Symbolically charged, colorful, fragile, and mass produced in small workshops, glass bangles are a fascinating but oft-overlooked category of object. Today, glass bangles are worn predominantly in parts of South and Southeast Asia, by women and children. Archaeologically, the findspots range from Europe to East Asia, although the types that are dealt with here occur mainly in North Africa, Western Asia, the Arabian Peninsula, and South Asia, reflecting the association of these bangles with Islam.

Glass bangles remain symbolically resonant to the present day. In Indian tradition, a woman’s honeymoon period is said to have ended when the last glass bangle (churi) that she wore at her wedding breaks. Dikshit notes the practice of breaking bangles when a woman enters widowhood, which was apparently brought to India by Islam, and points out that the (accidental) breaking of bangles came to be “looked upon with horror, a sign of ill-luck and a forerunner of bad events.” Literary references allude to the pain experienced by a bride in passing the rigid ornaments over her hands without breaking them, and even to the innocence and youth of a bride whose bangles are too loose.

Many of the glass bangles reported in the literature to date have been surface finds or of poorly understood chronology, and much work remains to be done before we can develop a full understanding of their changing morphology over both time and region. Fine examples of African and Asian bangles dating to the 19th and early 20th centuries can be found in museum collections, but the traditions of making them were in operation for centuries before. The bangles presented in this article were collected in Fazzan (southwestern Libya), in the central Sahara, and interviews with local inhabitants revealed that bangles very similar
to those recovered archaeologically were still worn by some families in recent times. Another reason that has been offered for the relatively small number of well-dated Islamic glass bangles is the lack of grave goods in Muslim burials.

Despite the difficulties, there exists an important corpus of research into bangles, which is largely the work of a few individuals. We are also aware of several excavation reports and interim reports that include more or less extended discussions and illustrations of bangles, and others in which these objects are limited to a small number of catalog entries and accompanying illustrations. Numerous other full and interim reports mention glass bangles but do not provide illustrations, and in many cases bangles have been excavated but not yet published. It is thus clear that the large number of glass bangles known from African and Middle Eastern sites are not currently reflected in publication.

The remainder of this article is divided into two parts, dealing with the historical-archaeological analysis and the chemical analysis respectively, followed by a brief concluding section. The findspots and typological assessment of the bangles analyzed, as well as the tables of chemical results from two analytical techniques, will be found in Appendixes 1–3.

**HISTORICAL AND ARCHAEOLOGICAL ANALYSIS**

*A Technical History of the Glass Bangle*

Although the primary focus of this article is the medieval period and later, the history of the glass bangle is much longer. Drawn glass canes that could be heated and manipulated to form bangles were in use from the earliest period of vessel making in the latter half of the second millennium B.C., and such canes were later used in other ways. One of these involved closing them around a mold to make bangles, in a procedure that can often be recognized because of the presence of a “seam” on the finished bangle, where the two ends were joined. Our earliest unequivocal evidence of the use of this technology to construct glass bangles comes from La Tène burials of the late first millennium B.C. The lack of a seam on many La Tène bangles may suggest that they were also constructed by the seamless method (outlined below), although their flattish cross section could alternatively indicate that they
were made by folding a strip and then reheating to disguise the seam.\textsuperscript{11} As with most things glassy, the Roman period was marked by an increase in the range and distribution of bangles, but they did not appear anywhere in volume until about the third century.\textsuperscript{12} Particularly popular at that time were monochrome bangles made with ‘black’ glass (in reality, a very dark purple, blue, or brown),\textsuperscript{13} presumably in imitation of jet.\textsuperscript{14} These early bangles were often further decorated by pressing, stamping, pinching, or crimping. Twisted bangles—formed by twisting the cane of hot glass as it was drawn out—are among the early La Tène corpus, and varieties of these continued to be made until recent times, with the later ones often incorporating both colored and colorless glass.\textsuperscript{15}

After the Roman period, bangle production appears initially to have become concentrated in certain areas within the former empire, although the different research biases from one area to the next might also be a contributing factor to this archaeological pattern. A Byzantine style of glass bangle developed and was exported to the Balkans,\textsuperscript{16} where local imitations seem to have cropped up using a less sophisticated manufacturing technology. From the seventh century, in the emerging Islamic world, polychrome bangles gradually increased in popularity, but there was also a continuation of some of the types known between the third and sixth centuries, confirming that the tradition of bangle manufacture went on relatively uninterrupted throughout this time of widespread social and economic change. Spaer tentatively suggests that Byzantine and Eastern European bangles could also have influenced the Islamic production from an early stage,\textsuperscript{17} although it should be noted that the decoration on Byzantine bangles was very different, for example, in the preference for monochrome bangles and the occasional addition of silver stain.

Perhaps the greatest expansion of glass bangle production occurred between the 13th and 15th centuries.\textsuperscript{18} Its output is commonly referred to as Mamluk because most of the work on bangle typology has focused on areas ruled by the Mamluk dynasty at that time. There is good evidence that glass bangles were being made in Egypt,\textsuperscript{19} in Syria-Palestine from perhaps the Roman period on,\textsuperscript{20} in Yemen,\textsuperscript{21} and in India, possibly by as early as the third century B.C.\textsuperscript{22}

Most of the later polychrome and monochrome bangles were fashioned using the “seamless” technique, which, in contrast to the Roman production, did not require the joining
together of two ends of a cane. The key to the seamless technique was the use of particular tools, some of which are illustrated in Figure 1 and described in more detail below.

In the 12th-century treatise *On Divers Arts*, Theophilus Presbyter relates a method of forming seamless glass rings: he describes in some detail a wooden-handled tool with an iron overlay at the point (see Figure 1a), which could be used to first pierce and then widen a blob of glass by lifting the point and constantly rotating the tool. Bangle making seems to have proceeded along similar lines, with the blob being pierced and picked up by a tool such as that illustrated in Figure 1b, and then transferred to a clay cone for further widening. In today’s traditional production centers, the clay cone is held at the end of a long rod and constantly rotated, while other tools (such as those illustrated in Figure 1c) are used to push the bangle to the wider part of the cone. Flattened interior surfaces with traces of adhering material and horizontal striations in the glass, encountered in several of the Saharan bangles analyzed in this study (as illustrated in Figure 2), may be indicative of such processes.

Tools similar to those illustrated in Figure 1c could also have been used as a pair, either without or before transfer to a cone. Meyer describes a method of producing seamless bangles “by taking up a bit of hot glass on an iron rod and rotating and hitting the rod with a second one until the glass opens up into a bangle-size loop”—that is, production without the use of a cone-shaped tool.

Developments in bangle-making tools may have significantly increased the scale of production. Chaudhuri notes that, using a clay cone, “one skilled workman at the big centers of the trade can turn out one thousand plain bangles in one day, working for nine hours,” and even at the smaller factories, the use of a similar tool can result in an output of up to 500 bangles in a day. It is possible that the introduction of the clay cone technique was responsible for the 13th-century increase in glass bangle production within the Islamic world. (We can assume that, if a similar tool was used in La Tène Europe, the technology was lost before the third century A.D., by which time bangles were of the seamed, Roman variety.)

Polychrome Islamic bangles were for the most part made by forming a seamless bangle using the methods described above, and then applying strips, canes, or prunts (small blobs of glass) of monochrome or polychrome glass to the exterior of the ring. Evidence for this can be seen in the ends of decorative trails found on some bangle fragments, and in the
frequently uneven thickness of applied trails by comparison with the relatively even bangle body. The high relief of much of this colored decoration tells us that it was applied relatively late in the bangle-making process. Lane and Sarjeant report a few “short straight strips with strands of two or more colors laid together,” found at Kawd Amsayla near Aden, Yemen,\textsuperscript{27} that may be remains of the production of polychrome canes for bangle decoration dating broadly between the 12th and 15th centuries.

The decorative techniques described here continued to be employed for several hundred years, until at least the 19th century in Hebron, and until the present day in parts of India. As noted above, and elsewhere by Carboni,\textsuperscript{28} it is difficult to provide a firm chronology for bangles as a group because of the persistence of many types. The potential mobility of bangles as trade objects can also serve to hinder the construction of regional typologies. The volume of published material on these items is growing steadily, however,\textsuperscript{29} and our understanding is gradually becoming more nuanced.

Glass Bangles in a Saharan Context

Trans-Saharan trade (some of the key locations for which are mapped in Figure 3) has long been a subject of external scholarly interest, from the description of what seems to be a Libyan caravan route in Herodotus\textsuperscript{30} and references by Pliny the Elder to Garamantian carnelian (“carbunculi”)\textsuperscript{31} to the writings of medieval Muslim geographers such as al-Ya’qubi and al-Idrisi,\textsuperscript{32} European explorers of the 19th and early 20th centuries,\textsuperscript{33} and, more recently, university-based academics.\textsuperscript{34} Yet it is becoming increasingly clear that throughout the first and second millennia A.D., local and regional trade within the Sahara was at least as important as external trade,\textsuperscript{35} and that it relied upon the development of complex networks between traders, nomadic pastoralists (who knew the terrain and drove the pack animals), and oasis dwellers. Such relationships are apparent from as early as the first millennium A.D.,\textsuperscript{36} although a realignment and eventually an expansion of trans-Saharan trade seem to have accompanied the arrival of Islam, facilitated by the spread of the Arabic language and text.

The glass bangle fragments that are the focus of this article, illustrated in Figure 4, were recovered during a surface collection survey conducted by Charles M. Daniels in Fazzan, southwestern Libya, from 1958 to 1977. Between the 1950s and the early 2010s, 67 glass bangle fragments were collected by British fieldwork in Fazzan. They were found in
the settlement sites of Zinkekra, Jarma, Saniat Jibril, al-Hatiya, and Qasr ash-Sharraba, as well as in the cemetery sites of Saniat bin Huwaydi, Zinkekra, Zuwila, and the “Royal Cemetery,” by Daniels, the Fazzan Project, and the Desert Migrations Project. This article examines a sample of the Islamic-era bangles.

**Dating and Typology**

Because the analyzed bangles are surface finds from sites that were occupied and used for long periods of time, their dates could not be established based on context. To contend with the lack of well-dated regional parallels, we used a simplified form of Spaer’s Palestinian chronology as the basis of our initial typological assessment, combined with references to parallels in publications or museum collections. A summary will be found in Appendix 1. More recently, 14 polychrome glass bangles with D-shaped or triangular (pointed) cross sections were excavated in Jarma as part of the Fazzan Project. Although these are unavailable for analysis, it is worth noting that they were recovered from contexts dated to various periods from the mid-13th to 20th centuries. Surface scatters of glass bangles were also encountered during a survey conducted as part of the Desert Migrations Project in Libya. Unfortunately, the onset of the Libyan Civil War in 2011 interrupted this fieldwork before it could be completed, and we do not possess any photographs or quantifiable information on the bangles. However, we can note that they were found in relatively high numbers at abandoned villages in the region of Murzuq, the occupation of which has been dated to the Early Modern period (radiocarbon dates fall in the 16th and 17th centuries, and between the 16th and 19th centuries).

The Murzuq bangles were spread around habitation sites (mainly outside of buildings), along with large quantities of pottery and other finds. They were noted to be mainly polychrome, but with several monochrome examples, and they bore a varied range of decoration—in other words, they were similar to the analyzed assemblage. On the basis of the typological and archaeological evidence, we suggest that the analyzed bangles presented here are highly unlikely to predate the 13th century, and that dates between the 16th and 19th centuries are the most likely.

An examination of bangles listed as “African” from various museum collections, but invariably lacking in dating information, shows that the Fazzan bangles are generally more
closely related to their Saharan/Sahelian and West African counterparts than to the Palestinian and Egyptian examples. The strongest published parallels yet found for the assemblage as a whole are those illustrated by Monod from Djado and Azelik (Tadekka) in Niger. The bangles presented by Monod show applied bichrome twisted trails or patch decoration not combined with applied trails, which are typical features of much of the Fazzan assemblage. Applied monochrome and twisted bichrome trails are often encountered on Syrian and Egyptian bangles of the 14th century and later, but they are frequently combined with patch decoration or prunts (Fig. 5), or otherwise distinct from the “African” corpus. Prunts are relatively common on Palestinian, Egyptian, and Indian bangles, and they are reported among the Jordanian examples discussed by Boulogne and Henderson. They also turn up at East African sites, such as the example illustrated in Figure 5, but they are rare in the bangles presented by Monod, and entirely absent from the Fazzan assemblage.

Other decorative motifs that are encountered on Middle Eastern and Egyptian bangles, but not on those from Fazzan, include crumb decoration, polychrome twisted bangles, and vertical ribbing (horizontal ribbing is found on one of our examples: TSG027). The limited Saharan corpus of bangles thus seems to be restricted to only certain of the types found farther east. The possible implications of this are discussed following the chemical evidence presented below. Our attempts to group the bangles stylistically, with reference to either findspot or chemical composition, were unsuccessful, which may indicate that decorative variation was as much a product of meaning as of different workshops, and which may also help to explain the longevity of some of the decorative styles in the Islamic world.

**Symbolism, Value, and Meaning**

Assessing the meaning or the symbolic and exchange values of bangles is difficult without deeper contextual evidence than we currently possess, although historical accounts allow us access to the later centuries under consideration. European observers seem to have been surprised by the apparent weight of the bangles and other jewelry worn by Saharan women. In her diary, Mrs. Tully, sister-in-law of the British consul in Tripoli, who lived there from 1783 to 1795, notes that the Bedouins living in an oasis outside Tripoli did not “remove their arm or leg bracelets, nor the earrings, with which they may be said to be weighed down. . . .” This note seems to refer primarily to metal bracelets, particularly of gold (worn by the Pasha family) and of silver (to which those “not of the royal blood” were
Among the notes compiled by a French surgeon in Tripoli, where he was imprisoned between 1668 and 1676, are descriptions of the dress and abundant jewelry worn by local women, including a note that “on their arms and legs they wear thick anklets and bracelets which probably weigh a pound.”

Bangles of a range of materials, including bone and ivory, stone, and metal, have been recovered from sites in Fazzan. A segmented example of a metal bangle from Saniat Jibril (Fig. 6) provides an interesting comparison with the twisted glass bangle TSG030. Were glass bangles merely substitutes for bangles in more expensive materials such as metal and stone? It is difficult to tell. Antonio Mordini, an Italian scholar of the early 20th century who described the contemporary ornaments of Fazzan women and in particular those from Ghadames of Tuareg origin, noted that the more wealthy among them wore silver bangles and other jewelry, while leather and glass beads were generally worn by poorer women, but there is no explicit mention of glass bangles. Writing in 1826, Denham and Clapperton discussed the suk in Kano, where relatively valuable artifacts were sold, and they mentioned beads of glass and brass armlets/bracelets, but not glass bangles.

One of the advantages of metal bracelets or bangles is the tinkling sound they produce when two or more are worn together on the same wrist, which might have elevated their symbolic value over those of glass. On the other hand, glass bangles could be produced in a range of vivid colors, potentially increasing their apotropaic properties. In any case, bangles made of several different materials could be worn together, as shown in an early 20th-century image of women from Fazzan presented by Alberini. The evil eye (ain) was a particular danger for younger women because of their beauty, so we might expect to find a higher use of polychrome glass bangles among them in warding off this threat. In recent times, at least, bangles were predominantly, if not exclusively, worn by women. Images from 19th- and early 20th-century European accounts of travels in North Africa, such as those presented in Figure 7, show women wearing bangles, often multiple bangles of different colors and/or materials, but we are not aware of any comparable images showing men thus adorned.

Movement of Things and Ideas
Glass bangles found in East Africa may well have originated in the factories of India and the Middle East. Meyer points out that, in the Indian Ocean trade during the Mamluk period, glass “seems to have been a consistent item in the trade, but low in bulk.”

A key question is whether these same bangles made it by some route farther west, perhaps directly across the Sahara, or whether it was the production technique, rather than the objects themselves, that traveled. Monod, who provides the most comprehensive survey of Saharan glass bangles to date, points to finds from sites in Mali (fragments known = >102), Niger (n = >525), Libya (almost five kilograms recovered in a survey lasting under two hours), and Ethiopia/Eritrea (n = >46, including some modern examples).

In a Saharan context, glass bangle fragments often turn up in large quantities in oasis sites, the stopping points in Saharan and trans-Saharan trade, but they have only rarely been recorded in stratified contexts. Indeed, Monod collected the aforementioned five kilograms of Libyan glass bangles at Awjila, an oasis town in Cyrenaica, which was a major stopping point on the route from Fustat in Egypt to Zuwila in Fazzan.

The large volume of finds at Awjila indicates that glass bangles were being traded west from Egypt, via this and other stopping points, to Fazzan. Documentation of east–west trade can be found in early 19th-century records, which also provide evidence that Venetian glass bangles (“glass armlets of black and blue”) were traded from Fazzan to Chad, Darfur, and West Africa. Earlier, medieval sources, which do not explicitly mention bangles, indicate that the Saharan glass trade was directed primarily south and west, and that glass was traded along with various other goods in exchange for gold.

We must be cautious, however, in hypothesizing a single directionality of glass trade routes (east to west, north to south) without a larger body of evidence than that currently available, especially because the majority of the historical evidence is limited to the 19th century. It is worth noting that there is evidence for the remelting of imported glass in Fazzan from the early first millennium A.D., and for primary glass production from local raw ingredients in southern Nigeria from at least the 11th century. On the other hand, we might view the Saharan bangles as simply a more “restricted” subgroup of West Asian bangles, with traders responding to local tastes and preferences.

**CHEMICAL ANALYSIS**
Analytical Methodology

For all 30 bangles, a <3mm thick slice was taken from one of the broken ends, mounted in epoxy resin, ground, and polished (<1 μm diamond paste). Because several of the bangles were polychrome, 66 samples of different colors were analyzed for the 30 bangles.

Quantitative electron microprobe analysis (EPMA) was conducted by Chloë Duckworth and Victoria Smith at the Research Laboratory for Archaeology and the History of Art, University of Oxford. We used a JEOL-8600 wavelength-dispersive electron microprobe with 15 kV accelerating voltage, 7 nA current, and 10 μm diameter beam. Peak counting times were 20 s for calcium and potassium; 30 s for silicon, aluminum, and magnesium; 40 s for iron; 50 s for chlorine, manganese, and lead; 60 s for tin and antimony; and 80 s for phosphorus and copper. The microprobe was calibrated using a suite of mineral standards, and quantified using the PAP absorption correction method. The accuracy of the electron microprobe analyses was verified using Corning reference glasses.

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) was conducted by Simon Chenery and Chloë Duckworth at the Centre for Environmental Geochemistry, British Geological Survey, Keyworth. We used a NewWave FX 193 nm excimer laser with integral microscope and ablation cell coupled to an Agilent 7500c series ICP-MS using a helium gas flow. It was calibrated using SRM610 glass (NIST, USA), and quality was assessed using SRM612 and Corning glass. Comparisons with the EPMA data have shown good agreement for most elements between the two techniques (see tables of results), although, as might be expected, there is some discrepancy between the results for the elements that are heterogeneously dispersed in the glass, notably lead and tin.

Internal calibration of the ICP-MS data was realized using the silica (SiO₂) results obtained by EPMA. In the text below, EPMA data (presented as oxides in weight percentage) have been used for the analysis and reporting of major and minor elements, whereas LA-ICP-MS data (presented as parts per million, ppm) were used for trace elements. In some cases, the high amount of lead colorant in several of our glasses, and the heterogeneous dispersal of lead and tin (PbO and SnO₂), necessitated the use of reduced results to allow comparison between the major element compositions of the various samples.
Because coloring elements such as manganese may be useful indicators of recycling, however, we took a departure from Robert H. Brill’s method of reducing to just seven oxides and removed only the heterogeneous PbO and SnO₂ before normalizing the remaining oxides to 100 percent. The use of reduced oxide results in the text and figures below is indicated by an asterisk (e.g., Na₂O*).

Results

The two sets of results are reported in Appendixes 2 and 3. All of the bangles fall into the compositional range of silica glasses made with a soda flux, with 14.68%–22.61% soda (Na₂O*), and 64.94%–74.92% silica (SiO₂*). The lime content of the bangles is rather variable (1.07%–10.47% CaO*). In addition to soda, silica, and lime, the samples exhibit a broad range of lead contents (from trace to 34.10% PbO, with 41 samples containing >1% PbO); many of the samples contain more lead than lime.

Silica for glass production can be obtained from siliceous rocks or minerals or the products of their physical weathering (e.g., pebbles, sand). The most convenient source, because it does not require costly crushing and grinding, is sand, which also contains mineral detritus of variable quantity and type, depending on the location from which it is quarried, but potentially including iron (Fe), aluminum (Al), titanium (Ti) and zirconium (Zr). The iron content of the bangles from Fazzan is relatively low, with only three samples having in excess of 1% Fe₂O₃. Alumina contents range from 0.85%–2.21% Al₂O₃ (the highest alumina was found in the same three samples with >1% Fe₂O₃). The low but nonetheless appreciable quantities of iron, and its correlation with alumina, suggest that the bangles were produced using an intentionally purified or a relatively mature sand source.

The generally low concentration of other impurities not directly associated with coloration, particularly magnesia (MgO), suggests that the soda was derived from a soda-rich mineral, rather than from the halophytic plant ashes that are typical of medieval Islamic production, because the latter introduce a number of characteristic impurities including, notably, lime (variable amounts of CaO), magnesia (typically >1.5%–3% MgO), and potash (>1.5% K₂O). This being the case, the low lime, low magnesia, but elevated potash contents of a number of the bangles, with reduced levels up to 4.8% K₂O, suggest an alternative source of potash. Similar results were found by Boulogne and Henderson for
Mamluk- to Ottoman-period Jordanian bangles, discussed below, and a high K\textsubscript{2}O:MgO ratio was a feature of several fragments of vitrified waste also recovered from Fazzan, from first-millennium A.D. contexts at Jarra.

Boron (B) is a common element in evaporite sequences, so it can be a useful marker of the source of soda in glasses. Our results indicated that B is present in elevated but relatively consistent traces throughout the sample set (55–146 ppm B), which could imply the use of the same soda source for all of the bangles. The boron levels of the bangles are within the lower range of those encountered in Roman glass (the Roman vessel glasses from Fazzan that we also analyzed have 13–279 ppm B). Similar boron levels (50–150 ppm B) were encountered in six of the seven unstratified beads we analyzed from Jarra and Zuwila. The four beads from Zuwila, like the bangles, have relatively high soda contents, variable lead, and relatively low calcium, but—unlike the bangles—they have higher alumina.

Lime, which acts to stabilize glass against corrosion in water, could have been introduced either deliberately or incidentally in the form of calcium carbonate (CaCO\textsubscript{3}) because of its presence in plants used as alkali fluxes, coastal sands (in which it is found in seashells), and/or limestone present as detritus in the sand. As shown in Figure 8, there is a broad correlation between elements associated with the silica source (iron, aluminum, titanium) and those associated with the source of lime (magnesium, calcium), so it is likely that the lime was brought in primarily along with the silica in some form.

An important indication of the source of lime is provided by strontium (Sr), which is found in higher concentrations in seashells, and can thus be indicative of the use of coastal sands in glass production. The strontium content of the analyzed bangles is far from consistent, ranging from 24.73 (diluted in TSG011 because of the high PbO content) to 397 ppm (unsurprisingly, the highest quantities of Sr were in the high-lime bangle TSG001, discussed below). In order to account for the variable and (for much of the data) unusually low lime in the bangles, we took the ratio of calcium to strontium and compared it with that of unstratified beads, vitreous waste broadly identified to the first millennium A.D., and stratified Hellenistic and Roman vessel glasses recovered from the survey and excavation in Fazzan. The results are presented in Figure 9, plotted against boron.
It is immediately apparent that the bangles show a very different calcium to strontium (Ca:Sr) ratio from that of the Roman vessel glasses. It is well established that lime in Roman glasses was derived from seashells present in the coastal sands used for glassmaking, so we can be reasonably confident that these were not the source of lime in the majority of the bangles, which is corroborated by the low overall quantity of lime. Exceptions are TSG005, 021, 025, and 030, all of which are monochrome, and the two colors of TSG022. Limestone, having undergone diagenesis, has a higher Ca:Sr ratio than seashells, and it could have entered the glass in the sand source. The unstratified beads from Fazzan, several of which exhibited signs of mixing and low-temperature working, plot more closely to the bangles, and could feasibly have been made using similar raw ingredients. The vitreous waste is problematic in several ways, and it may have been discarded because of contamination.

**African Parallels**

No convincing parallels for the composition of the glass bangles have yet been reported from other African sites. Analysis of African glass beads has illustrated the strength of Indian Ocean trade connections with East and Sub-Saharan Africa. The most prevalent Asian glass type at African sites of the second millennium A.D. is a mineral alkali type, the so-called M-Na-Al glass, which is similar to the glasses reported here in its high alkali, low magnesia, and relatively low lime, but which differs significantly from our material in the presence of high quantities of alumina (5%–15% Al₂O₃), the result of using a granitic sand in production.

Analyses of West and North African glasses (mainly beads) have illustrated a wide variety of compositional types, reflective of a range of trade routes and—in some cases—local glassmaking. The clearest example of the latter is in the high-lime, high-alumina (“HLHA”) glass characteristic of southern Nigerian production from the early second millennium on, and found in small numbers at other West African sites, indicating regional trade. Plant-ash glasses, which by the medieval period were predominant in the Mediterranean, are frequently found at North African sites and along the West African north–south trade routes. Analysis of glass beads from Garumele, Niger, showed them to be mixed-alkali, lead-silica, or lead-silica with added potash. They are chemically close to European glasses of the 17th and 18th centuries, and they were probably Venetian and Dutch trade beads. From at least the mid-19th century, characteristic black glasses from Nupe,
Nigeria, were made using local sand and mineral soda imported from the Lake Chad area, in addition to slag from the blacksmith’s forge. This locally produced glass was mixed with colored European bottle glass and/or beads.\footnote{77}

**Coloration**

Various colorants, both deliberately added and otherwise, were used in the bangles. These include “natural” colorants (mainly iron), present as impurities in the raw ingredients, which lent a green, brown, or green-blue tint to the glass; manganese, which was primarily responsible for dark glasses of black appearance; lead and/or tin, which produced opaque white glasses; and lead combined with tin (and, in some cases, antimony), which opacified glasses and created shades of yellow, orange, and (when associated, for example, with copper) green.

Most of the bangles exhibited heterogeneous features both macroscopically and under the microscope, including streaks and patches of different colors or variation in the hue/translucence of the glass, and numerous air bubbles. One of the clearest examples is TSG028, shown in Figure 10. These features are indicative of low-temperature mixing, either of differently colored glasses or of colorants in the glass batch.

**Compositional Groups and Mixing Lines**

To facilitate discussion, the bangles have been divided into three broad compositional groups, which can be distinguished in a plot of the two main alkalis (soda and potash), as shown in Figure 11. With the exception of TSG013, all of the colors in each bangle fall within the same groups and are chemically similar for elements not directly associated with their coloration. A word of caution is advised, however, because much of the patterning observable in the data is indicative of mixing, suggesting a fluid rather than stepwise relationship between different samples and their raw materials. The implications of this are discussed below.
**Compositional Group 1: Bangle TSG001.** The most clearly defined discrete compositional grouping consists of the three colors of glass employed in a single bangle, TSG001. These samples exhibit the highest lime (CaO), phosphorus (P), strontium (Sr), arsenic (As), and uranium (U), and the lowest zirconium (Zr). They also have among the highest barium (Ba, except for the black glass from TSG002) and among the lowest titanium (Ti, except for the high-lead portion of the yellow glass from TSG011), soda (Na₂O, except for some glasses in which the soda content was diluted by high lead), and chlorine (Cl, with <1% in only three other samples). The particularly low Zr and Ti are indicative of a purer silica source, lacking detrital minerals such as zircon and rutile.

All three of the colors in bangle TSG001—orange, yellow, and blue—contained appreciable quantities of lead (9.28%, 7.91%, and 2.80% PbO respectively) and antimony (0.87%, 1.10%, and 1.36% Sb₂O₃ respectively), and some tin (0.54%, 0.57%, and 0.04% SnO₂ respectively). Lead antimonate and lead stannate crystals are responsible for the opacity of the orange and yellow colors, while the blue color could have come from the iron impurity. The technically unnecessary presence of considerable lead and antimony in the blue glass and of copper oxide (1.08% CuO) in the yellow glass, as well as the gratuitous inclusion of both antimony and tin together in the same glasses, indicate that the three colors in this bangle could have been the result of some measure of recycling, with colorants from the recycled glasses being present as impurities in the finished bangle.

**Compositional Groups 2 and 3.** Groups 2 and 3 are distinguished by their different quantities of alkali: <19% Na₂O* + K₂O* in Group 2, and >19% Na₂O* + K₂O* in Group 3. Most of the Group 3 samples can be seen to fall along an apparent mixing line between soda (Na₂O) and potash (K₂O), which are negatively correlated for this group, as shown in Figure 11. In some cases, there was also a significant amount of potash: up to 4.93% K₂O*. By contrast, the samples in Group 2 are unanimously low in potash (<0.22% K₂O*). What little potash is present indicates a weak positive correlation with alumina (R² = 0.239) and is probably derived from K-feldspar in the sand used as a source of silica.

With the exception of the three colors of TSG009, the soda (Na₂O*) and chlorine (Cl*) in Groups 1 and 2 are positively correlated (R² =0.92), which might indicate that sodium
chloride was added to the glasses, although it is unclear whether this could have been the main alkali source. In several of the samples from both groups, the Cl was found to be higher than its supposed solubility limit in soda-lime-silica glass, but this is presumably because of the very low lime contents of the majority of the bangles analyzed: experiments have demonstrated an inverse relationship between chlorine solubility and calcium content.\textsuperscript{79}

All but one of the Group 2 bangles have translucent green bases (TSG024 has a translucent brown base), with two or three applied opaque colors and both monochrome and bichrome applied twisted trails. All are obliquely or evenly pointed in cross section. The applied black trail on bangle TSG002 had 7.42% MnO, which was responsible for its coloration. In general, the Group 3 bangles are darker in color than those of Group 2, and they include many more browns, oranges, and greens, as well as a “muddying” of colors, which is typical of recycled glasses. All of the monochrome bangles were found to fall into Group 3.

In order to better understand distinctions within Group 3, that group was subdivided on the basis of sodium (Na) and potassium (K) into a number of subgroups, as shown in Figure 11. For comparison with the data in the appendices, the subgroups are as follows:

- 3a) TSG028 (total number of samples, n=2)
- 3b) TSG008, TSG011, TSG014, TSG019, TSG023 (n=12)
- 3ci) TSG004, TSG006, TSG018, TSG027 (n=11)
- 3cii) TSG003, TSG005, TSG022, TSG026, TSG030 (n=8)
- 3d) TSG010, TSG012, TSG015, TSG021, TSG025, TSG029 (n=15)

The negative correlation between soda (Na\textsubscript{2}O) and potash (K\textsubscript{2}O) indicate that, in addition to the main alkali source, which brought in most of the soda, there was a less significant source of potash, which was not brought in along with either the soda or the sand. The low magnesia of these glasses does not correspond to the established compositional features of halophytic plants as an alkali source, so the additional potash is unlikely to be accounted for by these (the small amount of magnesia present is correlated in Groups 1 and 2 with calcium, R\textsuperscript{2}=0.67). Potassium feldspars in the sand contribute to the composition of some glasses, but they are usually correlated with alumina, as can be traced for the Group 2
samples (see above). It is possible that potash was added in a relatively pure state, which would explain why there are so few contaminants associated with it.

Rare-earth elements (REE) can be useful in determining the geological origin of glassmaking components. The REE profiles for the Group 2 and 3 bangles show a negative europium (Eu) anomaly in relation to crustal abundance, but—as with TSG001, discussed above—both groups are heterogeneous for the heavier REEs, showing a range of profiles that we are unable to relate to any particular compositional feature or subgroup. The REE profiles for the Group 3 glasses do not show any discernible patterns either within or across the subgroupings that could be related to other compositional features discussed above. Even within a single bangle, there can be a wide variation in the profile. It is likely that the REEs have been affected by a number of factors, including mixing of raw materials or glasses, raw material processing, and the addition of colorants.

**DISCUSSION: RECYCLING AND TECHNOLOGICAL “KNOW-HOW”**

Taking this data set as a whole, it is apparent that we are not dealing with a number of distinct and clearly demarcated compositional groupings. Nor are we dealing with a set of homogeneous results such as we might expect as the output of a single workshop using an established recipe and consistent raw ingredients. Instead, we find that, in several cases, there are compositional gradations (notably CaO, PbO, and K2O) that crosscut the data set, indicating that, although the bangles are part of a single broad compositional group (soda glass with low impurities), they have been subjected to numerous manipulations, possibly involving both recombination (i.e., recycling) and addition.

*Recycling End Products?*

In a well-organized system of cullet (scrap glass) collection and remelting, such as that which might be geared towards glass vessel production, it is perfectly feasible that, for example, colorless glasses could have been recycled to produce more colorless glasses that would have a composition relatively close to that of the originals (although compensation for loss of alkalis on reheating may have been necessary). Glassblowers require a fair degree of predictability in their materials. Different compositions of glass behave in different ways, and an unaccounted-for compositional alteration could have disastrous consequences for
vessel production. Thus the type of well-organized recycling that leads to the production of colorless or naturally colored vessel glass is probably difficult to recognize in compositional terms.

There is another type of recycling, however, which involves less careful control over the cullet used. When looking for the likely end products of the latter type of recycling, or glasses that have undergone multiple episodes of recycling and are thus no longer viable for glassblowing, we should expect to find (1) glasses that were discarded as no longer capable of being reintroduced into the pool of material to be recycled because they were contaminated and/or compositionally heterogeneous (reducing the predictability of working temperature and other mechanical properties of the glass); (2) strongly colored glasses, with the coloration serving to mask any adverse effects of mixing several different glasses (e.g., muddied colors, streaks, and air bubbles); and (3) types of objects that required less high-temperature manipulation than blown vessel glass, and that were therefore less susceptible to the adverse effects of the unpredictable glass compositions we might expect from less controlled recycling.

The glass bangles discussed here—highly colored, found in surface scatters at Saharan oases, and often with evidence of low-temperature working and mixing but not associated with evidence for production at the locations in which they are found—are strong candidates for tracing the “end point” of glass recycling. Théodore Monod, noticing the great volume of glass bangle fragments at known Saharan trading points, suggested that they were being transported as cullet, destined for reworking.80 An alternative explanation, however, is that the bangles were abandoned at these locations precisely because they were no good for recycling, being highly contaminated, highly colored, and compositionally heterogeneous as a set. Like glass beads, bangles were probably never the main objects of trans-Saharan trade, but they may well have made useful secondary exchange items, being small and easily transportable. At stopping or trading points, any broken bangles, being relatively low in value and—given their unpredictable and contaminated compositions—unsuited to further trade as cullet, may simply have been abandoned.

In their study of Mamluk- to Ottoman-period bangles from Jordan, Boulogne and Henderson also identified a mineral soda glass with elevated potash but low magnesia (their “type 3”), a convincing parallel for the Saharan bangles. This small group of five bangles
also contained two typological parallels for the Fazzan bangles (AB13 and AB15 from Khirbat Faris), with bichrome twisted trails, pointed (“triangular”) sections, and a color range similar to that of the Fazzan corpus.\textsuperscript{81} It is thus likely that these bangles are the product of the same workshop or regional production as those from Fazzan. The location of this activity cannot be determined on the basis of our current evidence, but it is worth noting that this glass type was one of many encountered in the Jordanian sites, whereas the Fazzan bangles form a much more homogeneous compositional group, despite the clear indications of mixing within that group. It is possible that the source of these bangles was located between Fazzan and Jordan (e.g., Fustat or another Egyptian production center),\textsuperscript{82} or else within the Sahara itself.

\textit{Technological Practices}

The elevated potash but low magnesia and alumina that are characteristic of many of the bangles from Fazzan raise the question of the form in which the potassium was added to the glasses. The simplest explanation is that we have two glasses, one of which was high in potassium, and that they were mixed together in different proportions, resulting in the observed “mixing line.” It is difficult to trace supporting evidence for this, however, because the potassium source does not seem to have introduced any clear compositional markers aside from a weak correlation with some of the other alkali metals and antimony.

Lead-silica glasses with high potash and low magnesia are reported in European trade beads from Garumelle in Niger, but the ratio of lead to potash (average 7.5 PbO:1 K\textsubscript{2}O) is too high for them to be suggested as the primary source of potash in the bangles from Fazzan.\textsuperscript{83} High-potash Asian glasses are also known, and although most of them have high alumina, examples with very low quantities of alumina, magnesia, and other impurities have been reported.\textsuperscript{84} Most of them are Korean or Southeast Asian, but six examples of relatively pure potash-silica glass production waste from Arikamedu in southern India are reported by Brill, and at least one of these seems to have made its way as far as Jenné-Jeno in Mali.\textsuperscript{85} These are much earlier than the proposed date range of our bangles (the Jenné-Jeno bead is dated to between 250 B.C. and A.D. 50), and the examples to date are few, but they demonstrate that the possible inclusion of high-potash, low-impurity glasses cannot be ruled out.
An alternative – and perhaps more likely – explanation is that we are seeing evidence for the addition of a relatively pure form of potash-rich alkali. One reason for adding potash in this way would be to compensate for the loss of alkalis during reheating of the glasses, particularly if they were reheated in an open crucible and/or on a number of occasions (e.g., because of recycling or small-scale working). The addition of potash on several occasions (e.g., to glasses that were recycled more than once) could account for the observed “mixing line” between low- and high-potash glasses.

Alkali minerals including potash could have been sourced locally in more than one site of significance to trans-Saharan trade: in addition to the well-known Egyptian sources of natron (which were somewhat depleted by that time), mineral alkalis are found in the Lake Chad area, and in Fazzan itself. The latter have been shown to have elevated and highly variable potash contents, between 1,700 and 69,000 ppm K in the four samples analyzed by Marijke Fabri, which are significantly higher than the 170–720 ppm K in the mineral alkali samples from Egypt analyzed in the same study. Halophytic plants are also encountered in the Sahara, and they provide a crucial source of salt for camels, but it should be recognized that if such plants account for the potash found in the glasses, they must have undergone extensive purification prior to their addition to the batch.

Significantly, when we consider the possibility of deliberate technological practice, the inclusion of both soda and potash in a glass could also have beneficial results for its working properties. At constant total alkali concentration, ternary mixed-alkali silicate glasses have been shown to have a lower viscosity than either of the two corresponding binary alkali silicates. Furthermore, this effect is most pronounced at lower temperatures, and would thus extend the glassworking range.

Lead can be added to glasses as a colorant and/or an opacifier. In many of the samples analyzed, lead was found in combination with antimony and tin, with which it could combine to opacify glasses. If the data are split between the “base” glasses (i.e., those that formed the main body of the bangle) and the applied trails, we find only three base glasses with >1% PbO and none with >3% PbO. None of the monochrome bangles had >1% PbO. This may in part relate to the color of the bangles—the bright, leaded orange, yellow, green, and white glasses being preferred for applied decoration—but it may also be the case that the choice of lead was also made from a practical perspective: it could allow the viscous trails to
be applied to the exterior of the bangle at a lower temperature than the bangle body, allowing the latter to retain its shape. The addition of strong colorants would also have the effect of ‘masking’ the muddying of colors which might result from recycling. Although we can ultimately only speculate as to the intention behind the technological practices involved, the end result of the various manipulations to which the glasses were subjected was clearly successful, as evidenced by the vast quantities of bangles which have been produced and the survival of some of these techniques to the present day.

CONCLUSIONS

To date, much of the compositional recognition of recycling in glasses and metals has been approached from a geological perspective, rooted in isotope studies, which assumes a “blind” mixing of components. The chemical evidence presented above has demonstrated the importance of considering the intentionality of human productive activities: human decisions are present at every stage of the production process, from the selection of the raw materials and recipe to the addition of a little potash or lead-based opacifiers to ease the working or improve the appearance of a batch of recycled glass. Furthermore, the demands of different glassworking practices mean that certain objects (blown glass vessels, beads, and bangles) may have been subjected to different scales of compositional manipulation, falling at different points along the chaîne opératoire, which included recycling and compositional manipulation. We believe that this case study illustrates the importance of providing a more nuanced and ultimately more social reading of chemical data for the making, recycling, and reworking of glass. In particular, it must be appreciated that, for those using it, glass cullet may have been simply a raw material, the compositional characteristics of which needed to be manipulated and modified before it was suitable for use. Boulogne and Henderson point to the lack of evidence for mixing between the compositional groups of Jordanian glass bangles as evidence that these objects were not subject to recycling, but we would extend this, by suggesting that this is, in fact, exactly what we would expect from objects that were recycled but are no longer recyclable: each compositional group of bangles represents the end result of a “flow” of materials to which no further mixing can be applied.88

Glass bangles are a hitherto underrepresented category of archaeological find, but recent work, some of which has been reviewed here, is increasingly illustrating their richness as objects of scholarly attention. Further investigation of the identity of bangle wearers in
different times and places, as well as the various symbolic connotations of the glass bangle, is certainly needed. Equally, we recommend the increased application of high-resolution analytical techniques, such as trace-element analysis, to objects such as bangles, in order to help us determine the relationship between provenance and hypothesized technological practices. Most importantly, we will need increased publication and illustration of bangles, particularly from African sites, upon which these related strands of work can feed. In the preparation of this article, the first author has received many anecdotal tales of African bangle finds, but most of these remain unpublished. Bangles from secure stratigraphic contexts will be essential in refining our typological understanding, and in developing a more nuanced sense of the symbolism and value of these objects.

ABSTRACT

This article presents a new approach to the archaeological and chemical evidence for glass in Africa, using the case study of 13th–19th-century Islamic glass bangles from the Libyan Sahara. The authors explore the technology of bangle production from a range of perspectives, beginning with a review of bangle making in its wider Asian and European context, and going on to discuss the ubiquitous but understudied Saharan glass bangle. The second half of the article provides new chemical data for 30 Islamic glass bangles from Fazzan, Libya, analyzed using EPMA and LA-ICP-MS. The discussion includes the dating of the bangles, evidence for their trade, and the possibility of secondary production practices, such as recycling and the addition of extra raw materials (e.g., potash and lead). The authors argue that, by focusing on secondary production and deliberate compositional manipulation of materials, as well as geological provenance, we are better equipped to use chemical analysis to reconstruct the long- and short-term meaning, manipulation, and trade of glasses in North and West Africa—an approach that may also be of value to those studying glass beads and other objects.
FIG. 1. Examples of some of the tools used for the production of seamless bangles. The scale of these tools could be expected to vary, but tool (a), which was used for the production of glass rings, was approximately a foot in length, and the larger cone on tool (b) would have a maximum diameter consistent with the maximum internal diameter of the bracelets produced. (Drawings: C. Duckworth, based on sources cited in the main body of the text)
FIG. 2. Closeups of outside (*top*) and inside (*bottom*) faces of bangle TSG001, showing the horizontal striations, as well as adherent material seen on the flat inside surface of most of the analyzed bangles.
FIG. 3. Map of sites mentioned in the text or related to trans-Saharan trade, with expanded view showing sites in Fazzan. (Map: M. Sterry)
FIG. 4. Color illustrations of bangles from Fazzan that were sampled and analyzed in the present study. Scale shown is five centimeters. (Drawings: Mike Hawkes, University of Leicester)
FIG. 5. Bangles, probably of Ottoman date, from surface survey collection in Kubbaniya, about 15 kilometers north of Aswan on the western bank of the Nile. The smaller fragment has patch decoration overlain with a bichrome twisted trail in relief. The larger fragment shows opaque white prunts that were probably attached by gathering viscous chunks directly onto the bangle. (Photos: Courtesy of the archive of the Aswan-Kom Ombo Archaeological Project, Yale University and University of Bologna, directed by Maria C. Gatto (University of Leicester) and Antonio Curci (Università di Bologna).

FIG. 6. Segmented copper alloy bangle of unknown date from Saniat Jibril, Fazzan, consisting of leaded brass with an unusually high amount of antimony (3.3% Sb). (Photo and analytical results: Courtesy of A. Cuénod)
FIG. 7. Illustration and photograph of women wearing bangles: (a) Tebu woman wearing multiple bangles of different colors, 1822–1824, from Lyon’s A Narrative of Travels in Northern Africa in the Years 1818, 19 and 20 [note 33]; and (b) Zuwaya woman adorned with jewelry, including what appears to be a metal bangle, from a report on the travels of Rosita Forbes in The Illustrated London News, June 4, 1921, p. 757.
FIG. 8. Correlations based on LA-ICP-MS results (TSG001 was omitted because of its much higher calcium content). The x-axis is arranged by iron content, with the highest Fe to the right.
FIG. 9. Boron plotted against the ratio of calcium to strontium from various categories of analyzed material from Fazzan.

FIG. 10. Closeup of mounted and polished section of TSG028, showing air bubbles and streaks of different colors within the body of the bangle.
FIG. 11. Soda (Na$_2$O) plotted against potash (K$_2$O), using reduced EPMA results. The letters a–d refer to the subgroupings discussed under Group 3 (see page XX).

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1. We opt to use the term “bangle” here because it refers exclusively to rigid wrist (or ankle) adornments, whereas the English “bracelet” indicates loose, flexible jewelry. The term is derived from the Hindi bangrī, which specifically refers to glass.


3. Dikshit [note 2].


5. Illustrated examples can be found in the collection databases of The Metropolitan Museum of Art, The British Museum, the Pitt Rivers Museum (University of Oxford), the Petrie Museum (University College London), the Fitzwilliam Museum (University of Cambridge), and the University of Pennsylvania Museum of Archaeology and Anthropology. See also Stefano Carboni, “Glass Bracelets from the Mamluk Period in The Metropolitan Museum of Art,” Journal of Glass Studies, v. 36, 1994, pp. 126–129.

6. David J. Mattingly and others, eds., The Archaeology of Fazzān, v. 4, Survey and Excavations at Old Jarma (Ancient Garama) Carried Out by C. M. Daniels (1962–69) and the Fazzān
8. The publications are too many to list here, but notable contributors include Stéphanie Boulogne, Stefano Carboni, Théodore Monod, Yoko Shindo, Maud Spaer, Margreet L. Steiner, and Carolyn Swan.
11. Recent experimental work on the reconstruction of La Tène glass bangles has incorporated both seamed and seamless methods, drawing on traditional techniques in Nepal, and both have been shown to be successful in the production of this style of glass bangle. See Joëlle Rolland and others, “Des parures celtiques aux verriers du Népal: Un Projet d’expérimentation des techniques de fabrication des bracelets en verre,” Bulletin de l’Association Française pour l’Archéologie du Verre, 2012, pp. 6–10.
14. In China, glass imitation of jade has also been popular throughout the centuries. See, for example, two green glass bangles in the Pitt Rivers Museum, Oxford (acc. nos. 1896.62.143.1, 2).

Meyer [note 18], p. 91.

Spaer [note 12], p. 60.


27. Lane and Sarjeant [note 21], p. 130.

28. Carboni [note 5], p. 126.

29. For a recent survey of published (and some unpublished) glass bangle finds, particularly in the Middle East, see Stéphanie Boulogne, The Libyan Caravan Road in Herodotus I, v. 47, no. 4, 2012, pp. 409–418, esp. p. 418.
The results are summarised in Appendix 1.

This assessment was made from memory by Martin Sterry, University of Leicester.

Finds catalogues from the following museums were examined: The Metropolitan Museum of Art, The British Museum, the Pitt Rivers Museum, the University of Pennsylvania Museum of Archaeology and Anthropology, the Fitzwilliam Museum, and the Petrie Museum. A particularly striking parallel for the analysed bangles from Fazzan is in the University of Pennsylvania Museum (acc. no. 2003-82-215): a semitranslucent bangle with applied opaque orange and black/white twisted dichrome trails; it is listed simply as “African.”


For a good representative sample of prunted, trailed, and twisted Mamluk bangles, see Meyer [note 18], pp. 90-94.

Boulogne and Henderson [note 29].

See ibid. and references therein.

The imprecise dating of the glass bangles from Fazzan is naturally problematic here, but it should be noted that the Eastern decorative styles that are not found in Fazzan—including prunts and polychrome twisted bangles—have been encountered in contexts dating from the Mamluk period to as late as the mid-19th century (i.e., throughout the period to which the Fazzan bangles might date).


Denham and Clapperton [note 33].


Alberini [note 48], p. 23.

Mordini [note 51].

Lyon [note 33]; Denham and Clapperton [note 33].
58. Monod [note 42].
60. Monod [note 42], p. 707.
61. Lyon [note 33], pp. 154–159.
67. These figures have been established by countless studies following the seminal work of E. V. Sayre and R. W. Smith, “Compositional Categories of Ancient Glass,” *Science*, v. 133, no. 3467, 1961, pp. 1824–1826.
68. Boulogne and Henderson [note 29].
69. Duckworth, Mattingly, and Smith [note 65]. The vitreous waste fragments varied greatly in their composition, with K₂O:MgO ratios between 1.3:1 and 10.3:1. The K₂O:MgO ratios for the mean composition of bangle groups 1 and 2 are 3:1 and 4.73:1 respectively.
71. Duckworth and Fenn [note 63].
73. Freestone [note 64]; Lankton, Ige, and Rehren [note 64].
Kaniana (Inland Nile Delta, Mali), the 1981 Season, ed. S. K. McIntosh, Berkeley: University of California Press, 1995, pp. 246–256 [Note to ed.: Brill’s section is contained within the chapter by McIntosh, which is credited as: “Susan Keech McIntosh with a contribution by R.H. Brill, The Corning Museum of Glass”. This section ends on p.256, not p.255.].


78. Although the findspot of TSG001 was unrecorded, a typological parallel for this bangle was identified by the 2008 OXY Survey, at a site (LGR002, buildings surrounding a qasr) about five kilometers from Jarra in the Wadi al-Ajal. The site, which was in use since the first millennium B.C., was abandoned within the last 200 years. The bangle was colorless, with green and orange bands, in a form very similar to that of TSG001.


80. Monod [note 42], p. 702.

81. Boulogne and Henderson [note 29].

82. Note, however, that analysis of medieval glass bangles from Fustat returned results typical of plant-ash glasses: Brill [note 66], pp. 168-170.

83. Robertshaw and others [note 76].


85. Sample 5530 in Brill, “Chemical Analysis” [note 85].


88. This idea of a “flow” is borrowed from the work on metal recycling recently summarized in P. J. Bray and others, “Form and Flow: The ‘Karmic Cycle’ of Copper,” Journal of Archaeological Science, in press.