Things that travelled: A review of the Roman glass from northern Adriatic Italy

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Abstract

The present chapter summarises the results of an ongoing research project, developed during the last decade at the University of Padova and carried out, until now, on 260 samples of Roman glass coming from various sites (Adria, Aquileia, Iulia Felix) in north Adriatic Italy. A combined approach, geochemical and archaeological, was employed to investigate the type and the provenance of raw materials used, and to fill a gap in the knowledge of consumption of glass in an area which, thanks to its strategic position, played a central role in trade during Roman time. The majority of the samples are silica-soda-lime glass in composition and produced with natron as flux, although some soda ash glass samples here named as NE-I/Soda Ash group, all intentionally coloured, have also been identified. In the case of natron glass, five compositional groups (NE-I/Sb-Colourless, NE-I/Mn-Colourless, NE-I/Sb-Mn-Colourless, NE-I/unintent-Coloured, NE-I/intent-Coloured) are distinguished, suggesting various sources, production technologies or degrees of recycling. The isotopic data suggest that the primary production of the Roman glasses from northern Adriatic Italy likely took place in the eastern Mediterranean, although alternative hypotheses are possible.

Introduction

Glass may be considered a ‘precious’ material, due to its properties, both aesthetic and functional (e.g., transparency, lustre, colour,
chemical resistance). Glass was initially used for decorative purposes (e.g., beads, necklaces) and later became functional (e.g., tableware, containers for transporting food, window panes, mosaic tesserae). In particular, the Roman period saw a prodigious use of glass in domestic and funerary contexts, primarily for the production of vessels, although mosaic tiles and window panes were also made. Roman glass generally falls within certain compositional ranges for major elements ($\text{SiO}_2 \approx 65–71 \text{ wt\%}, \ \text{Na}_2\text{O} \approx 15–18 \text{ wt\%}, \ \text{CaO} \approx 6–7 \text{ wt\%}, \ \text{Al}_2\text{O}_3 \approx 2.00–2.60 \text{ wt\%}, \ \text{Fe}_2\text{O}_3 \approx 0.30–0.90 \text{ wt\%}$), as testified by the abundant archaeometric literature (e.g. Nenna et al. 2000; Foster and Jackson 2009; Foster and Jackson 2010; Gliozzo et al. 2013). The majority of Roman glasses are blue-green or aqua (Price and Cottam 1998), without the intentional addition of colouring or decolouring elements; on the other hand, both deeply coloured and clear colourless glasses were popular in certain periods: deeply coloured glasses (black, purple, blue, emerald green, amber) were particularly fashionable in early Roman times, while clear colourless glass was in demand during the late first–third century CE (Price and Cottam 1998). Obtaining a truly colourless glass was not easy in preindustrial times: it required pure (i.e., low iron) sand and a strong control on firing conditions; nevertheless, a slight tinge was almost impossible to avoid, therefore antimony or manganese could be added to the glass batch in order to mask the undesired colour of the natural-occurring iron. So far, many studies have been carried out on unintentionally coloured and/or colourless Roman glass from the Mediterranean basin and northern Europe (e.g. Mirti et al. 1993; Aerts et al. 2003; Foy et al. 2003; Foy et al. 2004; Paynter 2006; Arletti et al. 2008; Foster and Jackson 2009; Arletti et al. 2010; Foster and Jackson 2010; Gliozzo et al. 2013; Rosenow and Rehren 2014; Jackson and Paynter 2016), but little attention has been paid to findings from north Adriatic Italy, which, thanks to its strategic location between the eastern Mediterranean and continental European areas, played a central role in trade during the Roman period. In this context, the present work summarises the results of a systematic study on Roman glasses from northern Adriatic Italy, developed during the last decade at the Departments of Geosciences and Cultural Heritage of the University of Padova and still in progress. Aims of the study are: (1) characterisation of raw materials and production technologies employed in glass circulating in the northern Adriatic area during the Roman period; (2) study of the provenance of raw materials; and (3) comparison between analysed samples and coeval glass found in the Mediterranean basin, in order to clarify main commercial routes and to advance hypotheses on production models for the period of interest.
Materials and methods

In the present study, 260 samples from three sites are considered and discussed: (1) 57 samples, mainly from the first–second centuries CE, housed in the Archaeological Museum of Adria (Rovigo, Italy), one of the most important ports in the northern Adriatic area from the sixth century BCE until the second century CE (Bonomi 1996; Gallo et al. 2013); (2) 30 samples, mainly dated from the first to third century CE, found in the domus of Tito Macro (known also as domus of Fondi Ex Cossar) in Aquileia, one of the main archaeological sites of north-eastern Italy during Roman and Late Roman periods (Bonetto and Ghedini 2014; Maltoni et al. 2016); (3) 173 samples, found in the Iulia Felix, a ship wrecked in the northernmost section of the Adriatic Sea and dated to the first half of the third century CE (Toniolo 2007; Silvestri et al. 2008; Silvestri 2008). The majority of the selected types are composed of tableware (i.e., cups, plates, bottles and beakers), made of transparent glass naturally coloured in pale blue, pale green or pale yellow, but colourless and intentionally coloured glasses are also represented. The assemblage also includes two pieces of glass-working waste from Adria and Aquileia, blue and colourless, respectively. A full list of the samples subdivided by site, colour and macro-type is reported in Table 14.1. It should be emphasised that the domus of Tito Macro has a very complex stratigraphy and, only for this particular site, the dating of each fragment is assumed as coincident with the widest accepted chronological range of the archaeological form. Therefore, notwithstanding some types, such as the beakers Isings 106, and 109, the cup Isings 117, the bottle Isings 104 and the goblet Isings 111 are dated from the fourth to eighth century CE (Maltoni et al. 2016), they are here included due to their chemical composition.

Major and minor elemental bulk chemistry was determined by X-Ray Fluorescence (XRF) for those samples of sufficient weight (≥700 mg) for this technique. The instrument was a Philips PW 2400, equipped with a Rh tube with a rated capacity of 3 kW (60 kV/125 mA max.). The XRF analyses allowed determination of 27 elements (Si, Na, Ca, Al, K, Mg, Fe, Ti, Mn, P, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Nd, Pb), excluding Cl, S, Sn and Sb, which were checked by Electron Probe Micro-Analysis (EPMA). Instrumental parameters, analytical conditions and standards used for quantitative analysis were the same as reported by Silvestri et al. (2011). The major and minor element concentrations of samples, with weights not sufficient
for XRF analysis, were determined by EPMA. The instrument used for quantitative analysis was a CAMECA SX50, equipped with four wavelength-dispersive spectrometers (WDS). The detailed analytical conditions, properly selected for glass analysis, and the detection limits are given in Silvestri and Marcante (2011). Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) was applied as a complementary technique to XRF and EPMA to measure trace element concentrations of the Adria glasses. The probe was composed of an Elan DRC-e mass spectrometer coupled to a Q-switched Nd:YAG laser source (Quantel Brilliant). The analytical conditions, precision, accuracy and detection limits of LA-ICP-MS measures are detailed in Silvestri and Marcante (2011).

In order to make inferences on provenance of glass, 66 samples were selected for the analysis of strontium and neodymium isotopes, and 95 for oxygen isotope. The selection was carefully conducted, in order
to represent the various archaeological types, colours and the different compositional groups identified and detailed in Silvestri et al. (2008), Silvestri (2008), Gallo et al. (2013) and Maltoni et al. (2016).

After a suitable sample preparation for Sr and Nd analysis (Ganio et al. 2012b), all Sr and Nd isotope ratios were obtained using a Thermo Scientific Neptune Multi Collector Inductively Coupled Plasma Mass Spectroscopy (MC-ICP-MS), equipped with a micro-flow PFA-50 Teflon nebuliser and running in static multi-collection mode. The operating parameters and the analytical protocol adopted are given in Gallo et al. (2015).

Oxygen isotope measurements were performed according to the well-established technique of high-temperature fluorination and detailed in Silvestri et al. (2010) and Gallo et al. (2015).

Results and discussion

Chemical data and the compositional groups identified

The complete chemical data of 260 glass samples, subdivided by site, are reported in Silvestri (2008), Silvestri et al. (2008), Gallo et al. (2013) and Maltoni et al. (2016). The chemical data are here discussed in a comparative perspective, in order to identify compositional groups related to specific raw materials and/or production technologies, and to provide further insights on the consumption of glass in northern Adriatic Italy during the Roman period.

All the samples are silica-soda-lime glass in composition and the majority of them have been produced using natron as flux, although six samples from Adria and one from the Iulia Felix shipwreck (defined as Outlier in Silvestri 2008), here named as NE-I/Soda Ash group, show higher contents of MgO, K₂O (Figure 14.1) and P₂O₅, suggesting the addition of a soda-rich plant ash as flux. It is worth noting that these samples are all strongly coloured: four of them are emerald green, one is dark green, one black and one blue. The presence of soda ash glass in Roman assemblages is rare. Natron was the major flux used in the Mediterranean area and Europe from the middle of the first millennium BCE to the ninth century CE (Sayre and Smith 1961). However, some authors have observed that high potassium/magnesium/phosphorous compositions are frequent in glasses of particular colours, such as emerald green, “peacock” and black, but the reasons of this have yet to be clarified, although useful insights on Roman black and emerald green glasses are reported in Ceglia et al. (2014) and Jackson and Cottam (2015), respectively.
Two main compositional groups may be distinguished in the natron glass of the present assemblage: ‘NE-I/Colourless’, comprising samples with a variable amount of decolourisers (antimony and/or manganese)
Table 14.2 Average chemical composition and standard deviation for compositional groups discussed in the present chapter. Major and minor elements expressed in weight per cent of oxides (wt%). Total number of samples for each group (N) and number of samples, subdivided by site (AD = Adria; AQ = Aquileia; IF = Iulia Felix), for each group also shown.

<table>
<thead>
<tr>
<th>wt%</th>
<th>NE-I/Sb-Colourless</th>
<th>NE-I/Mn-Colourless</th>
<th>NE-I/Sb-Mn-Colourless</th>
<th>NE-I/unint-Colourled</th>
<th>NE-I/intent-Colourled</th>
<th>NE-I/Soda Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AD = 3 AQ = 7 IF = 65</td>
<td>AD = 1 AQ = 9 IF = 14</td>
<td>AD = 2 AQ = 6 IF = 43</td>
<td>AD = 18 AQ = 4 IF = 50</td>
<td>AD = 27 AQ = 4 IF = 0</td>
<td>AD = 6 AQ = 0 IF = 1</td>
</tr>
<tr>
<td>SiO₂</td>
<td>70.19 ± 0.85</td>
<td>69.96 ± 1.03</td>
<td>69.69 ± 0.57</td>
<td>69.76 ± 1.25</td>
<td>67.92 ± 1.32</td>
<td>63.64 ± 2.50</td>
</tr>
<tr>
<td>Na₂O</td>
<td>19.53 ± 0.82</td>
<td>15.31 ± 0.77</td>
<td>17.71 ± 0.76</td>
<td>16.60 ± 1.03</td>
<td>17.96 ± 1.09</td>
<td>17.62 ± 1.91</td>
</tr>
<tr>
<td>CaO</td>
<td>4.92 ± 0.62</td>
<td>7.88 ± 0.40</td>
<td>6.40 ± 0.55</td>
<td>7.69 ± 0.55</td>
<td>7.48 ± 1.13</td>
<td>6.91 ± 0.92</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>1.98 ± 0.22</td>
<td>2.63 ± 0.15</td>
<td>2.28 ± 0.09</td>
<td>2.49 ± 0.10</td>
<td>2.48 ± 0.40</td>
<td>2.23 ± 0.44</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.42 ± 0.08</td>
<td>0.54 ± 0.11</td>
<td>0.58 ± 0.04</td>
<td>0.58 ± 0.13</td>
<td>0.66 ± 0.15</td>
<td>1.51 ± 0.39</td>
</tr>
<tr>
<td>MgO</td>
<td>0.38 ± 0.16</td>
<td>0.56 ± 0.10</td>
<td>0.57 ± 0.05</td>
<td>0.58 ± 0.13</td>
<td>0.55 ± 0.08</td>
<td>2.06 ± 0.48</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.40 ± 0.14</td>
<td>0.33 ± 0.19</td>
<td>0.48 ± 0.04</td>
<td>0.43 ± 0.13</td>
<td>0.71 ± 0.44</td>
<td>1.26 ± 0.32</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.07 ± 0.03</td>
<td>0.07 ± 0.01</td>
<td>0.09 ± 0.01</td>
<td>0.07 ± 0.02</td>
<td>0.06 ± 0.04</td>
<td>0.17 ± 0.06</td>
</tr>
<tr>
<td>MnO</td>
<td>0.02 ± 0.02</td>
<td>1.41 ± 0.27</td>
<td>0.41 ± 0.16</td>
<td>0.47 ± 0.23</td>
<td>0.58 ± 0.66</td>
<td>0.73 ± 0.37</td>
</tr>
<tr>
<td>Sb₂O₃</td>
<td>0.81 ± 0.16</td>
<td>&lt;0.04</td>
<td>0.43 ± 0.15</td>
<td>&lt;0.04</td>
<td>0.09 ± 0.13</td>
<td>&lt;0.04</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.03 ± 0.01</td>
<td>0.12 ± 0.04</td>
<td>0.11 ± 0.02</td>
<td>0.14 ± 0.05</td>
<td>0.12 ± 0.05</td>
<td>0.83 ± 0.38</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.29 ± 0.04</td>
<td>0.15 ± 0.04</td>
<td>0.25 ± 0.04</td>
<td>0.16 ± 0.08</td>
<td>0.24 ± 0.09</td>
<td>0.26 ± 0.13</td>
</tr>
<tr>
<td>Cl</td>
<td>1.44 ± 0.13</td>
<td>1.16 ± 0.16</td>
<td>1.22 ± 0.10</td>
<td>1.22 ± 0.13</td>
<td>1.36 ± 0.28</td>
<td>1.33 ± 0.29</td>
</tr>
</tbody>
</table>
and ‘NE-I/Coloured’, comprising the naturally coloured and intentionally coloured samples. On the basis of the colouring/decolouring elements, the above compositional groups are further divided into subgroups, named NE-I/Sb-Colourless, NE-I/Mn-Colourless, NE-I/Sb-Mn-Colourless, NE-I/unintent-Coloured, NE-I/intent-Coloured. The average composition and standard deviation of each group for major and minor elements are reported in Table 14.2.

The **NE-I/Sb-Colourless group** is composed of 74 vessels (31 cups, 23 plates, 15 bottles, 5 beakers) from the three sites here considered and 1 working waste from Aquileia. The main chemical feature of this group is the high antimony content \( \text{(Sb}_2\text{O}_3 = 0.81 \pm 0.16 \text{ wt\%}) \) without manganese; other characteristics are high silica \( (70.19 \pm 0.85 \text{ wt\%}) \) and soda \( (19.53 \pm 0.82 \text{ wt\%}) \), low lime \( (4.92 \pm 0.62 \text{ wt\%}) \) and relatively low (although variable) alumina \( (1.98 \pm 0.22 \text{ wt\%}) \) (Table 14.2 – Figure 14.1). Samples of the ‘antimony colourless’ composition are frequently recorded in the archaeometric literature (Sayre and Smith 1961; Foy et al. 2004; Baxter et al. 2005; Jackson 2005; Paynter 2006; Huismann et al. 2009; Foster and Jackson 2010; Ganio et al. 2012a; Rosenow and Rehren 2014; Jackson and Paynter 2016). The Sb-based decolourisation of glass, typical of the first–third centuries CE, is more efficient than the one based on manganese; in addition, while helping gas bubbles escape from the melt, antimony also worked as a refining agent and aided the transparency and clearness of the final object. These could be some of the reasons of the choice of Sb-glass for high-status glass vessels, such as *diatreta*, cameo-cut and other cut-decorated vessels (e.g. Jackson 2005; Foster and Jackson 2010; Jackson and Paynter 2016).

Nevertheless, Sb-decoloured glass was not only reserved for the production of very high-status objects, as demonstrated by the large assemblages published in the past, which report the presence of abundant undecorated tableware made with Sb-colourless glass. This evidence is also confirmed by the present assemblage, where high- and low-status vessels are included. Comparisons among the published data from Great Britain (Jackson 2005; Foster and Jackson 2010; Jackson and Paynter 2016), France (Foy et al. 2004; Ganio et al. 2012a), Egypt and Tunisia (Foy et al. 2004; Rosenow and Rehren 2014) and the present assemblage show that the largest part of the Sb-decoloured samples are characterised by low-alumina content, generally below 2.0 wt\%, suggesting that a pure sand, rich in silica and poor in feldspars and accessory minerals, was exploited for their production. Only a few British and Egyptian samples (Foster and Jackson 2010; Rosenow and Rehren 2014; Jackson and Paynter 2016) contain high alumina levels (between 2.20 and 2.50
wt%), similar to five ‘high-alumina’ samples from Aquileia and *Iulia Felix*. If we consider the major elements and neglect Mn and Sb, the mean composition of the above high-alumina subgroup fits the general compositional patterning of the unintentionally coloured Roman glasses rather than that of the majority of Sb-colourless. Such uncommon composition could derive from recycling different glass compositions, although this hypothesis is hard to support, due to the absence of manganese, in the above samples. Therefore, a different location of primary production that employed impure sand, naturally poor in manganese, could be hypothesised. This picture is further complicated by the chronology of antimony technology, which is supposed to have a rapid decline in the fourth century CE (Jackson and Paynter 2016), which does not coincide perfectly with the dating of two types from Aquileia included in the present group, i.e., the beaker Isings 109 and the cup Isings 117 dated at the fourth century CE (Figure 14.2). The possibility that Sb colourless glass recycled in later times preserved its ‘pure’ composition without contamination is difficult to support. It is more likely that Sb-decoloured glass did not disappear suddenly from the market, and Sb-decoloured and Late Antique compositions coexisted in Aquileia in the fourth century CE. For more details on Late Antique glass from Aquileia see Maltoni et al. (Chapter 9, this volume). Finally, as regards the single glass-working waste from Aquileia detected in this group, it testifies to the presence of some kind of secondary working of Sb-colourless glass in the area, but, in view of its sporadic finding and in absence of archaeological dating, it is not possible to define whether it derives from an occasional or a regular activity, nor to collocate this activity in a time scale.

The NE-I/Mn-Colourless group is composed of 24 vessels (4 cups, 13 bottles, 5 beakers, 2 goblets) from the three sites here considered. This group is characterised by very high manganese (MnO = 1.41 ± 0.27 wt%), in the absence of antimony; other common characteristics are low soda (15.31 ± 0.77 wt%), high lime (7.88 ± 0.40 wt%), and relatively high alumina (2.63 ± 0.15 wt%) (Table 14.2 – Figure 14.1). The very high manganese content, coupled with a very high MnO/Fe$_2$O$_3$ ratio (above 3 in all the samples of the present group), is fully consistent with the intentional addition of manganese, whose threshold value was recently increased to 1 wt% MnO by Brems et al. 2012. Mn-Colourless glasses from northern Adriatic Italy are close in composition to the more common unintentionally coloured glasses, although they show lower soda and relatively higher lime and alumina contents. Comparisons with literature data from Great Britain (Jackson 2005; Foster and Jackson 2010; Meek 2013; Jackson and Paynter 2016), France (Nenna et al.
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1997; Foy et al. 2003; Ganio et al. 2012a) and Morocco (Gliozzo et al. 2013) show that this composition is quite common, although manganese glass samples with high lime, high alumina, high soda (e.g., Foster and Jackson’s 2010 group 2b) and with low lime, low alumina, high soda (e.g., Meek’s 2013 group 2a and Foster and Jackson’s 2010 group 2a) appear from the fourth century onwards, as reported in Jackson and Paynter (2016).

Finally, it is interesting to note that some samples of the NE-I/Mn-Colourless group from Aquileia (i.e., the beaker Isings 109, the bottle Isings 104 and the goblet Isings 111) are dated to a wide chronological range (Figure 14.2), which, once again, is not fully consistent with the chronology of the Mn-decoloured Roman glass. In addition, what seems surprising is that, as in the case of Sb-decoloured glass, Roman glass made it almost unmodified to Late Antiquity and early Medieval times, preserving the ‘purity’ of its chemical composition. It is possible, although hard to prove, that large quantities of early Roman raw chunks were still available in the fourth–fifth century CE in Aquileia (when

Figure 14.2 Chronology during which NE-I/Sb-Colourless, NE-I/Mn-Colourless, NE-I/Sb-Mn-Colourless, NE-I/unintent-Colourled and NE-I/intent-Colourled groups were circulated in north-eastern Italy. Dotted lines indicates the possibility that NE-I/Mn- and NE-I/Sb-Mn-Colourless groups continued to circulate until the eighth century CE, these compositions being identified in goblets Isings 111 from Aquileia, whose accepted chronological range is from fifth to eighth centuries CE.
considering the vessels as locally shaped) or in the place of origin of the objects (when considering the objects as imported). Another possibility is that this high-lime, high-manganese, low-soda composition derives from a specific primary production that continued its activity throughout the fourth–fifth century CE. What is evident is that in the current assemblage and in the majority of the literature where this composition is documented, manganese was added to a glass batch that slightly differs from the common unintentionally coloured glass composition and is closer at some points (lime, alumina, soda, manganese content) to the Levantine 1 production (Freestone et al. 2000), that started to circulate in the eastern Mediterranean in the fourth century CE and dominated the glass market in the sixth–seventh century CE.

The NE-I/Sb-Mn-Colourless group is composed of 51 vessels (41 bottles, 5 cups, 2 plates, 2 beakers, 1 goblet) from the three sites here considered. The main feature of this group is the presence of both manganese (MnO = 0.41 ± 0.16 wt%) and antimony (Sb₂O₃ = 0.43 ± 0.15 wt%). Apart from the decolouring elements, these samples are within the compositional ranges of the common unintentionally coloured glass: high SiO₂ (69.69 ± 0.57 wt%), Na₂O (17.71 ± 0.76 wt%), CaO (6.40 ± 0.55 wt%), Al₂O₃ (2.28 ± 0.09 wt%), Fe₂O₃ (0.48 ± 0.04 wt%) and very low titania (0.09 ± 0.01 wt%) (Table 14.2 – Fig 14.1). The presence of mixed Sb + Mn glasses is frequent in large Roman assemblages (e.g., Jackson 2005; Foster and Jackson 2010; Jackson and Paynter 2016). Jackson (2005) interpreted them as an intermediate decolouring technique, although later studies (Silvestri et al. 2008; Foster and Jackson 2010; Jackson and Paynter 2016) interpreted those glasses as recycled, due to the fact that the presence of both decolourisers was not necessary and probably unintentional. Antimony decolouring was efficient and did not require the addition of manganese; conversely, manganese decolouring is efficient only when the manganese/iron ratio is very high (MnO/Fe₂O₃ >2, as reported in Silvestri et al. 2005). The mixed Sb + Mn samples usually have manganese in low concentrations when compared to iron; therefore the addition of low quantities of antimony would have almost no benefit. In addition, the samples belonging to the NE-I/Sb-Mn-Colourless group show intermediate compositions between the NE-I/Sb-Colourless and NE-I/Mn-Colourless groups (Table 14.2 – Figure 14.1), supporting the idea that the glasses with both manganese and antimony represent mixtures of two end-member types (i.e., Sb-colourless and Mn-colourless glass) rather than the result of adding different amount of antimony and manganese to a single glass type, as also observed by Freestone (2015) for the Iulia Felix assemblage.
The intermediate composition is also probably a consequence of the selection criteria of cullet for recycling, when the intention of glass-makers is to produce colourless glass. The selection is likely based on cullet macroscopic colour, with a preference for colourless fragments, which are more probably ascribed to Sb-colourless and Mn-colourless glass from the chemical viewpoint. When these colourless cullets were remelted together, a colourless glass containing both antimony and manganese, added unintentionally, should be produced, although the present assemblage demonstrates that the remelting procedures do not ever result into a truly colourless glass. This is the case of some samples from the *Iulia Felix* (all the group Ic1b and some samples from Ic1a and Ic2b, as reported in Silvestri 2008), which are included in this group due to their chemical composition, although macroscopically they show a slight tinge. The chronology of the NE-I/Sb-Mn-Colourless group is also quite interesting: it was in circulation in northern Adriatic Italy from the second to the fifth century CE, suggesting that from the fourth century glass obtained by recycling and ‘new’ Late Antique compositions (Maltoni et al. Chapter 9, this volume) coexisted in the considered area. In the present group, the occurrence of one goblet Isings 111 from Aquileia, dated typologically from the fifth to eighth century CE, allows us to extend its diffusion until the eighth century CE (Figure 14.2), although this actually remains only an hypothesis, due the absence of other stratigraphic data, for better constraining the date of the goblet and, consequently, of the group.

The NE-I/unintent-Coloured group is composed of 72 vessels (52 bottles, 16 cups, 3 jars, 1 beaker) from the three sites here considered, dated from the first to the fourth century CE (Figure 14.2). They are homogeneous in composition with high silica (69.76 ± 1.25 wt%), medium soda (16.60 ± 1.03 wt%) and alumina (2.49 ± 0.10 wt%), and relatively high lime (7.69 ± 0.55 wt%). They are also characterised by low manganese (MnO = 0.47 ± 0.23 wt%) and no antimony (Table 14.2 – Figure 14.1). In this group, the only colouring element is iron; the content of manganese is too low to be considered as intentionally added (i.e., below 1 wt% in all samples) and it is rather introduced with sand or recycling. This group is consistent with the compositional field of ‘typical’ silica-soda-lime Roman unintentionally coloured glass, suggesting the use of similar raw materials. The extraordinarily consistent composition of Roman glass from different sites in western Europe has already been noted by many authors and led to the hypothesis of a common origin for this type of glass of the entire empire (Nenna et al. 1997; Foy et al. 2003; Silvestri et al. 2005; Silvestri 2008).
The **NE-I/intent-Coloured group** is composed of 31 samples (14 cups, 6 jars, 5 bottles, 3 ewers, 1 beaker, 1 plate and 1 glass chunk) from Adria and Aquileia, blue, purple and amber in colour. The blue and amber samples are attested in both sites, the purple ones only in Adria. This group, dated from the first to second century CE (Figure 14.2), shows a quite homogeneous composition in terms of silica (67.92 ± 1.32 wt%), soda (17.96 ± 1.09 wt%), lime (7.48 ± 1.13 wt%) and alumina (2.48 ± 0.40 wt%) (Table 14.2 – Figure 14.1), which is consistent with the field of ‘typical’ silica-soda-lime Roman unintentionally coloured glass, except for three blue samples from Adria, defined as Outliers 1, 2 and 3 in Gallo et al. (2013). The outliers are characterised by lower lime (CaO = 4.15–4.66 wt%) with respect to the blue glasses (CaO = 7.43–9.22 wt%), suggesting a sand poorer in calcite. Outlier 3 also shows the highest alumina contents of all the natron glasses (Al₂O₃ = 4.29 wt%), indicative of raw material very rich in feldspars. Further considerations about the three blue outliers can be found in Gallo et al. (2013).

The various colours (blue, purple and amber) differ in their colouring and related elements. The **blue** glasses total 15 and are characterised by high iron (Fe₂O₃ ranged from 0.50 to 1.77 wt%), copper (340–1730 ppm) and cobalt (210–1740 ppm), all positively correlated, indicating that they were intentionally added to the glass from a similar source. Cobalt is probably the main colouring element, since its absorption coefficient is higher than that of copper and iron (Mirti et al. 2002; Gliozzo et al. 2010), and possible sources may be trianite (2CoO₂·CuO·6H₂O) and skutterudite (Co, Fe, Ni)As₃ (Henderson 1985), although further studies are required to constrain better the type of cobalt source.

In the five **purple** glasses from Adria, manganese was employed as a colourant, as these samples have high MnO contents (1.8 ± 0.2 wt%). However, it is interesting to note that the purple samples show manganese contents and a manganese/iron ratio comparable to those of the NE-I/Mn-Colourless group, but different colours. This is a further demonstration that the final colour of the glassware is the result not only of the chemical composition of the batch in terms of iron and manganese content, but also of the redox conditions in the kiln, as described in Bingham and Jackson (2008). The use of manganese as a colourant in purple and pink glass has been well documented since the Iron Age (Tite et al. 2008) and its presence in Roman glass is frequent (Arletti et al. 2006; Jackson et al. 2006). Wad, an ore composed of manganese oxides/hydroxides, often of poor crystallinity, with small quantities of psilomelane [(Ba,H₂O)₂Mn₃O₁₀], is indicated as a possible source of
manganese (Silvestri 2008). This hypothesis is supported by the positive correlation between Ba and Mn. Only one sample, AD-V-2, clearly differs from other purple glasses for its higher barium and iron (Ba = 1277 ppm and Fe$_2$O$_3$ = 1.13 wt%; Gallo et al. 2013), perhaps suggesting other raw materials as a source of manganese.

_Amber_ glasses are 11 in total and form a very homogeneous group, which shows the lowest contents of iron and manganese (Fe$_2$O$_3$ = 0.31 ± 0.03 wt%; MnO = 0.03 ± 0.01 wt%). Except for iron, no other discernible colouring elements were revealed, so that the amber tint is probably due to the presence of Fe$^{2+}$ ions and Fe$^{3+}$-S$^2-$ complex, which formed when the glass was melted in strongly reducing conditions, produced by altering the furnace atmosphere and/or the addition of carbon to the batch (Schreurs and Brill 1984; Green and Hart 1987; Jackson et al. 2006). Comparisons to amber glass reported in literature are difficult because of the scarcity of published data. However, some amber glasses were published from a secondary workshop of the mid-first century CE from Lyon (Nenna et al. 1997) and show comparable compositions, suggesting that this colour is the product of high technological skill and strict control on the raw materials and furnace conditions.

Isotopic data and implications for provenance of glass

To trace the provenance of the raw materials employed in primary production, important information can be obtained from the isotopic composition of the glass combined with the chemical data. In this study, isotopic compositions of strontium, neodymium and oxygen are obtained on a selection of samples from all the compositional groups, described in the previous section. Full isotopic datasets are published in Silvestri et al. (2010), Ganio et al. (2012a), Degryse (2014) and Gallo et al. (2015); here the most valuable insights obtained by isotopic data on Roman glass from the northern Adriatic area are reported.

The $^{87}$Sr/$^{86}$Sr ratios of the majority of the Roman glass samples from northern Adriatic Italy range between 0.70884 and 0.70916 (Figure 14.3a), independent from site and compositional group, and are close to the ratio of present-day seawater ($^{87}$Sr/$^{86}$Sr = 0.7092). Along with their high Sr contents (Sr = 413 ± 83 ppm), this suggests that the source of strontium was marine shell and consequently that beach sands were most likely used.

Some samples show clearly different Sr isotopic signatures. In particular, the lower Sr signature of NE-I/Mn-Colourless group can be
This variation could be explained by the fact that sand is not the only source of strontium in glass, but also Mn-bearing raw material, added as decolourant, introduces strontium in the batch, and consequently modifies the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (Ganio et al. 2012a; Gallo et al. 2015). However, the ‘inhomogeneous’ Sr signature in the two purple Adria samples, belonging to NE-I/intent-Coloured group (sample AD-V-4 with $^{87}\text{Sr}/^{86}\text{Sr} = 0.70854$ and AD-V-2 with $^{87}\text{Sr}/^{86}\text{Sr} = 0.70955$, Figure 14.3a), seems to be indicative of the use of more than one type of Mn-bearing raw material, as also hypothesised on the basis of chemical compositions (Gallo et al. 2013; Gallo et al. 2015).

The majority of Roman glass from the northern Adriatic area show $\varepsilon\text{Nd}$ values between $-4.0$ and $-6.0$, although higher and lower values are also measured (Figure 14.3a). Relationships between isotopic composition and compositional groups are not observed. Therefore the large
spread in this isotopic composition may indicate the use of multiple sand sources or, alternatively, an intense recycling of glass with different primary origins and thus different signatures.

The εNd values of the majority of the Roman glasses from the northern Adriatic area are very similar to those of the majority of first–fourth centuries. ce glass published in literature, and also to the known fourth-to-eighth-century ce primary production centres in the Levant (εNd = −4.0 to −6.0, Degryse 2014). This suggests an analogous provenance, i.e., the eastern Mediterranean. It should be stressed here that two glasses dating to the first century ce from Adria, one purple (sample AD-V-2) and one blue (sample AD-B-6), belonging to the NE-I/intent-Coloured group, show relatively low εNd values (εNd = −10.04 and −7.41 in AD-V-2 and AD-B-6, respectively – Figure 14.3a). These signatures are inconsistent with any published data from sediments or raw glass in the eastern Mediterranean but correspond well to the range in isotopic values of beach and deep-sea sediments from the western Mediterranean, from the Italian peninsula to the French and Spanish coasts, and from north-western Europe (Degryse and Schneider 2008; Brems et al. 2013). Comparisons between the Nd isotopic and trace element patterns of the two above Adria glasses and possible sand sources led us to hypothesis that pretreated sand from the Campanian littoral, location mentioned by Pliny the Elder in his Naturalis Historia, may be a suitable raw material. This actually remains only a speculation due to the low number of compared samples and the absence of further data on sand sources from other areas of western Mediterranean (Gallo et al. 2015).

The majority of the Roman natron glasses from northern Adriatic Italy show fairly homogeneous δ18O values, ranging between 15.1‰ to 16.2‰ (VSMOW), with a mean value of 15.6‰ ± 0.3, except for the NE-I/Sb-Colourless group having δ18O value significantly higher with respect to the other compositional groups (Figure 14.3b). A greater addition of natron as flux, very positive in isotopic composition, in the NE-I/Sb-Colourless group, which led to a higher percentage of sodium in the final glass may explain their systematically heavier isotopic values (Silvestri et al. 2010). In addition, it should be underlined that, notwithstanding the overlap, the samples belonging to NE-I/Sb-Mn-Colourless group have intermediate δ18O values between the NE-I/Sb-Colourless and NE-I/Mn-Colourless groups (Figure 14.3b), and this may be a further confirmation of the hypothesis that these samples were produced by recycling/mixing of these two basic compositions. It is also interesting to note that the two Roman samples from Adria with ‘exotic’ neodymium signature (AD-V-2, AD-B-6), indicative of a western Mediterranean provenance of raw
materials, are perfectly indistinguishable on the basis of oxygen isotopes data. A possible explanation of this evidence may come from the similarity in oxygen isotopic composition of probable raw materials (siliceous-calcareous sand), which, in addition to the same flux (natron) in similar ratios, make the glass samples isotopically indistinguishable (Gallo et al. 2015).

The NE-I/Soda Ash group shows higher \( \delta^{18}O \) values than the majority of the Roman natron glasses, except for NE-I/Sb-Colourless group (Figure 14.3b). Taking into account that the addition of ash did not contribute isotopically heavy oxygen and the \( \delta^{18}O \) of glass essentially reflects the silica source (Silvestri et al. 2010), the higher \( \delta^{18}O \) of the Adria soda ash glass may reflect the use of a different silica source, although further analyses on Roman soda ash glass are required to clarify this point.

Conclusions

The combined approach, involving chemical, isotopic and archaeological data, proved a powerful mean to clarify type and provenance of raw materials and production technologies of the Roman glass found in northern Adriatic Italy, and to fill the void of knowledge on the consumption of glasses in the area of interest of the present study.

The majority of the samples are silica-soda-lime glass in composition and produced with natron as flux, although some soda ash samples, all intentionally coloured, have also been identified. In the case of natron glass, five compositional groups (NE-I/Sb-Colourless, NE-I/Mn-Colourless, NE-I/Sb-Mn-Colourless, NE-I/unintent-Coloured, NE-I/intent-Coloured) are distinguished, suggesting various sources, production technologies or degrees of recycling. In general, no close relationships were noted among compositional groups, types and/or sites, although the absence of intentionally coloured glass in the cargo of Iulia Felix underlines the careful selection of glasses meant for recycling in Roman times. In addition, it is worth noting that dependence on bulk composition has been observed for some intentional colours, such as emerald green and amber. Exceptions are the blue glasses, which are the only ones showing a certain variability in bulk chemistry, although their chromophore agent is always the same (cobalt), suggesting technological homogeneity in colouring techniques. The NE-I/Sb-Colourless and NE-I/Mn-Colourless groups may be considered two compositional end-members, obtained by sand of high purity, poorer in calcite and feldspars and with high natron/sand ratio in the first case, and by less pure sand, i.e., higher in calcite and feldspars, and with low natron/sand
ratio in the second. This not only suggests that different sources and/or production technologies may have been exploited during the Roman period, but also that the raw materials were intentionally and carefully selected in the workshops devoted to the production of colourless glass.

Isotopic data, particularly those related to Sr and Nd isotope ratios, proved to be a powerful tool to source primary glass-making and suggest an eastern Mediterranean origin for the samples from northern Adriatic Italy, although the existence of other primary glass producers located in the western Mediterranean cannot be completely excluded. However, the number of samples with these ‘exotic’ compositions is low, and further isotopic analyses on Roman glass need to shed light on this interesting topic.

In conclusion, the present work provides an interesting picture of the different compositional groups that were circulating throughout the Roman world and particularly those reaching northern Adriatic Italy, which confirms its role of ‘outpost’ in the western Mediterranean trades.

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