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THE SUPPLY OF GLASS AT *PORTUS ILICITANUS* (ALICANTE, SPAIN): A META-ANALYSIS OF HIMT GLASSES*

J. DE JUAN ARES

IRAMAT-CEB, UMR 5060, CNRS, Orléans, France

N. SCHIBILLE†

IRAMAT-CEB, UMR 5060, CNRS, Orléans, France

J. MOLINA VIDAL

Universidad de Alicante, Spain

and M. D. SÁNCHEZ DE PRADO

Universidad de Alicante, Spain

Portus Ilicitanus (Picola, Alicante) was the main sea harbour of the Roman Colonia Iulia Ilici Augusta and as such played a crucial role in the supply of fundamental commodities to the Iberian Peninsula. Excavations yielded large quantities of glass in fourth- and early fifth-century contexts. Elemental analysis of 60 samples by laser ablation – inductively coupled plasma – mass spectrometry (LA–ICP–MS) confirmed that the glasses were imported from the Eastern Mediterranean. A majority of the glasses correspond to the HIMTa primary production group, which originates from Egypt. The statistical evaluation of published data of 589 HIMT glasses further revealed differential distribution patterns of the HIMTa and HIMTb subtypes between the Eastern and Western Mediterranean, suggesting chronological trends that are linked to wider geopolitical changes. This demonstrates the need for systematic large-scale approaches to identify supply patterns and possible factors underlying geographical differences and/or chronological developments.

KEYWORDS: HIMTA AND B GLASS, LATE ROMAN SPAIN, JALAME, TRADE, LA–ICP–MS, MEDITERRANEAN, META-ANALYSIS

INTRODUCTION

Recent archaeological and analytical evidence of glass assemblages from the Mediterranean region and Europe supports a centralized model of production and circulation of glass during the Roman and early medieval periods (Nenna *et al*. 1997; Freestone *et al*. 2002). According to this model, the vast majority of raw glass was produced on an industrial scale in Egypt and the Levant and then circulated to secondary glass workshops all over the Mediterranean (Foy *et al*. 2000a,b; Gorin-Rosen 2000; Nenna *et al*. 2000; Freestone *et al*. 2002). Distinct compositional groups, differing in date and origin, have now been established and are well

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†Corresponding author: email nadine.schibille@cnrs-orleans.fr

characterized (Gratuze and Barrandon 1990; Freestone 1994; Freestone *et al*. 2000; Foy *et al*. 2003b,b; Tal *et al*. 2004; Phelps *et al*. 2016; Schibille *et al*. 2017b). Less is known about the spatio-temporal distribution patterns of these glass groups because of the uneven spread of the evidence. A major gap in glass studies, for example, consists in a near-complete lack of reliable analytical data from the Iberian Peninsula (De Juan and Schibille 2017a). Iberia, with its well-documented exchange across the Roman Empire, provides a fertile ground for the investigation of glass as a proxy to re-evaluate economic connections and possible trade routes. In addition, by exploring what type of base glasses are represented in the archaeological record of Roman Spain, it will be possible to shed further light on the ongoing debate about the possible existence of non-identified primary glass-making centres in the Western Mediterranean (Degryse *et al*. 2014).

To address these issues, we have examined the typological and compositional characteristics of a significant collection of late Roman glasses from Picola – *Portus Ilicitanus* in Santa Pola (Alicante) on the east coast of Spain (Ibarra 1879; Molina 2005). Founded probably sometime in the fifth century BCE, Picola experienced an important urban development during the Roman period, particularly with the establishment of the *Portus Ilicitanus,* the main sea harbour of the Roman *Colonia Iulia Ilici Augusta*, around the year 27 BCE (Molina 2005). Substantial refurbishments and the construction of new buildings related to the commercial activities of the harbour in the second century CE were followed by a last phase of occupation that began in the second half of the fourth century. Previous structures were demolished to make way for a fish factory, specializing in the processing and commercialization of fish sub-products such as *garum* (Molina 2012). The factory comprised commercial as well as production areas, including furnaces and cisterns. The activities appear to have ceased in the first half of the fifth century, when the *Portus Ilicitanus* was abandoned. The study of the ceramic finds shows close commercial links with other regions of the empire, particularly with Carthage (large amounts of ARS ware), Africa *Tripolitana*, Italy, southern Gaul and other Hispanic sites. Imports from the Eastern Mediterranean, such as late Roman C, D or E ceramics, are far less common (Márquez 1999; Frías and Llidó 2005; Frías *et al*. 2007). As a major harbour city and producer of fundamental Roman commodities, Picola was evidently a central part within the wider commercial system of the late Roman Empire.

Excavations conducted at Picola by the Museo del Mar de Santa Pola, the CNRS and the museum and the University of Alicante since 1987 have yielded a considerable number of glass artefacts, particularly from the last phase of occupation (Molina 2012). All the glass samples selected and analysed for the present study stem from these late Roman contexts. They can thus be dated with relative certainty to between the late fourth and the end of the fifth century CE. Even though, from a typological point of view, the materials do not seem to postdate the first half of the fifth century, there are a few samples for which a date in the first decades of the sixth century cannot be ruled out (Table S1). Hence, our new analytical data address the supply of late Roman glass to the Iberian Peninsula at the time when glass compositions diversified (De Juan and Schibille 2017a,b). To resolve the networks of exchange, we compared the analytical results from Picola with the compositional data of contemporary glass assemblages. This concerns particularly HIMT (high-iron, -manganese and -titanium) glass, which dominates the archaeological record of the western provinces during the fourth and fifth centuries (Foy *et al*. 2003b; Ceglia *et al*. 2015, 2017; Freestone *et al*. 2018). Building on recent advances on the characterization and the geographical dissemination of this particular glass type, most notably by Nenna (2014) and Freestone *et al*. (2018), we propose a refined chronology and distribution pattern of the two main known subgroups, HIMTa and HIMTb (Ceglia *et al*. 2015, 2017).

MATERIALS AND METHODS

The archaeological context and the glass samples

Samples were chosen from the vitreous material in the Museo del Mar de Santa Pola (Alicante). The samples were taken from different artefacts that have previously been studied typologically (Sánchez 2009, 2016). The glasses are mostly yellowish-green, with some colourless, bluish or amber samples. The majority of the objects belong to common functional types, typical of fourth- and fifth-century tableware. On the whole, undecorated drinking vessels prevail, making up almost half of the entire assemblage (Table S1 and Fig. 1). For analysis, glass fragments from late antique contexts were grouped to establish the minimum number of vessels (Orton *et al*. 1993). Sixty samples were selected to include all individual vessels identified from each archaeological context while avoiding duplicate sampling of the same artefact (Fig. 1). When two colours were present in the glass vessel, each colour was sampled and evaluated separately, as in the case of the colourless beakers with blue decorations. As already mentioned, the samples are attributed to the fourth- to fifth-century deposits of the fish factory and originate mostly from a rubbish heap dated to shortly before its abandonment in the second half of the fifth century (Table S1).

Analytical method

The glass samples were mounted in resin blocks and polished and analysed by LA–ICP–MS analysis at IRAMAT-CEB in Orléans (for the detailed analytical protocol, see Gratuze 2014, 2016; Schibille *et al*. 2016). The Resonetic UV 193 nm Excimer laser microprobe was operated at 5 mJ, a frequency of 10 Hz and a spot size diameter of 100 μm. The analytical time was set at 30 s, following a 20 s pre-ablation time and measuring 58 elements, which were converted into quantitative results using an internal standard and a set of international glass standards (NIST SRM610, Corning B, C and D) as well as an archaeological glass of known composition (ALP1) for the determination of chlorine (Gratuze 1999, 2014). In order to determine the accuracy and precision of the analyses, NIST SRM612 and Corning A were repeatedly run alongside the archaeological specimens (Table S2).

Statistical data analysis

In order to differentiate the two subgroups of the HIMT glass family (HIMTa and HIMTb) and to define their compositional characteristics and geographical distribution, we collated the published data of 589 HIMT samples from more than 97 sites around the Mediterranean basin as well as from Central and Northern Europe (including Picola). The iron-to-titanium-oxide ratios (Fe_2O_3/TiO_2) of all the gathered data points ($n_{\text{total}} = 589$) were distributed in 51 bins of a width of 0.2, and show a bimodal distribution. The experimental data were fitted with two normal distributions of equal width σ:

$$n_1\mathcal{N}\left(\mu_1, \sigma^2\right) + n_2\mathcal{N}\left(\mu_2, \sigma^2\right), \quad \text{with } n_1 + n_2 = n_{\text{total}} = 589;$$

using χ^2 minimization and assuming that errors are Poisson distributed. The following parameters were extracted: $n_1 = 511$, $n_2 = 78$, $\mu_1 = 3.75$, $\mu_2 = 6.25$, $\sigma = 0.70$, yielding $\chi^2 = 53.9$; DOF (degrees of freedom) = 51 − 4 = 47; χ^2/DOF = 53.9/47 ≈ 1.15.

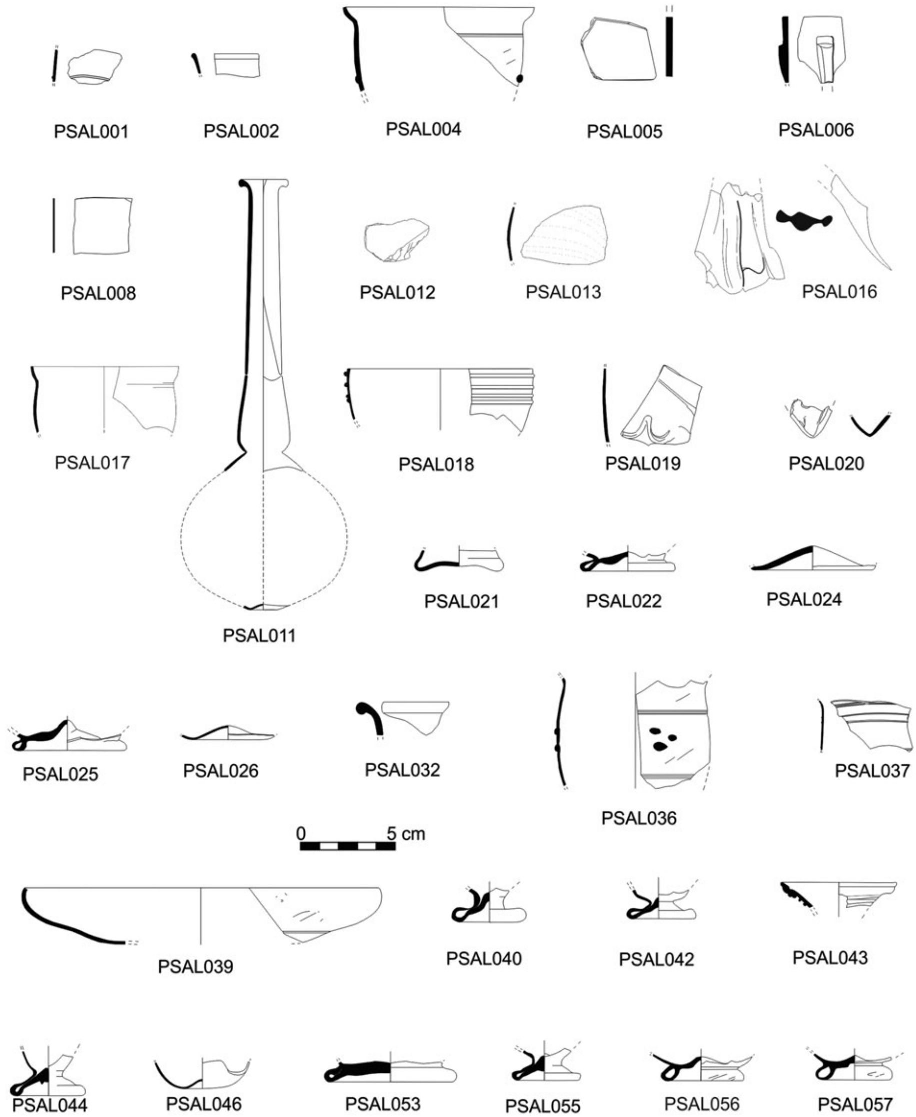

Figure 1 *Selection of glass vessels from Picola – Portus Ilicitanus analysed in this study.*

RESULTS AND DISCUSSION

Compositional groups

As might be expected from the chronology of the site, the compositional characteristics of all the glasses analysed from Picola – *Portus Ilicitanus* are consistent with natron-type glass of the late Roman tradition. The assemblage as a whole can be separated into two main groups that were made from different silica sources, as reflected, for instance, in the varying aluminium, calcium, iron and titanium oxide contents as well as differing rare earth elements (REE) (Fig. 2).

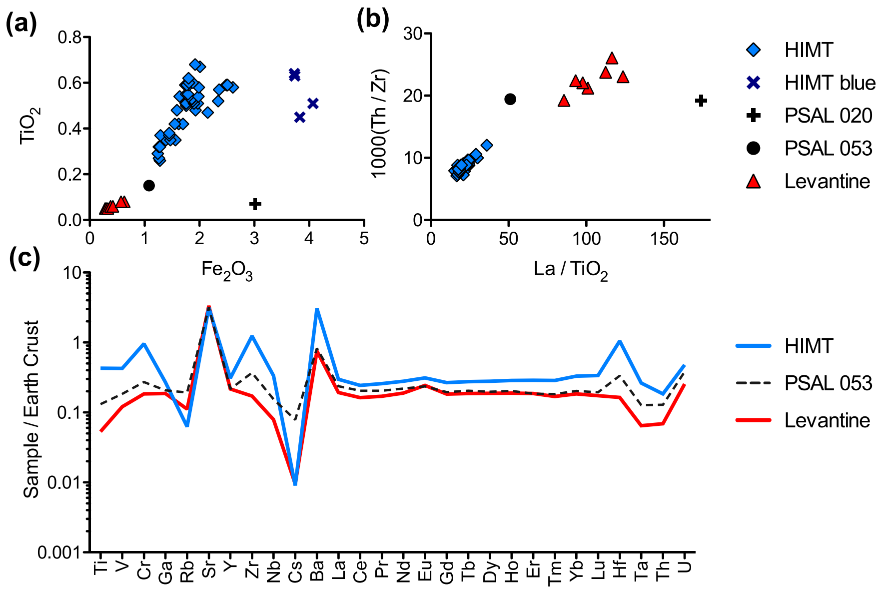

Figure 2 *Base glass compositions of the glasses from Picola – Portus Ilicitanus. (a) Differences in TiO_2 and Fe_2O_3 identify glass groups. Both elements occur in higher concentrations in HIMT glasses. Iron is even more elevated in the cobalt-coloured samples, reflecting the use of an iron-rich cobalt source. (b) Differences in Th/Zr (in units of 0.001) and La/TiO_2 ratios confirm the use of different silica sources. (c) Average trace element patterns of the different glass groups normalized to the mean values in the upper continental crust (Kamber et al. 2005). [Colour figure can be viewed at wileyonlinelibrary.com]*

The largest group ($n = 51$) has elevated iron, titanium, zirconium and manganese contents, and corresponds to the HIMT group (Freestone 1994) or Foy's 'série 1' (Foy *et al*. 2003b) and HIMT 1 (Foster and Jackson 2009). These glasses can be clearly isolated from the other compositional groups by their titanium-to-iron ratios (Fig. 2 (a)) and their titanium and zirconium concentrations in relation to lanthanum and thorium, respectively (Fig. 2 (b); Freestone *et al*. 2018). These geochemical characteristics suggest an Egyptian origin (Freestone *et al*. 2002, 2003, 2009; Foy *et al*. 2003b; Nenna 2014). The higher soda levels of HIMT as compared to Levantine glasses have been attributed to the closer proximity of its primary production centres to the Egyptian natron sources (Freestone *et al*. 2005; Nenna 2014). HIMT glasses can be further divided into subcategories HIMTa and HIMTb based on their varying Fe_2O_3/TiO_2 and Fe_2O_3/Al_2O_3 ratios (Ceglia *et al*. 2015, 2017) as well as different barium, cerium and europium patterns (Freestone *et al*. 2018) (Figs 3 (a) and 3 (b)). According to this subdivision, the glasses from Picola – *Portus Ilicitanus* are clearly consistent with HIMTa, with the apparent exception of the cobalt-coloured samples (Fig. 3 (a)). The elevated iron of the blue glasses, however, is linked to the cobalt source, which skews their profile towards the HIMTb group (details below). The HIMT glass family was widespread during the fourth and fifth centuries and has been identified amongst assemblages throughout the Mediterranean [e.g., Albania, Bulgaria, Cyprus, Egypt, France, Italy, Tunisia and the United Kingdom (UK)], with the exception of Syria–Palestine, where it is very scarce (Foy *et al*. 2003b; Foster and Jackson 2009; Nenna 2014; Ceglia *et al*. 2015; Freestone *et al*. 2018). On the Iberian Peninsula, HIMT has likewise been found in fourth- and fifth-century

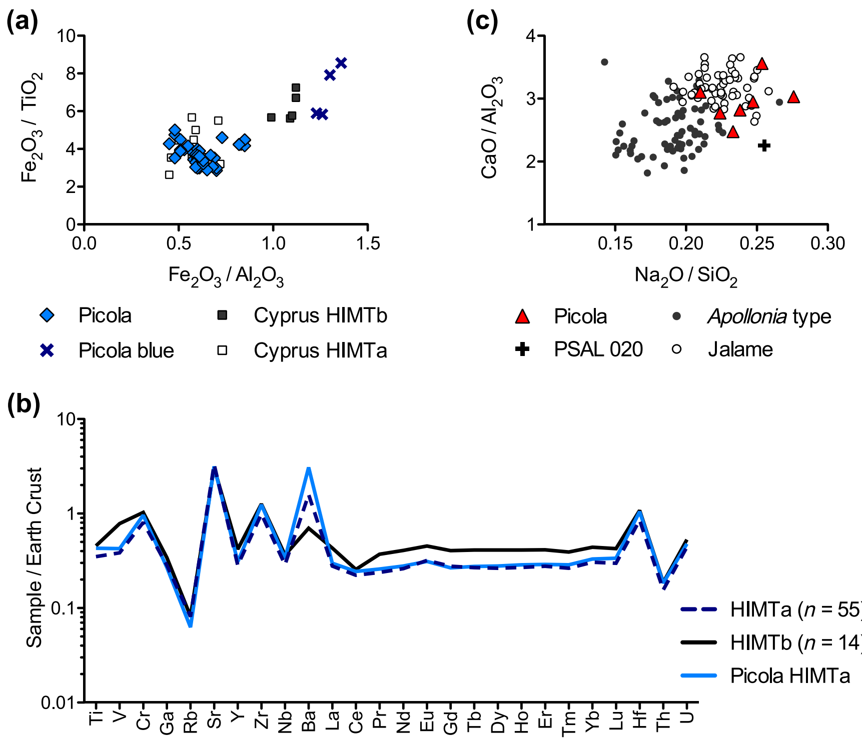

Figure 3 *A comparison of the glass groups from Picola – Portus Ilicitanus with published data. (a) The Fe_2O_3 to TiO_2 and Fe_2O_3 to Al_2O_3 ratios of the HIMT samples from Picola compared to the HIMTa and HIMTb subtypes as defined by Ceglia et al. (2015). (b) Average trace element patterns of HIMTa and HIMTb glasses (Ceglia et al. 2017; Freestone et al. 2018; and unpublished data from Labraunda, Turkey) normalized to the upper continental crust (Kamber et al. 2005) compared to the average trace elements of the HIMTa samples from Picola. (c) The CaO/Al_2O_3 and Na_2O/SiO_2 ratios of the Levantine samples from Picola compared to well-dated assemblages from fourth-century Jalame (Brill 1988) and sixth- to seventh-century Apollonia-type glasses (Phelps et al. 2016) suggest a late Roman date. [Colour figure can be viewed at wileyonlinelibrary.com]*

contexts in Portugal, Galicia, Alicante, Catalonia, Extremadura, Madrid, Cuenca, Valencia, Murcia, Leon and Seville (De Juan and Schibille 2017a,b and references therein).

A small set of samples ($n = 7$) exhibits compositional features commonly associated with glass produced on the Levantine coast, having substantially lower REE and heavy elements and higher alumina and lime levels (Brill 1988; Freestone *et al*. 2000; Foy *et al*. 2003b; Tal *et al*. 2004; Foster and Jackson 2009; Maltoni *et al*. 2016; Schibille *et al*. 2016) (Fig. 2). A chronological differentiation of the glasses produced on the Levantine coast has been proposed elsewhere (Phelps *et al*. 2016; Schibille *et al*. 2016, 2017b) and it seems that Iberian glass assemblages adhere to the same compositional developments. Whereas the later *Apollonia*-type Levantine I category, for example, dominates the sixth- to eighth-century assemblage from *Recópolis* (Schibille et al. 2017a), the Levantine finds from Picola – *Portus Ilicitanus* correspond more closely to Roman manganese decoloured glass or fourth-century glass from Jalame (Fig. 3 (c)). The manganese levels are highly variable, however, ranging from virtually absent to over 1% MnO (Table S1). An early date is corroborated in some cases by the typology of the vessels. Sample PSAL006, for instance, is a moulded bluish glass bowl with a clear Roman Isings 3 typology (Isings 1957; Paz and Ortiz 2004; Sánchez 2016) (Table S1 and Fig. 1).

Two samples do not match either of the two main groups. Sample PSAL020, with relatively low levels of titanium, zirconium and strontium but intermediate lime and high iron concentrations, is a clear outlier that cannot be easily explained, while sample PSAL053 is probably a mixture of Roman antimony and manganese decoloured glasses (Table S1 and Fig. 2). Judging from the elevated contents of secondary additives such as antimony, cobalt, copper, zinc and lead, many of the glasses from Picola have undergone some form of mixing and recycling (Table S1). These elements are not linked to the silica or alkali sources but are generally associated with recycling (Vichy *et al*. 2007; Freestone 2015; Jackson and Paynter 2016; Schibille *et al*. 2016, 2017b; Ceglia *et al*. 2017).

Cobalt as a deliberate colourant was detected in the applied decorations of four hemispherical drinking glasses (Isings 96/Foy 13) (Isings 1957; Foy 1995; Sánchez 2009). Cobalt colourants tend to introduce only a limited number of impurities, which during the Roman period pertain mostly to iron, copper and lead (Gratuze *et al*. 2018). The ratios between iron and cobalt in the cobalt colourants calculated by subtracting the iron content of the vessel body from the iron content of the cobalt blue drops ($6 < Fe_2O_3/CoO < 11$) are consistent with the ratios of iron to cobalt typically encountered in Roman glasses (median of 7.6; Gratuze *et al*. 2018). The base glass composition of the blue drops can thus be assumed to have been made of HIMTa glass similar to that used for the vessel body, to which a cobalt source rich in copper, lead and iron was added (Table S1 and Fig. 2 (a)). This compositional correspondence suggests that the colouring of the decorative features took place in the secondary workshops where the vessels were formed. Similar observations were made with respect to comparable vessels of HIMT glass with applied blue drops from Aquileia (Maltoni *et al*. 2016).

Typology in relation to the compositional groups

The typological range of late Roman glass assemblages from the Iberian Peninsula was more restricted than during the preceding centuries (Sánchez 2009). In Picola – *Portus Ilicitanus*, all but one sample are tableware, mostly drinking vessels, while dishes, bowls and jars, sometimes decorated with applied threads, are less abundant. Despite the limited number of samples for which the typology can be firmly established, it is possible to identify a correlation between vessel type and compositional category. Of the 51 HIMT glass fragments, 31 can be assigned to known drinking glass types. They belong to either of two broad families: hemispherical beakers of Isings 96/Foy 13 (Isings 1957; Foy 1995; Sánchez 2009) or conical beakers with a pushed-in foot of Isings 109/Foy 19 or Isings 106/Foy 14 (Isings 1957; Foy 1995; Sánchez 2009). All the hemispherical drinking glasses with blue glass drops and the vessels with applied decorative threads belong to the HIMT group. Only two jars, one pitcher, one bowl and one glass chunk could be identified among the HIMT glasses. A similar typological (Isings 96, 106, 109) and functional (wine glasses) specialization of HIMT glass has been found at other Western Mediterranean sites such as France and Carthage (Foy *et al*. 2003b; Grünewald and Hartmann 2014; Schibille *et al*. 2017b).

As regards the Levantine samples, the typology of only a small number of specimens can be determined and the conclusions we can draw are thus limited. Among the Levantine glasses are a bottle, a pitcher and a bowl, as well as a window glass fragment. One engraved sample (PSAL 039) is likewise made from Levantine glass (Table S1 and Fig. 1). There is a general macroscopic difference between Levantine and HIMT glasses in that the latter were employed for more delicate forms and, on average, thinner walls than the Levantine glasses (1.4 mm compared to 3.1 mm). A difference in thickness between Egyptian and Levantine glasses, which might in fact be related to a better workability of glass with higher soda levels, has been observed before (Foy *et al*. 2003b; Freestone *et al*. 2018).

Meta-analysis of HIMT glasses

There have been several attempts to determine the internal variability of HIMT glasses here characterized by high TiO_2 (> 0.25%), Fe_2O_3 (> 1%), MgO (> 0.8%) and Na_2O (> 16%), generally low CaO (< 7%) and variable MnO contents (Foy *et al*. 2003b; Foster and Jackson 2009; Ceglia *et al*. 2015, 2017; Freestone *et al*. 2018). Two main subgroups (HIMTa and HIMTb) have originally been recognized in the context of late antique glass assemblages from Cyprus, where HIMTb was discriminated on account of its higher iron concentrations ($Fe_2O_3 > 3\%$) (Ceglia *et al*. 2015). Freestone *et al*. (2018) have since noted that the clearest difference between HIMTa and b consists in different correlations between iron and titanium. They further observed exceptionally high barium concentrations in HIMTa, while HIMTb shows a strong negative cerium anomaly (Fig. 3 (b); Freestone *et al*. 2018).

While trace elements become increasingly important in the investigation of ancient glasses to confirm group affiliations, not many of the earlier publications report the entire range of trace and rare earth elements. The ratios of iron to titanium oxides are therefore the most useful discriminants, since the two elements are reported in essentially all analytical studies of archaeological glasses and the measurements of these elements are generally relatively accurate across different methods and laboratories. The histogram of the iron-to-titanium ratios of 589 HIMT glasses from 97 Mediterranean and European sites (including Picola) was fitted with a double Gaussian function (Fig. 4 (a)), revealing a major component with a mean ratio of $\mu_1 = 3.75$ and a minor component at $\mu_2 = 6.25$. The two curves intersect at an iron-to-titanium ratio of about 5.4, which was used to distinguish between HIMTa and HIMTb. The combined curve is in good agreement

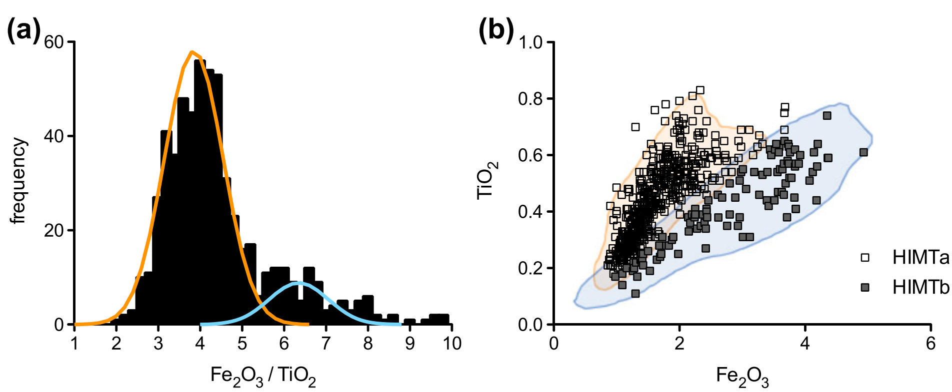

Figure 4 *A meta-analysis of 589 HIMT glasses, including the samples from Picola (for sites and references, see Figure 5). (a) The frequency distribution of the iron-to-titanium ratios was fitted with two Gaussian components (orange and blue curves), with peaks at 3.75 and 6.25 corresponding to HIMTa and HIMTb, respectively. (b) Application of the threshold of $Fe_2O_3/TiO_2 = 5.4$ to the entire data set separates the two components, which are outlined by a 95% kernel density estimation using the open-access RESET resource (Ramsey et al. 2015; https://c14.arch.ox.ac.uk/resetdb/db.php). Note the overlap of the two groups at low iron and titanium concentrations. [Colour figure can be viewed at wileyonlinelibrary.com]*

with the experimental data, as judged by a χ^2 test ($\chi^2 = 53.9$; χ^2/DOF = 53.9/47 ≈ 1.15), justifying the separation into the two subgroups. Applying the threshold of $Fe_2O_3/TiO_2 = 5.4$ to the entire data set of HIMT glasses, we find that the majority of the published data belong to HIMTa, and less than 20% to HIMTb (Fig. 4 (b)). The 95% outlines of a kernel density estimation of the two populations overlap more significantly at lower iron and titanium oxide concentrations, even though they are clearly separated at higher values. The attribution of the samples with low iron ($Fe_2O_3 < 2\%$) and low titanium (TiO2 < 0.31%) to HIMTb is therefore less certain. Whether this may, in fact, indicate the existence of another subgroup of HIMT in addition to HIMTa and HIMTb cannot be decided on the basis of the available data.

Looking at the geographical distribution patterns of HIMT glasses throughout the Mediterranean, a clear east–west divide emerges, especially with respect to the relative abundance of its subgroups (Fig. 5). HIMTa is evidently the more dominant type, particularly in the peripheral western and northern regions of the Roman Empire during the fourth and fifth centuries CE. Among a large set of HIMT glasses from the UK dating to between 350 and 410 CE, not a single

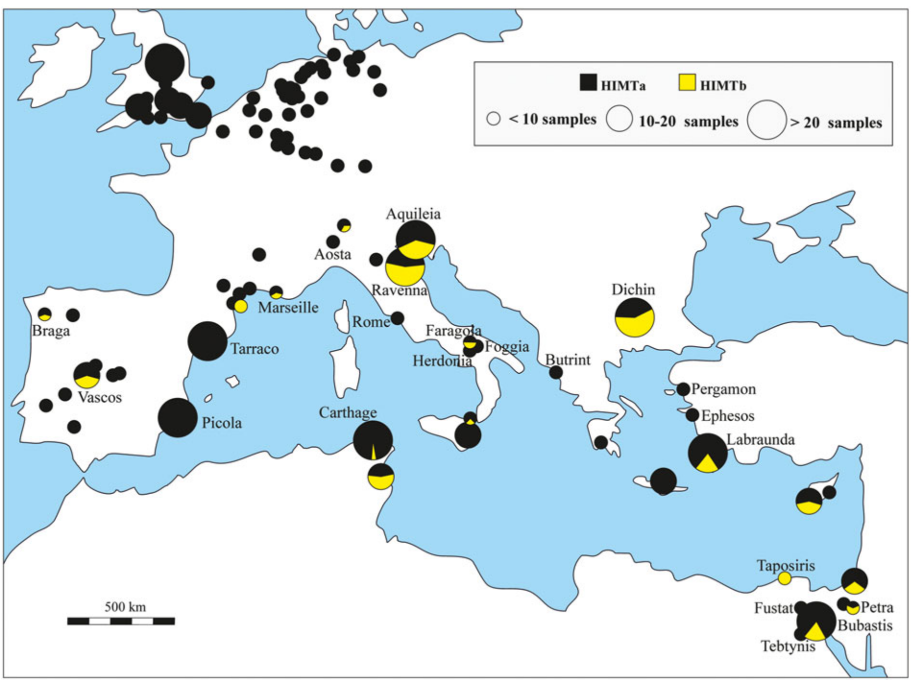

Figure 5 *A map of the relative distribution of HIMT subgroups a and b based on published data (except for samples from Labraunda, Turkey), highlighting a clear north–south and east–west divide. The threshold of $Fe_2O_3/TiO_2 = 5.4$ was applied to separate HIMTa from HIMTb, as defined in Figure 4. Given the overlap of the two groups at low iron concentrations, a second criterion was applied, whereby all samples with $Fe_2O_3 < 2\%$ were attributed to HIMTa. Data were taken from Rius et al. (1989), Mirti et al. (1993), Freestone et al. (2002, 2018), Foy et al. (2003b), Uhlir (2004), Arletti et al. (2005, 2010), Wolf et al. (2005), Blin and Vanpeene (2006), Gómez-Tubío et al. (2006), Carmona et al. (2008), Da Cruz (2009), Foster and Jackson (2009), Rehren et al. (2010), Castelo et al. (2011–12), Schibille (2011), Palomar et al. (2012), Schiavon et al. (2012), Schibille et al. (2012, 2016), Conte et al. (2014), Möncke et al. (2014), Rosenow and Rehren (2014), Agua et al. (2015), Di Bella et al. (2015), Gliozzo et al. (2015), Gliozzo et al. (2016a,b, 2017a,b), Maltoni et al. (2015, 2016), Rehren and Brüggler (2015), Jackson and Paynter (2016), Smith et al. (2016), Ceglia et al. (2017), De Juan Ares and Schibille (2017a,b) and Siu et al. (2017). [Colour figure can be viewed at wileyonlinelibrary.com]*

fragment can be attributed to the HIMTb subgroup (Foster and Jackson 2009). Likewise, none of the *Helle* bowls from north-western Germany and the Netherlands corresponds to the HIMTb composition (Rehren and Brüggler 2015). HIMTb seems to occur sporadically on the French Mediterranean coast, in Tunisia (Freestone 1994; Foy *et al*. 2003b; Blin and Vanpeene 2006), in Switzerland (Wolf *et al*. 2005) and in Sicily (Arletti *et al*. 2010; Di Bella *et al*. 2015). The HIMTb subgroup seems to be more common on the Adriatic coast of Italy. Seventeen out of 47 HIMT samples analysed from Aquileia and the late Roman harbour of Classe correspond to HIMTb (Maltoni *et al*. 2015, 2016). In the rest of Italy, in contrast, as well as at Carthage, HIMTa tends to be the dominant type (Schibille *et al*. 2017b; Siu *et al*. 2017). For example, all the HIMT glasses documented at *Augusta Praetoria* in Aosta (Mirti *et al*. 1993) and in *Herdonia*, Foggia, Faragola and Rome (Gliozzo *et al*. 2016a,b, 2017a,b), as well as several sites in Emilia Romagna (Arletti *et al*. 2005), are consistent with HIMTa characteristics (Fig. 5). The picture of the Iberian Peninsula remains unclear. HIMTb has been identified at Vascos (De Juan and Schibille 2017b) and Braga (Da Cruz 2009), while HIMTa prevails at all other Spanish sites (Gómez-Tubío *et al*. 2006; Carmona *et al*. 2008; Castelo *et al*. 2011; Palomar *et al*. 2012; Schiavon *et al*. 2012; Agua *et al*. 2015).

In the western Balkans and in Greece, HIMTb is conspicuous by its absence (Fig. 5). No HIMTb samples have been found among the published data from Slovenia (Šmit *et al*. 2013), Butrint, Albania (Conte *et al*. 2014), Crete (unpublished data) or Greece (Möncke *et al*. 2014). In Bulgaria, on the other hand, more than half of the 15 HIMT glass fragments from Dichin were of the HIMTb type (Rehren and Cholakova 2010; Smith *et al*. 2016). Only limited analytical data are available from archaeological glass assemblages from Asia Minor, where HIMT glasses seem generally in relatively short supply. No HIMTb was detected among the samples from Ephesos (Uhlir 2004) or Pergamon (Schibille 2011). However, the relative abundance of HIMTb seems to increase further south. For example, at Labraunda, close to Bodrum, about 20% of the identified HIMT glasses ($n = 34$) have the compositional characteristics of HIMTb (unpublished data) and of the 20 HIMT glasses identified in Cyprus, about a quarter belong to the HIMTb subgroup (Ceglia *et al*. 2015). In the vicinity of Egypt, from where HIMT is believed to originate, HIMTb is generally more numerous. In Petra, Jordan, about half of the HIMT glasses correspond to HIMTb (Schibille *et al*. 2012) and 6 out of 15 samples analysed from the Sinai Peninsula are probably HIMTb (Freestone *et al*. 2002), while one out of six samples analysed from Tebtynis, Taposiris and Fustat (Foy *et al*. 2003b) and 4 among the 27 samples from Bubastis are likewise of the HIMTb type (Rosenow and Rehren 2014).

Historical implications

The differences between north and south and east and west may be related to chronological differences between the two subgroups and wider historical developments that have probably impacted the supply networks. On the basis of the study of ceramic imports to the Western Mediterranean provinces, it has been claimed that diverging trade routes connected the Levant with the Aegean, and Egypt via Carthage with the Iberian coast (Reynolds 2016). If it is accepted that both HIMTa and HIMTb originated in Egypt, then our results cannot support the hypothesis of diverging trade routes (Fig. 5). The relative differences in the presence or absence of the two HIMT subgroups might instead be due to changes in the connectivity of the Mediterranean as a result of the changing geopolitical landscape towards the end of the fourth century. The assemblages from Germany, the Netherlands and the UK, where only HIMTa was found, date to the second half of the fourth and the first decades of the fifth century (Foster and Jackson 2009;

Rehren and Brüggler 2015). HIMTb seems to appear only at the beginning of the fifth century and typically either in the Eastern Mediterranean (Cyprus, Egypt) or in Ravenna, to where the imperial residence had been transferred under the emperor Honorius in 402 CE. The data thus suggest that the production of HIMTb may have commenced after the territories of Britain and Germany were no longer part of the Roman Empire, and Ravenna had become the nominal capital of the western half. However, this can only partially explain the dearth of HIMTb in the Western Mediterranean, such as in France, at Carthage and in the Iberian Peninsula. Our data suggest that the geopolitical changes of the later fourth and early fifth centuries may have affected the circulation and consumption of raw glass more generally. Hence, the analytical study of well-dated glass assemblages can potentially help to unravel how the complex historical events of the fifth century, such as the arrival of the Visigoths on the Iberian Peninsula or the Vandals at Carthage and the Balearic Islands, had an impact on the trade with the east, and possibly explain the typological and compositional similarities of glasses from French, Iberian and Carthaginian workshops.

In any case, the available chemical data confirm the prevalence of HIMT glasses in the Western Mediterranean and Northern Europe during the fourth and fifth centuries CE. At Picola – *Portus Ilicitanus*, HIMT makes up 87% of all glass consumed at the site, and similarly high proportions were found in the fifth-century glass workshops of Braga (Portugal), where 80% of all analysed glasses correspond to HIMT glass (Da Cruz 2009). In France, HIMT was the main glass type during the fifth century (Foy *et al*. 2003b). A similar preference for HIMT during the second half of the fourth and the first decades of the fifth century has been established for the UK, Belgium and German areas (Aerts *et al*. 2003; Foster and Jackson 2009; Greiff and Hartmann 2013; Rehren and Brüggler 2015). Raw glass chunks of HIMT glass, testifying to the working of this type of glass, have been found at Braga (Da Cruz 2009), Tarraco (Rius *et al*. 1989), Carthage (Siu *et al*. 2017), Marseille, Bordeaux, Port Vendres and Toulouse (Foy *et al*. 2003b) and Rome (Gliozzo *et al*. 2017b), as well as at Ravenna and Aquileia (Maltoni *et al*. 2015, 2016). In contrast, HIMT seems less widespread in Syria–Palestine and Asia Minor (Fig. 5), where Levantine glass types constituted the bulk of the analysed assemblages. It has to be stressed, however, that ultimately differences in sampling (number of samples, choice of archaeological sites and contexts etc.) can create a certain bias in the observed frequency of materials.

CONCLUSION

Our findings exemplify the need for systematic large-scale approaches to identify distribution patterns that may eventually reveal some of the underlying factors that led to differences. The differential geographical spread of HIMTa and HIMTb appears to be related to geopolitical dynamics, adding a chronological dimension to the two HIMT subgroups. The absence of HIMTb from Northern Europe meant that this subcategory was probably produced and dispersed at a time when supply to the edges of the empire was already constrained. Consequentially, the lack of HIMTb and, in fact, any glass group postdating the fifth century from Picola furthermore implies that *Portus Ilicitanus* no longer played a major role in the commercial networks of later periods. The analytical results of the glasses from Picola in comparison with contemporary developments clearly confirm the more general trends reflected in the archaeological record of the Iberian Peninsula. As the main harbour of the Roman *Colonia Iulia Ilici Augusta*, Picola – *Portus Ilicitanus* was evidently well connected to the wider Mediterranean through extensive exchange networks, suggesting that the harbour city was actively involved in the supply of glass to Hispania during the fourth and early fifth centuries CE. During the final occupation, commercial connections were cultivated particularly with northern Africa and not so much with the imperial capital, Italy or the Levantine coast. The glasses from Picola exhibit clear parallels with the assemblages from Carthage, both in terms of the compositional as well as the typological characteristics. The comparative data reveal similar relative proportions of HIMT and Levantine glass types. At both Carthage and Picola, there was a clear tendency to employ HIMTa for the same vessel types. Similarities exist also with assemblages from southern France. Noteworthy is the almost exclusive use of HIMT glass for the production of vessels associated with the consumption of wine. A close connection between HIMT glass and wine has been noted before, not least due to the occasional glass imitations of the Spatheion amphora for the transport of Egyptian wine that have been found in Egypt, Italy and Spain (Nenna 2014). That Egyptian wine was imported to Picola is reflected in the large quantities of wine amphorae and there is evidence that the activities of the fish factory included the consumption of fish products and wine. It is thus perfectly feasible to assume that Egyptian wine and Egyptian HIMT glass might have been traded in parallel along long-established sea-routes via the Carthaginian port.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. LA-ICP-MS data of the analysed glasses from Picola-*Portus Ilicitanus*. Major and minor elements are expressed as oxides [wt %] and trace elements as elementary metals [ppm].

Table S2. Means of repeated LA-ICP-MS measurements of NIST 612 and Corning A glass standards in comparison with published values