Journal of Archaeological Science: Reports 7 (2016) 303–311

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Mosaic tesserae from Italy and the production of Mediterranean coloured glass (4rd century BCE–4th century CE). Part I: Chemical composition and technology

Cristina Boschetti [a,*], Julian Henderson [a], Jane Evans [b], Cristina Leonelli [c]

[a] University of Nottingham, Department of Archaeology, NG7 2RD University Park, United Kingdom
[b] NERC-British Geological Survey, Keyworth, Nottingham, United Kingdom
[c] Faculty of Engineering "Enzo Ferrari", University of Modena and Reggio Emilia, Via Vignolese 905, 41100 Modena, Italy

ARTICLE INFO

Article history:
Received 1 February 2015
Received in revised form 30 March 2016
Accepted 3 May 2016
Available online xxxx

Keywords:
Mosaic glass tesserae
Roman coloured glass
Coloured glass technology
Ancient glass compositional types
Glass micro-structure

ABSTRACT

Roman highly coloured glass is well represented amongst mosaic tesserae, occasionally found in Italy from the middle of the 2nd century BCE and commonly used from the early 1st century CE. SEM-EDS microstructural and chemical analysis has revealed colouring elements and opacifiers. Chemical analysis has identified both natron and plant ash glasses, the former fitting five compositional types of ancient natron glass (Levantine I and II, HIMT, Wadi Natrun and Egypt II) and of Roman colourless glass. The apparent Levantine and Egyptian provenance for the 'raw glasses' (once the colourants and opacifiers were removed) is discussed critically in the light of Nd and Sr isotopic results in part II.

1. Introduction

Glass is composed of three major components: silica, which acts as network-former, calcium, which acts as a network-stabilizer and an alkaline fraction, which has the principal function of lowering the melting point of the batch. In antiquity, silica was added in the form of sand or crushed quartz. Calcium and minerals rich in alumina, iron and other impurities are often present in (quartz) sand and are introduced into glass batches. Alkaline metal oxides were added as natron, a soda rich evaporitic mineral (Na_2CO_3 $10H_2O$), found at Wadi el-Natrun, in Egypt (Shortland, 2004) or as halophytic plant ashes. Over the centuries, the ancient glass-making industry has selected different species of coastal and semi-desert plants for their ability of concentrating sodium carbonate in their tissues. Whereas natron is a relatively pure alkali source, plants and their ashes can vary in chemical composition quite widely, depending on the genus and the geology of the soil in which they grow (Barkoudah and Henderson, 2006). The chemical identification of the type of alkali used in glass provides the basic distinction between natron and plant ash glasses (Sayre and Smith, 1961). During the first millennium CE, either natron or plant ashes have been the dominant alkali sources in glass-making in Europe and the Middle East (Henderson, 2002). In Roman times, natron was the primary alkali source used, but a small proportion of plant ash glasses were nevertheless produced (Henderson, 1991).

Given that natron is relatively pure, researchers have tended to chemically characterize natron glass by focusing on the impurities introduced with the minerals in the sands used to make them (Freestone et al., 2000; Freestone et al., 2002; Arletti et al., 2008; Degryse and Shortland, 2009; Ganio et al., 2012). The chemical analysis of raw furnace glasses from primary glassmaking sites has led to compositional distinctions between them linked to Levantine or north African origins. The provenance of a natron glass can therefore apparently be traced by using major, minor and trace elements associated with silicates and carbonates. However, published results are beginning to demonstrate that some glasses that fall into these major compositional groups are characterized by different chemical and isotopic signatures (Jackson, 2005; Arletti et al., 2008; Degryse and Schneider, 2008; Ganio et al., 2012; Degryse, 2015; Gallo et al., 2015), suggesting that they have different origins from those initially indicated by their chemical characterization. Consequently, isotopic characterization is starting to make an important contribution to our understanding of the dynamics of the ancient glass industry and its associated trade (Degryse and Schneider, 2008; Degryse and Shortland, 2009; Henderson et al., 2010; Ganio et al., 2012; Degryse et al., 2015).

In Roman times, the production of glass reaches a high level of specialization, both in terms of glass-making and glass-working. The most significant development, in the middle 1st century BCE, was the

* Corresponding author at: Department of Cultural Heritage: Archaeology, History of Art, Cinema and Music, University of Padua, Piazza Capitaniato 7, 4th Floor, 35139 Padova, Italy.
E-mail address: c.boschetti@nottingham.ac.uk (C. Boschetti).

http://dx.doi.org/10.1016/j.jasrep.2016.05.006

invention of glass-blowing. This new technique, which originated on the Levantine coast (Harden, 1969; Israeli, 1991; Stern, 1999), led to mass production, allowing glass vessels to be manufactured more quickly than by moulding them. This led to a decrease in price and value of vessel glass and also an increase in the volume of glass in circulation. This major technological change was responsible for a revolution in the production and consumption of glass, and its effects are also visible in the circulation of glass objects not formed by blowing, including glass mosaic tesserae.

Mosaic tesserae are small parallelepipeds that were cut from cakes of glass. The cakes were usually of a circular shape, and were formed by pouring molten glass onto a flat working surface. In most cases the glass used for tesserae is opaque but translucent glass is also used. A separate category is glass tesserae decorated with a gold or silver foil, applied between two layers of transparent glass. Except for this last category, where the thin layer of glass protecting the foil was blown, glass blowing is not involved at all in the production process (Neri and Verità 2013, p. 4596). However, by analysing their context and distribution, we can observe that glass enters systematically into the palette of the mosaicists only at the beginning of the 1st century CE (Boschetti, 2011) by which time, the practice of glass blowing was fully established (Harden, 1969).

Coloured glasses may have been produced directly by adding colourants to the primary batch, or greater control would have been attained by adding the colouring agents to the raw glass in a secondary process. This last practice is mentioned by Pliny the Elder, who discusses the use of colouring, starting from the raw colourless or slightly coloured glass (Pliny, Naturalis Historia, 36, 66, 193). This may have occurred in the centres dedicated to the primary production, or in glass-working workshops, but currently the main archaeological evidence is for Roman and Late Antique natron glass making sites producing only 'naturally' coloured glass (Freestone et al., 2000; Gorin-Rosen, 2000; Nenna et al., 2000). However, highly coloured (cobalt blue, green, turquoise and amber) glass was being made in Late Hellenistic/early Roman Beirut (Kowatli et al., 2006) and worked in early Roman Lyon (Nenna et al., 1997; Motte and Matin, 2003). The relatively scarce archaeological evidence for glass trade does not help to shed much light on the problem. Although trade in blocks of lightly tinted raw glass is attested by the cargoes of Roman shipwrecks (Radic and Jurisic, 1993; Foy et al., 2000), the circulation of cakes and lumps of highly coloured glasses, for which there is evidence from as early as the Late Bronze Age, on the Uluburun shipwreck (Pulak, 1988; Jackson and Nicholson, 2010), has never been observed in Roman times. Earlier evidence is provided by a 4th-early 3rd century BCE Punic boat, that sunk off the coast of Su Pallosu (Oristano), in Sardinia, transporting lumps of cobalt blue and opaque yellow glass (Salvi and Sanna, 2006). About 550 kg of blue glass were discovered on the Sanguinaire A wreck, which sunk between 220 and the 200 BCE, next to the island of Sanguinaire, off the western cost of Corsica (Alfonsi and Gandolfo, 1997). A smaller quantity of similar glass, was also found in two other contemporary wrecks that sunk off the coast of Provence (Foy et al., 2000).

The creation of a reliable theoretical model for the production and trade of both raw and coloured glass needs to consider also the practice of recycling, that has been documented during the Roman Imperial period. The collection of glass cullet is mentioned by the Latin author Martial, in the first book of his *Epigrammata*, published in Rome around the 80 CE (Martial, Epigrammata 1.41). Here it is not specified whether this glass was intended to be re-melted, or whether it was due to be reused as fragments in wall mosaics, such as in 1st BCE–1st CE examples from Italy (Sear, 1975; Boschetti 2011, p. 76).

The earliest archaeological evidence for the circulation of glass cullet in the Mediterranean is from a wreck that sunk off Grado, in the Adriatic sea, that was transporting a barrel full of vessel fragments, dated to the late 3rd century CE (Auriemma, 1999). Therefore, we do not have any archaeological evidence for the Roman circulation of opaque coloured glass to be worked, or for colouring glass cullet.

According to this scarce material evidence, we can suggest a production model where carefully controlled amounts of colourant-rich minerals were added to faintly tinted glass in glass-working workshops (Henderson 2013, p. 232), as recently argued for the production of opaque yellow glass (Verità et al. 2013, pp. 33-34).

The process of production for highly coloured Roman mosaic glass tesserae is scarcely discussed, but analytical investigations on 4th century *opus sectile* slabs from Ostia have suggested a model of the existence of workshops specialized in specific glass colours (Verità et al., 2008).

Ancient glasses were commonly decolourized adding antimony oxide or manganese oxide, or both (Jackson, 2005; Foster and Jackson, 2009). Studies conducted on Late Antique glasses date the beginning of manganese-decolourized glasses in Italy since the late 2nd–early 3rd century CE (Silvestri et al., 2008). However, the lack of analytical data for decolourized glasses from Italy, between the late Hellenistic period and the first two centuries of the Roman Empire does not allow us to discuss comprehensively the chronology of decolourization technologies in the area.

Roman white and opaque yellow tesserae are generally coloured and opacified by crystals of calcium and lead antimonate added in a secondary process to colourless glass (Lahil et al., 2008; Lahlil et al., 2009; Lahil et al., 2010). The 4th century CE was considered the chronological limit of this technology, replaced by tin oxides both in the western and in the eastern Mediterranean (Tite et al., 2008). However, recent studies have demonstrated a more complex picture, with a coexistence of both the technologies since the 1st century CE (Verità et al., 2013).

Opaque red glasses are of particular interest, being attested in two technological variants. The first type, known as 'sealing-wax red glass', is a high-lead glass and is coloured and opacified by dendritic crystals of cuprous oxide, Cu_2O. It is not clear if sealing-wax red glasses were made in a two-steps process or in one single melt (Freestone, 1987). This glass, dating back to the 8th century BCE (Von Saldern, 1966; Brill, 1970), suddenly disappears from the Mediterranean and northern Europe around the 1st century CE (Hughes, 1972). At this time, it is replaced by a dullish red opaque glass, coloured by micron sized droplets of metallic copper. This glass usually contains low levels of iron and lead oxide and, in many cases, plant ashes have been used as an alkali source (Henderson, 1991; Brun and Pernot, 1992; Stapleton et al., 1999; Freestone et al., 2003; Arletti et al., 2006; Barber et al., 2009; Gedzevičiūtė et al., 2009).

The impact of recycling was probably very limited before the first decades of the 1st century CE, when the volume of glass circulating was significantly increased by the establishment of glass-blowing. The evidence of the Late Antiquity and the Early Medieval period indicates that coloured objects were also produced by recycling glass tesserae, both directly by including tesserae in new objects or adding tesserae as 'colourants' to colourless glass. The first case is documented in Italy, during the 7th century CE, in the Villa of Aiano, at Torraccia di Chiusi (Siena). Here, the 3rd–4th century CE wall mosaics were demolished to collect the glass tesserae, which were cleaned from the mortar and re-worked to be transformed in beads, in a workshop active on the site (Cavalieri and Giumlia-Mair, 2009). The hypothesis of selectively recycling glass mosaic tesserae is also discussed by Foy for French contexts of the 4th–5th century CE (Foy, 2008). The second case, described in the 11th century Theophilus treatise is evidenced, for the first time in the 4th century CE at Aquileia (Boschetti et al., in press) and, on a massive scale, by the 9th century glass workshop at S. Vincenzo al Volturno (Schibille and Freestone, 2013).

In this paper, we discuss the technology of glass mosaic tesserae from Roman Italy, the relation between their chemical compositions, the compositions of raw glasses and published compositions for Imperial Roman and mainly later types of glasses and their putative provenance. Samples, selected from well dated archaeological contexts, have been selected so as to shed light on the production of coloured glass over a long time period (3nd BCE–4th CE), starting from the late Hellenism, when glass is firstly produced on a large scale. The glasses