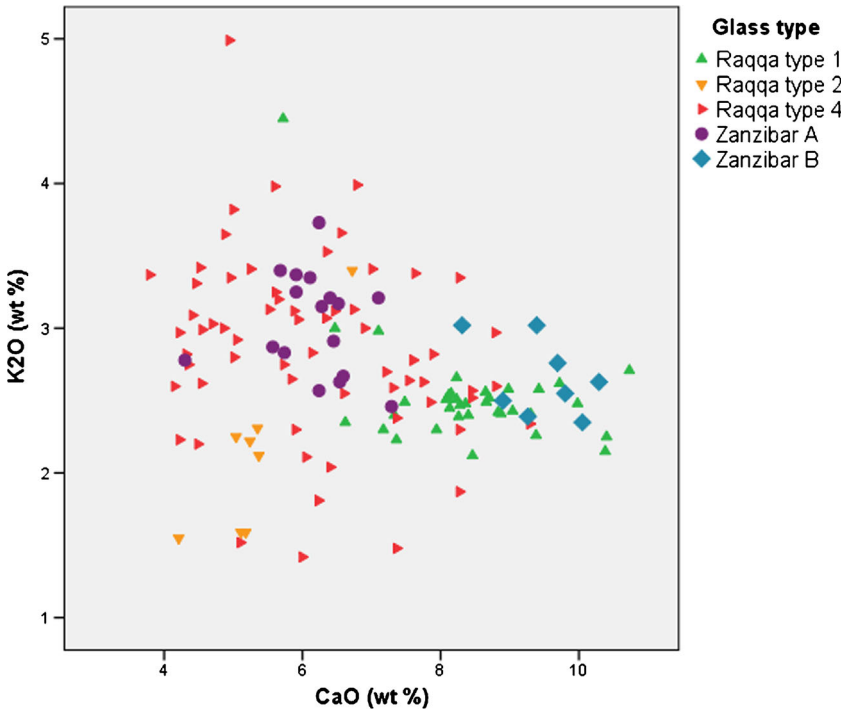

Fig. 12 Biplot of weight % potash vs lime in the Zanzibar and al-Raqqa plant ash glasses (data from Henderson et al. 2004)

In summary, we suggest that the Zanzibar plant ash subtype A glasses may have been made east of the Euphrates while those of subtype B more likely originate in the Levantine region. These ascriptions are tentative. More reliable sourcing of the glasses within the Middle East will require much more detailed investigation of both trace element and isotopic data.

The outliers The two beads that are outliers (UU091 and UU173), which are made from v-Na-Ca glass but with rather different chemistries, remain to be discussed. UU173 is blue-green, colored with copper, while UU091 is blue but not dark cobalt blue like the other blues—it contains both copper and cobalt with a Cu/Co ratio of about 3 which results in a blue tending toward green tones rather than purple ones.

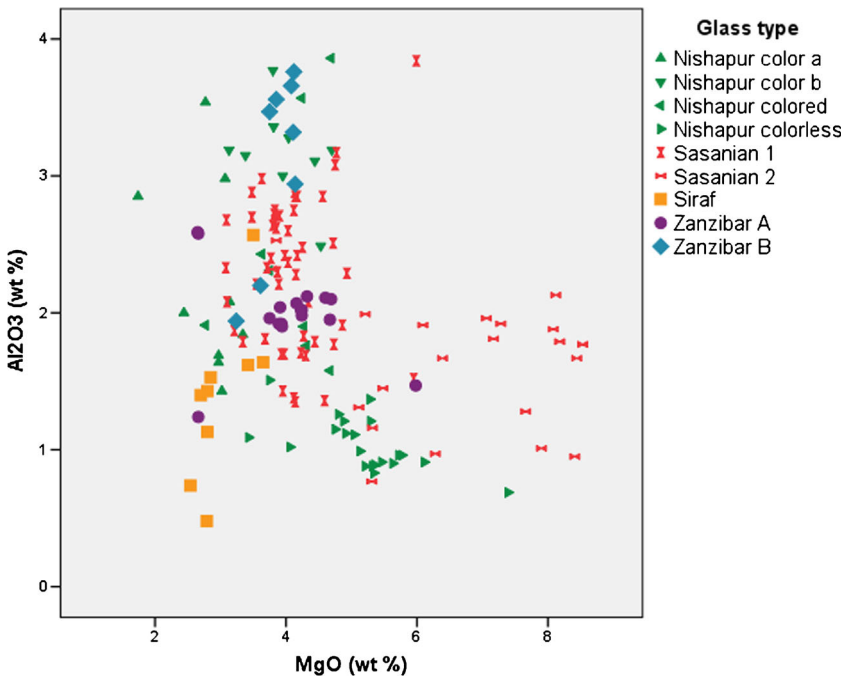

Fig. 13 Biplot of weight % alumina vs magnesia in the Zanzibar and eastern Middle Eastern plant ash glasses (data from Brill 1995, 1999; Mirti et al. 2008, 2009)

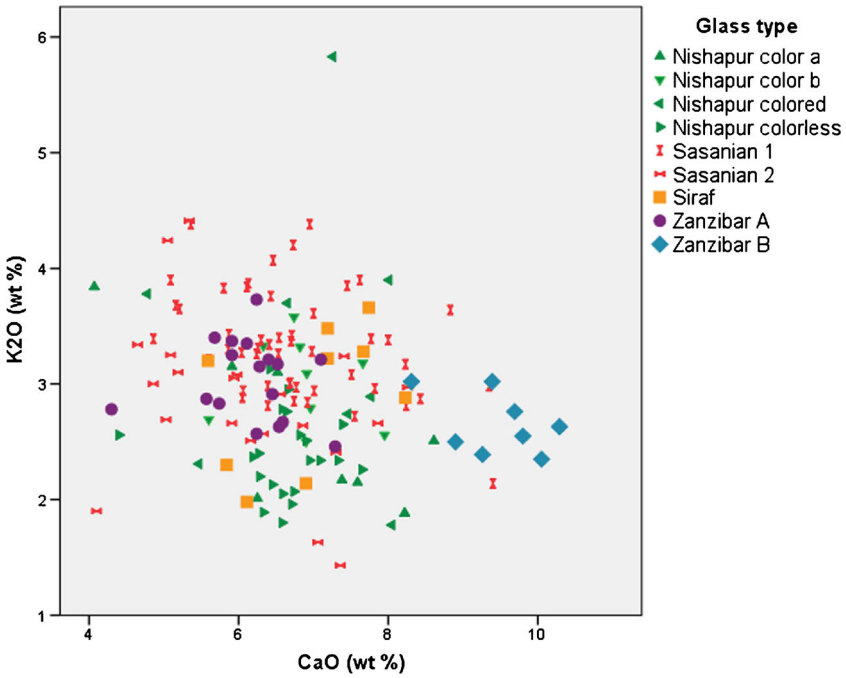

Fig. 14 Biplot of weight % potash vs lime in the Zanzibar and eastern Middle Eastern plant ash glasses (data from Brill 1995, 1999; Mirti et al. 2008, 2009). Note that one Sasanian type 1 sample with 8.9 % K_2O was omitted from the plot

UU091 is, in terms of its major oxides, broadly comparable to Zanzibar subtype B but includes more soda and less of the other oxides. It also exhibits some differences in trace element concentrations from the Zanzibar subtype B glasses, for example, the vanadium, zinc, silver, tin, and barium concentrations. UU091 also possesses a very distinct rare earth element (REE) profile (Fig. 15), which distinguishes it from other Middle Eastern glasses. This REE pattern, with a high enrichment of heavy REEs, is typical of cobalt blue glasses derived from cobalt alum sources, as found, for example, in Late Bronze Age Egypt (Shortland et al. 2007).

UU173 has an unusual major oxide chemistry with low levels of both alumina and lime, which align the bead with the glass of the Chibuene series (Wood et al. 2012). However, the trace element concentrations in UU173 show both similarities to and marked differences from those of that series, with, for example, similar concentrations of lime and zirconium but different quantities of alumina, chromium, and rubidium (Fig. 15; Table 7), presumably indicating closely related but not identical glasses. Wood et al. (2012, p. 66) remarked that the chemistry of the Chibuene series beads is "strikingly different from any of the assemblages in the Middle East," a conclusion that we can only echo for UU173.

v-Na-Al

The three plant ash glass beads with high alumina concentrations (v-Na-Al) were all found at Unguja Ukuu: UU001 is

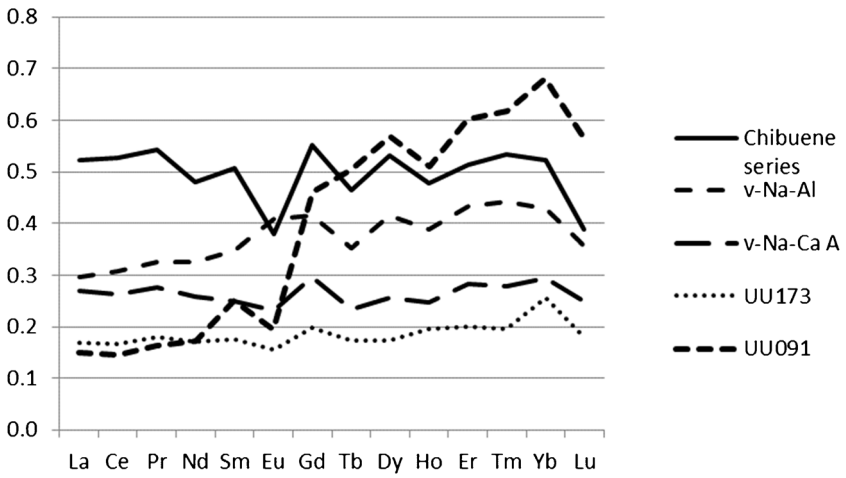

Fig. 15 Average REE patterns of the two outlier Zanzibar plant ash glass beads, compared with those of the Chibuene series (Wood et al. 2012), Zanzibar v-Na-Al and Zanzibar v-Na-Ca subtype A normalized to REE in the continental Earth's crust (Wedepohl 1995)

Table 7 A comparison of the composition (in weight percent and ppm) of UU173 with the average of the v-Na 3 beads of the Chibuene series (data from Wood et al. 2012)

	Chibuene series (v-Na 3n)	UU173
SiO_2	66.4 ± 2.0 %	68.03 %
Na_2O	15.1 ± 0.8 %	18.24 %
MgO	2.3 ± 0.2 %	1.92 %
AI_2O_3	3.9 ± 0.4 %	2.48 %
K_2O	4.9 ± 0.3 %	3.21 %
CaO	3.7 ± 0.3 %	3.88 %
Cr	20 ± 3	60
Rb	52 ± 7	21
Zr	78 ± 12	79
Cs	2 ± 0.2	n/a
Ba	705 ± 160	148
La	16 ± 2	4
Nd	13 ± 2	5
U	3 ± 1	0.5

yellow, UU002 blue-green, and UU227 green. The differences between this v-Na-Al glass and the other plant ash glasses from Zanzibar are demonstrated in their REE profiles (Fig. 16). Subtypes A and B derive from very similar bedrock geology, whereas v-Na-Al is markedly different, notably with its large positive Eu anomaly, its lack of a negative Ce anomaly, and its overall higher concentrations of REE.

Two of these v-Na-Al beads came from trench 11 in contexts 001 and 002, which are made up of overburden mixed with modern intrusions, while the third, UU227, is from trench 13 context 006, which is over half way down the trench depth. These beads have a chemistry that is somewhat related to that of the Mapungubwe Oblate and Zimbabwe series beads which are found at thirteenth- to fifteenth-century sites in southern Africa and Madagascar (Robertshaw et al. 2006, 2010b), as well as to that of vessel glass from Mtwapa on the southern Kenyan coast (Dussubieux and Kusimba 2012), but they all vary enough to make direct correlations difficult at this point (Dussubieux, 2015, personal communication). Thus, based on our present knowledge of this glass type, these Zanzibar beads may represent an as yet unclassified variation of this glass type.

Bead types in the overall 2011 Zanzibar assemblages

It is relatively easy to separate the m-Na-Al and v-Na-Ca beads in these assemblages based on morphology. First, cobalt blue does not occur in m-Na-Al 1 glass (Dussubieux et al. 2008, p. 815, 2010, p. 1650), so all beads of this color belong to the v-Na-Ca group. In addition, this type of glass is often filled with rows of small bubbles aligned parallel to the perforation. When these bubble rows are near the surface of the bead, they lead to the appearance of striations (Fig. 17: UU115 and UU007), and when seen in cross section, the bead ends can appear porous and sponge-like (Fig. 17: FK019a and b). Drawn beads are generally made by cutting bead-length segments from a glass tube. This results in beads with sharp, even jagged, ends so they are normally reheated to round or smooth the ends. The most common way this was done during this period—especially with South Asian beads—was to place the beads in a large pan packed with ash or another medium to prevent them from sticking together, then they were reheated while stirring until the edges slumped. This resulted in beads with shapes that are more or less the same on both ends. All m-Na-Al beads were treated in this manner. In contrast, most of the Zanzibar v-Na-Ca beads were rounded in an unusual way: the cut tube segments were placed on a flat surface and then reheated for a short time resulting in beads that are somewhat flat on one end and slightly rounded on the other (Fig. 17: UU229, UU231, and UU063). The effect can be subtle and difficult to see in a photograph since many of the beads were not reheated for long. Finally, all polychrome, wound, and/or unusually shaped (i.e., segmented) beads are made of v-Na-Ca glass.

Thus, based on color, bubbles in the glass, unusual end treatment, and shape, it has been possible to determine

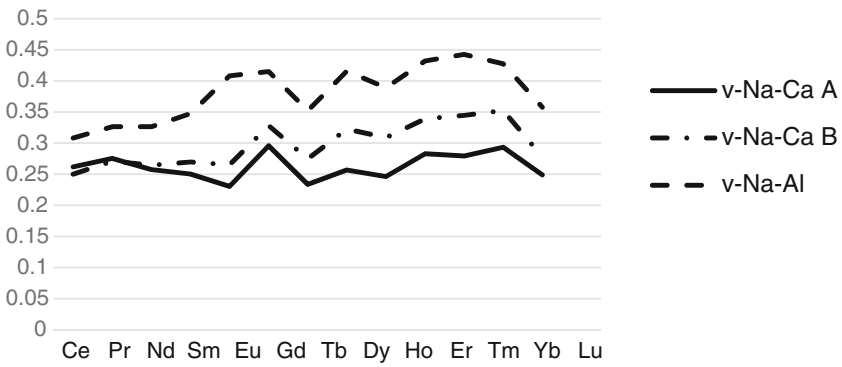

Fig. 16 Average REE pattern of the Zanzibar plant ash glasses normalized to REE in the continental Earth's crust (Wedepohl 1995)

Fig. 17 Unguja Ukuu and Fukuchani tested glass beads. Beads in the *top left panel* are from Fukuchani, all the rest are from Unguja Ukuu and are grouped by color. As can be seen in the *lowest center panel*, UU174 is not a bead but probably a glass weight

that 14 (46.7 %) of the Fukuchani beads are made of v-Na-Ca glass and 16 (53.3 %) are m-Na-Al glass. At Unguja Ukuu, only 36 (4.2 %) are made of v-Na-Ca glass, while the remaining 827 (95.6 %) are made from m-Na-Al or v-Na-Al glass (unfortunately, it is not possible to separate the v-Na-Al beads from the m-Na-Al ones based solely on morphology but given that v-Na-Al glass is rare at Unguja Ukuu and on the East Coast in general, it is unlikely that they form more than a small portion of the assemblage).

Beads and Indian Ocean trade patterns in the first millennium CE: East Africa and southern Africa compared

East Africa

Two main types of glass that date to the second half of the first millennium CE have been identified in the beads from Unguja Ukuu and Fukuchani. Based on bead distribution in trench 11 (see Table 8), which had the deepest stratigraphy (2.92 m) in the 2011 Unguja Ukuu excavations, it appears possible that m-Na-Al 1 beads—probably made in Sri Lanka or southern India—were the first to arrive. As can be seen, the three deepest, and thus earliest, contexts are made up almost entirely of m-Na-Al 1 beads. Of the 192 m-Na-Al 1 beads in those contexts, 167 are translucent blue-green. Juma (2004: Table 7.2.1), in his excavations at Unguja Ukuu, also recorded a preponderance of drawn translucent blue-green beads in Period Ia (500 to 750 CE): they accounted for 145 of the 178 glass beads recovered. Thus, it appears likely that m-Na-Al 1 beads are the earliest glass beads yet recognized on the East Coast.

The second type of glass, whose beads probably arrived somewhat later than the m-Na-Al 1 beads but ended production at about the same time, is a plant ash glass (v-Na-Ca subtype A) that was made in the Middle East, possibly east of the Euphrates. The beads, however, may well have been made elsewhere since that region is not known for making drawn beads and this glass was widely traded in raw and cullet form (Lankton and Dussubieux 2006, p. 135, 2013, p. 431; Carboni 2013, pp. 347–348). Regions where the beads could have been made include Thailand and Sri Lanka/South India, but other regions, including the Middle East, cannot be ruled out. However, given that m-Na-Al 1 beads from South Asia were being traded to Zanzibar, it would not be unreasonable to entertain the possibility that some of the v-Na-Ca beads could have been produced in that region or in Thailand, which was making beads from this glass and, in its role as a key link in east-west commerce at the time, was trading actively with Sri Lanka and India. The simple monochrome drawn v-Na-Ca beads that were briefly reheated on a flat surface, as found at Thung Tuk, Thailand, would be the most likely to fit this profile. The more complicated eye beads and striped beads may have been made in Thailand, as suggested by Francis (2002, p. 97), or they could have been produced in the Middle East. In either case, they could have arrived in Zanzibar through the South Asian trade links under discussion because such beads are not uncommon in South and Southeast Asia, especially the "Takua Pa" eye beads which were found in large numbers at Thung Tuk and were present at Mantai as well.

A few beads made of v-Na-Ca subtype B glass with elevated lime levels were found at both Unguja Ukuu and Fukuchani. This glass was also made in the Middle East but possibly farther to the west. It is not known where the beads were produced but, apart from the segmented beads, the techniques used to produce them are the same as those of the cut or pinched and flat reheated v-Na-Ca subtype A beads, suggesting that they were all made in the same region.

Table 8 m-Na-Al 1 and v-Na-Ca beads from trench 11 by context

Trench 11 beads		
Context	m-Na-Al 1	v-Na-Ca
002	1	
003		1
004	5	4
005	1	
006	2	2
007	2	
011	1	
012	1	1
014	20	3
016	4	1
017	158	4
018	16	
019	18	
Totals	229	16

Southern Africa

Evidence of Indian Ocean trade to southern Africa begins in the seventh century CE in the form of beads, made from a subtype of v-Na-Ca glass (v-Na-Ca 3), called the Chibuene series (Wood et al. 2012). As has been noted (Table 6 and Fig. 10), it is a distinct subtype but forms part of the plant ash glasses produced in the Middle East. Beads made of this glass type are rare and seem to have had a short life span. None have been found at any site in East Africa, including the Zanzibar sites in this study. In southern Africa, they were found at Chibuene and a few sites in Botswana as far west as the Tsodilo Hills (Wilmsen and Denbow 2010; Daggett et al. Glass trade beads at Thabadimasego, Botswana: analytical results and some implications, in publication; Denbow et al. 2015). They were replaced by beads known as the Zhizo series made from a related glass, v-Na-Ca 1 (Robertshaw et al. 2010b). As has been shown (Table 6 and Fig. 10), this glass is closely related to Zanzibar subtype A but the morphological differences between the two sets of beads make it unlikely that the beads themselves were manufactured in the same place. Almost all Zhizo beads are simply made by cutting bead lengths from drawn glass tubes; they are not reheated so their ends remain fairly sharp and often rather ragged. They are never pinched, segmented, or decorated (multicolored)—characteristics that are found in Zanzibar subtype A beads.

A few v-Na-Ca beads that do fit the Zhizo series chemically and morphologically have been found in East Africa, but only one site has produced more than one and that site is Tumbe on Pemba Island (Fleisher and LaViolette 2013) which also produced the cobalt blue bead with white stripes discussed above (section "v-Na-Ca subtype A").

East and Southern Africa compared

To Medieval Arab geographers, the eastern African coast comprised three sections, Bilad al-Barbara, Bilad az-Zanj, and Bilad as-Sufala. While the exact boundaries were not fixed, Barbara was the coast north of Mogadishu, Zanj southwards from there to the Rovuma River, and Sufala between the Rovuma and the Limpopo (Trimingham 1975, p. 120). The bead evidence from Zanzibar and southern Africa suggests that the Zanj and Sufala coasts may have been linked to distinct trading systems in the late first millennium. Historical sources offer some support for the possibility that the Medieval period saw direct sailing to Sufala from the Persian Gulf region that avoided the East African ports apart from Qanbalu, a port that is thought to have been located on the island of Pemba (Trimingham 1975, pp. 122, 135; Chittick 1977, p. 192; Hourani 1995, p. 148; Horton and Middleton 2000, p. 66). Al-Mas'udi, for example, noted that Sufala was "the extreme limit to which the Umanis and Sirafis go on the coasts of the sea of the Zanj….the sea of the Zanj ends with the land of Sufala and the Waq Waq which produced gold and many wonderful things" (Pellat 1962, III, 5). The anonymous tenth-century *Authentic Tales of the Sea* mentions voyages to Sufala in six different tales. One describes a sea journey to Sufala in which the winds and currents drove the ship onto the "coast … despite the captains efforts" (Freeman-Grenville 1981, p. 104). It describes the normal place "where the ships go" as located 42 *zams* (approximately 500 miles) beyond Qanbalu, a location close to Mozambique island. Both gold and ivory were key attractions of southern Africa. The Persian scholar Al-Biruni described the actual gold trade, recording that "at Sufala of the Zanj there is gold of extreme redness" and noting that the trading practices of the seagoing merchants involved the local ruler and his elders giving themselves up as hostages, while "the goods that their people desire" were taken inland to trade for gold (Levtzion and Hopkins 1981, pp. 58–59; Said 2007, pp. 205–208).

Taken together, these sources provide some evidence that ships from Oman and the Persian Gulf sailed to southern Africa to trade for ivory and gold, among other goods. Given the continuity in beads involved in that trade during the period between the eighth and mid-tenth centuries, along with the near absence of those beads at East African sites, it would not be unreasonable to propose that this trading pattern existed throughout that time span. Al-Mas'udi noted that these voyages included a stopover at Qanbalu on their way south (Freeman-Grenville 1962, pp. 14–16). Thus, the observation that beads found at Tumbe (on Pemba Island) can be linked to those that are otherwise primarily found in southern Africa could be related to the sailing pattern mentioned by al-Mas'udi. It is tempting to think that the "goods the people desire" included glass beads. The trade of Sufala seems to have been well organized and, it is possible to argue, on a somewhat different basis from that of the ports further north on the Swahili coast.

Bead production

Because Zhizo beads were made of glass that is probably from the Iraq/Iran region, were possibly carried to southern Africa on ships from Oman and the Gulf, and are rarely found outside of southern Africa, it appears likely they were made in the Persian Gulf region or nearby. However, because they were made from drawn tubes, the artisans who made them were probably South Asian since this technology is recognized as being South Asian and tube drawing is not known to have been practiced in the Iraq/Iran region)[2]. The absence or rarity of Chibuene and Zhizo series beads outside of southern Africa is also significant: had they been produced in South or Southeast Asia (as is possible with both types of v-Na-Ca beads found in Zanzibar), one would expect that the traders who supplied those v-Na-Ca beads to the east coast would have carried Zhizo beads as well.

Thus, one could propose that between the eighth and mid-tenth centuries, Zhizo series beads were being made by South Asian artisans somewhere in the greater Persian Gulf region using local glass and were then carried to southern Africa by ships from Oman and the Gulf. Another scenario, however, could be imagined in which South Asian artisans, who lived and worked in the region where the v-Na-Ca subtype A glass was being made, produced glass tubes in a variety of diameters and four basic colors (cobalt blue, yellow, blue-green, and green) which were then shipped to widespread destinations where they were made into beads based on local tastes and skills. In this case, Zhizo beads would have been cut from imported tubes at Chibuene, where the skills to reheat them to round the ends were not available or perhaps consumers in the region preferred unrounded beads. Possible evidence for this proposal is present in the Chibuene glass assemblage which includes a number of useless tube ends, tubes with no perforation and other potential beadmaking debris (Wood et al. 2012). Other sites in Africa that might have worked beads locally from imported v-Na-Ca glass tubes include Gao in Mali (Cissé 2011; Cissé et al. 2013) and Igbo Ukwu in the Niger Delta; both date to around the ninth century. At Gao, tube segments were reheated on a flat surface but for longer

[2] For a discussion of artisans moving around the Indian Ocean, see Bellina (2003), Horton (2004), Ray (2004), and Francis (2002), pp. 35–36.

periods and/or at higher temperatures than those from Zanzibar, resulting in beads that are more rounded on one end, flatter on the other, and shinier (MW, personal observation). The Igbo Ukwu beads were ground flat after cutting (MW personal observation), a process that could have easily been undertaken locally; in addition, it is rarely seen elsewhere with these types of beads.

There is no physical evidence that the Zanzibar beads were worked at Unguja Ukuu or Fukuchani and in any case the variety of treatments found in those plant ash beads (reheated on a flat surface, pinched from large tubes, segmented, decorated—and two subtypes of glass were involved) suggests they were produced either at several different locations or at a sophisticated complex one. In addition, their similarity to beads found in Thailand and Sri Lanka, which both have ample evidence of sophisticated beadmaking, suggests that it is more likely that they were made in one of those regions rather than in Zanzibar. Although the greater Persian Gulf region cannot be ruled out as a source, beads of these types, apart from eye beads, are not common at port sites, such as Siraf, and are absent from Nishapur (although it must be admitted that glass bead studies in this region are woefully limited).

Africa and its trade with the Indian Ocean

Like other types of material culture, including ceramics and diverse metal objects, the glass beads that reached Africa originated in a variety of far-flung regions of the Indian Ocean. That many of them were channeled through the Middle East is supported by both historical and archaeological evidence, although the possibility of some direct trade with South and Southeast Asia cannot be ruled out. Zanzibar's glass beads seem to originate mainly from the latter region, in contrast to those from southern Africa. This mirrors a key difference in the imported ceramic assemblages from Unguja Ukuu on Zanzibar and Chibuene on the southern African coast – Chinese ceramics are present, albeit in small quantities, at Unguja Ukuu, but are absent from Chibuene (Sinclair 1982; Sinclair et al. 2012, p. 728). Whether this reflects some input from direct trade to Zanzibar as opposed to further south, or whether it reflects different trading axes from the Middle East, remains to be determined. The possibility that agency on the part of African consumers may have played some role in the differences between the northern and southern sections of the east coast could be entertained for the East Coast, because traders from different regions appear to have been active there and the diverse types of beads, of different origins, that are found in assemblages from all periods support this possibility. Choice existed so could be exercised. However, in southern Africa, agency took a different and very conservative form: only one bead type from one source region was available (or at least in use) at any period between the seventh and seventeenth centuries and most of these bead "series'" were imported for more than a century or two (Wood 2005, 2011), being displaced only when the bead type went out of production (i.e., the Zhizo series) or because of significant changes in trade patterns that involved southern Africa. Portuguese traders learned of this conservatism in the early sixteenth century when they tried to introduce European beads—no one would accept them, so the Portuguese (and eventually other European traders) were forced to buy beads from India for the southern African trade (Wood et al. 2009). This pattern continued up to the late seventeenth century when European beads were finally accepted, partially because European beadmakers began to copy the Indian beads.

Conclusion

The glass beads from Unguja Ukuu and Fukuchani open new insights into Indian Ocean trade to Africa's eastern seaboard. Two major glass types are present at these Zanzibar sites: mineral-soda (m-Na-Al) and plant ash soda (v-Na-Ca). Most of the mineral-soda beads tested with LA-ICP-MS belong securely to a glass subtype (m-Na-Al 1) that was probably produced in Sri Lanka or South India, where the beads would likely have been made as well. This is the first time this glass subtype has been identified in East Africa or southern Africa. The fact that it was not produced after the tenth century CE confirms that the trade that brought the beads predates the second millennium. Most of the plant ash beads were made of glass (v-Na-Ca subtype A) produced in the Middle East, possibly east of the Euphrates. A smaller number of related beads (v-Na-Ca subtype B) were made of glass that may have been produced farther to the west. Based on method of manufacture and the presence of similar beads at other archaeological sites, however, it is possible that many of these beads were made in South or Southeast Asia. If this were indeed the case, they may well have arrived in East Africa via the same trade circuits as the m-Na-Al 1 beads. On the other hand, the beads found in southern Africa are likely to have come directly from the Persian Gulf region suggesting that during the latter part of the first millennium CE glass beads traded into East Africa and southern Africa arrived via two distinct trade networks.

The patterns observed in the Zanzibar bead data, and the contrasts with southern African datasets, allow us to propose a few possible scenarios for the late first millennium bead trade on the eastern African coast. The patterns may reflect the existence of distinct trading axes between the Middle East and the two sections of the African eastern seaboard, rather than a simple extension of the East African trade down to the southern coast. Or it is possible that they reflect the involvement of Zanzibar in a degree of direct trade with southern Asia that did not extend to the southern African coast.

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