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ORIGINAL ARTICLE

Evidence of glass bead-making in the early Islamic Iberian Peninsula

Cristina Boschetti¹  | Jorge de Juan Ares²  | Sophie Gilotte^{3,4}  |
Catherine Guerrot⁵  | Nadine Schibille⁶ 

¹Centre for Urban Network Evolutions (UrbNet), Aarhus University, Aarhus, Denmark

²Departamento de Prehistoria, Historia Antigua y Arqueología, Universidad Complutense de Madrid-UNIARQ, Madrid, Spain

³Centro de Arqueología da Universidade de Lisboa, Lisbon, Portugal

⁴Institut des Sciences de l'Homme, Lyon cedex 07, France

⁵BRGM, Orléans, France

⁶Institut de Recherche sur Les Archéomatériaux, Centre Ernest-Babelon (IRAMAT-CEB), Orléans, France

Correspondence

Cristina Boschetti, Centre for Urban Network Evolutions (UrbNet), Aarhus University, Aarhus, Denmark.

Email: cristina.boschetti@cas.au.dk

Nadine Schibille, Institut de Recherche sur Les Archéomatériaux, Centre Ernest-Babelon (IRAMAT-CEB), Orléans, France.

Email: nadine.schibille@cnrs.fr

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Abstract

Glass beads from two Islamic archaeological sites in the Tagus valley in central Spain were selected and analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), and a subset of samples ($n = 6$) was analysed for Pb isotopes by multicollector thermal ionization mass spectrometry (MC-TIMS). The analytical and isotopic data of the beads from Ciudad de Vascos (Toledo) and Albalat (Cáceres) demonstrate beyond reasonable doubt that glass beads were produced in the Iberian Peninsula during the Islamic period using local Pb-silica and soda-rich plant-ash glass. The bead workshops in al-Andalus were evidently part of an efficient system of glass collection and recycling, and used only relatively simple bead-making techniques such as winding and folding. At present it is unclear to what extent the Islamic bead-makers in the Iberian Peninsula were involved in the international trade in glass beads or whether their products were mainly destined for a regional market. Despite local production, some samples show compositional and typological features that suggest the import of finished glass beads, perhaps from Central Asia.

KEYWORDS

al-Andalus, glass beads, glass economy, glass recycling, glass technology, LA-ICP-MS, Pb isotopes, lead slag, Pb-silica glass, plant-ash glass

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INTRODUCTION

Glass beads are frequently found in late antique and medieval archaeological contexts. Due to their abundance as well as their morphological and compositional variability, and the fact that they often travelled over long distances, these artefacts are excellent markers of technological developments and changing trade networks (Boschetti et al., 2020; Neri, Gratuze, & Schibille, 2019; Pion & Gratuze, 2016; Robertshaw et al., 2010; Then-Obłuska & Dussubieux, 2016). Thus, they have considerable historical and economic interpretative potential and can reveal technological and cultural affiliations (O'Sullivan, 2015; Pallaver, 2009). For example, the glass beads and vessels exchanged along the early Islamic Silk Road (Henderson, 2021) as well as the early ninth-century glass beads from the city of Ribe (Denmark) suggest major realignments in long-distance trade systems following the Abbasid revolution in 750 CE and the subsequent establishment of Baghdad as the new capital of the Abbasid Caliphate (Sode et al., 2022). The influx of new types of glass beads with distinct Mesopotamian compositional characteristics indicates an increasing importance of the bead trade between northern Syria, Iran and Iraq and Scandinavia (Sode et al., 2022). In the Islamic world, glass beads were highly regarded for their aesthetic as well as their symbolic and ritual value, but the literature on the subject is very limited (Pinder-Wilson & Scanlon, 1987; Francis, 1989; Francis, 2002a; Robertshaw et al., 2010). It is becoming increasingly clear that glass beads were more than just body ornaments and had a strong symbolic value. They probably served as tokens for transactions and were part of rituals, for example, prayer beads that have their roots in Buddhist, Hindu, Islamic and Christian traditions (Henderson, 2021, 204; Maixner, 2021; Boschetti, 2023, 57–59; Jenkins & Keene, 1983, 30, 106).

Analytical and typological studies in recent years have firmly established that the region of Mesopotamia within the Tigris–Euphrates rivers system and Egypt played key roles in the production and trade of glass beads during the late antique and early medieval periods, but little is known about production sites. It is debatable whether all beads with Mesopotamian chemical compositions were made in the Tigris–Euphrates river valleys or if drawn canes and raw glass were shipped from these areas to bead workshops located in Asia and Africa (McIntosh et al., 2020). Drawn, cold-cut and hot-polished beads originated in India probably in the fourth century BCE (Francis, 2002b). Asian drawn beads were imported to the Mediterranean region and Europe until the end of the sixth century (Boschetti et al., 2020; Pion & Gratuze, 2016). It is unclear whether the drawing technique was transmitted from India to northern Syria, Iran or Iraq, or how this combination of ‘Mesopotamian’ base glass composition and Indian-forming technique came about. In any case, these beads circulated over long distances, as the archaeological finds of drawn, cold-cut of Mesopotamian composition throughout Europe prove. Specimens have been found in Italy during the second half of the seventh century (Boschetti et al., 2020), in ninth-century Albania (Neri, Gratuze, & Schibille, 2019) and Slovakia (Šmit et al., 2012). They are ubiquitous in Africa after the 10th century (Then-Obłuska & Dussubieux, 2023) and have been found as far away as Southeast Asia (Chaisuwan & Naiyawat, 2009) and north-west China (Xu et al., 2022).

There is no archaeological evidence of bead-making workshops in the Mediterranean region during the early Islamic period. The only published find potentially connected to bead-making, from a documented archaeological context, comes from Fustat. Colourful mosaic beads made of fused twisted striped canes, attested as early as the ninth century CE, are believed to have been produced locally, after a section of one colourful twisted cane was found in an ill-dated secondary deposit (Pinder-Wilson & Scanlon, 1987, 71). The possible identification of bead-making activities in Fustat was later strengthened by the publication of several sections of monochrome hollow canes and wasters excavated from the city's rubbish mounds in the first decades of the 20th century (Francis, 2002a, 14–15). Unfortunately, the exact location of the

bead workshop operating in Fustat cannot be determined, and it cannot be ruled out that these beads were produced earlier than the ninth century. The so-called Fustat beads were highly prized and traded as far away as Sweden and China (Francis, 2002a). In Egypt, beads were traditionally produced using either the mosaic or segmentation technique (Francis, 2002a; Pinder-Wilson & Scanlon, 1987). Segmentation, in which drawn tubes are divided into segments using stone moulds, was archaeologically recorded in Alexandria during the Roman and early Byzantine periods (Kucharczyk, 2011; Rodziewicz, 1984), but this Egyptian tradition probably has its origins in the Hellenistic period (Spaer, 1993). During the Middle Ages segmented beads were traded extensively (Then-Obłuska & Dussubieux, 2023, 280), and the identification of specimens made with Mesopotamian glass provide evidence that either segmentation may have been practiced in northern Syria, Iraq or Iran from the eighth century onwards (Then-Obłuska & Dussubieux, 2023, 280) or that Egyptian workshop started to work imported glass.

The mosaic-forming technique has been employed intermittently throughout the entire history of glass-making. The first examples date to the beginnings of the glass industry in Late Bronze Age Mesopotamia and Egypt (Grose, 1989, 51; Stern & Schlick-Nolte, 1994, 46, 82; Oates et al., 1994, 83, 237), and it becomes one of the signature techniques of Ptolemaic Egypt, where it was used in the production of inlays, vessels and beads (Bianchi, 1983; Liu et al., 2017; Then-Obłuska, 2018). Mosaic glass remained very popular during the Roman Empire, especially for the production of inlays (Gasparini, 2022), but from the fifth century it was used exclusively for beads. This may have been crucial for the transmission and continuity of the mosaic technique in the fifth and seventh centuries (Boschetti et al., 2020). Mosaic beads found in Europe in the fifth and sixth centuries have an Egyptian chemical composition and typology (Boschetti et al., 2020; Langbroek et al., 2022; Langbroek, 2021, 61). Due to their shape and the decorative patterns of the canes, they are comparable with beads and spindle whorls excavated in Egypt (Boschetti, 2023; Langbroek et al., 2022). Mosaic inlays and vessels resurfaced in ninth-century Iraq in the form of mosaic tiles with Mesopotamian plant-ash compositions (Schibille et al., 2018; Whitehouse, 2001). The earliest published mosaic beads with a Mesopotamian composition are from ninth-century burials in Albania (Neri, Schibille, et al., 2019), but in the absence of a comprehensive study of seventh–ninth-century beads from Egypt, Iran, Iraq and Syria, it is difficult to say how or when the mosaic glass technique was transmitted. One possible explanation is that the mosaic technique travelled to Mesopotamia after the annexation of Egypt by the Sasanian Empire or at the latest after the establishment of the Umayyad Caliphate.

Although there is now extensive evidence of the trade and exchange of Egyptian and Mesopotamian beads circulating in Central and Northern Europe in the late first millennium CE, the scholarly literature is largely silent on the manufacture of beads in the Western Mediterranean, and Spain is no exception. As a result, our understanding of the temporal and cultural mechanisms of glass bead production and trade remains limited. For instance, it is unclear whether the system of production of Islamic glass beads was centralized and standardized or if there was some degree of diversification. The combination of a typological and analytical study of beads is particularly promising for the early Islamic period. It is an era of fundamental political, economic and cultural transformations that affected the material culture of the Mediterranean, above all the primary production of glass. In the Islamic world, mineral soda was replaced by the use of soda-rich plant ash as the main fluxing agent, and regional glass production groups appear as early as the turn of the ninth century (Schibille, 2022a; Schibille et al., 2024; Shortland et al., 2006). By this time, the primary production of glass was spreading to regions outside the traditional glass-making centres in the Levant and Egypt. The chemical analysis of Islamic glass beads can therefore provide information about the origin of the raw glass and, by extension, about the probable region of secondary production. This paper presents the typological, compositional and some isotopic data of a group of 18 glass beads recovered from two archaeological sites in central Spain—Ciudad de Vascos and Albalat—where the final phase of



FIGURE 1 Map of Spain showing the location of the two archaeological sites of Ciudad de Vascos and Albalat.

occupation dates, respectively, to the 10th–11th and 12th centuries (Fig. 1). The compositional and isotopic characteristics are clear evidence that at least some of the beads were made in the Iberian Peninsula using winding and folding techniques. In addition to these local beads, the archaeological finds also included drawn beads imported from the Middle East.

ARCHAEOLOGICAL CONTEXT

The beads come from two well-known archaeological sites of al-Andalus: Ciudad de Vascos (Navalmoralejo, Toledo) and Albalat (Romangordo, Cáceres). Both sites are located approximately 55 km apart in the central valley of the Tagus River, which in the course of the 11th century became a political frontier between the Christian kingdoms in the north and the Islamic *taifas* in the south. During this period, the Christians took control of the area of Ciudad de Vascos and Albalat. During the early 12th century, the latter was briefly reconquered by the Almoravids (Gilotte & Cáceres, 2017).

Ciudad de Vascos was a small walled town of about 9.5 ha with well-preserved architectural features, including public baths, mosques and an extensive urban area. Excavations since the mid-1970s have uncovered Roman occupations dating to at least the first century CE, which intensified in the fourth and fifth centuries. Prosperity reached its peak in the 10th and 11th centuries, to which most of its excavated remains belong. Shortly after the fall of the Umayyad Caliphate of Córdoba in 1031, Vascos was integrated into the territories ruled by the Banū ʿU

l-Nūn of Toledo. It was conquered by the Christians in the last quarter of the 11th century and finally abandoned a few years later (De Juan, 2007; De Juan & Cáceres, 2016). The 11 glass beads analysed here come from a large building in the commercial area of Vascos, excavated in 2001 and 2006 (Izquierdo & De Juan, 2007). Most of the beads came from surface contexts and cannot be unambiguously attributed to a specific period, but since Vascos was abandoned in the last quarter of the 11th century, the chronology is unlikely to go beyond this point. Three beads—including one wound (VS005), one drawn (VS009) and one folded (VS011)—were recovered from stratigraphic layers that can be clearly dated in the 11th century, and one may be slightly earlier and date to the 10th century (see Table S1 in the Supporting Information section). Tenth- to 11th-century contexts in Ciudad de Vascos yielded beads similar to those discussed in this paper (De Juan & Cáceres, 2016).

The chronological sequence of Albalat is somewhat different and limited to the Islamic period. Its Arabic name was Majadat al-Balat (the ford of the road) because of its strategic location at a crossing point of the Tagus River towards Cáceres and the plains of the Guadiana River. The foundation date of this small walled town is unknown, but the few textual sources that mention it show that the site was already in use during the caliphal period, in the second half of the 10th century. Archaeological data meanwhile point to activities at the site since at least the ninth century (Romani, 1971). After a brief period under Christian rule, the Almoravids took over Albalat in the early 12th century. This lasted until c.1142 when an attack by Christian militias ended the stable occupation of the site. The excavations carried out within the city walls have revealed an urban fabric structured around a relatively regular street network that delineates large blocks. Within these clusters, over 20 buildings with various functions have been discovered, including residential spaces, smithies, bone-carving workshops, domestic food ovens and storage facilities. Outside the city walls, public baths and a burial area have been documented. Its rapid and brutal destruction, evidenced by numerous fires and signs of looting, facilitated the preservation of a wide range of artefacts. These are generally well-contextualized stratigraphically and date from the Almoravid rule, including 22 glass beads found during the excavation campaigns between 2009 and 2023 (Gilotte et al., 2015; Gilotte & Cáceres, 2017).

MATERIALS AND METHODS

Eight glass beads from Albalat and 11 beads from Ciudad de Vascos were selected for this study (Fig. 2; and see Table S1 in the Supporting Information section). The typology of the beads was established on the basis of their forming technique, which was determined by visual inspection. All the different colours of the cleaned but unprepared samples were analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at IRAMAT-CEB in Orléans (France). The instrumental set-up consists of a Resonetics M50E excimer 193 nm laser and a Thermo Fisher Scientific ELEMENT XR mass spectrometer. The standard working conditions are a 5 mJ energy, 10 Hz pulse frequency and a beam diameter that ranges from 30 to 100 μm (Gratuze, 2013, 2016). A pre-ablation was adjusted according to the thickness of the corrosion layer to ensure the analysis of healthy glass. To confirm the results and verify accuracy and precision, glass reference materials Corning A, Corning C and NIST 612 were analysed throughout the analytical run; for the differences between published and analysed values, see Table S3 in the Supporting Information section.

Lead isotope analysis (LIA) was carried out on six beads from Ciudad de Vascos and compared with the isotopic signatures of Iberian ore sources to identify possible origins of the Pb component. Small samples were processed following the standard procedures at the BRGM (French Geological Survey, DEPA-ISO unit), Orléans (Schibille et al., 2020). The Pb was extracted by dissolving the fragments with HF at 120°C in a Teflon container. After drying the



FIGURE 2 The beads from Albalat and Ciudad de Vascos divided by the forming technique.

solution, the dry residues were dissolved in 1 M HBr, and the Pb was purified with AG 1X-8 ion-exchange resin, using HBr and HCl acids. This solution was evaporated and re-digested in HNO₃ and dried again. LIA was conducted in static mode on a multicollector Finnigan MAT262 thermal ionization mass spectrometer (MC-TIMS). About 150 ng of Pb samples and the NIST NBS982 standard were loaded with H₃PO₄ on a zone-refined Re filament. All measurements were corrected for an internal mass bias of 0.13% per atomic mass unit as determined by repeated measurements of the NIST NBS982 standard. At < 100 pg, the total process blanks that were measured alongside the samples remained negligible relative to the amount of Pb extracted from each sample. The individual errors in all Pb isotope ratios were > 0.01% ($2\sigma_m$),

while external reproducibility (2σ) ranged from 0.06% for the $^{206}\text{Pb}/^{204}\text{Pb}$ ratio, and 0.07% for the $^{207}\text{Pb}/^{204}\text{Pb}$ ratio, to 0.09% for the $^{208}\text{Pb}/^{204}\text{Pb}$ ratio.

RESULTS

Forming technique

One of the beads (VS004) analysed in this study turned out to be a faience bead, and its forming technique is not discussed further. The glass beads from Ciudad de Vascos and Albalat represent three forming techniques, that is, wound, drawn and mosaic beads. The large majority of beads ($n = 15$) were formed by winding or folding the hot glass around the mandrel. Winding and folding are fairly simple forming techniques and were practiced in all regions where glass beads were made, from Asia to Europe. Wound beads can be fashioned by collecting some soft glass from the crucible with the tip of the mandrel, which is wound and eventually marvered to obtain the desired shape. The bead can be sculpted using moulding tongs and threads or dots in contrasting colours can be added to the surface. None of the wound beads from Ciudad de Vascos and Albalat appears to have been moulded, they are all sub-spherical or teardrop-shaped and part of them are decorated with applied threads (VS001, VS002, VS005, VS010, ALB047). Threads can be applied to the surface of the bead using with the heated tip of a glass cane as if using a pencil. The desired decorative pattern is obtained by winding the mandrel to wrap the thread around the body and moving the cane to create drawings. A pointed metallic tool can be used to work the thread and to obtain, for example, a combed decoration. Contemporary bead-makers in Murano, Italy, use the pointed tip of a thin glass cane for this process to this day (personal observation, C.B.). An alternative method for applying threads and dots is to collect a small gob of glass from the crucible with the tip of a second mandrel and proceed as described. This second method is used, for instance, by the bead-makers of Nazarkoy, Turkey (Küçükermann, 1988). After applying the decoration, the surface of the bead can be smoothed on the marver. If the body of the bead and the thread are soft enough, the applied decorations flattens into the bead body without the need for any further action. Six beads are tubular and were formed by folding (VS006, VS008, VS011, ALB029, ALB030, ALB039). In this process, a gob of soft glass or a small section of a heated cane is flattened on the marver and folded around the mandrel. The folded beads from the two sites are very simple in shape and decoration and it is not possible to assign them to a provenance based on their typology and shaping technique alone.

Three beads, one from Albalat (ALB046) and two from Ciudad de Vascos (VS007, VS009), stand out from the rest of the collection because they are drawn. Drawn beads can be fashioned by cutting hollow canes into sections. Different methods for producing hollow canes are known. The basic principle of this procedure is to trap an air bubble inside a mass of hot glass. When the mass of glass is pulled to form the cane, the air bubble expands and the perforation is created. In the Indian tradition, hollow canes are made in special furnaces, using a tool called a *lada* (Kanungo, 2004), while in the Venetian tradition the air bubble is inflated using the blowing pipe. A third, alternative method that can be practiced during flame-working is to pierce the mass of glass with a pointed tool (Spaer, 2001). The sharp edges of the three tubular beads from Albalat and Ciudad de Vascos show that the canes were cold-cut without hot polishing. Hot polishing was often used to smooth the beads by heating them either inside large iron pans, as is common in India (Kanungo, 2004) and Murano since the end of the 16th century, or by placing them directly in the reverberatory furnace (Zecchin, 2005). We do not know what technique was used in ancient times, but the effects of hot polishing can be observed in the Indian beads imported to Europe until the sixth century CE (Pion & Gratuze, 2016). With rare exceptions (Boschetti et al., 2020), the drawn beads with Mesopotamian composition remained untreated

and had sharp edges (Neri, Gratuze, & Schibille, 2019). The earliest production of drawn beads in Europe is documented in Murano in the second half of the 15th century (Zecchin, 2005). Considering the high specialization required to make drawn beads, it is likely that the three beads from Albalat and Ciudad de Vascos were made in a specialized workshop where this complex forming technique was mastered.

Chemical composition

Several distinct glass types were identified among the beads, including soda-rich plant-ash glass, soda-ash lead glass ($\text{PbO} \sim 20\%$), lead slag glass ($\text{PbO} \sim 50\%$) and a Pb-silica glass in the strict sense ($\text{PbO} \sim 70\%$) corresponding to the three main types of early Islamic lead glass (Schibille, 2022b) (Fig. 3). One sample from Albalat (ALB038) has an Iron Age or Roman natron-type base glass, and one bead from Vascos is in fact a faience bead (VS004; see Table S1 in the Supporting Information section). The beads are almost equally distributed among the different base glass types with a slight preponderance of Pb-silica glass ($n = 8$) that consists mainly of PbO ($\sim 70\%$) and silica ($\text{SiO}_2 \sim 24\%$). They occupy the lower right corner in the ternary diagram (Fig. 3). The decorative feature of one sample (VS001) is a Pb stannate similar to the composition of the tin yellow pigment made in bead workshops active during the seventh century (Heck et al., 2003; Sablerolles et al., 1997). The white thread used to decorate ALB047 is an almost pure tin-white pigment in a Pb-silica glass, high in alumina and calcium. Four beads show characteristics comparable to the composition of the lead slag glass identified in eighth–ninth-century Saqunda (Schibille et al., 2020), with an average composition of about 50% PbO , 32% SiO_2 , 4.5% Al_2O_3 and 3.7% CaO (Fig. 3), and notably high Ba levels characteristic of slag

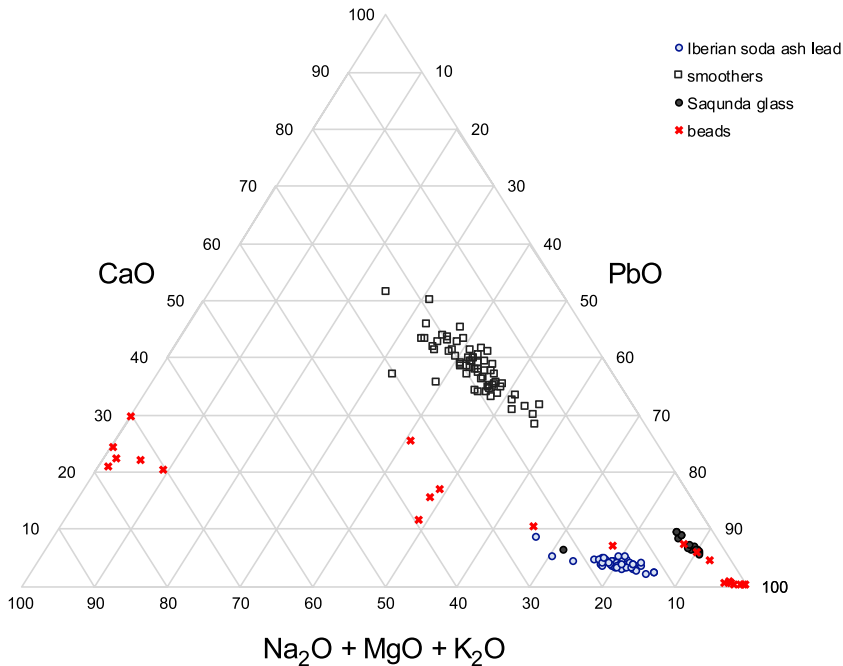


FIGURE 3 Ternary diagram comparing the Pb, alkali and alkaline earth contents of glass beads from Albalat and Ciudad de Vascos with published data of the different types of high-lead glass identified in the Islamic world. Data sources: smoothers (Gratuze et al., 2003); Iberian soda-ash lead glass (De Juan Ares et al., 2018; De Juan Ares & Schibille, 2017; Duckworth et al., 2015); and Saqunda lead slag glass (Schibille et al., 2020).

glass ($Ba > 3000$ ppm; see Table S1 in the Supporting Information section). One sample (red segment of VS001) has additionally elevated alkali concentrations, suggesting a mixture of two different glass-making recipes, namely the use of lead slag plus some soda-rich plant ash to obtain a hybrid glass. The red parts of VS002 seems closely related, but with half the PbO content of only 20% PbO and twice the soda concentration ($NaO_2 = 11\%$). The white/turquoise part of the same bead together with the white/turquoise decorations of two more beads (VS005, VS010) corresponds more closely to a soda-ash lead glass for which litharge instead of lead slag was used, and that additionally contain considerable alkali and alkaline earth elements (Schibille, 2022b) (Fig. 3).

Among the two assemblages were five soda-rich plant-ash glass beads with highly variable compositions. They are located on the left side of the ternary diagram due to their low Pb and high alkali contents (Fig. 3). Two samples (ALB031 and ALB047 orange) have high Al oxide ($Al_2O_3 > 4.5\%$) and Mg ($MgO > 4\%$) concentrations, hence relatively high MgO/CaO ratios (> 0.5) (Fig. 4, a), while three beads (VS007, VS009, ALB046) have moderate alumina levels ($Al_2O_3 = 2.5\%$) and relatively low magnesia ($MgO \sim 1.5\%$), but higher potash relative to P contents (Fig. 4, a). This means that the two types differ in terms of the fluxing agent (Fig. 4, a). When compared with different regional plant-ash glass production groups, the plant-ash beads show distinct Th/Zr ratios typical of Iberian plant-ash glasses (Fig. 4, b). However, the classification of the three samples with low Mg is ambiguous, as Iranian glass (G1a, G1b) can have similar Th/Zr ratios (Fig. 4, b). In combination with the forming technique (drawn and cold cut), an eastern origin seems more likely (see the discussion below).

In terms of colourants and opacifiers, nothing out of the ordinary was identified. Fe, Co, Cu, Sn and Pb were the main colouring and opacifying elements. Only the natron glass bead (ALB038) was coloured by Co (see Table S1 in the Supporting Information section). Copper turquoise, copper green and copper red are the most common colourants, and they differ in their Sn concentrations as well as the base glass type. The turquoise samples have on average the highest Cu ($CuO \sim 4.2\%$) and Sn ($Sn \sim 5.7\%$) levels, and they were made from soda-ash lead glass. All the copper red (except orange sample ALB046) were produced from lead slag glass and they tend to have somewhat lower Cu and only traces of Sn compared with the green samples (see Table S1 online). The green samples are either of a Pb-silica or a plant-ash glass composition. Five beads are black-appearing and the colour here is due to high Fe oxide contents (on average $Fe_2O_3 > 4\%$). They are again either of a plant-ash or Pb-silica glass.

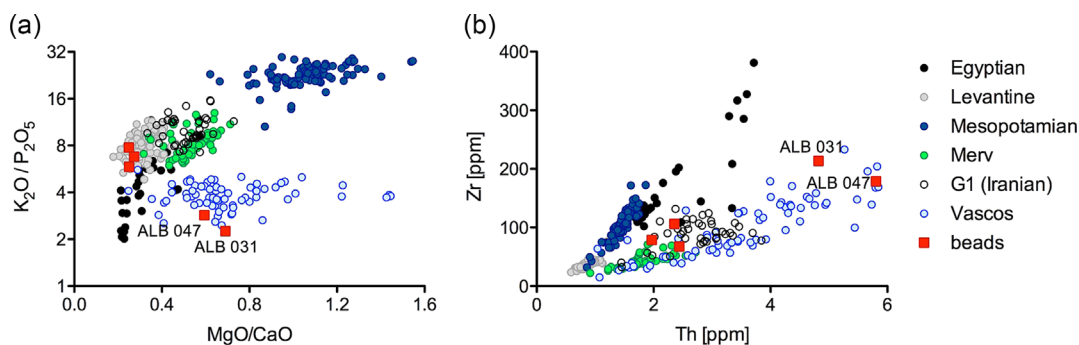


FIGURE 4 Plant-ash glass beads from Albalat and Ciudad de Vascos in comparison with glass reference groups: (a) K_2O/P_2O_5 versus MgO/CaO ratios reflect the plant-ash component; and (b) Zr and Th concentrations are indicative of the silica source. Data sources: Egyptian glass (Neri, Schibille, et al., 2019; Schibille et al., 2019); Levantine glass (Phelps et al., 2016); Mesopotamian glass from Samarra (Schibille et al., 2018); Iranian glass (Schibille et al., 2022); and glass from Ciudad de Vascos (De Juan Ares & Schibille, 2017).

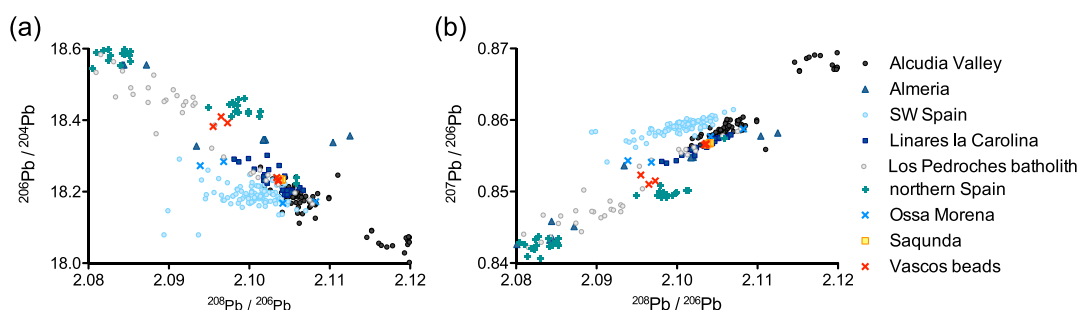


FIGURE 5 Pb isotope signature of six beads from Ciudad de Vascos compared with the isotopic data from Rabad of Saqunda (Schibille et al., 2020) and Iberian mining districts (Marcoux, 1997; Santos Zalduegui et al., 2004; Klein et al., 2009; Velasco et al., 1996; <http://oxalid.arch.ox.ac.uk>). Three beads match the data from Saqunda and, by extension, the mining areas of Los Pedroches and Linares la Carolina, while the other three cannot be clearly attributed to a specific ore deposit.

Isotopic signature

To identify a likely source for the Pb component, the Euclidean distance between the three Pb isotope ratios ($^{208}\text{Pb}/^{206}\text{Pb}$, $^{207}\text{Pb}/^{206}\text{Pb}$, $^{206}\text{Pb}/^{204}\text{Pb}$) of a datum point and the ore sample needs to be within the analytical accuracy of 0.1% (Wolf et al., 2003, *passim*). The Euclidean distance between the isotopic signature of the six beads (see Table S2 in the Supporting Information section) and data from Iberian mining districts was thus calculated to determine the closest match. Three beads (VS003, VS005, VS008) are isotopically compatible with the slag glass from the Saqunda and by extension with the mining districts north of Córdoba, specifically Los Pedroches Batholith and Linares La Carolina (Fig. 5) (Schibille et al., 2020; Marcoux, 1997; Santos Zalduegui et al., 2004; Klein et al., 2004). The other three beads (VS001, VS006, VS011) have lower $^{208}\text{Pb}/^{206}\text{Pb}$ ratios and all three have as their closest match a sample from Los Pedroches, while beads VS006 and VS011 have isotopic signatures that are also similar to deposits in the Basque–Cantabrian basin in Northern Spain at the south-western part of the Alpine belt of the Pyrenees (Velasco et al., 1996). However, it is unlikely that these mining districts were accessible to Islamic craftsmen from al-Andalus. Pb isotope data are sensitive to mixing, which could be the reason why we cannot clearly assign the three samples.

DISCUSSION

The integration of forming technique, chemical composition and Pb isotopic signature sheds light on the dynamics of bead supply in Iberia and provides the first conclusive evidence for the production of glass beads in the region during the early Islamic period. The monochrome blue wound bead ALB038 is clearly an Iron Age or Roman residual find made with a Levantine base glass and a Co pigment with a high Co/Ni ratio typical of Co sources up to the fourth century CE (Gratuze et al., 2018). All the other wound and folded beads from Albalat and Ciudad de Vascos are made from soda ash and different types of lead glass. Both the soda ash and the lead glasses have Iberian characteristics, including Pb isotopes that correspond to the lead ores in the region around Córdoba, and are intimately related to the slag glass from Saqunda. This type of lead slag glass was used for folded beads (ALB029, ALB030, ALB039, VS006, VS008, VS011) and small wound monochrome beads (ALB032, VS003). The fact that these local beads were produced using relatively simple techniques suggests that bead-making in al-Andalus was developed using a forming technique rooted in the earlier European tradition. The choice of

lead glass no doubt facilitated the productive process, as the low working temperature of this type of glass could have been achieved without having access to sophisticated furnace infrastructures. For example, a Pb-silica glass with about 70 wt% PbO has a T_g (glass transition temperature) of $< 500^\circ\text{C}$ (Ben Kacem et al., 2017). One of the beads in this group (ALB030) stands out for its increased Cl content, which is frequently encountered in Iberian soda-ash lead glass (Schibille, 2022c). Whether these elevated Cl concentrations are due to the deliberate addition of salt (NaCl), a practice suspected in forest glasses to increase the alkali concentration (Gerth et al., 1998), or simply reflect the increased solubility of Cl in lead glass is not clear (Coon & Shelby, 1990). In the case of the addition of salt, the glass can be assumed to be a mixture of lead glass (slag) and plant-ash glass, which would enrich the relevant elements such as Mg. If the Cl values are due to its higher solubility in lead glass, then the lead glass or slag was necessarily mixed with plant-ash raw materials and not with a pre-fused plant-ash glass, as otherwise there would not be enough Cl available. In either scenario, we can conclude that the beads were likely produced in Iberia from locally available glass types and recycled cullet.

The composition of the beads from Albalat and Ciudad de Vascos shows that the Iberian bead-makers had access to different base glass compositions. The mixing and/or recycling and combination of different base glass types in the same bead is clearly seen in the bichrome wound beads from Ciudad de Vascos, made with Pb-silica glass, in some cases with the addition of soda-ash glass. Remarkable is the use of some types of glass that were no longer used in the caliphate to make vessels, such as the ninth-century lead-slag glass from the Saqunda and the ninth- to 10th-century soda-ash lead glass from Córdoba (De Juan Ares et al., 2021; Salinas et al., 2021). To what extent this is an indication of the longevity of these types of glass compositions or that the beads are significantly older than the archaeological context in which they were found is difficult to prove. The yellow glass with high Pb and Sn contents used to decorate bead VS001 is compatible with the yellow glass used for the beads manufactured in the seventh century CE in what is now the Netherlands and Switzerland (Heck et al., 2003; Sablerolles et al., 1997). We hypothesize that old cullet was systematically collected, recycled and made into new artefacts, in line with customs in other parts of Europe. In the Middle Ages, bead workshops in Central and Northern Europe (Barfod et al., 2022; Crocco et al., 2021; Sablerolles et al., 1997; Sode et al., 2022) extensively used recycled glass as raw material because they had limited access to fresh glass, and because the absolute quantities required for the manufacture of beads were small (Ma et al., 2023, 92–98; Bertini et al., 2020). Recent studies suggest that glass recycling was more than just a coping strategy. Indeed, the identification of intensive recycling in urban centres located in close proximity to glass-making regions (Barfod et al., 2018; Boschetti et al., 2021) shows that recycling was a practice associated with the optimization of resources and the efficient management of urban waste (Furlan & Andreatta, 2023). The identification of recycled compositions in the beads in medieval Spain, where glass was made locally (Schibille et al., 2020), confirms the validity of this model.

Finally, the beads from Albalat and Ciudad de Vascos also bear witness to the long-distance trade in glass beads. As we have shown, the provenance of the soda-ash glass underlying two large wound beads from Albalat (ALB031, ALB047) and three drawn beads (ALBB046, VS007, VS009) is difficult to establish. Here, the forming technique may provide additional information, as the wound beads have a purported Iberian composition, while the drawn beads are compositionally closer to Iranian glass and an Iranian provenance of the beads is accordingly possible (Fig. 4). During the Middle Ages, bead drawing was practiced in the Mesopotamian region, and it is disputed whether this technique reached the Maghreb and Sub-Saharan Africa (McIntosh et al., 2020). The lack of published chemical data on Islamic glass beads limits our understanding of a potentially international distribution of Iberian beads. There is a compositional similarity between ALB031 and ALB047 and a green wound bead from al-Basra, Morocco (PR878FF; Robertshaw et al., 2010), but more comparative data would be needed to assess whether the Iberian beads travelled long distance or if they were products that merely circulated at a regional level.

CONCLUSIONS

The present study has shown the value of combining typological, elemental and isotopic data from glass beads to address questions of technological transfer and the movement of ideas, craftsmen and artefacts. Analytical evidence of bead-making and the location of secondary glass workshops more generally are uncommon, but the compositional and isotopic characteristics of the beads from Albalat and Ciudad de Vascos conclusively establish their production in Islamic al-Andalus. The variations in the base glass suggest that either a single workshop worked with different consignments of locally available cullet at different times or that there were several workshops active throughout the Iberian Peninsula. The use of lead slag glass from the area around Córdoba is unexpected, as this type of glass was used for vessels for only a relatively short period of time in the first half of the ninth century CE. This means that either lead slag continued to be exploited specifically for the manufacture of beads, perhaps because its material properties and particularly the strong decrease of its viscosity were recognized as advantageous for bead-making, or that this type of slag glass was more widespread than previously assumed. Furthermore, the possibility that these beads had been produced earlier cannot be discounted. The other types of base glass identified could be more or less contemporary with the production of the beads, but their mixing points to the use of recycled glass rather than fresh glass. Glass recycling, in particular for the manufacture of glass beads, was fairly typical, which is certainly, but not exclusively, connected to socio-economic considerations. Collecting and storing broken glass has been common practice since Roman times and must have been a relatively reliable source of raw material for bead-makers.

However, glass beads must also be understood as a socio-cultural phenomenon in a broader sense, reflecting the flow of people and know-how that has characterized and shaped the Mediterranean region during the Islamic period. The presence of glass bead-making in al-Andalus illustrates the social and cultural value and appreciation of these artefacts in the early Islamic world. The simple winding technique used for the local beads suggests that bead-making in the Iberian Peninsula may have developed based on the technical know-how of medieval Europe. Unsurprisingly, none of the more elaborate bead-making techniques such as mosaic beads or drawn beads was practiced locally. Although beads were produced in the Iberian Peninsula, some drawn beads of possible Iranian origin were imported. Given the differences in base glass as well as forming technique of these beads, it seems quite unlikely that specialized craftsmen from the Eastern Mediterranean or further east migrated west. The spread and circulation of the drawing technique throughout the Islamic world during this early period are not well understood, but the presence of a handful of drawn beads with an Iranian base glass in al-Andalus is a new piece of evidence for the diffusion of drawn beads. A large-scale study of the typological and chemical variability of Islamic glass beads is needed to better understand the transfer of production techniques, the cultural and symbolic value of beads in the Islamic society, and possible movement of craftsmen as well as the global dimensions of the bead trade.

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DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

ORCID

Cristina Boschetti  <https://orcid.org/0000-0003-4499-779X>

Jorge de Juan Ares  <https://orcid.org/0000-0001-9957-0342>

Sophie Gilotte  <https://orcid.org/0000-0003-1915-730X>

Catherine Guerrot  <https://orcid.org/0000-0001-8656-6897>

Nadine Schibille  <https://orcid.org/0000-0001-9242-0392>

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SUPPORTING INFORMATION

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