Glass bead production in Europe during the 17th century: elemental analysis of glass material found in London and Amsterdam

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Abstract

This article focuses on the elemental analysis of glass material found at the 17th c. glass bead production site at the Hammersmith Embankment in London, UK, using laser ablation – inductively coupled plasma – mass spectrometry (LA-ICP-MS). The glass beads manufactured at this site are similar to those found at some North American Native sites. In order to better understand how bead production was organized in Europe and assess the possibility of sourcing glass trade beads found in North America and perhaps Africa, data obtained for the Hammersmith Embankment site are compared to that obtained from the Kg10 site located in Amsterdam, Netherlands. This site yielded very similar material also dating from the 17th c. Results, including major, minor and trace elements reveal that the glass at both sites was manufactured according to similar recipes involving soda plant ash purified to different degrees. This recipe was quite likely imported from Venice. Trace elements reveal that sand from different origins was selected. Four different sub-groups were identified in the London samples and three in the Amsterdam samples. This indicates that the glass was not manufactured on site but instead obtained from different primary glass workshops. Although it is possible to distinguish most of the beads from the Hammersmith Embankment from the beads from Kg10, a slight compositional overlap between the sites makes provenance attribution for some types of glass beads difficult.

Key words

Glass, beads, LA-ICP-MS, post-medieval period, Europe

1. Introduction

In North America, made-man glass in the form of beads appears at Native sites with the first contacts with Europeans. Excerpts from Christopher Columbus' journal dated between October and December 1492 mention glass beads given as gifts or traded for water, gold and other goods (Brill and Hoffman, 1987; Francis, 1986:32-33). Beads were rapidly included in the repertoire of cultural artifacts favored by the different Native communities able to procure them directly from Europeans or through inter-tribal trade. The ubiquity of glass beads, the variability of the assemblages and the narrow dating of some sites created opportunities to establish chronologies that could be used for the dating of undocumented sites (e.g. Quimby, 1966:82-83; Spector, 1976). The classification system for trade beads in North America established by Kidd and Kidd (1970) later augmented by Karklins (1985a; 1983 and 2012) facilitated reliable bead description and comparison between sites; however, it became rapidly apparent that some beads could not be easily classified due to the lack of distinctiveness of their physical attributes.

Studies based on the measurement of the chemical compositions of the glass provided additional criteria for bead classification. The composition of European glass beads found at Native American sites has been extensively studied early on by means of instrumental neutron activation analysis (INAA) (e.g. Hancock et al. 1994; 2000; Kenyon et al. 1995; Moreau et al. 2002; Sempowski et al. 2000) and more recently using laser ablation – inductively coupled plasma – mass spectrometry (LA-ICP-MS) (Burgess and Dussubieux, 2007; Walder 2013a and b). Despite the large amount of data produced by these different studies, the trade mechanisms that moved the beads from their European production centers to North America and the organization of bead production and trade in Europe is poorly known and the rare attempts to track North American glass beads back to Europe have been limited in their success because of a lack of comparative data for contemporaneous European material.

While Venice is generally considered to have been the principal producer of glass beads for the world market during the early post-medieval period, other European countries produced them as well. A well-documented source is Holland where a number of factories manufactured drawn beads during much of the 17th c. (Baart 1988; Hulst et al. 2012; Karklins 1983; Karklins 1985b). In 2001 and 2005, excavators from the Museum of London Archaeology uncovered the remains of two furnaces with associated glass beads and production wasters at the Hammersmith Embankment in West London. Attributed to the mid-17th c., this site provides the first concrete evidence for the production of drawn glass beads in England during the post-medieval period (Jamieson 2006). Visually, the bead styles from the Hammersmith site are very similar to those from the factory sites in Holland and those from contemporary Native American sites in eastern North America (K. Karklins 2015: pers. obs.). In order to determine if there are any significant differences in the glass compositions of the beads from these different sources, LA-ICP-MS was used to identify the major, minor and trace elements of 37 objects from the Hammersmith Embankment. This report discusses the recorded compositions and compares them to those of 20 glass ornaments and wasters found at the contemporaneous site of Kg10 in Amsterdam.

2. Experimental and samples

2.1. Experimental

The analyses were carried out at The Field Museum in Chicago, USA, using an Analytik Jena inductively coupled plasma - mass spectrometer (ICP-MS) connected to a New Wave UP213 laser for direct introduction of solid samples.

For better sensitivity, helium is used as a gas carrier in the laser. We use the single point analysis mode with a laser beam diameter of 80 μm , operating at 70 % of the laser energy (0.2 mJ) and at a pulse frequency of 15 Hz. The ablation is performed without any prior sample preparation. A pre-ablation time of 20 s is set in order, first, to eliminate the transient part of the signal and, second, to be sure that possible surface contamination or corrosion does not affect the results of the analysis.

For each glass sample, the average of four measurements corrected from the blank is considered for the calculation of concentrations. The isotope Si29 was used for internal standardization. Concentrations for major elements, including silica, are calculated assuming that the sum of their concentrations in weight percent in glass is equal to 100 % (Gratuze, 1999). Two different series of standards are used to measure major, minor and trace elements. The first series of external standards are standard reference materials (SRM) manufactured by NIST: SRM 610 and SRM 612. Non certified values were taken from Pearce et al. (1997). The second series of standards were manufactured by Corning. Glass B and D are glasses that match compositions of ancient glass (Brill, 1999, vol. 2, p. 544).

The detection limits range from 10 ppb to 1 ppm for most of the elements. Accuracy ranges from 5 to 10 % depending on the elements and their concentrations. A more detailed account of the performances of this technique can be found in Dussubieux et al. (2009).

2.2. Samples

The glass artifacts from London were selected by Karlis Karklins to be representative in terms of color and object type of the excavated glass assemblage. They come from the Hammersmith Embankment excavations that have not been fully published yet. A more comprehensive description of the beads assemblage from this site is provided in Karklins et al. 2015. This site was formerly the grounds of a large mansion built in the early 17th c. by Sir Nicholas Crisp (ca. 1599-1666). Crisp was a slave trader and Commissioner of the Customs. The site yielded industrial features and among them, furnaces for the production of glass beads. All the beads and bead production tubes were of drawn manufacture (Jamieson, 2006). Thirty-seven objects were analyzed. Forty-nine measurements were carried out as some artifacts were polychrome and the composition of the different colored glasses was assessed separately. The analyzed glass objects were either translucent amber, dark blue, purple, colorless, opaque red or white (Table 1, Figure 1).

References LA-ICP-MS	References excavation	Description	Kidd and Kidd categories	Comments
LON051I and LON051I	WIZ05, ##196, 2100	Translucent amber bead	Ila*(a)	The glass around the perforation appeared different to the naked eye and was analyzed separately (LON051I)
LON052	WIZ05, ##196, 2100	Translucent amber bead	Ila*(a)	
LON009B, LON009R, LON009W	WIZ05, #229, 2142	Opaque red, white and translucent turquoise blue waster	?	
LON050	WIZ05, #137, 2132	Colorless and transparent piece of production tube	Ia3	
38db	WIZ05, #205, 2142	Small globule of translucent dark blue glass, waster	?	
26db_ext, 26db_int, 26w	WIZ05, #34, 2023	Tube fragment for the production of beads with a white glass layer between two translucent dark blue glass layers. The outer layer is decorated with longitudinal white stripes	IIIb*(j)	The white layer of glass was analyzed while the white stripes were not
LON032DB, LON032W	WIZ05, #59, 2070	Same as 26	IIIb*(j)	The outer and white layer of glass were analyzed
LON002db, LON002W, LON002Red	WIZ05, #110, 2023	Opaque red tube fragment for the production of beads decorated with white on dark blue stripes	Ibb*(b)	
41CoB	WIZ05, #317, 2114	Translucent dark blue with embedded white glass	?	Only the dark blue glass was analyzed
42CoB	WIZ05, #317, 2114	Translucent dark blue with embedded white glass	?	Only the dark blue glass was analyzed
43CoB	WIZ05, #317, 2114	Translucent dark blue with embedded white glass	?	Only the dark blue glass was analyzed
LON001db_int, LON001w, LON001db_ext	WIZ05, #54, 2070.	Bead fragment with a white glass layer between two translucent dark blue glass layers. The outer layer is decorated with longitudinal white stripes	IVb36	The blue outer layer is darker than the inner one
49CoB	WIZ05, #90, 2132	Translucent dark blue production tube	Ia18/19	
48CoB	WIZ05, #182, 2132	Translucent dark blue production tube	Ia18/19	

LON036	WIZ05, #316, 2114	Small globule of dark blue glass, waster	?	
LON035	WIZ05, #316, 2114	Small globule of dark blue glass, waster	?	
44CoB	WIZ05, #191, 2100	Translucent dark blue tubular bead	Ia18/19	
45CoB	WIZ05, #191, 2100	Translucent dark blue tubular bead	Ia18/19	
46CoB	WIZ05, #368, 2100	Translucent dark blue bead	Ila56	
47CoB	WIZ05, #368, 2100	Translucent dark blue bead	Ila56	
LON057	?	2 translucent purple beads fused together	Iva*(a)	Only one bead was analyzed
LON058	?	3 translucent purple beads fused together	Iva*(a)	Only one bead was analyzed
LON059	?	2 translucent purple beads fused together	Iva*(a)	Only one bead was analyzed
LON060	?	2 translucent purple beads fused together	Iva*(a)	Only one bead was analyzed
LON061	?	2 translucent purple beads fused together	Iva*(a)	Only one bead was analyzed
LON062	?	2 translucent purple beads fused together	Iva*(a)	Only one bead was analyzed
LON022R	WIZ05, #88, 2132	Fragment of opaque raw red glass	?	
LON022G	WIZ05, #88, 2132	Fragment of opaque raw red glass	?	
LON023	WIZ05, #88, 2132	Fragment of opaque raw red glass	?	
14Red	WIZ05, #50, 2070	Fragment of opaque raw red glass	?	
14xRed	WIZ05, #50, 2070	Fragment of opaque raw red glass	?	
15Red	WIZ05, #50, 2070	Fragment of opaque raw red glass	?	
16red	WIZ05, #50, 2070	Fragment of opaque raw red glass	?	
20red	WIZ05, #50, 2070	Fragment of opaque raw red glass	?	
13red, 13white	WIZ05, #227, 2142	Fragment of an opaque red bead with a dark blue on white spiral	?	The dark glass was not analyzed
11Red, 11white	WIZ05, #144, 2142	Fragment of opaque red tube with longitudinal white stripe	?	
LON053	WIZ05, #197, 2100	Translucent white bead	Ila12	Practically colorless but slightly corroded

Table 1. List of the glass samples from the Hammersmith Embankment site analyzed using LA-ICP-MS.

Figure 1. Examples of material from the Hammersmith Embankment site.

For comparative purposes, twenty glass artifacts excavated in Amsterdam at the Kg10 site, located in an area adjacent of the Keizersgracht canal, were also analyzed. The excavation yielded approximately 50,000 glass beads and other glass debris related to glass bead manufacturing along with drinking glass fragments, glass chunks of different colors and crucibles. The site was dated to the end of the 16th c. – beginning of the 17th c. (Baart, 1988; Karklins, 1985b). Glass material from this site was previously analyzed using INAA (Karklins

et al. 2002); however the small number of elements available with this analytical technique (11) greatly limited any comparison with the LA-ICP-MS results. The glass artifacts are listed in Table 2. A few of them are shown in Figure 2.

Reference	Color	Description	Kidd and Kidd categories
ABLA001	black	drawn beads	Ila7
ABLA002	black	drawn beads	Ila7
ABLA003	black	drawn beads	Ila7
ABLU001	translucent turquoise blue	drawn beads	Ila*
ABLU002	translucent turquoise blue	drawn beads	Ila*
ABLU003	translucent turquoise blue	drawn beads	Ila*
ARED001	opaque red	tube with broken (unpolished) edges	Ia1
ARED002	opaque red	tube with broken (unpolished) edges	Ia1
ARED003	opaque red	tube with broken (unpolished) edges	Ia1
ACOB001	translucent dark blue	drawn beads	Ila55
ACOB002	translucent dark blue	drawn beads	Ila55
ACOB003	translucent dark blue	larger broken drawn bead	Ila55
AINC001	colorless	hot-worked wastes	?
AINC002	colorless	hot-worked wastes	?
AWHI001	translucent colorless	drawn beads	Ila12
AWHI002	translucent colorless	drawn beads	Ila12
AWHI003	translucent colorless	drawn beads	Ila12
AYEL001	opaque yellow	tube	Ia7
AYEL002	opaque yellow	tube	Ia7
AYEL003	opaque yellow	tube	Ia7

Table 2. List of the samples from the Kg10 site in Amsterdam analyzed with LA-ICP-MS.

Figure 2. Examples of material from the Kg10 site in Amsterdam.

3. Results

Full compositions for all the samples, including 54 elements, are presented in Table 3. To determine the types of sand and flux that were mixed together, we considered the reduced compositions of the samples (only the concentrations of SiO_2 , Na_2O , MgO , Al_2O_3 , CaO , K_2O and Fe_2O_3), eliminating any contribution of coloring or opacifying ingredients, as suggested by Brill (1999, vol. 2, p. 9). After re-calculation, the sum of the concentrations for these constituents is 100 % (Table 4).

3.1. The Hammersmith Embankment glass beads

All the glass objects from the Hammersmith Embankment site are composed of soda-lime glass, the most abundant constituents after silica being soda (Na_2O) and lime (CaO). In general, magnesia (MgO) and potash (K_2O) concentrations are higher than 1.5 % suggesting the use of halophytic plant ash as a flux. Depending on the soda, lime and other constituent concentrations, four different groups were identified (Figure 3 and Table 5).

Group 1 encompasses most of the samples. It has an average soda concentration of 13.6 % and an average lime concentration of 11.1 %. Group 2 is characterized by lower lime concentrations (7.8 % on average) and higher soda concentrations (15.6 % on average). Group 3 has the highest soda concentrations but also the lowest lime contents. It also has the lowest magnesia concentrations and highest potash concentrations. Group 4 has low soda concentrations (9% on average) but lime concentrations in this group are fairly similar to the concentrations in group 1. This group has the highest alumina concentrations (3.5 % on average).

Figure 3. Na₂O-CaO biplot for all the samples from the Hammersmith Embankment.

	Group 1 (36)		Group 2 (5)		Group 3 (5)		Group 4 (3)	
	average	SD	average	SD	average	SD	average	SD
SiO ₂	65.7%	1.0%	67.0%	1.3%	67.9%	1.1%	69.0%	1.0%
Na ₂ O	13.6%	0.7%	15.6%	0.6%	18.5%	1.0%	9.0%	0.4%
MgO	3.0%	0.1%	2.4%	0.1%	1.9%	0.1%	2.5%	0.3%
Al ₂ O ₃	1.7%	0.6%	1.8%	0.2%	1.8%	0.1%	3.5%	1.2%
K ₂ O	4.2%	0.8%	4.7%	0.3%	3.6%	0.2%	3.5%	0.9%
CaO	11.1%	0.8%	7.8%	1.1%	5.6%	0.6%	11.8%	1.3%
Fe ₂ O ₃	0.7%	0.3%	0.7%	0.1%	0.6%	0.1%	0.8%	0.1%

Table 5. Average reduced compositions of the four soda-lime glasses identified for the Hammersmith Embankment samples. The number of specimens in each group is indicated in parentheses. SD stands for standard deviation.

Comparison of glass types 1, 2 and 3 reveals that the soda concentrations in these glasses are higher while the concentrations of lime and magnesia are lower. This may be due to the use of different types of soda plant ash or the use of soda plant ash with different degrees of purity.

The variation of trace element concentrations for such elements as zirconium and niobium, two elements expected to be associated with the sand, exhibits different trends with a correlation for groups 4 and 1 distinct from that of groups 2 and 3 (Figure 4). From a general point of view and independently of the considered groups, results show that zirconium always correlates positively with a large range of elements including aluminum, titanium or the rare earth elements. Niobium correlates systematically with tantalum, both elements being found in minerals of the pyrochlore type. This suggests the use of at least two types of sand containing different types of minerals.

Figure 4. Zr-Nb biplot for all the samples from the Hammersmith Embankment. Both element concentrations are expressed in ppm.

Group 1 contains samples of all colors except purple. Group 2 includes dark blue glass and one purple bead. Group 3 includes 5 purple beads while group 4 includes one dark blue and two white specimens. Beads with fairly similar typologies are in different glass groups.

Two glass beads are amber colored. They do not contain any element in a sufficiently high concentration that could explain the color. The presence of sulfur (not measured using LA-ICP-MS) can lead to the Fe^{3+} - S_n^{2-} group that will impart an amber to dark color to the glass (Schreurs and Brill, 1984).

LON009xB appears turquoise blue, a color that usually indicates the presence of copper. Yet this sample contained only 0.05 % copper. No other element in particularly high concentration (such as cobalt) is present in this glass, but it does contain significant concentrations of SnO_2 (2.6 %) and PbO (1.9 %). This blue glass is sandwiched between a white and a red glass containing much higher quantities of these two elements and a contamination (diffusion of these elements) could have occurred or white instead of turquoise blue glass was sampled.

Two colorless glass samples (LON050 and LON053) were analyzed. These samples contain as much iron as the other samples. This element, generally accidentally present in the sand, can

impart a range of colors to the glass that are usually eliminated by the use of decolorizing agents such as manganese, antimony or, more recently, arsenic. The colorless glass samples do not contain especially high concentrations of any of these elements suggesting that it was a careful control of the atmosphere in the furnace that was used to obtain a colorless glass rather than the addition of a special ingredient.

A large proportion of the glass samples from the Hammersmith Embankment are translucent dark blue. They all contain a significant amount of cobalt (215-1650 ppm), an element known to confer a dark blue color to glass. Such elements as As, Ni and Bi have higher concentrations in the dark blue glass samples compared to the other samples. These elements were certainly present in the cobalt ore. The mines of Schneeberg (Erzgebirge) in Saxony, Germany, are usually associated with a Co-As-Ni-Bi cobalt ore. Similar trace element patterns were identified in European glass or glazed artifacts dating from the 15th-18th c. period (Gratuze et al. 1992, 1996). The dark blue glass samples belong mainly to groups 1 and 2. One sample (38) belongs to group 4. The samples in group 2 (44CoB, 45CoB, 46CoB and 47CoB) are characterized by higher manganese concentrations (2.5-3.2 %). There is no correlation between the cobalt and manganese concentrations, suggesting that the manganese, which is often found in cobalt ore, was added separately to the glass, perhaps to enhance the color.

Five purple glass samples were analyzed. All contain higher concentrations of manganese than the other glass samples (1.0-2.3 %) with the exception of the high-manganese cobalt-blue samples mentioned above. All the purple glass artifacts but one (LON060) belongs to Group 3.

All the red glass contains significant concentrations of copper (0.4-2.5 %). Red glass is difficult to produce and requires reducing conditions that can be obtained by controlling the furnace atmosphere. It may also be produced by adding ingredients to the glass that will facilitate the reduction of the copper (see Ahmed and Ashour, 1974, 1977). Tin (2.3-4.4 %) and lead (3.1-12.4 %) were certainly added to the glass for this reason. All the red glass beads belong to Group 1.

All the white glass samples contain significant quantities of lead (10-27 %) and tin (4.5-21.5 %). Italian recipes from the middle of the 17th c. indicate the use of lead and tin oxides to obtain opaque white or lattimo glass (Moretti et al. 2004: 34-36). Tin oxide is a white opacifier and lead facilitates its stability. Two white samples belong to group 4 and the rest to group 1. No significant difference in the coloring recipes was noted between groups 1 and 4.

3.2. The Kg10 glass beads

All but three of the beads from the Kg10 site in Amsterdam are made of soda-lime glass. These three beads will be briefly discussed before dealing with the 17 other beads.

Three beads are opaque yellow: AYEL001, 2 and 3. Two beads are fairly identical in composition (AYEL002 and 3): they contain high concentrations of lead (72-73 %) and low levels of silica (23-24 %). The only other constituent present in significant concentrations is tin oxide (~2 %). Lead stannate, PbSnO₃, is a yellow opacifier used in glass (Rooksby, 1964). AYEL001 has a very different composition with more silica, soda, lime, magnesia and alumina but lower levels of lead. Tin is also present in this glass along with antimony that has a

concentration of ~6 %. Some recipes for 17th to 19th c. Italian glass describe an ingredient called “anime” that contains approximately 60% lead, 12%–17% silica, and 3%–8% antimony and tin with, in some cases, several percent zinc (Moretti and Hreglich 2005).

The other glass samples from Amsterdam have soda and lime concentrations that vary in the same way as the concentrations of the same constituents of the London glass samples in groups 1, 2 and 3; however, the identification of discreet groups is more difficult. No glass sample from Kg10 has a composition similar to that of group 4 identified in the Hammersmith glass workshop (Figure 5).

Figure 5. Na₂O-CaO biplot for all the samples from Kg10 and the Hammersmith Embankment.

Trace elements, especially zirconium and niobium, that were found useful to distinguish different types of sand correlate for most of the samples in a similar way as for Hammersmith Embankment group 1 (Figure 6); however, lower concentrations for both these elements suggest the use of a similar type of sand but with a different origin. Sample ABLA003, with a high soda concentration as measured for samples in group 3 also contains similar quantities of Zr and Nb as other Group 3 beads. Sample ACOB003 has a relatively high zirconium concentration and does not overlap with any other group.

Figure 6. Zr-Nb biplot for all the samples from Amsterdam and the Hammersmith Embankment. Both element concentrations are expressed in ppm.

Three samples from Kg10 appear black, including ABLA003, mentioned above. Two of these samples contains ~7 % of manganese oxide and the other (ABLA003) 1.3 %. These three beads also contain significant quantities of copper (0.1-0.2 %), tin (0.7-0.9 %) and lead (0.8-1.3 %) oxides. This suggests the recycling of different colored glasses.

The three turquoise blue glass samples all contain copper oxide concentration in the 1.1-1.2 % range. Traces of lead, tin and zinc might have been brought by the copper added as an alloy such as bronze.

The red glass samples from Amsterdam have surprisingly heterogeneous compositions as far as the coloring ingredients are concerned, despite a general composition for the three samples that is fairly similar. One sample contains very little copper (0.01 %) and very little of any element that could have been involved in the red coloring of the glass. It would be interesting to test this sample further to identify the coloring agent that produced the red color. Another sample has 0.4 % of copper oxide, a moderate amount of iron and 2.2 % of tin oxide and 5 % of lead oxide. The third sample contains more copper (1.8 %), more iron (5.4 %) and fairly similar concentrations of tin and lead.

Colorless glass samples have ~0.7 % of iron oxide. For comparison, some turquoise blue and red samples have lower iron oxide concentrations (0.4-0.6 %). The concentrations of manganese or of any other discoloring agent in this glass are not exceptionally high suggesting that a careful control of the furnace atmosphere might have been used to produce the colorless glass.

The dark blue glass contains cobalt and other elements in significantly high concentrations suggesting the use of the same cobalt ore as for the beads from the Hammersmith Embankment.

Those results combining major, minor and trace elements suggest that most of the Kg10 glass artifacts were manufactured using very similar recipes compared to the glass used at the Hammersmith Embankment but the glasses found at the two sites were manufactured with different raw materials.

4. Discussion

Although this study aims to characterize the glass found at a recently discovered glass beadmaking site in London to better understand the organization of glass bead production in post-medieval Europe, it is also laying a foundation for any future attempt to source European glass trade beads found at post-Columbian sites in North America and at contemporary sites in West Africa (e.g. DeCorse, 1989; Robertshaw et al. 2014).

Around the 17th c., different glass types coexisted in Europe. In such countries as France, Germany and Great Britain, glass was manufactured using forest plant ash and had a high lime-high potash composition. In southeastern Europe, halophytic plant ash was used, producing a soda-lime glass. The use of halophytic plant ash in Europe seems to have been influenced by the glass technology developed in the Levant (Near East) after the 8th c. A.D., when natron, was replaced by soda-rich plant ash (Shortland et al. 2006; Gratuze and Barrandon 1990; Henderson et al. 2004). Not only the technology but also raw materials were imported from this region. Indeed, soda plant ash was imported from Syria and Egypt to Venice at least until the 16th c. A.D. The southern parts of France and Spain then became the source of soda plants (*barilla*). Venetian glassmakers used high-purity silica sources that included quartz pebbles from the Ticino and Adige rivers in northern Italy (Jacobi, 1993; Verità, 2013). With the growing popularity of the *façon-de-Venise* glassware that started around the 16th c., Venetian and Italian glassmakers migrated to different regions of Europe to practice their art and contributed to the dispersion of some up-to-then secret recipes and glass technology (Maitte, 2013). This phenomenon is apparent through the analysis of Venetian and *façon-de-Venise* glasses found at different locations in Europe. Venetian and other European *façon-de-Venise* glass would be virtually indistinguishable if it was not for some trace-element concentrations that reveal the use of different silica sources (e.g. Van der Linden et al. 2005; Šmit et al. 2005; De Raedt et al. 2001; Cagno et al. 2012).

In 1567, a Lorraine glassmaker (Jean Carré) obtained a license to produce *façon-de-Venise* glass in London. He imported Venetian glassmakers and the use of soda plant ash as a source of flux (Newton and Davison, 1997:39). The Hammersmith Embankment glass was manufactured using this Venetian glass tradition. This is confirmed by the inverse correlation in the Hammersmith Embankment glass between the concentrations of soda and lime observed also for Venetian glass (Verità, 2013) and explained by the process of purifying the ash to increase the content of soda in the flux and decrease the proportion of all other constituents such as calcium. The same type of variation in the soda and lime concentrations was observed for the Kg10 glass.

In the analyzed glass samples from the Hammersmith Embankment as well as from Kg10, there is a certain intra-site heterogeneity for the glass compositions. This is apparent with the very singular composition of the yellow glass at Kg10 that contains high concentrations of lead. Other

glass samples have similar compositions but different coloring recipes. The color of the three red glass tubes at Kg10 was obtained by mixing very different ingredients. This would make it unlikely that the glass was produced on-site even if it cannot be excluded that these variations in the coloring recipes were due to experimentation, testing or constant improvement of the recipes. The different compositions found at the Hammersmith Embankment site suggest, that the different colors were procured from different sources, some primary workshops offering different color palettes compared to others. The fact that different recipes were identified at the Hammersmith Embankments and Kg10 sites would suggest a local (around London and around Amsterdam?) production for the different glasses. The unique sample from Kg10 with a composition close to the group 3 at the Hammersmith Embankment site (ABLA003) could be a coincidence or a glass produced at a larger center (Venice) which diffused its production through large portions of Europe.

This study reveals that it is not possible to characterize one type of glass for a single European production center that could be easily tracked to North America. The diversity of the compositions at one site along with the overlap of compositions between two sites makes glass bead sourcing complicated. A group 3 glass sample can be found in London as well as in Amsterdam. Group 1 glass from London has a composition that overlaps with most of the compositions identified in Amsterdam even if it seems that lower zirconium and niobium concentrations are associated more specifically with Amsterdam. The high trace element group 1, and group 2 and 4 compositions are unique to London according to this study but the analysis of more samples could blur this picture. More important, contemporary bead samples from a major beadmaking center such as Venice have not been adequately investigated. Thus, the variability of the compositions produced there is unknown and could well overlap with the compositions obtained at other European bead production centers.

5. Conclusion

At the Hammersmith Embankment site in London, all the glass artifacts are composed of soda-lime glass but different variations of this glass type were identified. Quite likely the glasses were produced from different qualities of soda plant ash. Ash could have been imported from different places or processed differently. Distinct types of sand were used as indicated by different trace element patterns in the glass. Based on the soda and lime concentrations, similar variations in glass recipes were found in Amsterdam. Because of the heterogeneity of the glass compositions at the Hammersmith Embankment and Kg10 beadmaking sites, the glass was quite likely not manufactured on site but was procured from different outside sources. Maybe some glass manufacturers specialized in a limited number of colors as suggested by the strong correlation found between glass types and colors. It does not seem that raw glass or semi-finished products (tubes, glass rods for applying stripes) were manufactured in a centralized place and distributed all over Europe as suggested by compositional variation in the glass artifacts found in London and Amsterdam. Perhaps smaller glass workshops provided glass for local glassworkers producing finished objects. Only the excavation of primary glassmaking centers and the chemical analysis of the glass finds at these sites will be able to clarify this point in the future.

The results of this study reveal that sourcing glass trade beads found in North America and West Africa will be challenging but might be possible in some cases. To fully assess the feasibility of sourcing these beads, samples from other bead manufacturing centers need to be tested and among them, the most important of all is Venice.

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Table 3. Composition of the glass samples found at the Hammersmith Embankment and Kg10 sites. Major and minor elements are in %w of oxide and trace elements are in ppm of element. "<ld" stands for "below the detection limits".

Location	London	London	London	London	London	London	London
Group attribution	Group 1	Group 1	Group 1	Group 1	Group 1	Group 1	Group 1
color	red	red	dark blue	red	dark blue	dark blue	red
reference number	LON022R	15Red	26db_ext	LON023	LON032DB	LON002db	LON022G
SiO ₂	60.6%	62.9%	58.1%	57.7%	63.5%	62.9%	57.0%
Na ₂ O	10.7%	11.1%	11.1%	11.3%	12.3%	12.4%	11.4%
MgO	2.70%	2.82%	2.59%	2.63%	2.63%	2.83%	2.66%
Al ₂ O ₃	4.27%	2.41%	1.25%	2.84%	1.43%	1.51%	2.48%
P ₂ O ₅	0.26%	0.28%	0.25%	0.25%	0.30%	0.23%	0.25%
K ₂ O	3.09%	2.96%	3.20%	2.98%	4.18%	5.12%	2.92%
CaO	10.1%	10.0%	11.0%	9.3%	10.2%	10.1%	10.0%
MnO	0.23%	0.53%	0.51%	0.28%	0.59%	0.63%	0.25%
Fe ₂ O ₃	0.97%	0.79%	0.15%	1.15%	0.55%	0.45%	1.07%
CuO	1.13%	0.39%	0.04%	1.32%	0.02%	0.04%	2.47%
SnO ₂	2.61%	2.35%	4.68%	3.54%	1.19%	1.42%	3.18%
PbO	3.04%	3.11%	6.51%	6.40%	2.43%	1.78%	5.99%
Li	80.3	57.1	26.3	51.0	24.6	28.0	72.8
Be	2.8	2.1	1.1	3.2	1.7	1.1	2.0
B	59.1	63.9	66.9	55.8	58.0	63.9	57.6
Sc	6.7	8.6	2.5	6.6	4.2	6.2	5.7
Ti	1480.4	535.4	421.8	831.8	439.0	434.7	812.9
V	112.3	46.1	22.5	63.1	21.0	20.7	61.5
Cr	33.2	39.3	13.7	30.1	19.5	26.9	27.7
Ni	94.5	94.2	236.0	101.9	222.5	610.8	90.4
Co	169.5	232.2	1175.4	223.8	1160.2	1650.5	164.0
Zn	106.6	78.2	80.9	111.0	73.0	84.7	109.1
As	266.3	225.8	2019.1	382.3	1327.6	6037.8	326.4
Rb	25.5	20.3	17.9	22.9	20.3	25.6	20.6
Sr	512.7	618.2	639.5	507.8	523.8	398.1	532.7
Zr	118.7	68.7	68.3	89.1	52.8	60.7	81.2
Nb	6.6	3.6	2.9	4.1	2.8	2.7	3.9
Ag	1.9	0.8	4.7	3.5	3.5	2.5	4.8
Sb	43.4	17.3	29.6	48.4	9.6	6.9	51.7
Cs	1.1	0.8	0.5	0.8	0.6	0.8	0.6
Ba	369.5	721.5	716.1	355.8	384.0	330.3	327.5
La	14.3	17.2	6.4	10.2	6.3	6.2	9.3

Ce	26.1	32.6	12.3	19.6	11.4	11.7	17.6
Pr	3.4	4.2	1.6	2.4	1.5	1.5	2.2
Ta	0.5	0.3	0.3	0.3	0.2	0.2	0.2
Au	0.6	0.2	0.4	0.6	0.6	0.3	0.3
Y	13.4	10.3	5.2	9.9	5.2	5.2	8.9
Bi	20.9	34.0	489.5	56.8	447.6	596.0	42.0
U	2.3	2.7	5.3	2.0	4.3	8.4	1.6
W	0.8	1.7	1.7	0.8	3.2	1.0	0.5
Mo	4.9	6.6	15.4	5.1	15.8	16.7	3.9
Nd	11.7	15.5	6.0	9.2	5.4	5.3	7.9
Sm	2.9	3.2	1.2	2.3	1.1	1.2	1.9
Eu	0.6	0.8	0.3	0.5	0.3	0.2	0.4
Gd	2.6	2.8	1.3	1.9	1.0	1.0	1.7
Tb	0.4	0.4	0.2	0.3	0.2	0.2	0.2
Dy	2.2	1.9	1.2	1.7	0.8	0.9	1.5
Ho	0.5	0.4	0.2	0.4	0.2	0.2	0.3
Er	1.4	1.1	0.6	1.1	0.5	0.5	0.9
Tm	0.2	0.2	0.1	0.2	0.1	0.1	0.2
Yb	1.5	1.0	0.7	1.1	0.5	0.6	1.0
Lu	0.3	0.2	0.1	0.2	0.1	0.1	0.2
Hf	2.9	2.3	2.6	2.4	1.6	1.7	2.1
Th	3.2	2.8	1.9	2.7	1.6	1.6	2.2

London Group 1	London Group 1 dark blue	London Group 1 red and blue	London Group 1 dark blue	London Group 1 dark blue ?	London Group 1 dark blue	London Group 1 white	London Group 1 dark blue	London Group 1 dark blue
16red	42CoB	LON009R	41CoB	LON001db_int	26db_int	LON009W	43CoB	LON001db_ext
54.5%	59.4%	57.4%	58.7%	64.9%	60.9%	51.3%	59.4%	65.3%
10.7%	12.0%	11.9%	12.0%	13.0%	12.3%	10.9%	12.4%	13.4%
2.49%	2.66%	2.63%	2.57%	2.90%	2.85%	2.45%	2.71%	3.00%
1.59%	1.30%	1.45%	1.35%	1.50%	1.34%	1.12%	1.27%	1.25%
0.25%	0.26%	0.20%	0.29%	0.27%	0.27%	0.17%	0.26%	0.29%
3.03%	3.29%	4.53%	3.38%	3.29%	3.51%	4.36%	3.53%	3.52%
8.9%	10.8%	9.5%	10.7%	10.5%	10.5%	10.2%	11.0%	10.7%
0.45%	0.47%	0.54%	0.45%	0.43%	0.52%	0.35%	0.51%	0.27%
0.75%	0.33%	1.48%	0.37%	0.54%	0.23%	0.56%	0.32%	0.43%
1.26%	0.04%	1.42%	0.03%	0.02%	0.04%	0.02%	0.04%	0.02%
4.44%	3.21%	3.87%	3.39%	0.56%	1.85%	8.40%	2.80%	0.42%
11.14%	5.30%	4.76%	5.89%	1.48%	5.07%	9.79%	4.90%	0.87%
23.8	38.8	22.8	30.1	25.6	27.7	17.9	30.7	25.5
1.1	1.0	0.5	1.4	0.7	1.0	0.5	1.5	1.0
58.6	65.4	53.1	71.2	66.2	71.8	48.3	70.3	70.9
5.6	2.0	4.3	2.2	6.8	3.1	3.9	2.0	4.8
391.8	485.5	468.2	527.7	395.2	380.4	441.8	488.8	358.8
27.0	21.5	17.3	32.9	24.5	19.8	11.2	20.9	17.3
23.1	11.6	20.4	16.7	32.9	16.7	20.0	10.9	26.1
79.9	173.1	45.7	166.5	49.6	134.7	13.3	127.8	194.5
172.2	898.2	49.1	870.4	215.2	679.7	6.4	641.3	1294.8
94.4	84.8	83.7	91.4	80.0	74.1	53.4	75.7	51.9
391.0	1788.4	188.8	1657.2	500.6	1388.6	127.1	1280.3	2609.7
16.6	18.3	21.7	17.5	17.3	19.7	19.6	17.0	18.8
586.8	605.7	373.9	576.9	687.0	690.2	308.9	598.1	706.7
63.4	55.7	52.9	52.0	66.8	64.9	51.7	53.0	64.2
2.8	2.5	2.5	2.5	2.9	2.9	2.3	2.5	2.7
5.3	3.4	5.3	3.9	1.3	3.0	4.4	3.0	1.9
38.8	29.5	42.9	26.8	13.2	29.2	8.3	28.4	6.7
0.4	0.5	0.5	0.6	0.4	0.5	0.5	0.4	0.5
602.5	595.7	271.0	583.1	444.7	686.5	227.1	628.9	200.2
7.7	5.7	5.5	5.5	6.6	7.0	4.3	5.2	6.0
14.1	10.9	10.6	10.7	12.1	12.5	8.4	9.9	11.8
1.8	1.4	1.4	1.4	1.6	1.7	1.1	1.3	1.5
0.2	0.2	0.3	0.2	0.2	0.3	0.2	0.3	0.3
0.2	0.3	0.3	0.4	0.2	0.3	0.3	0.3	0.2
5.9	4.4	4.2	4.4	5.0	5.3	3.2	4.0	4.8

84.0	285.7	18.3	261.5	70.9	261.0	2.0	209.8	390.0
1.9	3.3	1.7	2.9	1.7	3.7	0.6	2.6	5.6
1.2	1.2	2.1	1.1	0.7	1.3	7.2	1.2	1.5
5.6	10.3	1.9	9.4	4.3	8.6	1.4	7.4	14.3
6.9	4.9	5.3	5.0	5.4	6.6	4.1	4.8	5.6
1.6	1.3	1.3	1.1	1.3	1.5	1.1	1.1	1.3
0.3	0.3	0.2	0.3	0.3	0.3	0.2	0.2	0.2
1.2	1.1	1.2	1.1	1.4	1.5	0.9	1.0	1.1
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2
1.2	0.9	0.8	1.0	0.9	1.0	0.9	0.8	1.1
0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2
0.7	0.6	0.5	0.5	0.6	0.9	0.5	0.6	0.6
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0.7	1.0	0.6	0.6	0.7	0.7	0.4	0.5	0.6
0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
2.0	1.8	1.8	1.9	2.1	2.3	1.8	1.6	2.2
1.9	1.7	1.9	1.8	1.7	2.0	1.5	1.6	1.7

London Group 1 dark blue	London Group 1 red	London Group 1 dark blue	London Group 1 red	London Group 1 dark blue	London Group 1 dark blue	London Group 1 red	London Group 1 white	London Group 1 white
49CoB_4	20red	LON036	14xRed	48CoB	LON035	14Red	13white	26w
65.8%	54.2%	60.7%	57.6%	65.0%	61.6%	57.4%	48.6%	41.5%
13.6%	11.2%	12.7%	11.9%	13.6%	13.0%	12.0%	10.3%	8.8%
2.75%	2.46%	2.88%	2.56%	2.98%	2.95%	2.60%	2.28%	2.03%
1.50%	1.67%	1.45%	1.41%	1.47%	1.47%	1.31%	1.12%	0.85%
0.18%	0.27%	0.27%	0.27%	0.23%	0.28%	0.27%	0.19%	0.16%
4.76%	3.07%	3.33%	3.19%	5.05%	3.31%	3.28%	3.93%	2.14%
10.1%	8.2%	10.9%	9.2%	10.0%	11.1%	9.4%	7.6%	7.6%
0.06%	0.45%	0.49%	0.48%	0.05%	0.51%	0.49%	0.65%	0.36%
0.40%	0.72%	0.58%	0.72%	0.62%	0.65%	0.62%	0.42%	0.20%
0.02%	1.44%	0.04%	0.78%	0.01%	0.05%	0.78%	0.11%	0.01%
0.04%	3.38%	2.01%	3.07%	0.02%	1.94%	3.04%	10.56%	8.77%
0.07%	12.41%	4.05%	8.15%	0.04%	2.56%	8.24%	13.67%	26.98%
24.1	19.0	34.3	21.7	20.8	41.7	23.0	15.8	13.5
0.7	1.3	0.9	1.2	0.8	1.0	1.2	0.7	0.6
61.8	55.9	55.8	66.6	67.8	54.7	64.0	53.7	47.1
2.3	5.6	4.7	6.2	3.5	4.5	4.8	5.1	2.8
562.6	390.5	454.7	354.3	545.3	489.8	343.3	309.1	247.9
16.8	32.5	18.1	23.8	14.4	24.0	21.4	16.0	12.4
10.7	22.8	21.2	29.6	17.5	23.5	24.3	32.2	12.2
255.0	82.9	148.8	86.5	266.3	150.3	87.2	25.6	21.5
664.3	169.9	757.9	216.8	573.3	766.7	215.5	23.3	45.8
47.2	90.7	59.7	84.7	48.1	64.7	87.0	65.6	37.0
1080.5	420.2	1082.4	498.6	1522.3	765.9	525.4	181.6	183.5
22.8	16.6	16.2	16.7	21.6	16.4	16.1	20.0	10.8
354.3	572.0	557.8	599.2	329.0	565.9	588.2	333.5	542.4
57.9	58.6	52.6	57.3	51.6	52.1	54.4	44.0	51.1
2.7	2.8	2.4	2.6	2.4	2.5	2.4	2.1	2.0
0.4	8.2	2.2	4.1	0.6	1.1	4.4	5.4	7.9
1.9	42.5	33.5	26.9	2.2	30.1	28.4	11.4	20.9
0.6	0.4	0.4	0.4	0.6	0.5	0.3	0.5	0.2
135.5	606.8	531.0	624.9	110.0	553.0	620.2	320.8	923.1
5.6	7.6	4.8	6.7	4.4	4.9	6.0	5.1	5.2
11.0	14.2	8.7	12.5	9.3	9.5	11.3	9.6	9.7
1.4	1.9	1.2	1.6	1.2	1.2	1.5	1.2	1.3
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.1	0.3	2.4	0.3	0.1	1.2	0.2	0.3	1.0
4.4	5.6	4.3	5.0	3.6	4.2	4.6	3.7	3.6

123.9	89.4	228.1	109.4	133.9	149.1	115.6	23.1	68.0
3.5	2.3	2.5	1.9	2.7	2.5	2.0	0.8	1.0
0.4	1.2	0.9	1.5	0.3	1.0	1.5	2.2	0.8
7.1	5.3	9.4	6.0	7.8	9.3	6.0	1.7	1.3
4.9	6.4	4.2	5.9	4.1	4.1	5.6	4.6	4.7
1.0	1.3	0.9	1.4	0.8	0.9	1.2	1.0	1.1
0.2	0.3	0.2	0.3	0.2	0.2	0.3	0.2	0.2
0.8	1.4	0.9	1.2	0.7	0.8	1.2	1.1	0.8
0.2	0.2	0.1	0.2	0.1	0.1	0.2	0.2	0.1
0.8	1.1	0.8	1.1	1.0	0.7	0.9	0.9	0.7
0.2	0.2	0.1	0.2	0.1	0.2	0.2	0.2	0.2
0.5	0.8	0.4	0.6	0.4	0.5	0.7	0.4	0.5
0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.1
0.5	0.7	0.4	0.6	0.4	0.5	0.4	0.5	0.5
0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
1.7	2.1	1.5	1.9	1.5	1.4	1.8	1.5	1.9
1.9	2.2	1.3	1.7	1.7	1.4	1.6	1.6	1.6

London Group 1 red 11Red	London Group 1 red 13red	London Group 1 white LON002w	London Group 1 clear LON050	London Group 1 white LON001w	London Group 1 red LON002red	London Group 1 Blue LON009B	London Group 1 amber LON051	London Group 1 amber LON051I
55.9%	55.9%	45.8%	64.4%	50.4%	56.3%	60.2%	65.1%	64.0%
12.0%	12.0%	10.1%	13.9%	10.8%	12.2%	13.4%	14.0%	14.1%
2.62%	2.66%	2.20%	2.87%	2.42%	2.63%	2.97%	2.64%	2.75%
1.56%	1.52%	1.09%	1.26%	0.94%	1.54%	1.55%	1.58%	1.58%
0.27%	0.24%	0.16%	0.29%	0.21%	0.23%	0.26%	0.31%	0.34%
4.12%	4.17%	4.07%	3.13%	2.67%	4.01%	4.97%	4.33%	4.10%
8.5%	8.2%	7.9%	12.2%	8.5%	8.5%	10.2%	10.4%	11.3%
0.52%	0.50%	0.75%	0.56%	0.44%	0.48%	0.64%	0.58%	0.52%
1.05%	1.04%	0.30%	0.52%	0.44%	0.81%	0.91%	0.55%	0.78%
1.53%	1.61%	0.05%	0.07%	0.01%	1.30%	0.05%	0.01%	0.02%
4.27%	3.75%	12.67%	0.09%	4.45%	3.49%	2.51%	0.01%	0.02%
7.22%	7.98%	14.35%	0.18%	18.05%	8.03%	1.87%	0.02%	0.02%
22.3	22.2	17.2	18.1	13.9	21.3	28.3	22.0	21.3
0.8	0.9	0.7	0.5	0.8	0.7	0.7	0.8	1.2
63.2	65.5	48.3	103.5	53.9	59.0	60.8	86.2	85.0
5.9	5.7	4.8	3.9	5.5	5.6	4.7	4.5	4.2
414.0	395.8	312.8	428.6	265.5	387.1	529.6	593.6	540.4
32.5	23.9	12.2	12.5	12.5	21.2	17.9	16.1	15.1
35.3	28.8	20.7	20.7	23.1	21.8	32.9	22.2	25.6
112.7	102.6	21.8	9.0	23.4	107.8	24.9	21.7	16.4
216.0	195.0	13.0	11.5	47.2	221.9	36.3	47.9	29.0
92.7	87.9	54.3	26.7	43.9	76.1	53.2	70.1	58.1
695.8	651.1	139.2	140.9	207.7	656.6	179.8	171.3	178.8
20.8	21.5	20.4	14.4	13.0	20.9	22.6	27.1	24.1
424.3	434.5	317.7	657.9	591.6	466.2	372.5	456.2	490.7
53.2	52.9	44.8	56.4	48.5	53.9	52.9	74.8	56.1
2.9	2.8	2.1	2.4	2.0	2.6	2.7	3.2	3.0
8.0	7.4	5.7	0.8	5.2	5.8	2.5	0.6	2.7
47.2	59.9	9.5	1.4	37.7	66.9	10.3	2.0	2.2
0.5	0.6	0.4	0.2	0.3	0.5	0.7	0.5	0.4
390.4	442.8	244.3	575.4	914.4	520.7	205.1	365.8	216.4
6.5	6.5	4.6	4.2	4.7	6.4	5.2	6.9	6.2
12.5	12.3	8.8	8.2	8.9	12.2	9.7	12.8	11.8
1.6	1.6	1.1	1.1	1.2	1.5	1.3	1.6	1.5
0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2
0.2	0.5	0.2	0.3	0.8	0.3	0.7	0.1	0.3
5.3	5.1	3.5	3.5	3.4	4.9	4.2	5.4	5.2
76.6	79.7	12.5	3.6	61.8	89.0	10.4	20.1	26.0

2.3	2.4	0.6	0.8	1.1	3.0	1.1	1.3	1.0
1.5	2.2	3.1	0.2	0.5	1.3	1.0	2.0	1.6
4.2	4.0	1.3	0.8	1.6	4.2	1.8	1.6	1.3
5.7	6.0	4.1	3.9	4.3	5.6	5.1	6.0	5.5
1.2	1.3	1.0	0.8	1.0	1.1	1.9	1.3	1.2
0.5	0.3	0.2	0.2	0.2	0.3	0.3	0.2	0.2
1.2	1.1	1.1	0.7	0.9	1.1	1.5	1.1	1.0
0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2
0.9	1.0	0.7	0.6	0.8	1.0	1.3	1.0	0.9
0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2
0.6	0.6	0.5	0.3	0.5	0.5	0.7	0.6	0.5
0.1	0.1	0.1	0.1	0.0	0.1	0.2	0.1	0.1
0.7	0.5	0.5	0.3	0.4	0.6	1.3	0.5	0.5
0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1
1.6	1.9	1.5	1.6	1.9	1.8	1.7	2.2	1.6
1.8	1.9	1.6	1.4	1.3	1.9	1.8	1.9	2.0

London Group 1	London Group 1	London Group 2	London Group 2	London Group 2	London Group 2	London Group 2	London Group 3	London Group 3
white	amber	dark blue	dark blue	dark blue	dark blue	purple	purple	purple
LON053	LON052	45CoB	46CoB	47CoB	44CoB	LON060	LON059	LON062
62.5%	63.9%	64.5%	65.2%	65.0%	64.5%	63.5%	66.5%	67.7%
14.2%	14.6%	14.6%	14.8%	14.7%	14.7%	16.4%	19.1%	16.5%
3.02%	2.70%	2.12%	2.35%	2.40%	2.36%	2.52%	1.72%	1.99%
1.40%	1.53%	2.09%	1.70%	1.60%	1.68%	1.56%	1.77%	1.73%
0.25%	0.32%	0.35%	0.28%	0.28%	0.29%	0.26%	0.31%	0.33%
5.18%	4.55%	4.84%	4.42%	4.61%	4.49%	4.14%	3.21%	3.54%
11.5%	10.8%	6.6%	6.8%	7.0%	7.7%	9.4%	4.7%	5.1%
0.59%	0.50%	3.06%	2.70%	2.43%	2.67%	0.97%	1.25%	1.80%
0.46%	0.52%	0.67%	0.69%	0.82%	0.51%	0.57%	0.70%	0.57%
0.01%	0.01%	0.03%	0.02%	0.02%	0.02%	0.01%	0.01%	0.05%
0.19%	0.01%	0.01%	0.02%	0.04%	0.02%	0.00%	0.00%	0.00%
0.15%	0.03%	0.03%	0.03%	0.03%	0.03%	0.02%	0.01%	0.02%
23.7	20.8	23.1	19.6	19.1	20.6	16.9	12.6	16.0
0.3	1.0	4.7	2.9	2.3	2.9	2.0	2.9	2.9
75.5	83.0	78.3	70.2	64.9	78.1	64.9	63.8	63.5
4.5	4.5	2.8	3.6	4.3	2.2	4.3	4.1	4.5
562.8	609.1	878.8	682.6	651.1	716.6	668.1	929.3	921.1
14.1	16.5	31.9	20.3	21.3	23.5	17.0	19.3	20.9
20.6	20.6	17.6	19.9	24.0	12.3	23.9	24.0	25.8
13.4	19.6	203.1	249.2	248.2	252.2	8.2	11.3	13.6
14.6	41.8	589.2	667.8	669.2	706.0	8.0	16.3	16.9
41.6	75.3	111.0	87.0	88.7	102.7	66.7	68.5	283.2
132.5	171.5	1083.2	1333.5	1370.0	1282.3	95.8	115.1	112.5
25.7	29.2	22.7	18.0	20.2	18.8	19.3	13.7	22.2
455.7	456.9	299.3	280.6	280.5	304.5	315.9	196.7	202.9
59.5	73.1	67.7	59.9	56.3	59.0	61.0	77.7	74.3
2.7	3.6	7.6	5.4	5.0	5.0	5.0	10.0	9.4
0.6	0.3	0.4	0.3	0.3	0.5	0.3	0.2	18.7
1.2	1.9	3.1	2.6	2.4	3.0	1.7	1.6	2.2
0.6	0.5	0.6	0.4	0.3	0.5	0.5	0.2	0.5
214.3	314.3	465.3	392.2	329.2	431.6	296.6	342.6	339.7
5.7	7.1	8.4	6.6	6.1	6.9	6.2	8.7	8.7
11.1	13.1	15.8	11.1	10.8	12.3	12.1	15.4	15.3
1.4	1.6	2.0	1.5	1.4	1.6	1.5	1.9	2.0
0.2	0.2	0.4	0.3	0.3	0.3	0.3	0.6	0.6
0.4	0.2	0.1	0.3	0.1	0.1	0.3	1.1	1.1
4.2	5.5	6.4	6.2	5.7	5.9	6.2	7.2	8.8

4.9	19.8	184.7	167.5	151.3	161.1	2.1	2.9	2.4
0.6	1.5	3.5	3.5	3.5	3.7	1.2	1.4	1.7
0.2	1.6	3.9	2.7	2.3	2.6	2.2	3.2	3.2
0.8	1.7	4.8	5.5	5.5	6.2	0.8	0.9	1.0
4.9	6.2	6.9	5.5	5.2	5.7	5.6	6.8	7.4
1.0	1.3	1.6	1.4	1.1	1.4	1.3	1.5	1.7
0.2	0.3	0.3	0.2	0.2	0.3	0.2	0.3	0.4
0.9	1.0	1.3	1.1	1.0	1.2	1.1	1.3	1.9
0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.3
0.8	1.0	1.0	0.9	0.8	1.1	1.1	1.1	1.6
0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3
0.5	0.6	0.6	0.5	0.5	0.7	0.6	0.7	0.9
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0.5	0.6	0.6	0.5	0.5	0.6	0.7	0.6	0.8
0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
1.7	2.1	1.6	1.5	1.4	1.4	1.7	2.0	2.1
1.9	1.9	2.1	1.5	1.5	1.5	1.8	1.9	1.8

London Group 3	London Group 3	London Group 3	London Group 4	London Group 4	London Group 4 dark	Amsterdam ?	Amsterdam ?	Amsterdam group 3
purple	purple	purple	red	white	blue	black	black	black
LON058	LON061	LON057	11white	LON032W	38db	ABLA001	ABLA002	ABLA003
65.3%	65.5%	65.0%	42.1%	41.6%	69.6%	57.1%	58.8%	63.3%
18.4%	17.9%	18.1%	5.3%	5.5%	9.2%	12.2%	11.2%	17.9%
1.79%	1.89%	1.97%	1.37%	1.48%	2.80%	3.99%	3.71%	1.58%
1.77%	1.84%	1.69%	2.97%	1.83%	2.62%	2.86%	2.67%	2.36%
0.32%	0.33%	0.31%	1.06%	2.75%	0.23%	0.46%	0.44%	0.36%
3.58%	3.58%	3.59%	2.52%	1.51%	3.87%	2.39%	2.26%	5.18%
5.3%	5.9%	6.2%	7.2%	7.9%	10.5%	10.2%	10.7%	3.42%
2.24%	1.80%	2.10%	0.47%	0.29%	0.09%	6.80%	6.63%	1.28%
0.59%	0.59%	0.31%	0.46%	0.56%	0.71%	1.87%	1.72%	0.96%
0.01%	0.01%	0.01%	0.04%	0.01%	0.08%	0.17%	0.15%	0.11%
0.00%	0.00%	0.00%	21.43%	9.10%	0.08%	0.72%	0.64%	0.91%
0.02%	0.02%	0.01%	14.75%	26.97%	0.09%	0.78%	0.66%	1.30%
13.5	15.0	13.5	7.1	8.2	51.3	14.3	14.1	41.2
5.3	3.2	3.3	1.7	1.3	1.3	0.9	0.8	1.1
61.7	63.6	63.3	37.1	30.0	38.7	96.6	87.9	55.7
3.3	4.5	2.5	8.6	5.0	9.9	2.5	2.4	2.1
894.1	882.9	867.6	568.5	563.7	746.9	444.2	423.5	695.2
22.6	25.8	19.6	186.3	385.5	41.3	19.0	17.7	13.4
23.7	25.5	15.1	226.4	29.2	45.0	29.4	27.1	9.8
9.6	10.9	7.8	29.3	22.0	235.1	121.9	109.6	84.4
17.2	16.1	8.9	35.7	39.8	482.4	214.3	204.4	160.1
86.4	95.9	108.2	73.6	111.5	60.9	64.9	71.4	75.1
126.8	111.1	115.9	187.4	316.7	503.8	464.2	467.6	249.8
16.6	14.7	13.6	14.2	8.4	25.8	21.5	23.4	27.5
214.6	229.1	241.2	257.9	368.8	351.7	490.9	456.0	194.8
74.1	71.5	71.8	87.0	77.6	86.7	36.3	35.6	76.2
9.2	8.6	8.3	5.3	3.5	4.4	2.5	2.4	9.0
0.2	0.2	1.0	6.9	4.4	1.0	1.1	0.9	1.4
2.4	2.4	2.1	18.8	18.2	2.7	16.0	14.5	11.0
0.2	0.5	0.2	0.4	0.3	0.6	0.4	0.5	0.5
603.9	442.6	392.2	219.5	621.0	228.9	435.9	400.9	717.1
8.4	8.6	8.0	10.1	9.6	11.5	6.9	7.0	9.6
16.0	15.3	14.0	22.8	16.8	20.2	14.7	14.6	17.3
2.0	2.1	1.8	3.1	2.4	2.4	1.7	1.8	2.1
0.5	0.6	0.5	0.3	0.2	0.3	0.2	0.2	0.5
0.4	0.6	0.1	0.6	2.2	0.4	0.0	0.0	0.2
9.3	9.3	9.7	11.4	7.0	8.6	6.6	6.8	7.4
2.7	2.8	1.7	34.1	129.9	57.6	64.7	60.8	178.7

2.1	1.8	1.8	0.7	7.9	3.7	2.6	2.5	7.4
5.0	5.6	4.2	2.2	0.7	1.1	6.2	5.3	40.7
1.1	1.8	1.4	1.5	3.5	19.7	6.6	6.3	2.1
7.3	7.4	6.5	11.3	8.8	9.1	6.3	6.4	7.6
1.7	1.9	1.7	2.6	1.9	2.0	1.3	1.3	1.6
0.3	0.4	0.3	0.7	0.4	0.4	0.3	0.3	0.4
1.5	1.8	1.5	2.7	1.7	1.8	1.1	1.2	1.4
0.2	0.2	0.2	0.4	0.2	0.3	0.2	0.2	0.2
1.5	1.5	1.6	3.1	1.4	1.6	1.1	1.1	1.5
0.3	0.3	0.3	0.6	0.3	0.4	0.2	0.2	0.3
0.8	0.9	0.8	1.7	0.9	1.1	0.6	0.6	0.9
0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1
0.7	0.8	0.9	1.6	0.7	1.0	0.6	0.6	0.9
0.1	0.1	0.1	0.3	0.1	0.2	0.1	0.1	0.1
1.9	2.0	2.0	2.7	2.6	2.7	1.0	1.0	2.0
2.0	2.0	2.0	2.6	2.5	2.8	1.7	1.7	2.0

Amsterdam ?	Amsterdam ?	Amsterdam ?	Amsterdam ?	Amsterdam ?	Amsterdam ?	Amsterdam ?
turquoise blue	turquoise blue	turquoise blue	red	red	red	dark blue
ABLU001	ABLU002	ABLU003	ARED001	ARED002	ARED003	ACOB001
69.1%	65.6%	65.7%	65.5%	60.2%	56.2%	64.9%
15.5%	18.0%	18.8%	14.9%	11.9%	11.3%	14.8%
2.02%	2.22%	1.71%	2.39%	2.47%	2.36%	3.26%
1.46%	1.10%	1.09%	1.48%	1.32%	1.69%	1.81%
0.21%	0.21%	0.23%	0.27%	0.21%	0.21%	0.35%
2.64%	3.07%	2.95%	4.20%	5.82%	4.89%	2.70%
5.53%	6.19%	6.20%	9.27%	8.13%	6.85%	9.54%
0.19%	0.05%	0.05%	0.50%	0.50%	0.41%	0.39%
0.48%	0.43%	0.57%	0.47%	1.28%	5.34%	1.12%
1.10%	1.10%	1.24%	0.01%	0.41%	1.83%	0.05%
0.03%	0.03%	0.01%	0.02%	2.24%	2.56%	0.08%
0.16%	0.06%	0.03%	0.05%	4.91%	5.54%	0.15%
5.8	6.4	11.2	16.7	13.6	18.3	16.8
0.5	0.2	0.2	0.6	0.6	0.7	0.8
91.4	92.5	71.3	51.7	43.2	50.9	92.5
1.2	1.2	1.3	1.3	1.1	1.5	1.7
125.5	120.0	183.7	337.8	226.9	342.8	267.3
6.8	6.7	6.9	7.4	6.5	13.7	15.7
5.3	6.2	5.8	6.3	4.7	8.1	55.7
53.8	84.2	52.5	22.1	10.5	49.7	568.0
69.3	92.7	60.3	32.9	11.5	67.3	1668.5
50.8	43.4	49.4	35.9	54.1	231.0	93.1
178.1	81.9	225.2	44.2	28.0	196.1	2339.5
12.5	11.4	23.1	16.7	28.6	29.0	19.1
346.8	384.0	294.5	510.6	393.3	332.5	561.3
11.7	9.3	10.6	52.7	40.6	63.7	21.3
0.9	0.8	1.0	1.9	1.3	2.1	1.6
4.0	2.0	4.6	0.1	5.4	16.7	1.8
20.5	15.8	25.0	1.1	18.6	66.8	7.9
0.2	0.2	0.2	0.3	0.4	0.5	0.9
66.6	98.7	155.5	141.1	185.6	166.7	123.4
2.0	2.0	2.3	4.1	3.4	5.2	4.8
4.2	3.6	4.4	7.6	6.6	10.2	9.5
0.5	0.5	0.6	1.0	0.9	1.3	1.2
0.1	0.1	0.1	0.1	0.1	0.2	0.1
0.1	0.1	0.1	0.1	3.0	0.4	0.2
2.2	2.0	2.3	4.3	3.5	4.4	4.3
33.2	27.4	23.4	16.2	15.6	21.4	849.4

0.7	3.1	1.5	1.1	0.7	1.1	7.0
0.9	0.3	0.1	0.9	1.5	2.1	1.2
1.7	1.7	1.1	0.7	1.5	3.4	28.7
1.8	1.7	2.1	3.9	3.2	4.6	4.1
0.4	0.4	0.5	0.9	0.8	1.0	0.9
0.1	0.2	0.1	0.1	0.1	0.2	0.2
0.4	0.4	0.5	0.9	0.7	0.9	0.8
0.1	0.1	0.1	0.1	0.1	0.1	0.1
0.4	0.3	0.4	0.9	0.6	0.9	0.8
0.1	0.1	0.1	0.2	0.1	0.2	0.2
0.2	0.2	0.2	0.5	0.4	0.5	0.4
0.0	0.0	0.0	0.1	0.1	0.1	0.1
0.2	0.2	0.2	0.5	0.4	0.5	0.4
0.0	0.0	0.0	0.1	0.1	0.1	0.1
0.4	0.3	0.3	1.7	1.4	2.0	0.7
0.6	0.5	0.6	1.5	1.1	1.7	1.1

Amsterdam	Amsterdam	Amsterdam	Amsterdam	Amsterdam	Amsterdam	Amsterdam
?	high Zr	?	?	Si-Pb	High-Pb	High-Pb
dark blue	dark blue	colorless	colorless	yellow	yellow	yellow
ACOB002	ACOB003	AINC001	AINC002	AYEL001	AYEL002	AYEL003
62.7%	66.8%	67.7%	67.9%	40.1%	23.7%	23.0%
15.4%	12.5%	14.2%	14.3%	4.4%	0.01%	<dl
3.45%	2.79%	2.95%	2.57%	1.62%	0.06%	0.02%
1.65%	2.13%	2.04%	2.18%	1.27%	0.43%	0.10%
0.37%	0.32%	0.27%	0.26%	0.14%	0.02%	<dl
2.83%	4.20%	4.43%	4.48%	1.57%	0.15%	<dl
11.0%	8.43%	6.05%	6.09%	4.20%	0.14%	0.02%
0.43%	0.24%	0.40%	0.41%	0.48%	0.01%	0.004%
1.12%	1.03%	0.74%	0.73%	1.07%	0.42%	0.99%
0.03%	0.02%	0.01%	0.00%	0.42%	0.18%	0.03%
0.05%	0.22%	0.01%	0.01%	1.27%	2.18%	2.12%
0.09%	0.42%	0.02%	0.02%	36.80%	72.55%	73.32%
16.5	16.6	41.3	41.4	14.6	5.2	1.7
0.7	0.5	0.9	0.7	0.9	0.6	1.2
92.9	72.5	62.1	58.1	33.4	8.3	2.9
1.7	2.3	1.9	1.9	1.1	0.3	0.1
276.2	623.9	384.6	383.3	221.1	117.6	42.4
16.2	13.4	12.6	12.9	9.3	3.8	0.7
54.8	18.5	9.8	11.7	10.4	1.6	0.7
579.4	217.4	9.1	8.5	26.9	18.5	11.9
1702.1	720.8	10.1	10.3	21.4	3.4	0.6
80.9	48.8	52.4	40.7	115.4	32.5	7.0
2370.6	490.9	11.5	8.7	145.7	43.6	64.9
19.9	24.6	35.8	36.1	13.6	3.7	0.9
565.2	421.6	388.6	386.9	235.3	18.0	5.3
22.0	187.7	43.0	43.8	36.5	21.8	9.3
1.6	3.3	2.4	2.4	1.8	1.0	0.2
1.4	0.9	0.3	0.1	33.1	72.5	70.4
7.7	10.3	2.7	3.0	28033.4	746.7	1120.3
0.9	0.5	0.7	0.7	0.4	0.3	0.0
124.1	155.9	123.3	132.2	445.5	101.8	55.5
5.0	6.8	5.4	5.7	4.7	1.7	0.5
9.3	13.0	10.2	10.9	9.3	2.9	0.8
1.1	1.6	1.3	1.4	1.3	0.4	0.1
0.1	0.3	0.1	0.1	0.1	0.1	0.0
0.1	0.0	0.1	0.1	0.5	0.1	0.0
4.3	6.2	5.0	4.9	4.1	1.2	0.5
849.1	260.8	3.1	2.9	25.1	17.4	2.0
7.4	7.2	0.6	0.6	1.5	0.2	0.3

1.2	0.9	0.5	0.5	2.5	0.5	1.3
29.2	8.3	0.7	0.7	2.4	0.6	1.3
4.1	5.6	4.3	4.7	4.7	1.2	0.3
0.9	1.1	0.9	0.9	1.0	0.2	0.1
0.2	0.2	0.2	0.2	0.2	0.1	0.0
0.8	1.0	0.8	0.8	0.9	0.2	0.1
0.1	0.2	0.1	0.1	0.1	0.0	0.0
0.8	1.1	0.7	0.7	0.8	0.2	0.1
0.2	0.2	0.2	0.2	0.1	0.0	0.0
0.4	0.7	0.5	0.4	0.4	0.1	0.0
0.1	0.1	0.1	0.1	0.1	0.0	0.0
0.4	0.8	0.4	0.4	0.4	0.2	0.0
0.1	0.1	0.1	0.1	0.1	0.0	0.0
0.7	5.3	1.1	1.1	1.1	0.7	0.3
1.1	2.0	1.5	1.5	1.4	0.5	0.1

Amsterdam	Amsterdam	Amsterdam
?	?	?
white	white	white
AWHI001	AWHI002	AWHI003
63.0%	62.7%	62.4%
14.1%	13.7%	14.1%
3.84%	3.30%	3.19%
1.82%	1.70%	1.67%
0.23%	0.32%	0.34%
5.19%	5.50%	5.74%
9.13%	9.48%	9.21%
0.51%	0.63%	0.64%
0.68%	0.63%	0.61%
0.00%	0.01%	0.01%
0.10%	0.33%	0.29%
0.12%	0.32%	0.36%
27.6	15.9	16.1
0.8	1.0	0.9
50.0	62.6	60.8
1.5	1.3	1.3
483.3	382.6	383.4
10.7	10.4	10.4
7.8	7.3	6.9
13.2	6.7	7.7
17.0	23.3	23.2
119.2	80.6	82.0
5.6	18.8	23.0
22.8	44.2	47.2
479.0	417.5	409.9
50.1	55.9	54.7
2.1	1.7	1.7
0.2	0.1	0.1
2.0	5.5	6.3
0.3	0.3	0.4
180.9	148.5	147.1
5.1	4.2	4.3
10.2	8.0	8.1
1.2	1.0	1.0
0.1	0.1	0.1
0.0	0.1	0.2
4.3	3.8	3.6
7.0	3.1	3.2
1.1	0.6	0.7

0.5	0.7	0.6
1.1	0.8	0.9
4.1	3.5	3.6
0.8	0.7	0.7
0.2	0.1	0.1
0.7	0.6	0.6
0.1	0.1	0.1
0.7	0.5	0.6
0.1	0.1	0.1
0.4	0.3	0.3
0.1	0.0	0.0
0.4	0.3	0.3
0.1	0.0	0.0
1.2	1.3	1.4
1.4	1.2	1.2

Table 4. Reduced compositions.

		SiO2	Na2O	MgO	Al2O3	K2O	CaO	Fe2O3
Group 1	LON022R	65.5%	11.6%	2.93%	4.61%	3.34%	10.98%	1.05%
Group 1	15Red	67.6%	12.0%	3.04%	2.59%	3.18%	10.79%	0.85%
Group 1	26db_ext	66.4%	12.7%	2.96%	1.44%	3.66%	12.64%	0.17%
Group 1	LON023	65.7%	12.8%	2.99%	3.23%	3.39%	10.57%	1.31%
Group 1	LON032DB	67.0%	13.0%	2.78%	1.51%	4.40%	10.80%	0.58%
Group 1	LON002db	66.0%	13.0%	2.97%	1.59%	5.38%	10.57%	0.48%
Group 1	LON022G	65.1%	13.0%	3.04%	2.83%	3.34%	11.47%	1.22%
Group 1	16red	66.5%	13.0%	3.04%	1.94%	3.70%	10.90%	0.91%
Group 1	42CoB	66.2%	13.4%	2.96%	1.44%	3.66%	12.04%	0.37%
Group 1	LON009R	64.6%	13.4%	2.96%	1.63%	5.10%	10.68%	1.67%
Group 1	41CoB	65.9%	13.4%	2.89%	1.51%	3.80%	12.04%	0.42%
Group 1	LON001db_int	67.2%	13.4%	3.00%	1.55%	3.41%	10.83%	0.56%
Group 1	26db_int	66.5%	13.5%	3.11%	1.46%	3.83%	11.41%	0.25%
Group 1	LON009W	63.4%	13.5%	3.03%	1.38%	5.39%	12.59%	0.70%
Group 1	43CoB	65.5%	13.7%	2.99%	1.41%	3.89%	12.14%	0.35%
Group 1	LON001db_ext	66.9%	13.7%	3.07%	1.28%	3.61%	10.98%	0.44%
Group 1	49CoB_4	66.6%	13.7%	2.79%	1.52%	4.81%	10.18%	0.40%
Group 1	20red	66.4%	13.8%	3.02%	2.05%	3.76%	10.11%	0.88%
Group 1	LON036	65.6%	13.8%	3.11%	1.57%	3.60%	11.79%	0.62%
Group 1	14xRed	66.5%	13.8%	2.96%	1.62%	3.68%	10.64%	0.83%
Group 1	48CoB	65.8%	13.8%	3.02%	1.49%	5.11%	10.16%	0.63%
Group 1	LON035	65.4%	13.9%	3.13%	1.56%	3.51%	11.84%	0.69%
Group 1	14Red	66.3%	13.9%	3.01%	1.52%	3.79%	10.85%	0.72%
Group 1	13white	65.4%	13.9%	3.07%	1.51%	5.30%	10.23%	0.57%
Group 1	26w	65.7%	13.9%	3.21%	1.35%	3.40%	12.11%	0.32%
Group 1	11Red	65.2%	13.9%	3.06%	1.82%	4.81%	9.91%	1.23%
Group 1	13red	65.4%	14.0%	3.12%	1.78%	4.88%	9.61%	1.22%
Group 1	LON002w	64.1%	14.1%	3.08%	1.53%	5.69%	11.09%	0.42%
Group 1	LON050	65.5%	14.1%	2.92%	1.29%	3.19%	12.41%	0.53%
Group 1	LON001w	66.2%	14.2%	3.18%	1.23%	3.50%	11.20%	0.57%
Group 1	LON002red	65.5%	14.2%	3.06%	1.79%	4.67%	9.86%	0.95%
Group 1	LON009B	63.9%	14.2%	3.16%	1.65%	5.27%	10.88%	0.96%
Group 1	LON051	66.0%	14.2%	2.68%	1.60%	4.39%	10.51%	0.56%
Group 1	LON051I	65.0%	14.3%	2.79%	1.60%	4.16%	11.42%	0.79%
Group 1	LON053	63.6%	14.4%	3.07%	1.42%	5.27%	11.74%	0.47%
Group 1	LON052	64.8%	14.8%	2.74%	1.55%	4.61%	10.95%	0.53%
Group 2	45CoB	67.6%	15.3%	2.22%	2.19%	5.07%	6.96%	0.70%
Group 2	46CoB	67.9%	15.4%	2.46%	1.77%	4.61%	7.08%	0.72%

Group 2	47CoB	67.6%	15.3%	2.49%	1.67%	4.79%	7.25%	0.86%
Group 2	44CoB	67.2%	15.4%	2.46%	1.75%	4.68%	8.06%	0.53%
Group 2	LON060	64.7%	16.7%	2.57%	1.59%	4.22%	9.61%	0.58%
Group 3	LON059	68.1%	19.5%	1.76%	1.81%	3.29%	4.82%	0.71%
Group 3	LON062	69.7%	17.0%	2.05%	1.79%	3.64%	5.25%	0.58%
Group 3	LON058	67.5%	19.1%	1.85%	1.83%	3.70%	5.49%	0.61%
Group 3	LON061	67.4%	18.4%	1.94%	1.89%	3.68%	6.07%	0.61%
Group 3	LON057	67.1%	18.7%	2.03%	1.74%	3.70%	6.41%	0.32%
Group 4	11white	68.0%	8.5%	2.21%	4.80%	4.07%	11.65%	0.74%
Group 4	LON032W	68.8%	9.2%	2.45%	3.03%	2.50%	13.14%	0.93%
Group 4	38db	70.1%	9.3%	2.82%	2.64%	3.89%	10.57%	0.71%
?	ABLA001	63.0%	13.5%	4.4%	3.2%	2.6%	11.3%	2.1%
?	ABLA002	64.6%	12.3%	4.1%	2.9%	2.5%	11.7%	1.9%
group 3	ABLA003	66.8%	18.9%	1.7%	2.5%	5.5%	3.6%	1.0%
?	ABLU001	71.4%	16.0%	2.1%	1.5%	2.7%	5.7%	0.5%
?	ABLU002	67.9%	18.6%	2.3%	1.1%	3.2%	6.4%	0.5%
?	ABLU003	67.7%	19.4%	1.8%	1.1%	3.0%	6.4%	0.6%
?	ARED001	66.7%	15.1%	2.4%	1.5%	4.3%	9.4%	0.5%
?	ARED002	66.1%	13.1%	2.7%	1.4%	6.4%	8.9%	1.4%
?	ARED003	63.4%	12.8%	2.7%	1.9%	5.5%	7.7%	6.0%
?	ACOB001	66.2%	15.0%	3.3%	1.8%	2.8%	9.7%	1.1%
?	ACOB002	63.9%	15.7%	3.5%	1.7%	2.9%	11.2%	1.1%
high Zr	ACOB003	68.3%	12.8%	2.8%	2.2%	4.3%	8.6%	1.1%
?	AINC001	69.0%	14.5%	3.0%	2.1%	4.5%	6.2%	0.8%
?	AINC002	69.1%	14.5%	2.6%	2.2%	4.6%	6.2%	0.7%
Si-Pb	AYEL001	73.9%	8.2%	3.0%	2.3%	2.9%	7.7%	2.0%
High-Pb	AYEL002	95.1%	0.1%	0.2%	1.7%	0.6%	0.6%	1.7%
High-Pb	AYEL003	95.3%	0.0%	0.1%	0.4%	0.0%	0.1%	4.1%
?	AWHI001	64.4%	14.5%	3.9%	1.9%	5.3%	9.3%	0.7%
?	AWHI002	64.6%	14.2%	3.4%	1.8%	5.7%	9.8%	0.6%
?	AWHI003	64.4%	14.5%	3.3%	1.7%	5.9%	9.5%	0.6%