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Characterisation of Byzantine and early Islamic primary tank furnace glass

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ABSTRACT

In order to improve the understanding of glass production and provenance, we present trace element and Sr, Nd and B isotope ratio data for 15 samples of raw natron glass from a single tank furnace in Apollonia (6th–7th century CE) and eight glass samples from two tank furnaces in Bet Eli'ezer (8th century CE) in Israel. This data provides information about the geochemical homogeneity within a single batch of raw glass and about the differences and/or similarities between different tank furnaces on a single site. Four glasses from a secondary workshop at Tell el-Ashmunein, Egypt (8th–9th century CE) are analysed for comparative purposes.

All raw glass samples have uniform trace element patterns and ratios. Because of poor mixing of the glass batch before and during firing, absolute concentrations however can vary significantly within a single tank furnace. The concentrations of trace elements commonly associated with (de)colouring are very low and can be attributed to background concentrations in the sand raw materials. This indicates that there was no obvious recycling of glass cullet at this stage of the production process and that the tank furnace glass is primary glass in the true sense of the word. The isotopic compositions of Sr, Nd and B in the tank furnace glasses are relatively homogeneous. This confirms their potential as provenance indicators. The isotopic composition of Sr in tank furnace glass from Apollonia and Bet Eli'ezer indicates that the lime was derived from seashell, suggesting the glass was produced from beach sand. Glass from Tell el-Ashmunein contains Sr with lower $^{87}Sr/^{86}Sr$ ratios, pointing to the use of limestone as the source of lime. All primary glasses from Israel analysed have Nd isotopic compositions typical for an Eastern Mediterranean origin. $\delta^{11}B$ indicates that natron used in the tank furnaces in Apollonia and Bet Eli'ezer was most likely imported from Egypt.

1. Introduction and objectives

Ancient natron glass is a complex material. It was produced by melting a calcareous silica sand together with a soda-rich flux. The currently preferred model for natron glass production in the Hellenistic to early Islamic period is one of a division of production (Nenna et al., 1997, 2000, 2005; Gorin-Rosen, 2000; Freestone et al., 2000, 2002a, 2002b; Picon and Vichy, 2003; Tal et al., 2004; Freestone, 2006; Degryse, 2014). The glass was first produced from sand and natron raw materials in tank furnaces on primary production sites. Examples of such installations have been discovered in Egypt and Syro-Palestine. In the Wadi Natrun region, Egypt, three primary production sites were dated between the 2nd century BCE and the 3rd century CE (Nenna et al., 2005; Nenna, 2015). Near Alexandria, two other primary workshops were discovered dating from the Imperial period to the 8th century CE (Nenna et al., 2000). An early Roman (1st century BCE – 1st century CE) production site was found in Beirut, Lebanon (Kouwatli et al., 2008; Henderson, 2013). By far most of the remnants of primary natron glass production have been discovered in Israel. 17 tank furnaces with a (minimum) capacity of 8 to 10 t of glass each were found at Bet Eli'ezer (Gorin-Rosen, 1995, 2000). A number of similar installations for glass production from the 6th to 7th century CE were found in Apollonia (Tal et al., 2004; Freestone et al., 2008) and an in situ failed glass slab was discovered in Bet She'arim (early 9th century; Brill, 1967; Freestone and Gorin-Rosen, 1999). Evidence of primary production is also found on other archaeological sites in Israel.

The large tank furnaces were capable of producing several tonnes of raw glass in a single firing, which probably lasted in the order of two weeks or more (Gorin-Rosen, 2000). Numerical simulations using a 3D computation fluid dynamics model based on the primary tank furnaces

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at Bet Eli'ezer predict that the average temperature of the glass reached 1200 °C with a minimum of 1080 °C at the bottom of the tank (Van Beeumen, 2011; Van Beeumen et al., 2011). Sand and natron raw materials were probably introduced into the furnace in several smaller batches during the firing process (Freestone et al., 2000). In this way, the added batch would float on top of an already molten layer of glass, heating the raw materials from below while hot gasses heat them from above. When all raw materials were melted, the glass was allowed to cool down in the tank itself. Once solidified, the furnace was dismantled and the glass slab broken into chunks which were traded widely to be shaped into vessels in secondary workshops (Nicholson et al., 1997; Rehren and Pusch, 1997; Foy et al., 2000; Freestone et al., 2000; Nenna et al., 2000). Additives such as colourants and/or opacifiers were added to the glass at this stage (Freestone et al., 2002a; Picon and Vichy, 2003).

The very nature of glass, with its amorphous structure, limits the number of techniques that can be used to relate it back to its original production site. The provenance determination of natron glass relies solely on consistent and measurable differences in bulk geochemical characteristics between glass from different primary sources. In the literature, several major compositional groups have been identified (e.g., Bimson and Freestone, 1985; Gratuze and Barrandon, 1990; Freestone et al., 2000, 2002a; Foy et al., 2003). Each is restricted in chronological and geographical distribution and some can be related to the identified primary glass production centres in Egypt and the Levant. For others, the actual production sites are still unknown.

Unfortunately, the compositional ranges of different glass groups are not clearly defined. There are subtle differences in composition within groups and there can be considerable overlap in geochemical signatures of different possible sources. Small differences in the relative proportion of (alumino-) silicates and carbonates in a sand deposit can result in local variations in, e.g., CaO and Al_2O_3 concentrations of a few weight percent (Brems et al., 2016). The local concentration of heavy minerals due to changing hydraulic conditions, would result in strong peaks in the concentrations of certain trace elements (Brems and Degryse, 2014). It is not unreasonable to assume that the mixing of a great volume of sand with natron in a tank furnace would eliminate some of these heterogeneities. However, incomplete mixing of the sand and natron before firing would result in significant local variations in, e.g., Na_2O vs. SiO_2 and CaO contents. Convective currents in the volume of molten glass during firing, could result in at least some degree of homogenisation in the geochemical characteristics of the glass (Van Beeumen, 2011; Van Beeumen et al., 2011), but the extent of this is not well known. Freestone et al. (2000) and Tal et al. (2004) already noted significant variation in major element concentrations in glass samples from a single tank furnace.

During the last decades, the emphasis in studies of ancient glass has shifted more and more towards trace elements and isotope ratios (Wedepohl and Baumann, 2000; Freestone et al., 2000, 2003; Degryse et al., 2006, 2009a; Shortland et al., 2007; Degryse and Schneider, 2008; Degryse and Shortland, 2009; Brems et al., 2013a, 2013b; Brems and Degryse, 2014; Degryse, 2014; Devulder et al., 2014). These are likely to be more indicative of the geological (and geographical) source of the sand raw materials than major elements. However, up till now it is unclear how much variation in these geochemical characteristics can be expected within and between primary glass batches. The aim of this paper is to provide a comprehensive geochemical characterisation of raw natron glass from Byzantine and early Islamic tank furnaces in order to investigate the magnitude of variation in trace elemental and Sr, Nd and B isotopic properties within a single batch of raw natron glass. Also the similarity in geochemical composition between different tank furnaces from a single site is investigated.

2. Materials

In this study, we provide a geochemical characterisation of raw glass from primary tank furnaces from two sites in Israel: Apollonia and Bet Eli'ezer. We determined trace element compositions and Sr, Nd and B isotopic signatures for 15 samples of raw glass recovered from a single tank furnace in Apollonia, dated to the 6th–7th century CE (Area N tank; Tal et al., 2004). Major element compositions of these samples have previously been characterized using EPMA (Tal et al., 2004). Additional major element data and selected trace element data for other samples from the site are given by Freestone et al. (2000, 2008) and Phelps et al. (2016). The glasses from the Apollonia furnaces are soda-lime-silica glasses typical of late Byzantine and early Islamic glass from the Levantine coast. They are characterized by Al_2O_3 contents of about 3.0–3.5% and CaO levels in the range of 7–9%. The Na_2O content is about 12–15% and that of SiO_2 is typically about 69–73%. The Apollonia glass has been grouped under the name ‘Levantine I’ (Freestone et al., 2000; Tal et al., 2004), together with, among others, 4th century glass from Jalame (Brill, 1988) and 6th–7th century glass from Bet She'an, Dor and Ramla (Freestone et al., 2000, 2003; Tal et al., 2008). Although these assemblages have slightly different compositions, they are all believed to be produced along the Palestinian coast using very similar ‘Belus-type’ sand raw materials (Brill, 1988; Freestone and Gorin-Rosen, 1999; Freestone et al., 2000). All 15 samples came from the same tank furnace. Most of them had a natural blue-green (aqua) colour, but five samples (AP04, AP12, AP13, AP14 and AP15) were olive green. Sample AP10 contained stones visible to the naked eye and shows anomalously high Al_2O_3 and Fe_2O_3 concentrations, and low Na_2O and CaO ones, attributed to contamination by contact with the wall or floor of the furnace (Tal et al., 2004). This sample was split in two. One part (sample AP10a) was composed of relatively clear, transparent aqua glass with no macroscopic inclusions. The second part (AP10b) was almost completely composed of fritted material, i.e. crystalline grains, mostly of quartz, embedded in a glassy matrix. These two samples were analysed separately for their trace elemental and Sr and Nd isotopic signatures.

At Bet Eli'ezer, 17 tank furnaces were found, dating to the 8th century CE (Gorin-Rosen, 1995, 2000). Freestone et al. (2000) analysed the major element compositions of glass from four furnaces at Bet Eli'ezer. They showed that there are no consistent compositional differences between furnaces on the same site and that the full spread of compositions can be found within glass from a single furnace. Although there is considerable overlap in composition between glass from Apollonia and Bet Eli'ezer, the Bet Eli'ezer glass tends to be lower in soda (mostly 11–13%) and lime (6–8%) and higher in silica (73–77%). This indicates a slight difference in mineralogical composition of the glassmaking sands used and a decrease in the amount of natron flux that was added to the batch (Freestone et al., 2008). The Bet Eli'ezer glass has been termed ‘Levantine II’ (Freestone et al., 2000). A total of eight raw glass samples were analysed from two tank furnaces in Bet Eli'ezer: five samples from a first furnace (context L22.B261; Freestone et al., 2000) and three from a second (context L14.B190; Freestone et al., 2000). Major element compositions of these samples are reported by Freestone et al. (2000). Sample BE39 showed some variation in colour on a scale of a few mm and was subsampled for the trace element and isotopic analyses. Sample BE39a was mostly blue coloured, while BE39b was darker green.

To put the degree of heterogeneity within the tank furnaces into perspective, we included some other glass from a very different context in the analyses. Three vessel glasses (TA01, TA02 and TA03) and a piece of glass waste (TA04) from a secondary glass workshop at Tell el-Ashmunein, Egypt, were also analysed. These glasses were dated to the 8th–9th century CE (Freestone et al., 2003). The major element composition of these glasses was previously determined by Bimson and Freestone (1985). They belong to a glass group called ‘Egypt II’, characterized by rather high lime and relatively low alumina contents (Bimson and Freestone, 1985; Gratuze and Barrandon, 1990; Freestone et al., 2000).