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Changes in the supply of eastern Mediterranean glasses to Visigothic Spain

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ABSTRACT

This study presents the first comprehensive analysis of glass compositions from Visigothic Spain using high resolution laser ablation-inductively coupled plasma mass spectrometry (LA-ICP-MS). Major, minor and trace element patterns of 169 well-dated samples from three rural Iberian sites (Congosto, Gózquez and El Pelícano) have brought to light major chronological developments in the production, circulation and use of glass between the fifth and the eighth century CE. The data identify four distinct compositional groups of Egyptian and Levantine origin. Egyptian Foy 2.1, Foy 2.1 high Fe and so-called Magby alongside Apollonia-type Levantine I were the main glass types of the Visigothic period. Due to the tight dating of the majority of the samples, we were able to reveal fundamental changes in the geographical scope of glass supplies to the Iberian Peninsula, and to refine the chronological range of the known primary production groups. The glass group commonly known as *série* 2.1 or Foy 2.1 started being produced already during the second half of the fifth century. The appearance of Foy 2.1 high Fe can likewise be moved forward to the first half of the sixth century. A plant-ash group referred to as Magby was introduced around the middle of the sixth century. Egypt was undeniably the main supplier of raw glasses to the Iberian Peninsula up to the mid-sixth century CE, after which the Levantine I group became the prime glass type among the analysed assemblages. In the final stages of the Visigothic Kingdom and the early years of Islamic dominion, there is a noticeable drop in the absolute quantity of glass available, together with an increase in recycling. The implications of these transformations in the supply of glass for the organisation of Mediterranean trade are discussed.

1. Introduction

Low magnesium and potassium (< 1.5%) natron-type glasses dominated in the Mediterranean region from the Hellenistic period up to the early ninth century CE, when mineral soda was gradually replaced by vegetable fluxes (Gratuze and Barrandon, 1990; Henderson et al., 2004; Phelps et al., 2016; Sayre and Smith, 1961; Shortland et al., 2006). Syria-Palestine and Egypt were the main producers of raw glass throughout this period. Analytical studies of archaeological glasses have been successful in distinguishing different compositional groups of natron glasses with diverse distribution patterns and chronologies. Roman glass recipes prevailed until the fourth century, when new primary production groups emerged, both in Egypt and the Levant. In the late fourth-century Levantine workshops at Jalame, for instance, primary glass was produced with on average higher lime, alumina and potash and slightly lower soda concentrations compared to earlier Roman blue-green or manganese decoloured glasses (e.g. Brill, 1988; Silvestri et al., 2008). After the mid-fourth or early fifth century CE, manganese seems to have been no longer intentionally used as decolourant by Levantine glass manufacturers (Barfod et al., 2018; Jackson and Paynter, 2016; Schibille et al., 2017). The evolution of glass produced on the Levantine coast, from fourth-century Jalame, through sixth- to seventh-century Levantine I Apollonia-type glass to eight-century Levantine II from Bet Eli'ezer shows that over time there is a progressive increase in aluminium oxide levels that reflects changes in the silica source (Brems et al., 2018; Phelps et al., 2016). Soda contents simultaneously decreased, possibly due to shortages in natron supplies to the Levantine coast (Freestone et al., 2000). Archaeological data indicate that with the disappearance of natron glass production in the Levant sometime during the eighth century there was a clear increase of Egyptian imports to the region (Phelps et al., 2016).

Egyptian glasses tend to have higher silica-related heavy element

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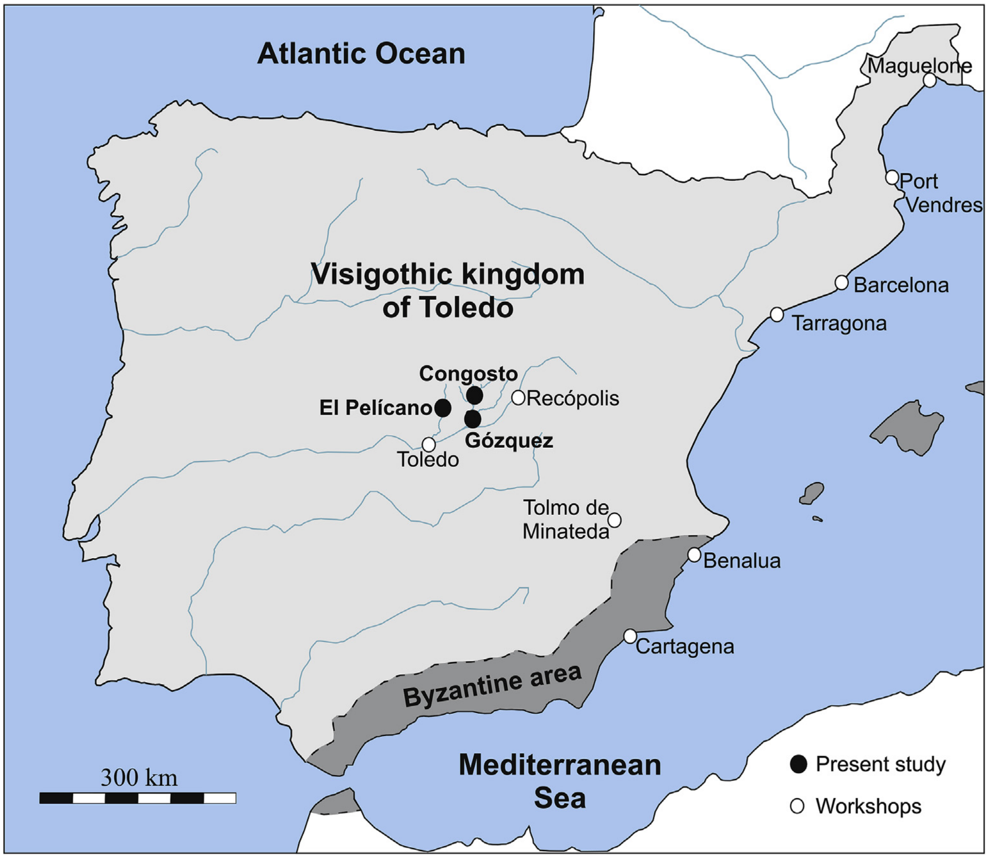

Fig. 1. Map of Visigothic Spain at the end of the sixth century CE. Archaeological sites (filled circles) from where the glass samples of this study were retrieved are indicated as well as the locations of known Visigothic and Byzantine glass workshops (open circles) (Foy et al., 2003; De Juan Ares and Schibille, 2017b).

impurities compared to glasses produced in the Levant. Antimony decoloured glass, one of the main outputs of Egyptian glass production ceased towards the middle of the fourth century (Gliozzo, 2017; Jackson and Paynter, 2016). At around the same time so-called HIMT glass appears throughout the Mediterranean and particularly in the western and northern regions of the Roman Empire. HIMT is characterised by high iron, manganese, titanium and zirconium levels, reflective of some silica source rich in accessory minerals, as well as relatively high soda contents typical of Egyptian glasses, and it is primarily dated to the fourth and fifth century CE (Freestone et al., 2018). A sub-type with elevated iron levels and iron to titanium ratios (HIMTb) has been singled out (Ceglia et al., 2017; Ceglia et al., 2015; Freestone et al., 2018). Compared to the common HIMTa type, high Fe HIMTb has been attributed to the beginning of the fifth century, and its geographical range is restricted mostly to the eastern Mediterranean basin (De Juan Ares et al., 2018b). A related primary production group dated to the end of the fifth century is so-called HIT glass that lacks manganese but otherwise exhibits the same compositional characteristics as HIMT (Rehren and Cholakova, 2010).

Another fourth-to fifth-century type originally defined by Foy and colleagues (Foy et al., 2003) in relation to glass finds from Tunisia and France as *série 3.2*, is increasingly recognised among assemblages in Italy (Maltoni et al., 2016; Maltoni et al., 2015) and on the Balkans (Balvanović et al., 2018; Cholakova and Rehren, 2018). Compositional similarities with Roman antimony decoloured glass in the form of low aluminium and calcium and slightly elevated titanium to aluminium ratios suggest an Egyptian origin for these glasses as well. *Série Foy 2.1* (Foy et al., 2003), in contrast, has been attributed to the sixth century (Cholakova et al., 2016). Foy 2.1 shares some characteristics with HIMT glasses in that it has elevated iron, manganese, titanium, and zirconium levels, but the absolute concentrations always remain below those of HIMT, while having substantially higher lime contents. Samples belonging to this group have been found throughout the Mediterranean and specifically in western workshops in France (e.g. Marseille, Bordeaux, Maguelone and Port-Vendres, Foy et al., 2003). Closely related to this group is Foy 2.1 high Fe (1.5% < Fe_2O_3), with elevated associated elements such as vanadium, titanium and zirconium (Ceglia et al., 2017; Schibille et al., 2016). This sub-type has been defined in the context of Byzantine glass weights and has thus been dated to the mid- to late sixth century (Schibille et al., 2016). It is present among French and Tunisian assemblages dating from the sixth to the eight centuries CE (Foy et al., 2003). A plant ash variant of the Foy 2 compositional family, dubbed Magby on account of its elevated magnesia levels, is a late sixth- to seventh-century type that has been recognised as an independent primary production group based on the analyses of Byzantine glass weights (Schibille et al., 2016). It had also been reported from contemporary Anglo-Saxon Britain where it was termed high magnesia Saxon II glass (Freestone et al., 2008), from Caričin Grad in Serbia (Drauschke and Greiff, 2010), and Merovingian France (Velde and Motteau, 2013). A plant ash component is assumed to underlie these glasses due to the potassium, phosphorus and magnesium concentrations that exceed those typically encountered in natron-type glasses. The last natron glasses produced in Egypt are the eighth-century Egypt I group, followed by Egypt II that dates to the last quarter of the eight and first half of the ninth century CE (Gratuze and Barrandon, 1990; Schibille et al., 2019).

Here we present the first extensive set of LA-ICP-MS data of Visigothic glasses in Spain. The glass samples were collected from three archaeological sites in the central Iberian Peninsula and derive from well-stratified contexts with a high chronological resolution, covering the entire Visigothic period from the fifth to the eighth century CE. The high precision of the analyses and the high temporal resolution allow us to trace in great detail the chronological distribution patterns of different primary glass production groups in Visigothic Spain: their chemical characteristics, geographical origins and developments over time. The primary objective of the study thus was to firmly establish the chemical composition of glasses used in Visigothic Spain, the degree of variability and the significance of recycling. Our data also help to refine the temporal attribution of some of the glass groups previously defined in the literature as well as the global trends in glass trade and consumption in the western Mediterranean, which in turn can be related to wider geo-political and socio-economic mechanisms.

2. Archaeological contexts and materials

Three archaeological sites have been selected because of their precisely dated stratigraphic contexts: Gózquez (GO), Congosto (CON) and El Pelícano (PEL) in the province of Madrid (Spain) near Toledo, the capital of the Visigothic Kingdom (Fig. 1). Chronologically the samples range from the early fifth to the early eight centuries CE, thus covering the entire Visigothic period in Spain. The three sites are rural settlements, which minimises residual material from earlier times. El Pelícano (Arroyomolinos) was a village with an associated necropolis that evolved from a late Roman settlement and remained active from the fifth to the eighth century (Vigil-Escalera Guirado, 2009a; Vigil-Escalera Guirado, 2009b and references therein). Congosto (Rivas-Vacíamadrid) has been interpreted as a farmstead made up of two households that were occupied roughly for five generations between the last third of the fifth and the seventh century (Vigil-Escalera Guirado, 2007; Vigil-Escalera Guirado, 2013). Gózquez (San Martín de la Vega) was an open village with habitational structures and agrarian fields, a graveyard in between and two residential areas dated to the second quarter of the sixth to the middle of the eighth century (Vigil-Escalera Guirado, 2007; Vigil-Escalera Guirado, 2009a). The three sites have been analysed and interpreted in great depth, both in terms of their stratigraphy and associated material. A firm chronology of the archaeological contexts was defined based on a combination of carefully evaluated stratigraphic data, detailed investigations of the ceramic finds as well as some radiocarbon dates. The systematic typological study of the ceramic corpus from the three sites (e.g. Vigil-Escalera Guirado, 2013) has established a complete chronology that is currently considered as an essential reference for ceramic finds of the Visigothic period. Except for El Pelícano, where some samples come from burials, all the glasses analysed derive from domestic contexts.

As is usual for the period from the fifth to eighth centuries, the typological range of the assemblages is limited to dishes, bowls, beakers and cups. Decorations are very scarce and restricted to incised lines or grooved surfaces (Table S1). No significant evolution of types is evident during this period, except for an increase in the diameter of dishes, a relative surge in drinking vessels, and the appearance of high solid-stem goblets at the later stages (Fig. 2). The sampling strategy consisted in selecting all types and colours represented among the assemblages to obtain a complete picture of the glass in circulation. The colours include naturally coloured bluish, greenish and yellowish to amber hues as well as colourless samples. From Gózquez and Congosto, all identifiable glass objects from all archaeological contexts with good chronological and stratigraphic reliability were systematically analysed. For comparative reasons, a selection of ten samples from El Pelícano mostly from burials were also included in this study.

3. Methods

Fragments of approximately 3 mm size of 169 samples were mounted in epoxy resin blocks, polished and analysed by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) at IRAMAT-CEB following the procedure described elsewhere (Gratuze, 2014, 2016). The mass spectrometer was a Thermofisher Element XR and the laser ablation system a Resonetic UV laser microprobe (193 nm Excimer laser). The operating conditions were set at 5 mJ with a frequency of 10 Hz and a spot size of 100 μm, reduced when necessary to avoid saturation. Pre-ablation time of 15 s was followed by 30 s of analysis, during which fifty-eight elements were measured. Quantitative results were calculated based on an internal standard and a comprehensive set of international glass standards (NIST SRM610, Corning B, C and D). The glass standards (NIST SRM612, Corning A, B, D) were analysed alongside the archaeological glasses and were used to establish the accuracy and precision of the analyses (Table S2). The analytical precision is better than 5% (relative) for most elements with very few exceptions. The results obtained for Corning A, B and D are better than 5% for all major and minor element oxide concentrations above values of 0.5%, except for alumina and lime values in Corning A that regularly deviate more strongly from the expected concentrations. The accuracy for all trace elements (excluding cadmium, tantalum, and tungsten) is generally within 10% of the NIST SRM612 certified composition (Table S2).

4. Results

4.1. Primary glass groups

The analytical data (Table S1) show that the majority of the Visigothic glasses can be attributed to four of the primary glass production groups established in the literature as discussed above (Table 1, Fig. 3), namely Apollonia-type Levantine I, Foy 2.1, Foy 2.1 high Fe and Magby. All but the Magby group represent natron-type glasses. Two further identified groups are not primary glasses in the strict sense, but the result of recycling: ***série Foy 2.2*** (Foy et al., 2003) belongs to the Egyptian Foy 2 family, the other is a heterogeneous mix of different primary glasses. Two samples from El Pelícano with high titanium, manganese and iron and low lime are consistent with HIMTa characteristics, while one sample from Gózquez (GO 023) may be related to Levantine II, having the lowest soda and highest silica contents. Only two individual samples cannot be attributed to any of the known groups and have been considered as outliers (Table S1). These samples are not discussed further.

The samples categorised as Levantine I have relatively high CaO (9.2%) and Al_2O_3 (3%), moderate levels of Na_2O (15%), K_2O and MgO (0.65%), low concentrations of TiO_2 (< 0.11%) and Zr (41 ppm), and manganese at natural contamination levels (< 250 ppm). The members of the Foy 2 family, including Foy 2.1, Foy 2.1 high Fe and Magby, have consistently higher trace and rare earth elements than the Levantine I glasses, as well as higher soda, potash, magnesia and iron concentrations (Fig. 3a and b). Lime and alumina are lower except for the Magby group (CaO ≈ 9.3%) (Table 1). The differentiation between Foy 2.1 and Levantine I is not always straightforward based on the absolute values of trace elements alone, due to a varying degree of recycling evident in the two groups (see below). Although titanium contents of Foy 2.1 tend to be higher (> 660 ppm), this cut-off is somewhat arbitrary (Fig. 3a). Instead, TiO_2/Al_2O_3 ratios present a more reliable discriminant, with a cut-off for Foy 2.1 at $TiO_2/Al_2O_3 > 0.048$. Foy 2.1 as defined here has a mean TiO_2/Al_2O_3 ratio of 0.056, as compared to 0.027 of the Levantine I group (Fig. 3c). Manganese is commonly understood as a typical feature of Foy 2.1 and ranges from about 0.2% to nearly 2%. Despite the high variability it is usually present at levels exceeding those naturally contained in silica sources (> 250 ppm). Foy 2.1 high Fe has even higher major, minor and trace elements than Foy 2.1, but lower CaO (≈7.6%). The main distinguishing features of this sub-type are high Fe_2O_3 (> 1.5%) (Fig. 3b) and a negative Ce anomaly (Fig. 3d). Similar characteristics have previously been observed with respect to the high iron variant of the HIMT group (HIMTb) (De Juan Ares et al., 2018b; Freestone et al., 2018). In the case of Foy 2.1 high Fe, however, iron does not appear to be correlated either with alumina (Fig. 3b) or titanium, suggesting that iron was at least partially derived from an additional component other than the silica source. Since iron broadly

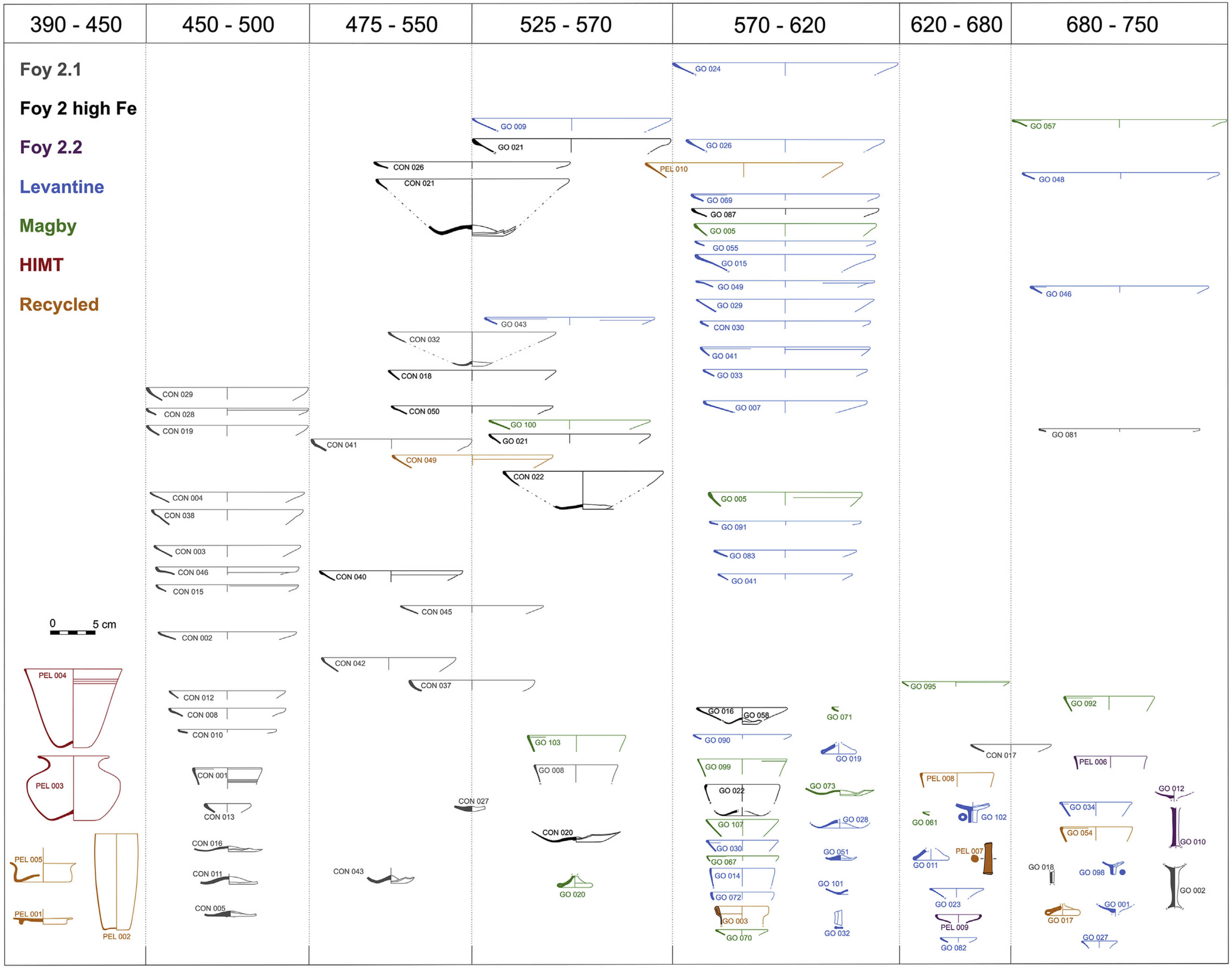

Fig. 2. Timeline of the different typologies encountered in this study. Drawings of objects from all three sites, Gózquez (GO), Congosto (CON) and El Pelícano (PEL) are colour-coded according to their chemical attribution to primary production groups (Table S1).

Table 1
Average compositions and standard deviations (SD) of the identified glass groups. Major and minor elements (as wt% oxides), strontium and zirconium [ppm] concentrations are given for the four main primary production groups (white) as well as the three recycled groups (grey).

	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Sr [ppm]	Zr [ppm]
Levantine (n=55)	**15.1**	**0.65**	**3.09**	**69.6**	**0.10**	**0.83**	**0.65**	**9.18**	**0.08**	**0.02**	**0.51**	**439**	**41.0**
SD	0.9	0.10	0.15	1.6	0.05	0.10	0.21	1.15	0.01	0.00	0.09	64	5.2
Foy 2.1 (n=43)	**17.1**	**1.13**	**2.47**	**66.3**	**0.15**	**0.82**	**0.77**	**8.58**	**0.14**	**1.31**	**0.94**	**654**	**75.2**
SD	1.0	0.12	0.16	1.0	0.05	0.06	0.17	0.69	0.01	0.48	0.14	76	8.0
Foy 2.1 high Fe (n=19)	**17.9**	**1.29**	**2.76**	**64.6**	**0.23**	**0.81**	**0.90**	**7.66**	**0.18**	**1.12**	**2.27**	**618**	**93.7**
SD	0.9	0.11	0.20	0.8	0.03	0.07	0.13	0.56	0.02	0.34	0.54	60	11.8
Magby (n=25)	**16.1**	**1.90**	**2.03**	**64.8**	**0.38**	**0.66**	**1.48**	**9.29**	**0.16**	**1.53**	**1.37**	**795**	**84.8**
SD	1.0	0.20	0.35	1.5	0.07	0.13	0.19	0.68	0.04	0.77	0.50	94	20.2
Foy 2.2 (n=5)	**16.1**	**0.79**	**2.74**	**68.4**	**0.14**	**0.76**	**0.94**	**7.79**	**0.13**	**0.65**	**0.96**	**483**	**68.9**
SD	0.6	0.06	0.16	0.4	0.02	0.16	0.13	0.27	0.02	0.04	0.15	12	11.1
recycled Lev (n=7)	**15.6**	**0.88**	**2.92**	**68.2**	**0.14**	**0.81**	**0.76**	**9.21**	**0.10**	**0.41**	**0.78**	**513**	**48.9**
SD	0.3	0.15	0.14	0.7	0.03	0.15	0.18	0.33	0.01	0.28	0.18	58	4.6
recycled (n=10)	**16.6**	**0.80**	**2.52**	**69.1**	**0.11**	**0.84**	**0.76**	**7.65**	**0.11**	**0.46**	**0.70**	**471**	**62.8**
SD	1.5	0.18	0.30	1.1	0.04	0.12	0.19	1.15	0.03	0.32	0.12	55	20.9

correlates with manganese, this source may have been material from manganiferous deposits that was added to a base glass to modify the colour as appears to have been the case with HIMT glasses (Freestone et al., 2018). In contrast to the Byzantine glass weights that express a deep olive green (Schibille et al., 2016), the colours of the Visigothic Foy 2.1 high Fe glasses are more variable, ranging from colourless to a deep olive green (Table S1).

The juxtaposition of the average base glass compositions (Table 1) confirms the identification of the Magby group as a distinct primary glass that, judging from the elevated magnesium (Fig. 3a), potassium, phosphorus and calcium oxides, contains a plant ash component. While it has on average lower Al_2O_3 ($\approx$2%), the other silica-related trace and rare earth elements express patterns very similar to Foy 2.1 (Fig. 3d). Its general compositional spread, reflected also in relatively high standard deviations (SD) for the heavier elements, suggests that Magby is not a homogenous group, which warrants a sub-division into low and high manganese types following the proposal by Freestone and colleagues (Freestone et al., 2008) with a cut-off at 1% MnO. In the samples with higher manganese (MnO > 1%), there is also an increase in magnesium, aluminium, iron and all trace elements, particularly strontium and barium, whereas sodium, lime and chlorine decrease compared to the low manganese Magby sub-group (Table S3).

4.2. Recycling practices

As has been extensively demonstrated elsewhere (e.g. Barfod et al., 2018; Cholakova and Rehren, 2018; Freestone, 2015; Paynter, 2008), certain compositional characteristics are reflective of recycling

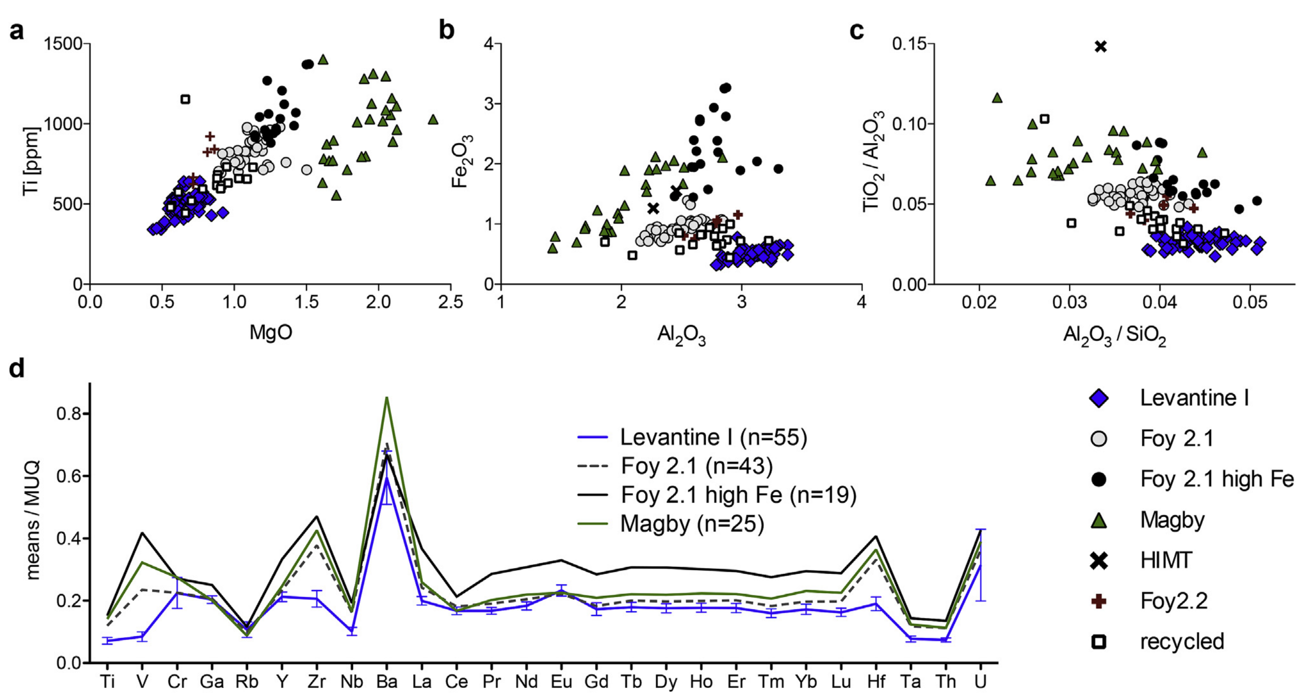

Fig. 3. Base glass characteristics of the Visigothic glasses from Spain. (a) Titanium and magnesium oxide levels separate the main glass groups and single out the Magby glasses that contain a plant ash component; (b) iron and aluminium oxide contents distinguish different silica sources and a different recipe for Foy 2.1 high Fe; (c) TiO_2 to Al_2O_3 ratios versus Al_2O_3 to SiO_2 ratios characterise the heavy mineral component, feldspar and quartz contents of the silica source; (d) mean trace element signature of the main primary production groups from Visigothic Spain normalised to the average upper continental crust (MUQ, Kamber et al., 2005).

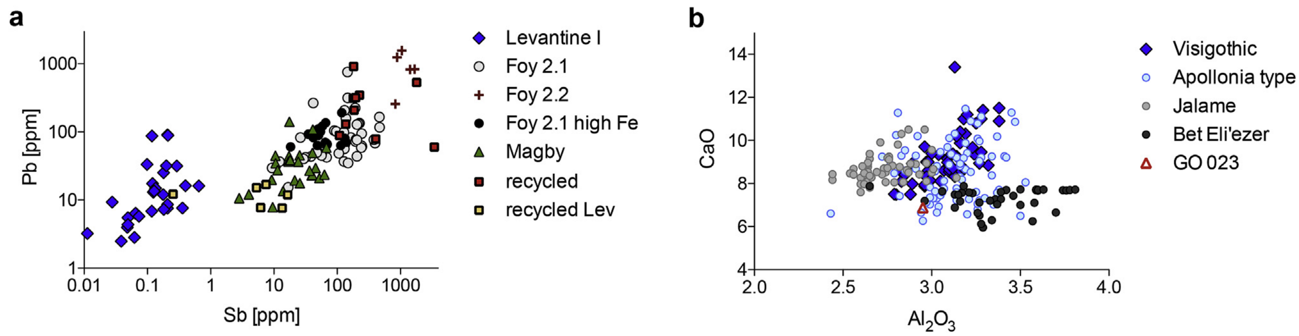

Fig. 4. Recycling practices and sub-type attribution. (a) Sb versus Pb levels indicate different degrees of recycling among the glass groups. Note that not all Levantine samples are shown due to Sb levels below the detection limit of 0.005 ppm; (b) comparison of the Levantine I group with a selection of published data for Levantine glasses (Apollonia, Dor and Bet Eli'ezer from (Freestone et al., 2000; Freestone et al., 2015; Phelps et al., 2016); Jalame from (Brill, 1999)) show chronological changes in the Al_2O_3 and CaO levels.

processes. These include mixing effects of different primary glass compositions, elevated levels of elements related to fuel ash and/or glass working tools, a potential loss of volatile components, and above all an increase in colouring, de-colouring and opacifying agents accidently introduced into the recycling batch. Antimony, for instance, is an effective indicator for mixing and recycling, because it is usually present at negligible levels in silica sources (Sb < 1.4 ppm, Degryse, 2014). A comparison of the antimony and lead concentrations of the Visigothic glasses (Fig. 4a) accordingly highlights varying degrees of recycling. Conspicuous are the very low Sb contents of the Levantine I group (Sb < 1 ppm). In contrast, Foy 2.2 has the highest levels of Sb (> 800 ppm) as well as other colouring elements (Cu, Sn, Pb; Table S1). It is otherwise compositionally closely related to Foy 2.1 and seems to be a recycled version of this glass type. Samples of the recycled Foy 2.2 type are known from a very limited number of assemblages in France, Italy and Spain that are typically dated to the end of the seventh and the eighth century CE (De Juan Ares et al., 2018a; Foy et al., 2003; Mirti et al., 2001). In the context of the Crypta Balbi, the positive correlation between antimony, copper and lead was thought to be the result of the recycling of opaque mosaic tesserae (Mirti et al., 2001). The copper, antimony, tin and lead concentrations in many of the samples of the Foy 2.1, Foy 2.1 high Fe and Magby groups confirm that some recycled cullet is likely to have been incorporated at some stage of the life-cycle of these glasses. The fact that raw glass chunks of the Foy 2.1 composition have been retrieved from the Visigothic *Narbonensis* workshops (Port-Vendres, Maguelone, Foy et al., 2003) demonstrates that cullet must have formed a considerable part already in the primary production process. It has been proposed that the substantial residues of antimony in the Foy 2 family might be linked to their Egyptian provenance and the greater availability of antimony decoloured glass in Egypt (Ceglia et al., 2017).

A group of 17 samples designated as recycled glass contain varying amounts of transition metals, and exhibit signs of mixing of different primary glass groups. They can be tentatively separated in two subgroups. A small set of samples (recycled Lev) with slightly elevated antimony levels has compositions very close to Levantine I glasses, except for their manganese concentrations above the natural threshold (> 250 ppm). It would thus seem that these glasses are predominantly produced from Levantine I glass with a minor contribution of either Roman manganese or Foy 2.1 type glass. The remaining recycled samples contain a greater portion of coloured or decoloured glass in the form of high antimony, lead and in most cases also copper (Table S1), and their base glass characteristics are shifted towards lower alumina and higher TiO_2/Al_2O_3 ratios compared to the Levantine I core cluster (Fig. 3). Amongst these samples might be some Roman mixed manganese and antimony recycled glasses (Table S1).

4.3. Dating of the Levantine group

Given the changes in the lime and alumina contents of glass manufactured in the Levant over time, a comparison with reference material from Jalame, Apollonia and Bet Eli'ezer can add a temporal dimension to the Levantine I samples studied here. The Visigothic Levantine I group is largely congruent with the sixth- to seventh-century Apollonia-type glasses in terms of lime and alumina, and less so with the fourth-century glass from Jalame (Fig. 4b). The compositional match of the majority of Levantine I glasses with the Apollonia primary production group is in agreement with the sixth- to seventh-century archaeological date of the assemblages. Some of the recycled Levantine glasses seem to correspond more closely to a Jalame-like base glass, which could also explain the elevated levels of manganese in this group (Table S1). Among these are some of the earliest samples from El Pelícano, dating to the late fourth to mid-fifth century CE. One sample (GO 023) possibly represents an early case of Levantine II-type glass similar to Bet Eli'ezer, but a positive attribution is not possible at this point.

5. Discussion

5.1. Chronological developments

Variations in the relative abundance of the different groups at the three archaeological sites might be anticipated from their distinct chronologies. In accordance with the late Roman history of the site, El Pelícano (n = 10) yielded some of the earliest glass groups, including HIMTa and some Roman mixed manganese and antimony specimens. The assemblage from Congosto (n = 49), founded in the last third of the fifth century and active through to the late seventh century, is principally made up of Foy 2.1 and Foy 2.1 high Fe. In contrast, the greatest profusion of Levantine I, Magby and Foy 2.1 high Fe derived from Gózquez (n = 110) that dates to the second quarter of the sixth- and into the middle of the eighth century CE.

The frequency of the individual compositional groups over time highlights some fundamental changes in the glass supply in Visigothic Spain (Fig. 5). The first phase (390–450) precedes the Visigothic period and is represented by five samples from El Pelícano: three almost complete vessels from funerary contexts, including a dish (PEL001) made from recycled Roman antimony and manganese glass, a jar (PEL003) and a beaker (PEL004), both made from HIMT glass, as well as two beakers (PEL 002 and 005) of recycled material. This compositional spread is compatible with what is known about the circulation of glass groups on the Iberian Peninsula, where recent analyses confirmed that Egyptian HIMT dominated the market during the fourth and first half of the fifth century, while Levantine glasses are relatively rare (De Juan Ares et al., 2018b). Likewise, Egyptian Foy 2.1 is the sole primary glass identified among the samples dating to the second half of the fifth

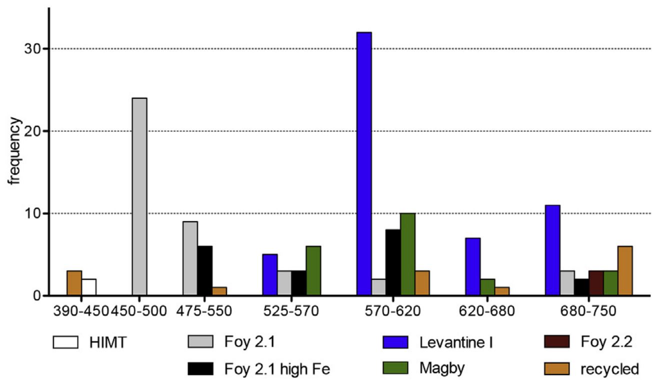

Fig. 5. Relative abundance of the identified compositional groups over time. Samples separated into seven periods of 50–70 years according to the chronology of the archaeological contexts. There are minor overlaps between phases at the end of the fifth and the beginning of the sixth century due to the limited temporal precision that cannot be fully resolved. In these cases, the samples were attributed to the later temporal bin. Samples of uncertain date and outliers are not included. The absolute sample numbers between periods are not necessarily representative of the overall quantity of vitreous finds, but this overview provides a good approximation of the relative abundance of compositional groups in each period.

century (Fig. 5, Table S1). Foy 2.1 has been mostly considered a sixth-century glass type (Cholakova and Rehren, 2018; Foy et al., 2003; Schibille et al., 2016). Our data support an earlier, late fifth-century onset of production of Foy 2.1-type glasses (Gliozzo et al., 2019).

Whereas the typology throughout the sixth century is limited to dishes, bowls and a few beakers with minor variations mostly in terms of the diameter of the dishes, the chemical make-up of the assemblage changes dramatically. Sometime in the first half of the sixth century, Foy 2.1 high Fe appears alongside Foy 2.1, while Levantine I and Magby glasses emerge on the scene slightly later. The Magby samples that are firmly dated are attributed to the second half of the sixth and the first half of the seventh century CE (Table S1). This chronological range fits well with glass identified as Saxon II (Freestone et al., 2008) and the Byzantine glass weights of this composition (Schibille et al., 2016). During the first half of the sixth century, Egyptian groups clearly still outweigh Levantine I glasses. This changes radically in the last third of the sixth century, when suddenly Levantine I makes up almost 60% of the analysed glasses (Fig. 5). Similar observations have been made with respect to the vitreous finds from the city of Recópolis, founded by the Visigothic king Leovigild in 578 CE (article in preparation), substantiating a more global trend in the supply of glass to the Iberian Peninsula. The other main glass types represented around the turn to the seventh century are mostly Foy 2.1 high Fe and Magby, while the share of Foy 2.1 decreases.

The overall volume of glass finds dwindles in the course of the seventh century, for which we have only a small number of objects dated through stratigraphy and typology (Fig. 2) (Coll Riera, 2011; Sánchez de Prado, 2018). Simultaneously, recycling practices are on the rise, implying a shortage of fresh glass and by extension disturbances in the supply from the eastern Mediterranean. It has to be stressed, however, that the Levantine glasses used throughout the Visigothic period are of a near pristine quality, which shows that the Iberian Peninsula continued to engage in overseas trade during this period. In the final stages of the Visigothic Kingdom and the first decades of Islamic period, Levantine I still dominates the glass assemblages alongside all other identified late antique glass types. One sample from Gózquez dated to 620–680 CE may be an early representative of the Umayyad Levantine II Bet Eli'ezer-type (Phelps et al., 2016). Of particular interest, however, is the growing evidence of recycling in the form of Foy 2.2 from Gózquez and El Pelícano, dating to the latter part of the seventh and early eighth century CE. This chronological attribution confirms the dating of other Foy 2.2 glasses identified among assemblages from early Islamic Spain (De Juan Ares et al., 2018a), French contexts related to the Umayyad attacks of Narbonne (Foy et al., 2003), and the Crypta Balbi in Italy (Mirti et al., 2000; Mirti et al., 2001). Some degree of recycling is evident also in the Foy 2.1, Foy 2.1 high Fe and Magby glasses that were employed in connection with distinctly seventh- and eighth-century vessel types such as solid-stem goblets (Table S1, Fig. 4a).

The diversity of compositional groups and degree of recycling in any one period seem to be reciprocally related. This effect may be the result of differential import mechanisms and interregional distribution networks of raw glass and/or finished products. A limited number of compositional groups suggest a greater influx of one particular type of raw glass and centralised control of interregional exchange. In contrast, when several groups converge at the same time, the flow of large quantities of fresh raw glass had likely receded, leading to a diversification of supplies and intensification of recycling practices (Fig. 5). In any case, the chronological distribution patterns over time are consistent with what is known about the circulation of glass groups from other regions around the Mediterranean.

5.2. Glass groups and trade networks

The archaeological perception of the Visigothic economy to date is overwhelmingly focused on ceramics (e.g. Reynolds, 2010) and, to a lesser extent, on numismatic evidence (Marot, 2000). The close analysis of archaeological glasses can shed new light on the issue, by yielding explicit information concerning the production and provenance of raw glass and its circulation within the western Mediterranean and in Visigothic Spain. The documentary evidence for the post-Roman economy in the Iberian Peninsula is extremely meagre. There are some legal provisions for international maritime trade in the Liber Iudiciorum (11.3) which mentions *transmarini negotiatores* but there is no certainty as to whether they were fiscal or commercial agents. It seems that international trade would be subject to strict control, governed by its own rules in the main port cities of the kingdom (D'Ors i Pérez-Peix, 1958; García Moreno, 1972). Textual and epigraphic sources testify to the presence of Greek and Syrian merchants who occasionally acquired a prestigious position within Hispanic society (García Moreno, 1972; Mariezkurrena, 1999), but they seldom give details about the nature of the trade goods or from whence they came. Similarly, written sources remain silent on the question of the ports of entry for primary glass from the eastern Mediterranean that fed Visigothic workshops. Even so, analytical studies have revealed the presence of raw glass chunks of Levantine and Egyptian origin in several locations of Visigothic *Narbonensis* (Foy et al., 2003) as well as in Alicante. Secondary glass workshops are known particularly from coastal centres such as Cartagena, Alicante, Barcelona and Tarragona, but also from sites further inland such as Recópolis, Tolmo de Minateda and Toledo (De Juan Ares and Schibille, 2017b). Much of the exchange and redistribution of resources was most likely controlled by the state, secular elites and wealthy institutions such as the church with privileged access to imported raw glass and the necessary capacity to develop the technology.

The wider political and economic implications of the chronological and geographical changes in the supply of the varied glass groups is more difficult to assess. The cause of the transition from HIMT to new Egyptian types such as Foy 3.2 followed by Foy 2.1 remains unclear. The end of HIMT, which had dominated the glass market for more than a century, coincides with the settlement of the Visigoths in Hispania, the Germanic invasions of Italy and especially the fall of Carthage to the Vandals in 439. This may be significant, because much eastern Mediterranean glass may have found its way to the Iberian Peninsula via the port of Carthage (De Juan Ares et al., 2018b). The dominance of Egyptian glasses waned in favour of Levantine productions towards the middle of the sixth century perhaps as a direct consequence of new overseas trade networks in the time of Justinian. The causes are unclear, but after Justinian's reconquest of Carthage in 533, the trading axis between Africa and the Byzantine capital was strengthened once more, which might very well have affected exchange patterns more generally. The sudden appearance of Magby in the sixth century, a plant ash member of the Foy 2 family, might in turn be related to ongoing political and religious conflicts in Egypt at the time (Haas, 2006; Shortland et al., 2006). Shortages in the supply of mineral soda and its substitution with plant ash cannot account for the presence of Magby glasses in numerous sixth- and early seventh-century contexts throughout the Mediterranean and Europe. Rather, the chemical characteristics in terms of the silica-related elements (Fig. 3) of the Magby type seem to reflect changes in glassmaking recipes at the level of primary production and very likely changes in the primary production location (Schibille et al., 2016). The occurrence of a (partial) plant ash glass recipe two centuries prior to universal introduction of the plant ash technology is intriguing and may hold the key to understanding the organisation and control of the primary glass industry in the eastern Mediterranean. The available data so far does not allow us to reconstruct the developments and mechanisms of this transition further, which will be an important task for future research.

A major problem for the qualitative and quantitative assessment of the medieval glass economy is that the archaeological and analytical evidence is restricted in geographical and chronological scope. For instance, there is a shortage of analytical data of glasses securely dated to the seventh and eighth centuries, a period of utmost importance for understanding the transformations in glass production patterns. From the present data it is clear that some Levantine glasses still arrived in central Spain at least during the early parts of the seventh century. The Persian invasion of Palestine, followed by the Arab conquests of the Levant, Egypt and North Africa in the seventh century do not seem to have had a direct effect on the primary glass industries in the eastern Mediterranean (Phelps et al., 2016). New compositional types are attributed to the eighth century, both in the Levant (Levantine II; Phelps et al., 2016) as well as in Egypt (Egypt I and II; Schibille et al., 2019). These glasses were not greatly exported to overseas markets, with the exception of some Egyptian glasses found in the adjacent Levant. Isolated samples of these explicitly eighth-century glasses have been identified among Italian, French and Spanish assemblages, but they remain the exception. The resurgence of significant eastern imports of early Islamic plant ash glasses to the Iberian Peninsula possibly as early as the ninth, but certainly in the tenth century as evidenced by the glass finds from Vascos (De Juan Ares and Schibille, 2017a) is interesting in this context. It thus appears that the circulation of glass was in part subject to exchange networks sustained by the state. What seems to have changed, however, is the use of glass in society. In Visigothic Spain, glass had been an everyday commodity that was found even in relatively modest archaeological contexts. During the Islamic period, glass was progressively transformed into a luxury item, less frequent and mostly reserved for the elites (De Juan Ares and Schibille, 2018; De Juan Ares et al., 2018c).

6. Conclusion

Our trace element analysis of vitreous materials from Visigothic Spain has established the main geographical and chronological trends in the supply of glass to the Iberian Peninsula from the fifth to the eighth century CE. Eastern imports continued throughout the Visigothic period covering the crucial transitions towards new glass technologies and towards a medieval Mediterranean economy. The Levantine and Egyptian glass industries do not appear to have been immediately affected by political upheavals and the Arab conquest of the region, and they were able to sustain the production and distribution of glass on an industrial scale. However, our analytical data emphasise a shift in glass supplies, first coming from Egypt, then from the Levantine coast. The dominance of Levantine productions within the overseas exchange system starting around the middle of the sixth century may not be exclusive to the glass industry and is likely to be representative of the Visigothic economy more broadly. None of the early Umayyad natron-type glasses such as Egypt I or Levantine II were unequivocally identified. Instead, much of the late seventh- and early eighth-century glass exhibits clear signs of recycling. The Levantine I glasses, in contrast, remain pristine until the end of the period. These findings imply the co-existence of a central and well-organised recycling system at the level of the secondary glass workshops in Visigothic Spain alongside close trade links with the eastern Mediterranean.

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Declaration of interests

The authors declare that they have no competing interests.

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Appendix A. Supplementary data

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