# Glass Beads from Songo Mnara, Tanzania: Chemical Composition and Evidence for Local Bead Manufacture

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**Abstract** The 14th-to 15th-century site of Songo Mnara, in the Kilwa archipelago in southern Tanzania, is a stonetown with many standing coral buildings. Extensive excavations there have produced over 9,000 beads, 7,444 of which are glass. A subset of 140 of these were chemically analyzed using Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry, revealing a notably diverse assemblage that included four main glass types: mineral soda – high alumina (m-Na-Al), vegetable soda – high alumina (v-Na-Al), high lead glasses, and vegetable soda – lime (v-Na-Ca) glass. Here we present these types, giving the first tightly dated assemblage for the 15th-century coast. We then focus on two notable features of the assemblage. Amongst the high-lead glass beads are two types from China, one that dates to the early 15th century and the other from about 1600. These later Chinese beads were accompanied by some of the earliest European beads (v-Na-Ca) that are found in eastern Africa. Their provenance and meaning are examined. Then, we discuss large folded beads that were decorated with trails of colored glass. Such beads have been recorded only at Songo Mnara and Kilwa Kisiwani and we suggest they may have been made locally from imported v-Na-Al glass.

**Résumé** Le site de Songo Mnara, dans l'archipel de Kilwa au sud de la Tanzanie, daté du 14ème au 15ème siècle, est une ville de pierre avec de nombreux bâtiments coralliens encore debout. Des fouilles importantes ont produit plus de 9 000 perles, dont 7 444 en verre. Un sous-ensemble de 140 perles de verre a été analysé chimiquement à l'aide de la spectrométrie de masse à plasma inductif couplée à l’ablation laser. Cette étude révèle un assemblage particulièrement diversifié qui comprend quatre principaux types de verre: verre sodo-alumineux à la soude minérale (m-Na-Al), verre sodo-alumineux à la soude végétale (v-Na-Al), verre à haute teneur en plomb et verre calco-sodique à la soude végétale (v-Na-Ca). Nous présentons ici ces types, pour le premier assemblage de la cote est de l’Afrique étroitement daté du 14-15ème siècle. Nous nous concentrons sur deux caractéristiques notables de l'assemblage. Parmi les perles de verre à haute teneur en plomb, provenant très certainement de Chine, deux groupes ont été identifiés, l'un datant du début du 15ème siècle et l'autre du début du 17ème siècle. Ces perles chinoises plus récentes étaient accompagnées des premières perles européennes (v-Na-Ca) que l'on trouve en Afrique de l'Est. Leur provenance et leur signification sont examinées. Ensuite, nous discutons de grosses perles obtenues par pliage du verre qui ont été décorées de traînées de verre coloré. De telles perles ont été identifiées uniquement à Songo Mnara et Kilwa Kisiwani et nous suggérons qu'elles pourraient avoir été fabriquées localement à partir de verre v-Na-Al importé.

## **Introduction**

Glass beads have been recognized as important trade items at sites across eastern Africa from the first millennium AD onwards, particularly at coastal sites associated with Indian Ocean trade. For many years they were subjected to typological evaluation in which size, shape, color and method of manufacture were recorded (Chittick 1974, 1984; Horton 1996; Radimilahy 1998:182; Wood 2002; Juma 2004) but comparisons of assemblages between sites were of limited value because almost all pre-European glass beads are relatively small and monochrome making it difficult to interpret differences or similarities. Advances in glass analysis in the past few decades have made it possible to distinguish different glass types and trace their probable origins, thus greatly increasing the value of these small colorful objects to archaeologists. Up to now there have been a limited number of published discussions of glass chemistry from eastern Africa and the value of some of those is limited because of broad time frames involved (i.e. Dussubieux et al. 2008 in which analyzed beads date between the 9th to the 19th c.). In southern Africa, several clearly delineated bead series have been associated with chronological periods, with one bead type present in each period (Robertshaw et al. 2010, Wood 2011), but trade patterns in eastern Africa are more complex with beads arriving from several regions in any given period. Thus, although bead knowledge from southern Africa can help with the study of East Coast assemblages, the two regions were often engaged in different trade circuits (Wood 2015).

Glass beads from the site of Songo Mnara thus offer a unique opportunity to study a large assemblage of materials from across a range of well-defined contexts in a classic, 14th-16th -century Swahili stonetown. The high-quality recovery efforts at Songo Mnara and the breadth of contexts sampled offer one of the most robust and representative assemblages of glass beads from a stonetown of this period. A full morphological analysis of the beads was carried out (which will be reported elsewhere) and 140 were selected for chemical analysis based on this inventory. Chemical analysis of these beads provides insights into three issues: 1) origins of the glass used to make the beads; 2) site chronology; and 3) evidence for on-site bead production. In terms of production origins, this paper describes four different glass groups from India, Central Asia, China, and Europe. The complex assemblage includes some of the most well-known bead types such as Indo-Pacific, but also some less well understood beads from China and Europe. Questions about site chronology are based on the analysis of Chinese and early European beads, offering evidence that a small part of the site may have been reoccupied in the early 17th century. Finally, the chemical analysis of a particular type of folded bead and some associated glass rods offers evidence that these beads may have been made on site.

## **Background**

Songo Mnara is a small coral island belonging to the Kilwa archipelago (Figure 1) off the coast of Tanzania, the latter being home to several Swahili sites dating from the ninth century AD, of which Kilwa Kisiwani is the most widely recognized and longstanding. The site of Songo Mnara comprises a remarkably well-preserved stone town with dozens of extant houses built from coral rag and lime mortar (Figure 2), six mosques, and hundreds of marked and unmarked graves. It was recorded and preliminarily studied by Dorman (1938), Mathew (1959), Chittick (1961), Garlake (1966), Pradines and Blanchard (2005) and Rüther et al. (2012) but has only received significant archaeological attention through the Songo Mnara Urban Landscape Project, directed by Fleisher and Wynne-Jones between 2009 and 2016. The data indicate that Songo Mnara was occupied for a relatively short time between the late fourteenth and sixteenth centuries AD. Extensive surveys and excavations have revealed complex urban and rural landscapes across the island with a presumably large and affluent elite presence and connections to Indian Ocean trade networks (Wynne-Jones and Fleisher 2016).

**Fig. 1** Kilwa archipelago

The Songo Mnara Urban Landscape Project conducted archaeological investigations of houses and open spaces at the site, as well as maritime and pedestrian surveys across the island (Pawlowicz et al. forthcoming). Excavations occurred in ten coral-built structures, excavated either completely or in part as a way of understanding how domestic space was structured (Wynne-Jones 2013). In addition, survey, systematic shovel testing and excavations have explored the public spaces of the site (Fleisher 2014). In the process, a series of wattle and daub houses were recovered in the western open area of Songo Mnara, with five structures sampled. This means that data are available from both stone and earthen forms of housing across the site, as well as from outdoor spaces and activity areas such as the wells and tombs around which people would have moved in their daily journeys (Figure 2). The wattle and daub houses contained comparable quantities of imported goods, coins and general material wealth to the stone houses and there is evidence that activities in them were related to craft-working or domestic activities for the stone house populations.

**Fig. 2** Songo Mnara site map

## **Glass analysis**

All deposits from the four seasons of excavation at Songo Mnara were sieved with 3 mm or smaller mesh. This resulted in the recovery of over 9,000 beads of various materials including semi-precious stone, shell, aragonite, terracotta, metal and a few pearls. Glass beads, however, formed the bulk, accounting for 7,444 beads. Of these, 7,156 are drawn, 235 are wound, 43 were made by the unusual process of folding and 10 were blobs or chunks of glass. One hundred and forty samples were chosen for chemical analysis using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). Sample selection focused on testing all the different bead groups present based on morphology, including method of manufacture, shape, size, glass translucency and color, which was important since several unusual colors were present and some colorants have known temporal parameters. Glass quality, which can be evident in the presence of bubbles or other inclusions in the glass and in surface luster, was considered as well.

The analyses were carried out at the Field Museum of Natural History in Chicago, USA in 2013 with a Varian Inductively Coupled Plasma - Mass Spectrometer (ICP-MS) and in 2018 with a ThermoFisher ICAP Q ICP-MS. Both instruments were connected to a New Wave UP213 laser for direct introduction of solid samples. LA-ICP-MS combines laser ablation for the micro-sampling of the objects using a laser beam of 100 µm or less that leaves invisible traces at the surface of the artifacts and mass spectrometry for the measurements of a wide range of elements (50 or more) with concentrations ranging from several percent to less than a ppm (parts-per-million, 1 ppm = 0.0001 %). This technique is now widely used to determine the compositions of ancient glass (e.g. Gratuze 2016). With the measurements of the major (present in the range of 1 % and more) and minor (less than 1 % but more than 0.1 %) elements, it is possible to reconstruct ancient glass recipes that are often specific to a region and to a particular time period. Trace elements, which are present in very small quantities in the glass (< 0.1 %), are indicative of the geological environment of the ingredients and can help discern different glass production centers using similar recipes but located in different places and using different sources of ingredients (Dussubieux, 2021). Reduced compositions, often used to describe the different glass types, are calculated by assuming that the main constituents of glass are SiO2, Na2O, MgO, Al2O3, K2O, CaO and Fe2O3 (Brill, 1999).

One hundred and fifty compositions were measured (Online Resource 1) because several of the 140 analyzed beads are multicolored and each color was tested. [One sample will be omitted from this discussion: the composition of bead SF35046-5 includes extremely high levels of lime (95 %) and 4.4 % of magnesia, suggesting it was made of shell]. Morphological descriptions of samples can be viewed in Online Resource 2.

Overall, the diverse assemblage points to a wide range of imported types and connections to an extensive geographic area. Chemical composition allows us to consider this variety within broad categories that correspond roughly with provenance. As will be described below, these groups based on chemistry encompass a range of typological and technological variability. We will discuss four main glass groups as shown in Table 1: mineral soda – high alumina (m-Na-Al); vegetable soda – high alumina (v-Na-Al); high-lead; vegetable soda – lime (v-Na-Ca).

|  |  |  |
| --- | --- | --- |
| **Glass type** | **# of beads by subtype** | **# in glass group** |
| m-Na-Al 1 | 1 |  |
| m-Na-Al 2 | 25 |  |
| m-Na-Al 4 | 1 |  |
| m-Na-Al 6 | 5 |  |
| m-Na-Al 7 | 11 |  |
| m-Na-Al 10 | 23 |  |
| *total m-Na-Al* |  | 66 |
|  |  |  |
| v-Na-Al folded, 2 with mixed glasses | 5 |  |
| v-Na-Al tubes | 8 |  |
| v-Na-Al wound beads | 14 |  |
| v-Na-Al drawn beads | 7 |  |
| *total v-Na-Al* |  | 34 |
|  |  |  |
| high lead Pb-Si-K early Chinese | 5 |  |
| high lead Pb-Si-K late Chinese | 12 |  |
| high lead Pb-Si European? | 6 |  |
| high lead Pb-Si-Na European? | 2 |  |
| high-lead Pb-Si-U European | 1 |  |
| *total high lead* |  | 26 |
|  |  |  |
| v-Na-Ca high Ti | 9 |  |
| v-Na-Ca stripe | 1 |  |
| v-Na-Ca European | 2 |  |
| high lead/v-Na-Ca mix | 1 |  |
| *total v-Na-Ca* |  | 13 |
|  |  |  |
| Total glass samples | 139 | 139 |

**Table 1** Summary of beads in glass composition groups in the Songo Mnara bead assemblage, based on LA-ICP-MS analysis

**Mineral Soda-High Alumina (m-Na-Al) Glasses**

Mineral soda-high alumina (m-Na-Al) glasses account for 66 of the 140 analyzed samples. After silica, soda is the most abundant component in these glasses, but their distinguishing feature is their high alumina content, which varies from 5 to 15 %. Both drawn and wound beads are made of m-Na-Al glasses, but drawn are by far the most common and are broadly referred to as Indo-Pacific beads (Francis 1986, 2002: 20). It is generally recognized that this glass and the beads were made in South Asia. Originally, five sub-groups of m-Na-Al glass had been recognized (Dussubieux et al. 2010) but recent work using concentrations of the elements Mg, Ca, Sr, Zr, Cs, Ba and U has identified an additional seven (Trivedi and Dussubieux, in preparation, see Table 2). Principal Component Analysis (PCA) using these 7 constituents and comparison with data in Table 2 show that the m-Na-Al beads from Songo Mnara belong to six m-Na-Al groups (Figure 3). They will be discussed in chronological order.

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| mNaAl group | 1 | 2 | 3 | 4 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| MgO | 0.72 | 0.94 | 1.24 | 0.83 | 0.7 | 0.86 | 1.02 | 0.48 | 0.96 | 0.65 | 0.98 |
| (wt %) | *0.78* | *0.28* | *0.24* | *0.28* | *0.2* | *0.2* | *0.19* | *0.14* | *0.45* | *0.19* | *0.31* |
| CaO | 2.51 | 4.37 | 2.3 | 1.33 | 2.22 | 2.55 | 1.35 | 2.68 | 2.17 | 2.63 | 2.06 |
| (wt %) | *1.41* | *1.22* | *0.56* | *0.41* | *0.53* | *0.73* | *0.22* | *1.04* | *0.88* | *0.98* | *0.5* |
| Sr | 348 | 222 | 112 | 86 | 188 | 159 | 90 | 170 | 143 | 200 | 151 |
| (ppm) | *103* | *52* | *18* | *19* | *70* | *41* | *14* | *44* | *57* | *74* | *40* |
| Zr | 460 | 162 | 162 | 237 | 212 | 178 | 241 | 286 | 198 | 207 | 224 |
| (ppm) | *147* | *66* | *49* | *110* | *64* | *64* | *31* | *55* | *86* | *60* | *53* |
| Cs | 0.5 | 0.6 | 3.3 | 3.7 | 1.3 | 0.7 | 3.3 | 0.8 | 1.9 | 0.8 | 2.5 |
| (ppm) | *0.2* | *0.2* | *0.8* | *1* | *0.4* | *0.3* | *0.5* | *0.1* | *0.9* | *0.3* | *0.7* |
| Ba | 951 | 358 | 320 | 500 | 442 | 264 | 329 | 821 | 303 | 388 | 442 |
| (ppm) | *270* | *81* | *44* | *196* | *243* | *41* | *45* | *924* | *54* | *130* | *105* |
| U | 13 | 123 | 64 | 100 | 54 | 29 | 209 | 31 | 244 | 14 | 133 |
| (ppm) | *10* | *59* | *25* | *58* | *27* | *12* | *63* | *7* | *87* | *5* | *18* |

**Table 2** Average concentrations of 7 glass constituents that are key to separate m-Na-Al glasses 1 to 4 and 6 to 12. The relative standard deviations are indicated in italics. Group 5 is unrelated to the Indian Ocean so is not included here

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**Fig.** 3a and b a: Scatterplot for PC1 vs PC2 calculated for samples from glass groups m-Na-Al 1 (unpublished data), 2 (Dussubieux et al. 2008), 4 (Dussubieux, 2009) and 6 (Dussubieux and Wood, 2021) and for the m-Na-Al glass samples from Songo Mnara that belong to these 4 glass groups. b: Scatterplot for PC1 vs PC2 calculated for samples from glass groups m-Na-Al 7 and 10 (Trivedi and Dussubieux, in preparation) and for the m-Na-Al glass samples from Songo Mnara that belong to these 2 glass groups

*M-Na-Al 1*

One unusual bead from Songo Mnara, which is opaque yellow and denticulated around the rim (see Online Resource 4 Plate 1), belongs to the m-Na-Al 1 sub-group. Another like it was found at Unguja Ukuu, Zanzibar, 7th -10th c. AD (Wood et al. 2017) and one at Kilwa Kisiwani in Period II (10th to 13th c.) deposits (Chittick 1974). The presence of this bead at Songo Mnara probably indicates it was heirloomed; it was found in a back room of a stone house (House 18). The m-Na-Al 1 group originated in Sri Lanka and South India and was manufactured beginning in the mid-1st millennium BC and throughout the 1st millennium AD (Dussubieux et al. 2021). This glass type is rather rare in sub-Saharan Africa and the only site that has yielded significant quantities is Unguja Ukuu.

*M-Na-Al 6*

Five Songo Mnara samples (individually listed in Online Resource 3A) are close to the m-Na-Al 6 cluster in Figure 3a. Before the recent identification of the new glass sub-groups, all m-Na-Al beads in eastern and southern Africa that did not belong to m-Na-Al 1 were assigned to m-Na-Al 2, thus covering the long period from the 9th or 10th century AD to the 17th century. Recent work by Dussubieux and Wood (2021) on beads excavated in East Africa at sites dating from the 9th to the 13th century identified the new sub-group, m-Na-Al 6. The five Songo Mnara samples of this group (see Online Resource 4 Plate 1) probably represent curated beads. Beads of this glass correspond to the K2 and East Coast Indo-Pacific series beads found in southern Africa (10-13th c.), which were originally placed in the m-Na-Al 2 group (Robertshaw et al. 2010) but now should belong to m-Na-Al 6. The place of production of m-Na-Al 6 glass remains uncertain but recent Sr isotope analysis conducted on m-Na-Al 6 samples suggests an origin in the Indo-Ganges region (Seman et al. 2021). Their distribution on the eastern African coast includes a number of sites that were occupied in the 11th to 13th centuries.

*M-Na-Al 2*

The m-Na-Al 2 sub-group, which accounts for 25 Songo Mnara samples (see Online Resource 3B and 4 Plate 1), corresponds to the glass used to make beads of the Khami series in southern Africa, which date from about 1430 to 1650 (Robertshaw et al. 2010), but they are commonly found at post 14th c. sites on the east coast. They might have been traded through a port on India’s west coast such as Chaul in Maharashtra. The beads were possibly manufactured at the site itself (Gogte et al. 2006; Federeci and Hickock, online), but the glass was probably made elsewhere in India (Dussubieux et al. 2021).

*M-Na-Al 4*

The single Songo Mnara m-Na-Al 4 sample is an unusual pumpkin orange striated tube (see Online Resource 4 Plate 2) and contains extremely high concentrations of iron. This sub-group was first identified in Indonesia on the island of Sumatra in the form of glass fragments, dated from the 15th to 16th century AD (Dussubieux, 2009). Subsequently, beads of this glass have been identified from several sites in Southeast Asia. In addition, a few m-Na-Al 4 beads have been found in East Africa (Dussubieux et al. 2008). Although this glass was certainly produced in India, the exact region of production is uncertain.

*M-Na-Al 7 and 10*

There are 34 beads from the m-Na-Al group at Songo Mnara that do not fall in glass groups 1-6 (see Online Resource 3C & D), but they show similarities to two of the newly identified m-Na-Al groups at Indor (in Rajasthan, northern India; Trivedi and Dussubieux in preparation; Figure 3 b); 11 beads are similar to m-Na-Al 7 and 23 beads are similar to m-Na-Al 10 (see Online Resource 4 Plates 2 and 3). The chronology and distribution of these glasses is poorly defined, but they belong to a period similar to or overlapping with glass groups m-Na-Al 4 and 2. This is the first instance in which these beads have been identified outside India.

### **Plant Ash - High Alumina (v-Na-Al) Glass**

Thirty-nine samples (representing 34 beads) belong to the vegetable-soda alumina (v-Na-Al) glass group (see Online Resource 4 Plates 4, 5 and 6). This glass is another soda-lime silica glass with elevated levels of alumina (> 4%), but it contains concentrations of potash and magnesia higher than 1.5% suggesting it was fluxed with plant-ash soda rather than mineral soda. It also has lower trace element levels than m-Na-Al glass indicating it was made with a different silica source (see Figure 4).

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**Fig.** 4 Concentrations of U and Hf in the m-Na-Al (dots) and v-Na-Al (triangles) glass samples from Songo Mnara

Robertshaw et al. (2010) identified two sub-types of v-Na-Al glass in southern Africa differentiated mostly on varying concentrations of P2O5, BaO, Zr and MgO. The Mapungubwe Oblate (MO) series is found in southern Africa in the 13th century and beads of the Zimbabwe (Z) series were present from the 14th to mid-15th century. The Z series beads have higher soda, phosphorus and barium and lower magnesia than the MO beads.

Up to now, researchers in eastern Africa (and even beyond) have been using the terms ‘Mapungubwe Oblate’ and ‘Zimbabwe’ to refer to these glass types but these terms are often confusing because morphologically and temporally the southern African bead series have little in common with beads of these glasses found elsewhere. For example, the MO series beads are mostly small (98% are <3.5 mm in diameter) drawn, well-shaped oblates in a limited range of colors (see Wood 2011). Morphologically Z series beads differ somewhat from the MO series and few beads of this glass type are found outside of southern Africa. To date they have only been identified in Madagascar at the sites of Mahilaka (10th – 15th c. AD) and Sandrakatsy (13th – 16th c. AD) (Robertshaw et al. 2006). As is evident from the Songo Mnara assemblage, beads of this glass outside of southern Africa are often quite large and are made in a variety of ways – drawn, wound and even folded. Roughly 72 % of v-Na-Al beads in eastern Africa are drawn, but in southern Africa drawn beads make up more than 99% of assemblages. Finally, whereas MO series beads date to the 13th century, beads of this glass appear elsewhere for a much longer period and are systematically present at coastal sites occupied during the 14th to 15th centuries.

Recently Siu et al. (2020) identified four types of v-Na-Al glass at the site of Mambrui, Kenya (15th – 16th c.). Two (Types C and D) were used only in vessel glass; Type A is related to MO glass and B to Z glass. We believe it would simplify and clarify discussion of this glass in the future if their system were employed, so we propose that the *glass* used to make Mapungubwe Oblate series beads should be referred to as v-Na-Al Type A and the *glass* of Zimbabwe series beads as v-Na-Al Type B. The terms ‘Mapungubwe Oblate series’ and ‘Zimbabwe series’ should henceforth be used to refer only to those series in southern Africa and not to the composition of these glasses found elsewhere.

The compositions of most of the v-Na-Al beads from Songo Mnara are remarkably close to the composition of the v-Na-Al Type A beads from Mambrui and the southern African MO series (Figure 5).

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**Fig.** 5 Bi-plot for the Al2O3 and Zr concentrations of MO and Z bead series (Robertshaw et al. 2010) and of the v-Na-Al glass beads from Songo Mnara

Plant ash – high alumina glass is particularly abundant in Central Asia (Dussubieux and Kusimba, 2012; Then-Obłuska and Dussubieux 2016; Carter et al. 2019; Siu et al. 2020) suggesting this glass type was produced there, but it is still uncertain where the beads themselves were made. More work needs to be done on the morphology and manufacturing techniques of beads of this glass to determine where they could have been made. It appears likely that numerous locations would have been involved because manufacturing methods and quality, as well as glass colors, vary considerably.

Among Songo Mnara’s v-Na-Al glass we find most of Songo Mnara’s distinctive folded beads (see Online Resource 4 Plate 4), which were probably produced at the site. Of the five that were analyzed, two included a mixture of glasses. SF32566-9, whose base glass and red trails are made of Type A glass, includes yellow glass that does not have a typical v-Na-Al composition: its alumina concentration is high (10 %) while soda is low (3.6 %) and magnesia and potash are a little above 1 %. SF37053 is even more unusual in that the red trails are made of v-Na-Al Type A glass but the cobalt blue, yellow and white trails are v-Na-Ca glass. It appears likely that the artisans who made these beads used what colored glass they had on hand at the time.

This suggests that Type A glass was traded either in raw form and/or perhaps in tube form to locations where it was worked into beads. Such a pattern is not unique: between the 8th and mid-10th centuries CE a plant-ash soda lime glass (v-Na-Ca) produced in the Iraq/Iran region was traded in raw and tube form across much of the Old World and formed into beads at various locations (Wood 2017, 2018).

### **Lead Glasses**

Twenty-seven of the tested beads are of glass with high concentrations of lead. As a percentage of tested beads this is an over-representation of their proportion in the assemblage; the morphological types represented by these beads were targeted specifically for analysis. They fall into three sub-groups based on concentrations of soda and potash (Figure 6). Three beads contain significant concentrations of soda but little potash. Six samples have exceptionally low concentrations of both potash and soda. The remaining seventeen samples contain low soda concentrations along with significant concentrations of potash.

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**Fig.** 6 Reduced concentrations of soda (Na20) and potash (K20) in the high lead glass beads

The three low potash – high soda beads in Figure 6 might be of European origin (see Online Resource 4 Plate 7). One (SF20125) contains high concentrations of uranium (10ppm), which was used to produce different shades of yellow, green and sometimes red from the end of the 19th century, indicating this bead is a later intrusion. The two other beads in this group (SF32252-3 and SF32316-5) are both transparent emerald green and contain significant concentrations of copper (1.1 and 1.4 % respectively). Their compositions differ from that of SF20125 in having lower alumina, titanium and other trace elements suggesting the use of different sands. The six low soda - low potash samples vary in composition and do not belong to any specific glass tradition known to the authors so will not be discussed further.

The low soda - high potash group contains seventeen samples of Chinese origin (see Online Resource 4 Plate 8). Potash lead silicate glass has a long tradition in China starting around the 2nd century AD and continuing until very recently (Gan Fuxi, 2009; Burgess and Dussubieux, 2008). All but one of the samples from Songo Mnara fall within two types of Chinese high lead glass identified based on the concentrations of Li and Rb in glass samples from Fort Canning Hill in Singapore, which dates to the 14th century AD (Borell 2010; Dussubieux, 2010), and from a burial site at Tanjay in the Philippines that was excavated by Karl Hutterer and was dated to the late 15th to early 16th century based on associated porcelain ceramics (Laura Junker, personal communication) (Figure 7).

These two groups of Chinese high lead beads can be separated both morphologically and chronologically. The earlier Singapore type, known as coil-wound, was formed with one or two quick winds of a rather thick glass rod and were not marvered or treated further. This resulted in beads with obvious wind marks and occasional ‘double’ beads where two windings were placed too close together (see Plate X a). They have large, tapered perforations and the most common color is transparent/translucent ruby red followed by transparent/translucent emerald green. The second type, associated with the beads from the Philippines, was made by winding many thin threads of glass onto a mandrel and then marvering the bead into a roughly elliptical shape. Colors of these beads were more varied: translucent ruby red and emerald green are similar to the first type but opaque glass was also used for yellow, pale blue, blue-green, white and black beads (Plate X xx).

As is evident in Figure 7, the four samples from Songo Mnara’s coil-wound beads plot with the type identified in Singapore. The glass of these ruby coil-wound beads was colored with copper (from 0.3 to 1.6 % CuO), a technology with a long tradition in China. The twelve samples from the elliptical beads are chemically similar to those found in the Philippines; our analysis suggests that they appeared later on the East African coast. Their red color was created using gold (~30 ppm Au) and the opaque beads were opacified with 2-3% arsenic oxide; both of these technologies suggest a date around the early 17th century AD. One final Chinese bead (SF57039-10) contains high Li and Rb concentrations. It is an anomalous bead with no analogs known to the authors.

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**Fig.** 7 Li vs Rb concentrations in beads from Singapore (Dussubieux, 2010), the Philippines (unpublished data) and Songo Mnara

### **Plant Ash Soda-Lime (v-Na-Ca) Glass**

Sixteen samples (representing 12 beads) (see Online Resource 4 Plate 6) are soda-rich with concentrations of MgO and/or K2O > 1.5 % suggesting that soda plant ashes were added as a flux (Figure 8b). Lime is often higher than alumina although there are some exceptions (Figure 8a). This is an extremely heterogeneous group, and some of the samples have no known analogs. They are discussed here in three groups. First, a group of diverse beads that seem to have European provenance; second a group of beads with distinctive composition and no known analogs; finally, a cluster of samples from a single folded bead.

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**Fig.** 8a and b Reduced Al2O3 vs CaO (a) and MgO vs K2O (b) for all the samples in the v-Na-Ca group with the European and non-European samples separated

Three of the samples in Figure 8a contain high lime concentrations (but appear as 4 points in the plot since SF21001-2 is bicolor and both colors were tested). Two of them (SF21001-1, SF21001-2) have a European composition characteristic of Venetian glass, with alumina less than 2% and lime more than 8%. Similar compositions were also used to make beads elsewhere in Europe after the 15th century AD (e.g. De Raedt et al, 1999; Dussubieux and Gratuze, 2012; Verità 2013*)*. The third bead (SF58012-4) is unusual in several ways. It is white with a high lead content (27 %) and concentrations of soda (5.7 %), potash (3.4 %) and lime (6.1 %). The white color is produced by arsenic (>3 %). Such a composition could be obtained by melting together v-Na-Ca European glass and Chinese high lead – potash glass in equal proportions, although it is not possible to say whether the glass used for this bead really results from such a mix. Morphologically this bead matches the Chinese high lead elliptical type (see Plate xx) but its chemistry does not. It was found together with a green elliptical Chinese bead (SF58012-5). Its unusual chemistry and shape might lead one to question whether it could have been created locally.

Figure 9 shows alumina vs titanium ratios for the non-European v-Na-Ca samples. Nine form a cluster with high titanium concentrations ranging from 2297 to 3252 ppm and low alumina concentrations; these distinguish these glasses from the v-Na-Al grouping. Although we have placed these samples in the v-Na-Ca group, they have low potash concentrations (often < 1.5 %) which is unusual for v-Na-Ca glass.

Chart, scatter chart

Description automatically generated

**Fig.** 9 Alumina vs titanium for the v-Na-Ca (non-European) glass samples (exes) and the v-Na-Al glass samples (triangles)

The cluster of three samples with lower alumina and titanium concentrations shown in Figure 9 represent three colors from one polychrome folded bicone (SF37053). Such beads were found to be made most often of v-Na-Al glass, as is the red glass on this bead, but the cobalt blue, yellow and white glasses are all v-Na-Ca. This variability of manufacture further points to the possible local production of these beads, to which we return below.

## **Discussion**

The glass beads recovered from the excavations at Songo Mnara indicate that the inhabitants of the town were connected to a complex set of trade networks, as might be expected at a prominent Swahili coastal town during the mid-second millennium AD. The assemblage is notable in its diversity, containing all glass groups known from this period (as well as a number of heirloom items). Although the size and diversity of the assemblage is not unexpected, there are no other well-published coastal assemblages and thus these data serve as a foundation for future work. Two particularly notable aspects of this assemblage are evidence of two types of Chinese beads, as well as evidence that a type of folded bead was being produced on site. We discuss these in turn.

### *Early Chinese beads*

As has been discussed, the coil-wound potash lead silicate Chinese beads (which are similar to those from 14th-century Singapore) pre-date the elliptical ones (compositionally similar to beads found in the late 15th/early 16th century Philippines although typologies are different) by at least a century. Similar coil-wound beads have been found in small numbers at several east coast sites (see Table 3), all of which have 15th-century components. Most of the coil-wound beads from Kilwa Kisiwani indicate a similar date: Chittick (1974b:464) reported that 30 were recovered from a hoard found just outside the western wall of the Husuni Kubwa, a palace complex that dates from the late 13th to beginning of the 15th century.

Although Chinese ceramics were a favored trade commodity in coastal communities over a long period and were brought by Western Indian Ocean traders who were not Chinese, the small numbers of these coil-wound beads suggests that they were not part of the same trade. Because these beads were individually created (and thus more expensive than the more common drawn beads), they could not have competed with the mass-produced Indo-Pacific beads that dominated the market. The small number of these beads at east African coastal sites and their 15th-century date might be linked to the travels of Zheng He, a Chinese admiral who reportedly visited the east African coast in the early 15th century, part of a series of voyages to Southeast Asia, South Asia and the western Indian Ocean. Many believe that his fifth voyage (1417-19) reached east Africa and that he may have returned on later occasions (Levathes, 1994:148–51; Dryer, 2007: 83, 91). The coil wound beads might be the first direct evidence that the Chinese fleet reached the southern coast of Tanzania.

Kilwa is mentioned in Chinese texts but it is sometimes confused with Malindi (Shen 1997:190). Yet, Kilwa was arguably the most important trading center on the coast during the 15th century and thus a likely destination for the Chinese fleet. In addition, these wound beads are found in greatest numbers at Kilwa and Songo Mnara (Table 3). Yet, their distribution at Songo Mnara does not indicate they were treasured or elite objects; they were found in a variety of deposits across the site including stone houses (5), earthen houses (3), and middens and other fill deposits (7).

|  |  |
| --- | --- |
| Eastern African site | Coil-wound Chinese beads |
| Lamu – northern Kenya | 1 |
| Manda – northern Kenya | 4 |
| Shaka – northern Kenya | 3 |
| Gedi – Kenya | 1 |
| Chwaka, Pemba Island – Tanzania | 1 |
| Mafia – Tanzania | 2 |
| Kaole Village - Tanzania | 1 |
| Kilwa Kisiwani - Tanzania | 33 |
| Songo Mnara – Tanzania | 15 |
| Great Zimbabwe, Zimbabwe | 1 |

**Table 3** Sites in eastern Africa that have produced coil-wound Chinese beads

## 

### *Later Chinese Beads*

The presence of later, elliptical high lead beads at Songo Mnara offer insight into parts of the site that may have been re-occupied in the early 17th century. Unlike the coil-wound beads, these elliptical ones would not have arrived in eastern Africa on Chinese ships. At Songo Mnara elliptical beads are associated with early European types, suggesting they appear close to the turn of the 17th century. Further evidence that these beads date to this period comes from their presence at late 16th-century Fort Jesus (pers. comm. Laure Dussubieux 2011) as well as Cape Delgado in northern Mozambique (see Madiquida 2007; the cover displays images of elliptical Chinese beads as well as large tubular beads of brownish-red on green (IROG) or cobalt blue glass, like the ones found in SM021). By that time the Spanish were active in Indian Ocean trade and it is possible they would have carried not only European glass beads but Chinese ones from the Philippines (a Spanish colony) or even from China as well. It might appear strange that European beads are not found in eastern Africa before the turn of the 17th century but, as Theal (1898:303) reported (citing early Portuguese documents) European beads were not accepted by populations in eastern Africa thus forcing Portuguese traders to purchase beads for that trade in India.

All but three of the elliptical Chinese high lead beads found at Songo Mnara came from House 47 near the northwest wall of the town. One came from a back room (SM021), 15 from a courtyard (SM020) and 12 from an open area (SM019). Surprisingly, all three of these trenches produced European beads as well: SM019 a pure white bead (a color not present in pre-European beads in eastern Africa), SM020 a yellow bead colored with uranium (probably an intrusion from the 19th century) and SM021 yielded two significant beads. One (SF21001-2) is the IROG mentioned above. Beads of this type were widely traded by Europeans around the world and were first produced in perhaps Venice or Holland in about 1600 AD (Karlis Karklins pers. comm. June 2021). In addition, a similar size tube of translucent cobalt blue glass (SF21001-1) was found. These two types, often accompanied by similar tube beads of white glass that have been coated with a clear layer of glass, appear together frequently as some of the earliest European beads found in eastern Africa. Their presence at House 47, along with the later Chinese beads, suggest that this area was occupied (or re-occupied) in the early 17th century.

### **Folded beads**

An assemblage of 43 folded glass beads from Songo Mnara offers insight into possible glass bead production on site. These are large bicone-shaped beads that seem only to be found at Kilwa Kisiwani and Songo Mnara. There is no evidence for such beads elsewhere in East Africa, or indeed elsewhere in the Indian Ocean world. At Kilwa, Chittick (1974: 488-9) records 34 such beads, all from Periods IIIb and IV contexts (c. 1400 – 17th century) which equate temporally to Songo Mnara where they appear to be present through most of the occupation including the late one (c. 1600) at House 47. At Kilwa most are formed into short bicones with diameters close to 20mm, the largest being 25mm and rare small ones of about 10mm. Two of the samples at Songo Mnara measure just below 19mm, all the rest fall between that diameter and 26mm.

LA-ICP-MS analysis allows us to categorize these beads as locally manufactured. The fabric of the beads is made up of imported glass types seen elsewhere in the assemblage. The core material is often rather grainy like partially fused frit but the surface is usually smooth, consisting of several glass colors. Chemically the five beads tested belong to the v-Na-Al Type A group, as described above. Yet the colored trails on the surface sometimes include glasses with different chemistry, including v-Na-Ca glass. As these types are both found elsewhere on the site, we might conclude that the folded beads are being made locally from imported glass. This is further supported by the production evidence found at certain locations of the site.

#### Evidence for local production

Chittick (1974: 466-8) offers a lengthy description of Kilwa’s folded beads, which he believed to have been imported. He noted that the matrix, or core, of the beads is usually dark with gray-white flecks. He suggests (1974: 467-8) that the core glass was wound onto a tapered mandril in a lenticular or elliptical shape after which the colored trails were applied. Next, “[t]he opposing pairs of quadrants of the circumference are drawn together, two on one side, two on the other” (1974:467) after which the result is marvered into a spherical shape and placed in a two-piece biconal mold whose pieces slip over each end of the mandrel. Among the Songo Mnara beads it looks like the core glass was often too frit-like to have been melted and wound; no evidence of winding is present. It also seems unlikely that a two-piece mold was used to form them since many are too lopsided or otherwise uneven to have been molded in this manner. From our observations it appears possible that shaping many of the beads could have been accomplished by rolling the viscid decorated glass, while on a mandrel, in a long V- or slightly U-shaped channel. Such a treatment could account for the standardization seen in the angles of the better made beads. It is also possible skilled glass workers could have accomplished this through simple marvering. It may be of interest that many of the terracotta bicones found at the site (see Online Resource 4 Plate 4) have similar sizes, shapes and angles and could have been formed in the same manner.

Excavations in earthen houses at Songo Mnara (SM011, SM032, SM035, SM058) account for all but two of the poorest examples of these folded beads (Table 3). SM058 included evidence that it could have been a workshop where beads, especially folded beads, were being made. The two folded beads found there were clearly rejects. One (SF58292) was over-fired or burnt resulting in a blocked perforation and pits all over the surface while the second (SF58339) was broken into three pieces (see Online Resource 4 Plate 4). Additional evidence from SM058 includes 11 thin (+/- 3 mm) glass tubes, some of which are very long (up to 22 mm) that may have been used to create the exterior surface of the folded beads. The ends of the glass tubes are mostly cut and sharp but a few appear to have been heated on one end resulting in closed perforations. Five are yellow, three brownish-red, two greenish and one is translucent cobalt blue. They are not beads; most are too long to be used in that manner. Chittick (1974: 481-2) mentioned finding a few similar tubes at Kilwa and concluded they might have represented tubes imported to be cut and heat treated to produce beads, but opined they were so rare it was more likely they were ‘fortuitously included with other consignments of imports.’ He unfortunately does not provide evidence of where these tubes were found. Such long thin tubes have not been reported elsewhere in eastern Africa and, as noted previously, these folded beads have never been recorded outside the Kilwa archipelago. The colors used to decorate these beads are the same as those of the long thin tubes, perhaps indicating that the tube ends were heated and used to trail the decorations onto the base material. In addition, our LA-ICP-MS analysis demonstrates that the same glass (v-Na-Al Type A) makes up both the thin tubes and most of the glass in the folded beads. These data suggest that the folded beads may have been made on site, using crushed waste glass for the cores and imported glass tubes for decoration.

Working with imported glass and beads is not unknown in Africa. In southern Africa in the mid-10th to early 12th century, for example, large Garden Roller beads were being produced locally from small imported beads using single-use terracotta molds (Wood 2005, 2011). Additionally, at Gao Saney in Mali there is evidence that imported glass tubes were being cut into bead-size lengths and reheated to produce beads in the 8th to 10th century (Cissé 2011, Cissé et al. 2013, McIntosh et al. 2020).

#### The distribution of folded beads at Songo Mnara

Table 4 shows the distribution of folded beads across Songo Mnara. The ranking of folded bead quality is divided into five categories based on how well the beads were made, with 1 being the best and 5 the poorest. The best ones are uniformly shaped with trailed patterns of colored glass that have been well marvered into the bead surface. The poor ones are misshapen, not well marvered and decorated sloppily or they were burned or overheated causing the glass to fill with bubbles that broke on the surface--these show as small pits. In Table 3, the ‘Houses’ are stone (coral rag) structures which are generally considered to be elite dwellings although they vary in size and elaboration. The ‘Earth’ structures can represent commoner dwellings but several, including SM032 and SM058, may have included workshop spaces or were fully workshops. Aragonite beads were being made in SM032 and, as proposed here, the folded beads were possibly being made in SM058. All but two of the poorest quality beads were from earth structures or a midden (SM056, just north of the earthen houses) while 14 of the top three qualities came from the stone houses along with 5 from earth structures and 5 from the midden.

The trench in House 44 (SM010) is very interesting. This was located in a relatively small stone house, set away from the larger houses to the south. SM010 was located in the back room of the house and likely had a thatch roof. The excavations produced 7 of the 15 folded beads in the two top-quality categories, as well as 650 other glass beads. These materials were found in the soft sandy fills of the room's floor; the space was clearly one of great activity with evidence for production (spindle whorls), cooking (*jiko* fragments), and possibly trade (Wynne-Jones 2013; Fleisher and Wynne-Jones 2010).

It is also unusual that five good-to-best quality folded beads were located in a midden deposit, especially because large beads would be hard to lose or overlook when waste was removed. This midden context, however, contained other high-quality finds, including 31 copper coins, dozens of beads (glass and aragonite) and more than 100 sherds of Chinese and Islamic pottery. These deposits might include fill removed from collapsed earthen structures to the south, as they contain a similar assemblage. Some of these beads may have been lost in the drains in entry rooms, such as those located beneath the floor in the entry rooms of stone houses 18 and 31. Such rooms were places where people might wash before entering a house, and they often contained floor drains where items could be lost.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Location** | **Context** | **1** | **2** | **3** | **4** | **5** | **Total #** |
| House 44, SM010 | Backroom | 1 | 6 |  | 1 |  | 8 |
| House 47, SM020 | Courtyard |  |  | 1 |  |  | 1 |
| House 47, SM019 | Yard |  | 1 | 1 |  |  | 2 |
| House 18, SM037 | Entry |  | 1 | 1 | 1 |  | 3 |
| House 31, SM016, SM017 | Entry & backroom |  |  | 2 |  |  | 2 |
| SM032 | Earth structure | 1 | 1 | 1 | 2 | 4 | 9 |
| SM011 | Earth structure |  |  |  |  | 2 | 2 |
| SM035 | Earth structure |  | 2 |  | 2 | 3 | 7 |
| SM058 | Earth structure |  |  |  |  | 3 | 3 |
| SM056 | Midden | 1 | 1 | 3 | 1 | 2 | 8 |
| GT125-5 | Test pit |  |  |  | 1 |  | 1 |
| **Totals** |  | **3** | **12** | **9** | **8** | **14** | **46** |

**Table 4** Songo Mnara folded beads by location, context and quality of the beads with 1 being the best and 5 the poorest

## **Conclusions**

This analysis of 140 glass beads from Songo Mnara has demonstrated that four broad compositional glass groups are present, including mineral soda-high alumina (m-Na-Al), vegetable soda-high alumina (v-Na-Al), high lead and vegetable soda-lime (v-Na-Ca). Within each of these groups a number of sub-types are represented. M-Na-Al glasses, which are recognized as originating in South Asia, account for 66 beads. Types m-Na-Al 1 and 4 are represented by one bead each while type 6 (9th to 13th century) accounts for 5 examples. M-Na-Al 2 (14th to 17th century) beads form the largest group at 25. Two additional types, newly recognized in eastern Africa, belong to the recently identified types from Indor in Rajasthan, India known as Indor 7 and 10. Eleven Songo Mnara beads belong to Indor 7 and 23 to Indor 10. This is the first instance in which these bead types have been identified outside India.

Forty beads were made of v-Na-Al Type A glass (related to the Mapungubwe Oblate series sub-type). They include drawn and wound beads similar to others found in East Africa but the most interesting are the large polychrome biconal folded beads that are known exclusively from Songo Mnara and neighboring Kilwa Kisiwani. Their limited distribution and unusual construction method have led us to question whether they may have been made locally, an idea that was augmented by the presence (in an unusual trench that may have been a workshop) of several long thin tubes of glass of the same chemistry and colors as the trailed decorations on these beads. V-Na-Al glass appears to have been produced in Central Asia but it seems that many of the beads may have been made in other locations.

High lead glass accounts for 26 beads which can be divided into at least four sub-types: two of these are Chinese from different time periods, the third would have been made in Europe and the fourth are of uncertain origins. The earlier coil-wound Chinese beads are found in small numbers up and down the East Coast and could possibly have been gifts from a visit of the fleet of Chinese admiral Zheng He in the early 15th century. The later elliptical ones appear in East Africa along with the earliest European beads at about the turn of the 17th century. Both of these bead types would have been carried by European traders, possibly Spanish. Some of the European high lead beads appear to be later intrusions.

The v-Na-Ca beads include 9 with elevated Ti levels. Morphologically they look similar to drawn Indo-Pacific beads but many are an unusual brown color. No glass with this chemistry has been reported in South Asia but little work has been done there on glass from this period. The two European beads that are diagnostic of European trade to eastern Africa around the turn of the 17th century (the brownish-red on green ‘IROG’ and cobalt blue tubes) are made of v-Na-Ca glass. Two additional beads related to this glass group are morphologically like beads normally made of other glasses. One is a white elliptical bead that mirrors the high lead Chinese examples and may be made of a mixture of v-Na-Ca and high lead Chinese glass. The other represents three of the colors used to decorate a biconal folded bead; the fourth color on the same bead is v-Na-Al Type A glass. These anomalies lead one to question whether these beads were made locally using glasses that were available.

Overall, LA-ICP-MS analysis of Songo Mnara’s beads has revealed a rich and complex range of imported goods. Songo Mnara is a wonderful case study because it provides a tight chronological context from the long 15th century, allowing us to view this complexity as a feature of urban life here, rather than a palimpsest of chronological trends. It allows us to confirm trends hinted at elsewhere, such as the long time span of v-Na-Al Type A beads at coastal sites, which far outlives the time span for Mapungubwe Oblates, the distinctive beads of this type in southern Africa. The exploration of Chinese Pb-Si-K beads also enables us to speculate about the destinations that might have been part of Zheng He’s itinerary in the 15th century, pointing to the prominence of Kilwa/Songo Mnara in this regard. These beads were probably given as gifts rather than traded, further adding to the complexity of the routes by which Songo Mnara’s inhabitants accessed these objects. Finally, the chemistry combined with morphological analysis argue strongly for the local production of folded beads at Songo Mnara (and by extension Kilwa) from imported glass (possibly in the form of beads) and glass tubes acquired specifically for that purpose.

The beads also enable insights into the archaeology of daily life at the site. All bead types were distributed widely across types of space at Songo Mnara. This includes the Chinese beads which, whether gifted or traded, were used by Songo Mnara’s inhabitants in similar ways to those acquired by other means. The patterning also allows us to recognize an area in the north west of the site where small quantities of Chinese and European beads suggest a later reoccupation in the 17th century; this is not hinted at by any other evidence or artefact class. Overall, then, the acquisition and use of glass beads at Songo Mnara offers a picture of complex urban lives, with trade, diplomacy and local production all contributing to a picture of material wealth and display among the inhabitants of a 15th-century town.

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## **Captions for Figures and Tables**

**Fig.** **1** Kilwa archipelago

**Fig.** **2** Songo Mnara

**Fig.** **3** Scatterplot for PC1 vs PC2 calculated for the m-Na-Al glass samples

**Fig.** **4** Concentrations of U and Hf in the m-Na-Al and v-Na-Al glass samples from Songo Mnara.

**Fig.** **5** Bi-plot for the Al2O3 and Zr concentrations of MO and Z bead series (Robertshaw et al. 2010) and of the v-Na-Al glass beads from Songo Mnara.

**Fig.** **6** Reduced concentrations of soda and potash in the high lead glass beads.

**Fig.** **7** Li vs Rb concentrations in beads from Singapore (Dussubieux, 2010), the Philippines (unpublished data) and Songo Mnara.

**Fig.** 8a and b Reduced Al2O3 vs CaO (a) and MgO vs K2O (b) for all the samples in the v-Na-Ca group with the European and non-European samples separated

**Fig.** **9** Alumina vs titanium for the v-Na-Ca (non-European) glass samples and the v-Na-Al glass samples.

**Table 1** Summary of glass composition groups in Songo Mnara bead assemblage, based on LA-ICP-MS analysis

**Table 2** Average concentrations of 7 glass constituents that are key to separate m-Na-Al glass 1 to 4 and 6 to 12. The relative standard deviations are indicated in italics. Group 5 is unrelated to the Indian Ocean so is not included here.

**Table 3** Sites in eastern Africa that have produced coil-wound Chinese beads

**Table 4** Songo Mnara folded beads by location, context and quality of the beads with #1 being the best and 5 the poorest.

**Online Resources**

Online Resource 1 Data from LA-ICP-MS analysis of Songo Mnara glass beads

Online Resource 2 Descriptions of analyzed Songo Mnara beads

Online Resource 3 Lists of m-Na-Al beads in various sub-groups

3A Beads belonging to m-Na-Al 6 sub-group

3B Beads belonging to m-Na-Al 2 sub-group

3C Beads belonging to m-Na-Al 7 sub-group

3D Beads belonging to m-Na-Al 10 sub-group

Online Resource 4 Plates with images of all analyzed beads plus others of interest arranged by glass groups

Plate 1: m-Na-Al drawn beads sub-types 1, 6 & 2

Plate 2: m-Na-Al drawn beads sub-types 4, 7 & 10

Plate 3: m-Na-Al wound beads sub-types 2 & 7

Plate 4: v-Na-Al folded beads and glass rods plus

Plate 5: v-Na-Al wound beads

Plate 6: v-Na-Al & v-Na-Ca wound beads plus v-Na-Al and v-Na-Ca high Ti drawn beads

Plate 7: European beads and high lead beads of unknown origin

Plate 8: Chinese high lead beads