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ARCHAEOMETRICAL AND TYPOLOGICAL ANALYSIS OF 17TH CENTURY GLASS PRODUCTION IN SA GERRERIA WORKSHOP (MAJORCA, SPAIN)

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ABSTRACT

In this article, we conduct a study of 104 samples (pieces, technological elements, lumps and frit remains) recovered from the 17th century glass workshop of Sa Gerreria (Majorca, Spain). A SEM-EDS analysis of the chemical composition of 104 samples and the analysis of distinct groupings obtained from a statistical treatment of the data using principle components analysis (PCA) have revealed the type of production developed in the workshop, at both the qualitative and the quantitative levels. On the one hand, this study has contributed interesting information regarding the characteristics of local production, particularly little known aspects such as the types of pieces manufactured and their diverse colourations and decorations. On the other hand, this study has allowed us to identify, for the first time through the study of the materials themselves, the existence of a group of typologically consistent samples that does not match the composition of the products made in this workshop and are most likely related to objects of an imported nature. In conclusion, this study has allowed us to develop a more in-depth understanding of the Island of Majorca's role in peripheral production, exchange networks, and the circulation of knowledge regarding the recipes and techniques used by the Sa Gerreria workshop and their relationship with production contexts closely linked to Barcelona and the territories that composed the ancient Crown of Aragon. This understanding has been developed for the first time from a new perspective that is not exclusively documentary.

KEYWORDS: Technology, History of Glass, SEM-EDS, Knowledge transmission, Trade.

1. INTRODUCTION

The quality and variety of forms of glass produced in 16th and 17th century Spain are largely due to the production of Catalonian workshops (e.g. Barcelona, Mataró) and workshops in other territories of the ancient Crown of Aragon. In these zones, the most innovative glassmakers fused the particularities of a rich local tradition with new technologies, typologies, and styles that originated on the Venetian island of Murano in the middle of the 16th century (Domènech, 1999; Rodríguez García, 1985). This process is similar to that which occurred in other European cities and is part of the phenomenon that specialized historiography has designated *à la façon de Venise* (Newman, 1977: 112). Some of the most significant techniques spread from Barcelona to other cities and peripheral zones through the trade of objects and the circulation of glass artisans (Camiade and Fontaine, 2006; Capellà, 2015). Being situated in a strategic enclave on the routes of the Western Mediterranean, the City of Majorca actively participated in these technical and cultural exchanges. For several years during the beginning of the 17th century, Domingo Barovier and his son, members of one of the most important families of master glassmakers of Murano, taught glassmakers on the island. However, it would appear that they had little success in this endeavour (Rodríguez García, 1988). In this respect, the work performed in Majorca was not isolated. To the contrary, the techniques used and the types of pieces manufactured were influenced by the workshops that developed in the surrounding area.

In this historical context, the main objective of the present study on the Sa Gerreria glass furnaces' materials is to provide more in-depth knowledge about regional production that revolved around Barcelona. This study begins with an initial archaeometric characterization of the materials (glass lumps, technological elements, and pieces) that were recovered from one of the few glass furnaces from the modern period archeologically documented in Spain. The analysis of these materials continues the work of previous studies that analysed the raw materials used in this furnace and some of the techniques used by 17th century glassmakers (Capellà and Albero, 2015). The archaeometric analysis performed using the materials from the Sa Gerreria workshop has been developed with several objectives in mind. On the one hand, the aim is to determine the chemical composition of the products manufactured by this furnace and to define a control group associated with the same, in addition to determining the degree of variability of the products. Doing so would allow us to identify what types of pieces were manufactured on the island and in this centre, which in turn would provide us with a much more complex understanding of the role that local production had within the general context described above. Finally, this study allows us to identify the possible existence of objects that follow differential production strategies and that could have been imported to the island. This is an important issue, since the pieces produced in the Western Mediterranean area have a noticeable typological similarity. We attempt to provide a more in-depth perspective on the typology of pieces and their possible relation with the recycling processes performed by local workshops and contrasted to the written documentation of the era (Capellà, 2015: 55). The information generated by this study is of great relevance because it will allow us to confirm, refute, or explain the data obtained from historical texts and from the typological analysis of objects held in private collections. Furthermore, it provides us with more solid knowledge concerning the networks that connected the islands with the continent. This knowledge forms not only part of the written documentation but also part of the material-based analysis itself.

2. MATERIALS AND METHODS

2.1. *The glass furnace of Sa Gerreria*

The glass materials analysed in this study were conserved in a ceramic container that was recovered during the archaeological excavations performed in the Sa Gerreria district, which is situated in the historic centre of the city of Palma (Figure 1). The archaeological campaign documented numerous industrial structures, which began to be installed in this sector of the city in the Middle Ages. In particular, structures related to pottery production were documented (Estarellas and Merino, 2006: 147-148). The clay vessel found appears to correspond to a structure associated with a glass furnace that gave the *Calle del Vídrio* (literally "Street of the Glass") its name, that disappeared during this urban reform, and that was previously referred to as the *Forn del Vidre Vell* (Zaforteza 1987). Documentary sources showing the urban layout in 1729-30 refer to block 151 as the *horno del vidrio viejo* (literally "old glass furnace") in, exactly where the studied workshop was located (Muntaner, 1977-78: 5-53). This urban toponymy was used in several occasions throughout the history of the city to refer to the place where a workshop, which was no longer active at the time that the document was written, was situated.

The container was buried underground in a zone with limited sediment potency and natural rock lying just below parts of the contemporary pavement. In some of the sectors, the first floors of the current buildings had been cut from the rock, destroying the remainder of the workshop's architectonic structures. Multiple indicators of this artisan activity appeared inside this deposit, in addition to some ceramic fragments produced in Pisa that had speckled and incised decoration. These vessels allowed us to perform a relative dating of the group of remains that linked them with the mid-17th century (Estarellas and Merino, 2006). There was also a highly deteriorated copper coin that had been minted in Majorca in the era of Felipe IV (1621-1665). This coin confirmed the chronological framework proposed for the use of the infrastructure. The conjecture that this workshop may have functioned beyond the first third of the 18th century can be discarded, given that no crystal fragments were identified amongst the recovered materials. Crystal is frequently found in the archaeological contexts and houses of this era, as can be inferred from the archival documents from the mid-18th century (Capellà, 2015: 216-217).

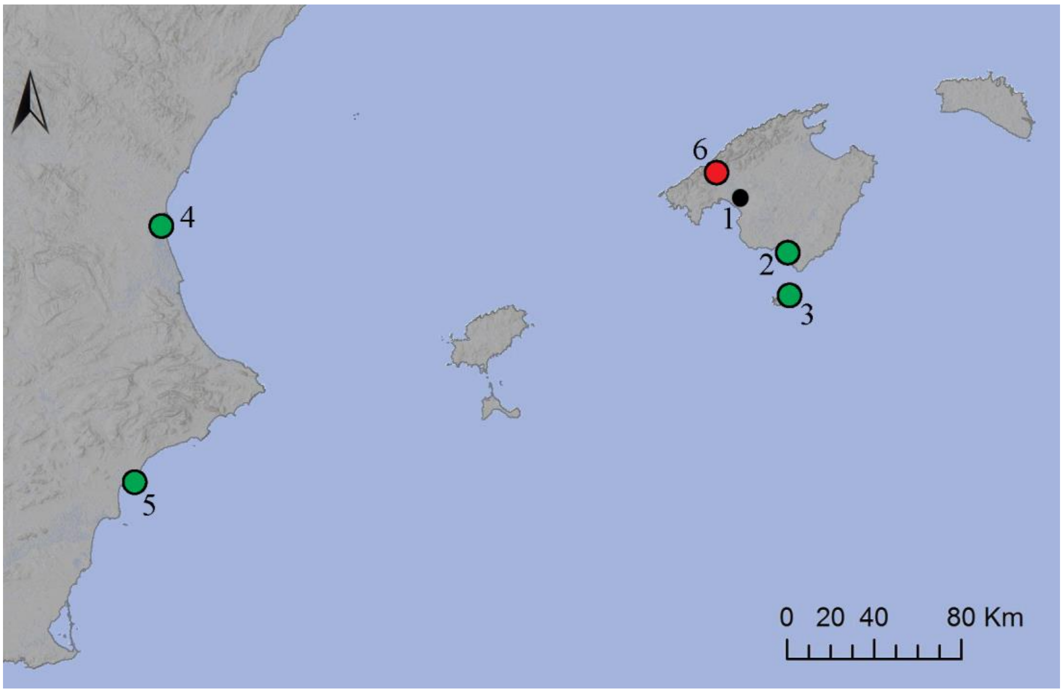

Figure 1. Map of the Balearic Islands and the area of "Levante" in the southeast of the Iberian Peninsula showing the location of the glass workshop of Sa Gerreria (1), the barilla plant production areas cited in the text (2 = Campos, 3 = Cabrera, 4 = Valencia, 5= Alicante) and the sand outcrops exploited according to the written sources (6).

The numerous remains associated with glass production are very well preserved because they have not come into direct contact with sediment and therefore show no signs of deterioration. The function of this deposit within the workshop's structure is not clear. The disparity of its contents indicates that it was a depository in which waste from the diverse labours of master glassmakers was accumulated. Another difficulty that presents itself in the interpretation of the deposit's function concerns the discernment of the length of time with which these materials are associated. They may be the product of a short period of activity, for example, an annual period, or they may be the result of a more prolonged period of production.

We have selected a total of 104 samples from the clay vessel to analyse their chemical composition by means of SEM-EDS. On the one hand, five glass lump fragments of diverse hues of green, honey-coloured, violet, and blue have been analysed. These glass lumps are the most important remains of the vessel's materials (3.808 g)[1]. The great majority respond to a standardized pattern of breakage, presenting similar dimensions of between 2 and 5 cm in length. The presence of direct impact on them suggests that they were broken with a metallic club (Figure 2A). The macroscopic analysis determines the existence of a conchoidal fracture that is characteristic of the impact and breakage patterns of glass. This finding shows the desire of the artisans to obtain fragments of regular dimensions that are then deposited in the crucibles to polish the glass lumps, preceding the blowing of objects. Additionally selected is a fragment that presents a more heterogeneous external aspect with defects from the fusion process (1.417 g) and that should be related to

[1] The weight in parentheses refers to the total number of samples recovered in the workshop.

the frits remains (Figure 2B).

On the other hand, we have selected 48 technological elements derived from the technical process of the production of pieces (Figures 2C and D). The most notable of these are flat pieces with one end folded over the other, flux-cored wires, flat elongated wires with a convex interior and a concave exterior that are most likely the result of scissor cuttings, and other remains identified by tong marks. Similarly, three flat glass fragments have been analysed (1.938 g). Seven samples that correspond to dark and light green, violet, honey-coloured, and colourless drops or teardrops that are also related to the production process have also been studied (2.324 g).

Finally, 50 fragments of glass pieces that had been conserved in the clay vessel have been selected. Everything suggests that these were gathered and stored so that they may be recycled. We suppose that the majority of these fragments are remains of pieces associated with the work of the glassmakers who used furnaces.

Figure 2. Photographs showing a selection of the materials recovered in the glass workshop of Sa Gerreria. A) Fragments of green glass lumps with the same standardized breakage pattern. B) Irregular frits fragments that present fusion defects. C and D) Production remains of green, violet, and diverse hues.

2.2. *Methodology*

The characterization of the chemical composition of the furnace's materials has fundamentally centred on the analysis of their major and minor elements using SEM-EDS. To that end, the concentrations of Na_2O, MgO, SiO_2, P_2O_5, K_2O, CaO, MnO, Fe_2O_3, Al_2O_3, and Cl^- of the 104 selected samples have been determined (Table I) through X-ray energy dispersion using a RX-EDS Bruker AXS XFlash 4010 microanalysis system connected to a scanning electron microscope Hitachi S-3400-N, using a 15kV operating voltage and Quantax 400 software to perform the quantification. This method of analysis has allowed us to characterize the major and minor elements of the materials. Thus, it should be noted that we have not been able to register trace elements using this technique. The instrument only makes it possible to detect those elements that have a weight greater than 0.3% of the total sample. Thus, this technique provided semi-quantitative data related to major components of the glass (vitrifying and stabilizing components) and the fluxes. Quantitative analysis related to the minor and trace elements will be conducted in future works. Even though we are aware that SEM-EDS has certain limitations for glass analysis, we hold that the chemical characterization conducted has been useful to carry out a first approach to the glass objects of this workshop and to establish certain assumptions that can be further developed in future studies.

All quantitative results are reported as weight per cent oxides with oxygen determined by stoichiometry. Between two and three measurements per specimen were collected on clean cuts in order to avoid potentially weathered points near the surfaces of the glass and their average calculated (Table I). Since the outside area of the glass is commonly subjected to lixiviation processes of virtually all elements (except silicon and aluminum), we avoided to analyze this area of the samples with the aim to promote replicate analysis and more reliable results. The accuracy and precision of the systems employed were checked against Corning B, C and D reference glasses. In order to explain the major variations in the set of compositional data, bivariate and multivariate approaches using Principal Component Analysis (PCA) and Cluster Analysis (CA) were performed using SPSS software package.

3. RESULTS

Our first observation in the statistical analysis of the chemical data obtained is the existence of a significant positive correlation between the concentrations of CaO and K_2O (correlation *r* Pearson = 0.725). However, a significant negative correlation is observed between the quantities of CaO and SiO_2 (correlation *r* Pearson = -0.77). These correlations indicate that the concentrations of these three oxides have a strong relationship to each other and that they are fundamental to understanding the data performance.

A factor analysis through principle components analysis (PCA) performed with the sub-composition Na_2O, MgO, SiO_2, K_2O, CaO, Fe_2O_3, and Al_2O_3 (MnO, P_2O_5, and Cl^- have not been considered because they presented missing values and because the latter two elements may have been contaminated) allowed us to establish three factors that accumulate a total of 84% of the variance in the data. In the first factor, accounting for 45.8% of the data variance, the oxides that had a significant positive correlation (*r* Pearson > 0.7) were CaO, SiO_2, and Al_2O_3. The last two oxides showed a negative correlation with the first. This finding indicates a clear differentiation of the samples as a function of the quantity of aluminosilicates and stabilizers present in the mixtures. Considering that the glassmakers of the era were not aware of the stabilizing effect of calcium oxide, found in its natural form in the selected sands (Capellà and Albero, 2015) or in the plant ashes used as flux (Freestone and Gorin-Rosen, 1999), we can suppose that the differential concentrations in these oxides may be closely related to the composition of the raw materials used to manufacture the pieces.

The second component represents 24.7% of the data variance, with an accumulated variance of 70.5%. The oxides that contribute the most to explaining the variance (> 0.67) are K_2O and Na_2O, which show a negative correlation to each other. The changes in both oxides allow us to propose that clear differences exist in the register analysed as a function of the fluxes used in the preparation of the glass. Thus, the analyses performed suggest that a classification of the register as a function of the use of different raw materials and fluxes can be performed *a priori*.

To classify the samples, we have generated a bivariate plot with the two factors obtained through PCA. The dispersion of the samples in the graph (Figure 3) allows us to establish diverse groups that are compositionally divergent from each other (Table II). The grouping of the samples included in each group was made according to the results obtained from a cluster analysis conducted using the squared Euclidean distance and the centroid agglomerative method. The level of similarity of the samples within each cluster is > 94%. In the next sections, we generate a description of the compositional traits of each - of the groups identified and of the types of samples that they included to then perform a specific analysis of the types of pieces and productions with which these are associated.

3.1. *Group 1*

This group is the best represented, given that it includes 71 samples that are characterized by concentrations that match with the use of soda-lime-silica glass (Melcher and Schreiner, 2005), that is, by the mixture of sand and sodium as a flux. The sodium is related to Na-rich plant ash that were used as flux to decrease the melting temperature of the quartz raw material used as a source of silica. The use of Na-rich plant ashes is suggested by both concentrations of K_2O > wt. 2% (Verità and Toninato, 1990) and the written sources available. These plants grow commonly in the island on saline marshes in marine coastal sedimentary environments. Thus, the documentary sources available demonstrate that the barilla plants (*Salsola soda*) located in the archipelago of Cabrera, the salty coastal area of Campos and its closest islets, in southern Mallorca (Figure 1), had been exploited since the Middle Age. Moreover, some historical sources of the period under study point out that the production of barilla plant aimed for the production of glass and soap significantly increased in Mallorca during the 17th Century. In this sense, it is documented in 1639 the existence of a glass furnace that used barilla produced in this area of the island. In addition to the locally produced fluxes, it is also well-known the import to the island of fluxes from Alicante and Valencia (Capellà, 2015: 49-51). Such areas of the Iberian Peninsula (Figure 1) produced fluxes of high quality (Amouric and Foy, 1981, 1991).

The soda-lime nature of the glass of this group is evident and constitutes the one with the highest concentrations of Na_2O (average = 10.3%) of the entire register analysed. Furthermore, SiO_2, CaO, and Na_2O are the three principle components of the samples. Taken together, these components constitute more than 85% of the weight of the samples. This group includes samples of a varied range of colours: green, dark green, colourless, honey-coloured, violet, and blue. A clear divergence in the composition as a function of colour could not be observed with the methodology used in this study. This majority group includes all the samples associated with technological elements and remains of drippings derived from the production process, in addition to frits remains and glass lumps. These are practically all (89.6%) of the sample materials that are directly and undoubtedly related to the glass production developed in this workshop. For this reason, we note that this group of artefacts, rich in sodium and MgO (Table I; Figure 4), composes the reference groups of this furnace, that is, the type of products that were produced the most.

However, despite these general trends, it should be noted that there is a great variation within this group regarding basic major oxides such as SiO_2 (wt. 53-74%), Na_2O (wt. 4-18%) and CaO (wt. 5-15%). This variation suggests the use of different raw materials or certain intra-deposit variability in the raw material used in this workshop. On the one hand, there can be a high variation in plant ash compositions, even of the same species. On the other hand, we suggested in previous works that these products were most likely manufactured with local raw materials and limited recycling processes (Capellà and Albero, 2015). Thus, there are written sources that confirm the exploitation of local sands located in the Serra de Tramuntana from the Middle Age to XIX century to produce glass (Capellà, 2015: 45). Unfortunately, compositional analyses of these raw materials have not been conducted yet in order to shed light on the internal variability of these deposits.

The high variability observed can be also associated with the archaeological context of the samples under study. As we have been noted above, we do not know if the glass samples analyzed recovered from the ceramic container are synchronic or related to diverse batches. In this sense, it must be considered that the samples analyzed had been stored to be recycled and they can be related to a long period of activity.

In addition, other postdepositional and analytical factors have to be considered to explain this wider variability. First, even though the samples were relatively well-preserved inside a vessel, the variations can result from the presence of potentially corroded surfaces in some samples. The detection of low concentrations of Na_2O, K_2O and CaO in some samples of the assemblage analysed may point to some alteration processes. Second, we have to consider also that the variations observed in Na_2O concentrations can be related, in some cases, to the migration phenomenon of the alkalis when they are irradiated with an electron beam (Gedeon et al., 1999, 2000).

The macroscopic and archaeometric study of the workshop allows us to confirm that the majority of the pieces fabricated in it were differing tonalities of green and honey-coloured glass. This type of glass should be associated with an industrial and simple production process that was commonly executed and low-cost. Among the samples of Group 1 we identify a fragment of the neck of a small bottle and two handles that were most likely attached to bowls (Figure 4, MO-88, MO-52, and MO-57). Furthermore, there is the base of an indeterminate object and a fragment of the stem of a cup with a simple ring knot (Figure 4, MO-86 and MO-47), which is similar to that of other cups found in other archaeological sites in Palma and dated to the end of the 16th century and the duration of the 17th century (Capellà, 2015: 190-191).

Additionally, amongst the studied samples that were assigned to the majority group associated with the workshop, there are a few pieces that stand out from the rest because they are related to productions of a more prestigious nature. This is the case with a small blue block (MO-14) used to make pieces and to decorate colourless objects. Such cases show that higher-quality works of art were produced in this workshop. Amongst the remains studied, the base of a cup (Figure 4, MO-45) crafted from colourless glass with a drop of colour at its centre as decoration was preserved. These ornamentations are associated with Catalan production of the modern era. Amongst the different parallels found, we can cite another cup, dated to the first half of the 17th century, which has a stem in the shape of a baluster and the aforementioned decoration on its base (Philippart, 2011: 142).

This statement can be also applied for the violet-coloured glass, which is another chromatic range related to Catalan production of quality sumptuary glass between the 16th and 17th centuries (Domènech, 2004: 97). The large number of elements of this lump and its evident grouping with the pieces in the control group leave no doubt that the workshop blew objects of this hue. This assertion is also corroborated by the large amount of waste generated during formal production that also shows tool marks (Figure 2D). This fact lends even more consistency to the evidence supporting the hypothesis that these pieces must be associated with this workshop's production. Amongst the recovered objects, there is a violet piece of a base (Figure 4, MO-22) and a bit of what appears to be a ribbon handle (MO-73). This glass can be associated with the objects described as "leonart" (*lleonat* or *lleonart* in Catalan) in the notarized inventories of the era. Leonart refers to a colour of paste that includes the hues honey-coloured, reddish yellow, and violet.

This hue, which is associated with Catalan production, is linked to a significant number of objects preserved in different collections, both European and Spanish. In the majority of cases, these objects are high-quality specimens with high decorative values. One of the oldest pieces is a footed bowl from the Prats-Sedó collection (Amatller Institute of Hispanic Art, Barcelona), dated to the beginning or first half of the 16th century and produced in Venice or Catalonia, with a ribbed decoration, *mezza-stampatura*, and *lattimo* glass thread (Carreras and Pastor, 2010: 122). In addition to this specimen, we can add a blow-moulded spouted jug that is decorated with white lines and dated to the first half of the 16th century, in addition to another jug of the same century. Both jugs are of Catalan manufacture, with a ribbed neck that is decorated with a chord with stamping and *lattimo* white lines. They belong to private collections that were displayed in an exhibit on Spanish glass in the Grand Curtius Museum of Lieja (Philippart, 2011: 113, 138). Another specimen of this colour with a painted gold decoration, dated to the second half of the 16th century or beginning of the 17th century, belongs to the Museum of Decorative Arts of Paris *(Musée des arts décoratifs de París)* (Baumgartner and Olivié, 2003: 116). We can also associate a few fragments, most likely of a bottle and with *lattimo a penne* thread ornaments, preserved in the Majorca Museum of Palma *(Museo de Mallorca)*. These fragments have been dated to the 17th century by the remainder of the excavation's archaeological materials (Capellà, 2015). Finally, due to the similarity of its form with the base that was recovered in this container, we should cite a table service preserved in the Museum of Glass and Ceramics of the Peralada Castle *(Museu del Vidre del Castell de Peralada)*, of Catalan manufacture and dated to between 1650 and 1750. In this regard, the existence of this material base, the production remains, and the two fragments of objects confirm that works of this range were made in Majorca. This is an unequivocal sign that techniques for the production of pastes of a certain quality, more sophisticated than common glass, had disseminated to the different territories that composed the Crown of Aragon.

3.2. *Group 2*

This small group of only eight samples is closely related to the former group with regard to its composition, given that it has a soda-lime-silica base. It includes six fragments, all of which are colourless glass, a portion of glass lumps, and a portion of green colour frits. These pieces are separate from those of Group 1 because they present concentrations of Na_2O (4.1-6%) that are significantly lower and concentrations of SiO_2 (71-78%) that are significantly higher. In previous studies (Capellà and Albero, 2015), we could observe that the samples of raw materials from this group differ notably from the rest of the glass lumps documented in this workshop particularly with regard to the quantities of MgO and Na_2O. As proven by written sources, this aspect is associated with the diverse origins of the soda used by glass makers in this period. The fact that a workshop can produce glass with a differential composition if it uses raw materials that come from different suppliers should be considered. Regarding this question, other archaeometric studies (Henderson, 2000; Freestone et al., 2002) have noted that the divergences in the concentrations of these elements can also be explained by the use of ash from different plants as fluxes.

Group 2, which is limited in size, is composed of four piece fragments, two more fragments with indeterminate forms and the two aforementioned glass lumps. Amongst these objects stands out a fragment of the wall of a drinking-glass (Figure 5, MO-48), which has a fluted decoration formed by blowing into a mould and subsequently twisting the piece while it is still hot to achieve the spiral effect. Furthermore, there are two bottleneck fragments with common glass (Figure 5, MO-90 and MO-54). Finally and perhaps the most significant of the remaining material, there is a wall fragment of an indeterminate object with a *latticinio* decoration that is undoubtedly of a higher-quality production than the rest of the objects described in this group.

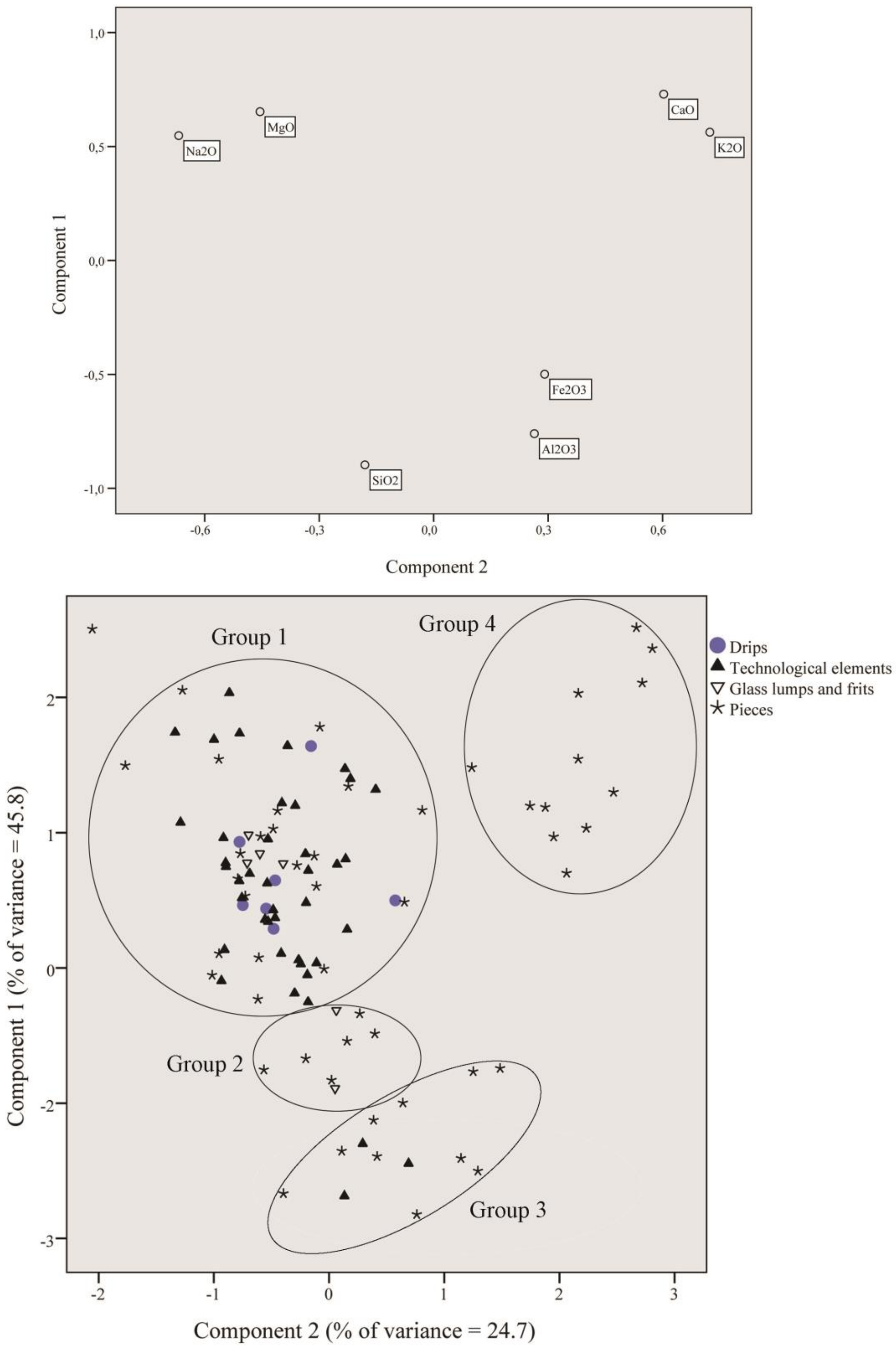

Figure 3. A) Bivariate plot generated with the first two factors obtained from principal components analysis (PCA) showing the dispersion of the different quantified oxides. B) Bivariate plot generated with the first two factors obtained from PCA showing the dispersion and grouping of the samples according to the type of artefact analysed.

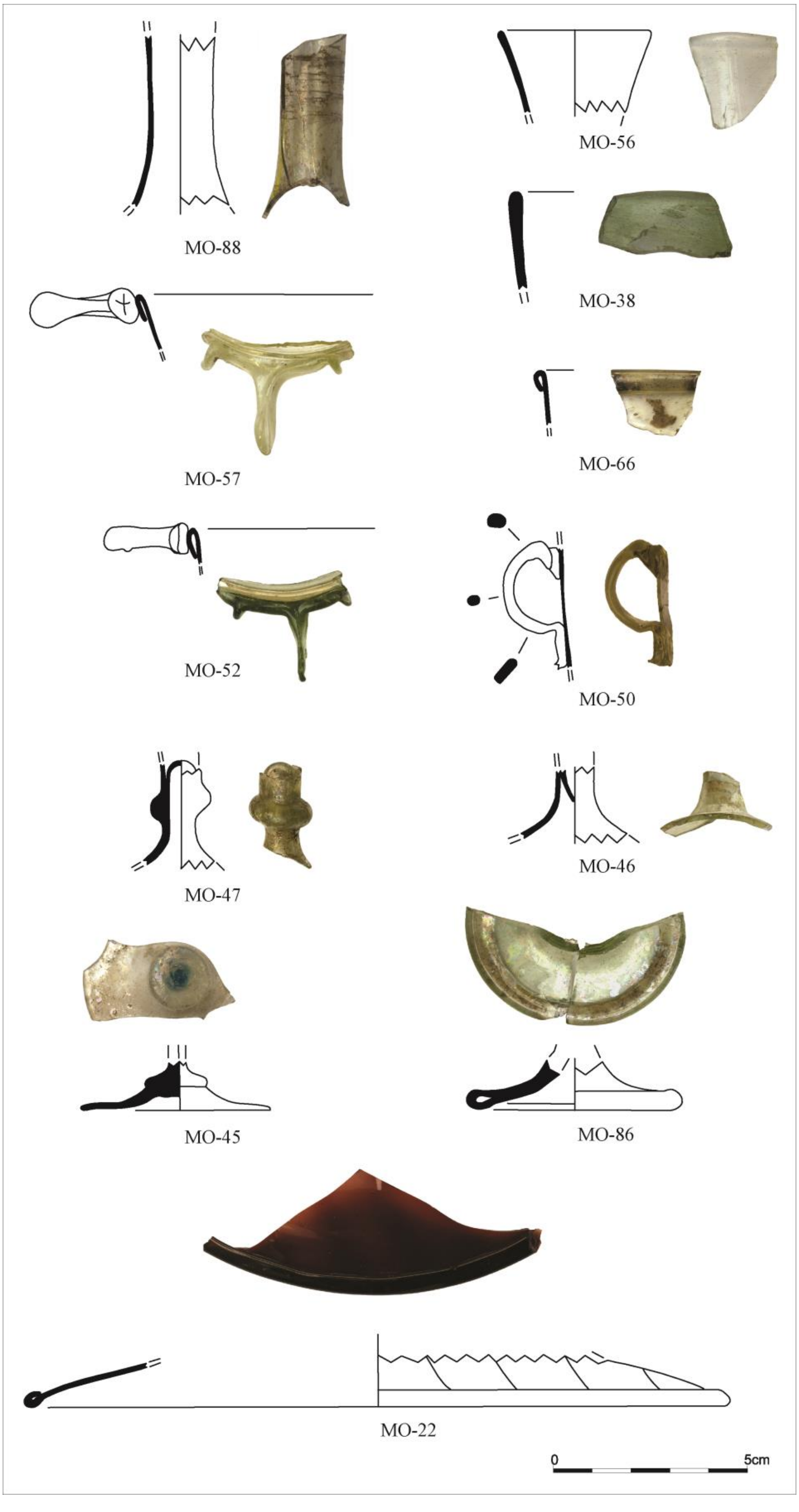

Figure 4. Group 1. Glass fragments: handle (MO-50), bases (MO-86 and MO-22), cup bases (MO-45), rims of indeterminate containers (MO-38 and MO-66), bottles (MO-88 and MO-56), handles of bowls (MO-57 and MO-52), and cup stems (MO-47 and MO-46).

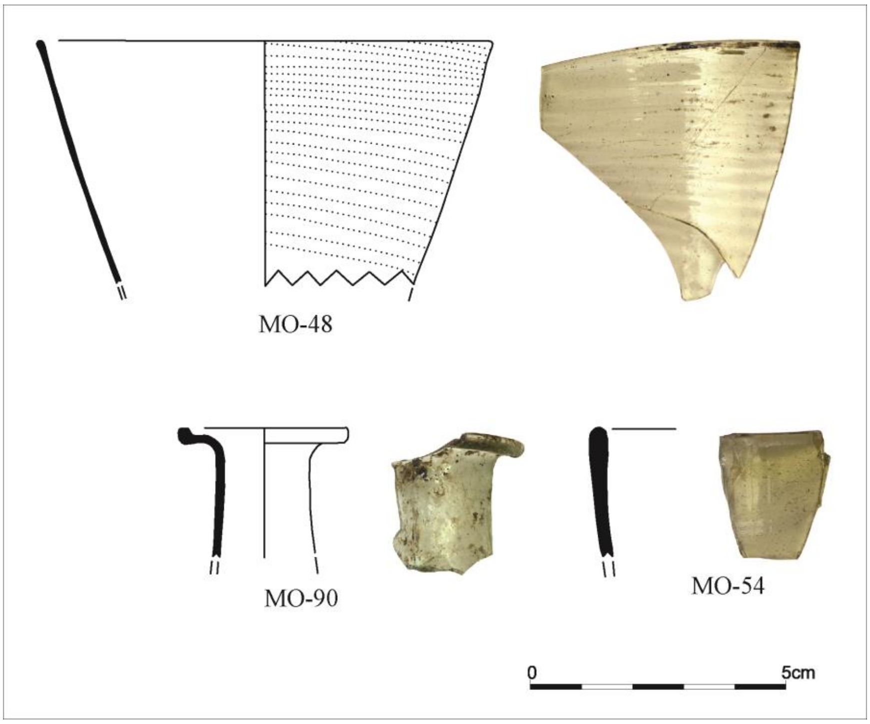

Figure 5. Group 2. Glass fragments: bottle (MO-90), rim of an indeterminate container (MO-54), and drinking-glass (MO-48).

3.3. *Group 3*

Group 3 contains 13 samples that include 10 pieces and three technological elements of colourless or green glass. This group stands out due to its high degree of compositional variability. That said, all of the samples present both low and similar concentrations of K_2O (1.5-4%) and Na_2O (1-5.2%). These samples present the highest concentrations of SiO_2 (average = 76%) and Al_2O_3 (4.2-9.5%), showing a composition in which the aluminosilicates weigh more and therefore have a higher concentration of sand. One hypothesis that allows us to explain the high variability and the characteristics of this group is that these are the result of recycling processes in which pieces of potassium carbonate and sodium carbonate have been mixed together – in addition to fragments of glass lumps – to produce new pieces. The absence of glass lumps associated with this group and the existence of technological evidence of mould blowing support this interpretation, which is based on the recycling activities developed in the workshop.

The majority of the forms associated with this group are objects of common use. The small bottle MO-89 (Figure 6) is a relatively frequent form in island archaeological contexts and was most likely used to store medicines, amongst other things (Capellà, 2015: 181). We also identify a fragment of a base, a handle, and a dark-green lid (Figure 6, MO-87, MO-51, and MO-53). A bit of dark-green wall (Figure 6, MO-49), belonging to an object that we cannot identify due to the lack of parallels, has a geometric decoration of raised diamond patterns formed by blowing into a mould. Finally, a fragment with a *latticinio* decoration (Figure 6, MO-80) is conserved. As explained above in reference to the previous group, this treatment is characteristic of higher-quality pieces.

3.4. *Group 4*

This group is of a limited size and is composed of 12 samples, the majority being of dark-green glass (n = 8) and, to a lesser extent, colourless glass. They are associated with eight objects and four flat pieces of glass characterized by a preferential use of Ca-K glass. Therefore, the main elements in the composition of these pieces (> 85%) are K_2O, CaO, and SiO_2, with potassium being related to the type of flux used. This fact determines that they are the samples in the analysed register that present the greatest quantity of K_2O (average = 5.5%). Indeed, the concentrations of K_2O (3.6-7.3%) in this group are always greater than those of Na_2O (0.8-5.7%). There is a notably large quantity of calcium oxide in this group (average = 24%), which must be related to the stabilizer present in the mixture. These glass pieces are associated with the use of raw materials, possibly ashes of caducifolian trees (Freestone et al., 2002; Gimeno et al., 2008), and recipes that are completely different from those that were typically used in this workshop. Such CaO concentrations are quite unusual, but they are documented in 16th century workshops located in northern Germany which were centered on the production of stained glass windows. In such Ca-K-glass productions, the concentrations of CaO can reach up to 23% (Basso et al., 2009; Orlando et al., 1996). Furthermore, there are French glass workshops dated in the 18th century that also produced glass pieces with similar CaO concentrations (Losier, 2012). In these cases, it can be suggested that high amounts of CaO were intentionally added in order to decrease the melting temperature of the quartz introduced as a source of silica.

Considering the different composition of these samples and the total absence of technological elements and lumps associated with this group, it must be assumed that these objects were most likely not manufactured in this workshop but rather imported to the island. Therefore, the fact that the clay vessel contains these objects must be connected with the processes used to collect waste that was stored in the workshop for the purpose of recycling. The imported objects that compose Group 4 are eight bottle bases and four flat pieces of glass that were most likely intended to be placed in leaded windows (MO-28, MO-30, and MO-31). The bottles, which were crafted by blowing into a mould, are characterized by a square sectioned base and body and also by an outward flaying neck with a simple semi-circular lip (Figure 7). The bottles present the pontil mark on their bases. The paste used is a common paste, generally of a dark-green colour. This type of bottle was used to store not only gin but also cognac, brandy, and other liquors. It originated in Germany and Bohemia at the end of the 16th century (Hollingworth, 1980: 41). Preserved in European collections are specimens with pictorial decorations in the glaze used in table services and simpler specimens that were used for transport. This form was also produced in Holland and Belgium from the beginning of the 17th century, whereas in England it did not appear until 1750. The German origin of the model is evident due to a reference made by the Belgian manufacturer Colinet, which refers to them as *"bouteille quarrée diste Allemande"* (Bossche, 2001: 136-137). This is the reason for the great difficulty presented in determining the models' origins based on the remarkable similarities of form that exist between specimens preserved in different collections, many of which are dated to the 18th century, a period when these liquors became widely popular. The form's square format facilitated its transport in wooden boxes that could hold 4, 6, or 12 specimens (Bellanger, 1988: 289). The rest of the eight specimens that were studied can be considered precursors of the 18th century forms. In other European sites, squared bottles also appear in archaeological contexts of the second half of the 17th century, as is the case with those found in the excavation in Santa Clara-a-Velha (Coimbra, Portugal) (Medici, 2009: 395).

In Majorca, the written documents of the era identify these forms as existing since the first third of the 17th century and becoming more frequent towards the middle of the same century. In Catalan, this form is referred to as *flascó*, which can also be used to refer to other forms. A documentary reference of 1658 and another of 1661 describe these forms as squared. Furthermore, they appear to be inevitably associated with wooden boxes and decanters, carved from more or less fine materials and possessing locks with which to close them. The importation of products in these containers that come from diverse European cities is also well documented. For example, in 1678, the ship "Nt[a] Sr[a] de Europa", which was travelling to Majorca, bought "two bottles of distilled spirits" in the port of Messina (López, 1986: 555). Nonetheless, although the analysis of the materials and the context of their removal indicate that these types of forms were imported to the island and stored for recycling upon being thrown out, we cannot rule out the possibility that the local workshops may have blown their own version of these simple squared forms of German origin and European dissemination. An indication of this is provided to us by a well-known document of 1655 that contains a record of a *flascó de vidre mallorquí* (literally *flascó* made of Majorcan glass) (Capellà, 2015: 182-184).

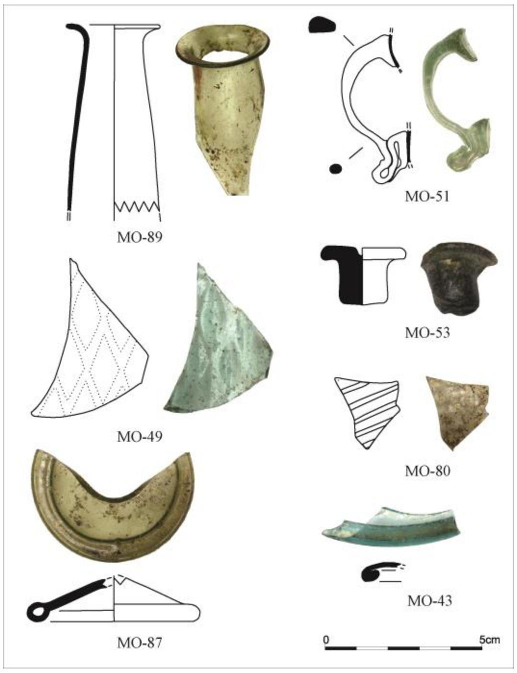

Figure 6. Group 3. Glass fragments: handle (MO-51), bases (MO-87 and MO-43), bottle (MO-89), tap (MO-53), wall fragment with decoration blown using an open mould (MO-49), and wall fragment with lattimo thread decoration (MO-80).

Figure 7. Group 4. Glass fragments: Square sectioned bottles (MO-32, MO-100, MO-101, MO-102, MO-106, MO-107, MO-85 and MO-88).

4. CONCLUSIONS

The archaeometric study of the glass materials of Sa Gerreria has allowed us to approach the chemical composition of the remains of the raw materials, technological elements, and pieces present in this 17th-century workshop and to establish groups of different natures. Even though the methodology applied in this research has certain limitations, we consider that the chemical characterization of the samples from this workshop by means of SEM-EDS allowed us to shed light on some interesting aspects regarding glass production and distribution that can be further developed in future works. On the one hand, we have been able to record the existence of a group with high concentrations of Na_2O that encompasses a large number of samples associated with the productions developed in the workshop, presumably using local raw materials. The types of pieces placed within this group are linked with an artisan activity primarily centred on utilitarian and low-cost products. However, this study has also allowed us to propose that several more sophisticated pieces were crafted in this workshop with finer-quality pastes and fashionable forms and were sold to more demanding clients. We refer here to the production of pieces of prestige such as those that present blue decorations or the violet pieces. The manufacture of these pieces on the island reveals a link with the Catalan region insofar as the taste and technical knowledge of Majorcan production are concerned. Similarly, the manufacture of these pieces in Palma reveals the dissemination of techniques associated with the production of pieces of a certain quality, more sophisticated than common glass, throughout the different territories of the Crown of Aragon. The diversification of production and the development of different types of products can be explained in part by the characteristics of the island market. This market, especially with regard to high-end pieces, was very much determined by glass imports from Barcelona and other zones of Catalonia as well as Venice.

On the other hand, we have recorded the existence of a group exclusively composed of pieces that differ significantly from the other groups due to its greater K_2O and calcium oxide content. These objects were manufactured using technological choices that have nothing to do with local production and therefore should be considered imported. We can associate them with very particular types – liquor bottles and flat pieces of glass, the origins of which most likely should be determined and as a function of typological parallels with Northern European cities. Everything points to the fact that upon falling into disuse, these products were deposited in the Sa Gerreria workshop so that they may subsequently be recycled. During this process, they were fused with the remains of local productions.

Ultimately, this study has generated significant advances in the characterization of the local glass production of Majorca in the modern era and in the identification of regional products linked to the Crown of Aragon and the Italian market. These analyses provide us with more detailed knowledge about the technical choices put into practice by the Sa Gerreria workshop and the dissemination of some techniques between different interconnected territories, in addition to importation of certain types of glass to the island.

Table II. Statistical summaries (average and standard deviation (σ)) for each of the groups obtained in the PCA analysis[2].

	Group 1 (*n* = 71)	**Group 2 (*n* = 8)**	**Group 3 (*n* = 12)**	**Group 4 (*n* = 12)**
Na_2O	10.2 ± 3.4	5 ± 0.7	2.5 ± 1.2	2.3 ± 1.6
MgO	3.4 ± 0.6	2.5 ± 0.6	1.6 ± 0.6	3 ± 0.5
SiO_2	64.4 ± 5.4	74 ± 2.2	76.3 ± 5.7	56.6 ± 2.2
P_2O_5	0.5 ± 0.2	0.2 ± 0.3	n.d.	1.3 ± 0.7
Cl^-	1 ± 0.3	0.8 ± 0.4	0.6 ± 0.2	0.5 ± 0.2
K_2O	3.3 ± 0.7	3 ± 0.4	3 ± 0.7	5.5 ± 1.2
CaO	10.6 ± 2.3	6.6 ± 1.6	5.9 ± 3	24 ± 2.8
MnO	1.6 ± 0.7	0.3 ± 0.6	3 ± 1.5	1.6 ± 0.5
Fe_2O_3	1.9 ± 0.6	2.2 ± 0.4	2.5 ± 0.8	1.8 ± 0.6
Al_2O_3	3.8 ± 1	5.4 ± 0.7	6.6 ± 1.5	4.1 ± 1.2

[2] Regarding P_2O_5, there have been multiple cases in Group 1 of missing values in which we have not been able to identify the quantities *wt%* > 0.3%. Therefore, the displayed mean represents only n = 52. Regarding MgO, the displayed mean represents only n = 54 for Group 1, n = 4 for Group 3, and n = 8 for Group 4. Finally, regarding Fe_2O_3, the displayed mean represents n = 66 for Group 1.

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Table I. Chemical composition (wt%) of the samples analysed from the Sa Gerreria workshop determined through SEM-EDS (n. d. = not detected).

Sample	Type of artefact	Colour	Group	Na_2O	K_2O	MgO	SiO_2	P_2O_5	Cl	CaO	MnO	Fe_2O_3	Al_2O_3
MO-10	Technological element	Dark green	1	16.6	4	3.8	56	0.4	1	12.1	1.2	1.5	3.4
MO-33	Technological element	Colourless	1	8.6	2.6	3.1	66.3	0.5	0.9	9.8	2.2	2	4
MO-34	Technological element	Colourless	1	14.5	4.1	3.5	56.4	0.3	0.8	13.6	1.9	1.6	3.3
MO-35	Technological element	Colourless	1	10	2.6	3.2	64.9	0.4	0.9	11.1	n. d.	2.1	4.8
MO-36	Technological element	Colourless	1	5.6	3.1	2.8	72.1	0.4	1	6.7	1.5	1.9	4.9
MO-37	Technological element	Green	1	6.7	2.7	2.7	70.1	0.8	1.4	9.6	n. d.	2.2	3.8
MO-82	Technological element	Dark green	1	11.3	2.9	2.9	61.6	n. d.	1.7	13.4	n. d.	2.8	3.4
MO-83	Technological element	Dark green	1	11.4	2.8	3.4	63.3	0.8	0.7	10.2	n. d.	2.8	4.6
MO-38	Piece	Dark green	1	11.3	3	3.5	59.7	0.7	0.8	12.9	2.3	1.8	4
MO-58	Technological element	Colourless	1	3.7	2.6	3	72.6	n. d.	1	10.3	1.6	1.6	3.6
MO-11	Technological element	Green	1	17.8	3.4	4.1	56.3	0.8	0.9	11	1	1.2	3.5
MO-60	Technological element	Violet	1	6.3	3.3	3.1	67.8	0.5	1.1	10	2.8	1.7	3.4
MO-61	Technological element	Yellow	1	6.8	2.1	3.7	70.1	0.6	1	6	3	2.4	4.3
MO-62	Technological element	Violet	1	10.6	3.3	3.9	68.9	n. d.	1.3	8.6	n. d.	n. d.	3.4
MO-84	Technological element	Colourless	1	10.1	2.5	3.5	63	1	1	12.4	n. d.	2.2	4.3
MO-63	Piece	Green	1	10.4	5.1	3	64.1	0.4	n. d.	9.1	n. d.	3.4	4.5
MO-99	Piece	Colourless	1	9.9	3.8	3.2	63.7	n. d.	0.8	11.3	1.6	1.8	3.9
MO-64	Piece	Colourless	1	9.1	3.1	3.1	68.1	n. d.	1.8	11	n. d.	n. d.	3.8
MO-12	Technological element	Yellow	1	16.5	3.8	3.7	57.3	0.5	1.2	11	1.7	1.2	3.1
MO-66	Piece	Colourless	1	4.1	2.5	2	73.9	n. d.	0.8	6	n. d.	2.7	8
MO-14	Lump	Blue	1	13	3.1	4	59.1	0.6	0.8	11.1	1.4	2.2	4.7
MO-15	Drip	Green	1	7.3	3	3.5	67.9	0.7	0.7	8.4	2.2	1.9	4.4
MO-16	Drip	Green	1	8.2	3	3.4	66.5	0.5	0.7	11.2	1.2	1.6	3.7
MO-17	Technological element	Yellow	1	8	2.8	2.9	67.6	0.4	0.6	8.7	1.6	2.8	4.6
MO-18	Drip	Violet	1	9.8	3.3	3.7	65.4	0.4	1.1	8	1.3	2	5
MO-19	Drip	Green	1	8.7	2.8	3.6	67.7	0.5	0.8	9.1	1	1.6	4.2

MO-2	Lump	Dark green	1	11	3.3	3.6	65.1	n. d.	0.7	10.8	n. d.	2	3.5
MO-20	Technological element	Dark green	1	10.8	4.9	2.3	61.4	0.4	1.6	13.2	1.6	1.3	2.5
MO-21	Drip	Yellow	1	9.1	3.1	3.6	67.4	n. d.	0.9	10.9	1	1.3	2.7
MO-22	Piece	Violet	1	11.7	4.9	2.1	55.9	0.5	1.1	13.6	4.4	2.2	3.6
MO-23	Piece	Colourless	1	12.1	4.7	2.8	60.4	0.4	1	12.6	1.5	1.9	2.6
MO-27	Drip	Violet	1	15.1	4.4	3.2	55	0.5	1.7	13.3	1.7	1.8	3.3
MO-3	Lump	Green	1	10.6	3.9	4.1	64	0.6	0.5	9.3	n. d.	2.1	4.9
MO-98	Technological element	Green	1	9.4	3	3.4	66.5	0.5	0.9	8.7	1	1.9	4.7
MO-40	Technological element	Colourless	1	12.4	4.4	2.9	57.8	n. d.	1.1	14	2.4	2	3
MO-67	Technological element	Colourless	1	9.6	3.8	2.5	66.6	n. d.	1.3	13.6	n. d.	n. d.	2.6
MO-68	Technological element	Dark green	1	8.4	3.9	2.8	64.5	0.3	1.1	12.3	1.6	1.7	3.4
MO-4	Lump	Violet	1	9.9	2.8	3.6	65	0.4	0.6	11.4	0.9	1.6	3.8
MO-79	Technological element	Dark green	1	8.3	3.9	2.9	65.4	0.5	0.9	11.7	1.3	1.7	3.4
MO-69	Technological element	Colourless	1	6.9	2.8	2.8	72.4	n. d.	1.4	10.9	n. d.	n. d.	2.8
MO-85	Technological element	Colourless	1	17.3	4	4.4	52.7	0.4	0.8	13.3	1.9	1.6	3.6
MO-70	Technological element	Green	1	9.1	2.9	3.5	67.6	0.4	0.8	8.9	1.3	1.6	3.9
MO-86	Piece	Colourless	1	16.6	3.4	2.9	58.9	0.2	1.1	12.2	1.1	0.9	2.7
MO-45	Piece	Colourless	1	0.9	1.8	3.7	71.7	n. d.	0.4	15	n. d.	2.2	4.3
MO-88	Piece	Colourless	1	18.4	2.1	4.4	54.2	0.8	1.3	11.1	1.8	1.7	4.2
MO-46	Piece	Colourless	1	7.1	2.9	3.5	70.1	0.5	1.2	7	1.1	1.7	4.9
MO-47	Piece	Colourless	1	13.4	4.8	3.2	58.7	n. d.	1	13.7	1.6	1.5	2.1
MO-91	Piece	Colourless	1	5	1.9	3.5	75.9	n. d.	0.8	8	n. d.	1.8	3.1
MO-50	Piece	Colourless	1	11.6	2.9	3.4	63.8	0.4	1	9.3	1.6	1.7	4.3
MO-6	Drip	Green	1	10.7	3.5	3.1	59.1	n. d.	0.8	14.1	n. d.	4.6	4.1
MO-57	Piece	Dark green	1	13	3	3.7	58.5	1.2	0.6	12	1.2	2.1	4.7
MO-52	Piece	Colourless	1	5.3	2.6	3.1	73.8	0.5	1.2	6.1	1.3	1.6	4.5
MO-55	Piece	Colourless	1	10	3.3	3.9	60.2	0.5	1.4	11.3	2	2.2	5.2
MO-56	Piece	Colourless	1	4.2	3	4.9	74.3	n. d.	0.9	5.3	0.8	1.6	5
MO-92	Piece	Colourless	1	7.7	3.9	3.1	67.7	0.3	0.8	9.6	1.7	1.6	3.6

MO-7	Technological element	Yellow	1	6.1	3.1	2.8	70.2	n. d.	1	8.7	2	2.3	3.8
MO-103	Piece	Colourless	1	16.6	2.6	5.2	57.2	n. d.	1	15.5	n. d.	n. d.	1.9
MO-8	Technological element	Yellow	1	12.9	4.7	2.8	58.9	n. d.	1.6	13.2	1.5	1.8	2.6
MO-108	Piece	Colourless	1	13.8	3.2	3.9	61.3	n. d.	1	15.2	n. d.	n. d.	1.6
MO-109	Piece	Green	1	12.6	3.7	3	61	0.7	0.8	11.3	2.3	1.5	3.1
MO-73	Piece	Violet	1	9.8	3	3.5	66.3	0.5	0.8	8.7	1.5	1.6	4.3
MO-9	Technological element	Green	1	13.6	3.8	3	59.7	0.7	1	11.5	1.8	1.7	3.2
MO-74	Technological element	Colourless	1	6.9	2.4	3.8	70.2	0.6	0.8	7.2	1.9	1.8	4.4
MO-75	Technological element	Colourless	1	10	3	3.5	64.6	0.7	1	9.7	1.9	1.6	4
MO-93	Technological element	Green	1	8.6	3	3.3	67.3	0.5	0.8	7.8	1.4	2.2	5.1
MO-94	Technological element	Green	1	8.8	3.4	3.5	63.4	0.3	0.8	12.5	1.5	1.7	4.1
MO-76	Technological element	Colourless	1	6.8	3.7	2.7	67.6	0.6	1	10	1.4	1.6	4.6
MO-95	Technological element	Colourless	1	11.4	3	4.1	62.5	0.4	0.8	10.1	1.9	1.7	4.1
MO-96	Technological element	Colourless	1	12.4	2.3	3.1	62.1	0.5	1.2	11.8	0.9	1.2	4.5
MO-77	Technological element	Colourless	1	6.6	3.6	3.3	71	0.1	0.9	11.6	n. d.	n. d.	2.9
MO-78	Technological element	Colourless	1	6.4	2.6	3.4	71.1	n. d.	1.2	8	n. d.	3.8	3.5
MO-97	Technological element	Colourless	1	10	2.5	3.6	65.2	0.5	1	11.3	0.8	1.4	3.7
MO-13	Lump	Dark green	2	4.7	3	1.4	78.5	n. d.	0.9	5.1	n. d.	1.7	4.7
MO-44	Piece	Colourless	2	4.1	2.6	3.1	73.2	n. d.	1	6.6	n. d.	2.9	6.5
MO-5	Lump	Green	2	5.6	3.1	2.5	71.6	0.5	0.3	8.2	1	1.9	5.3
MO-90	Piece	Colourless	2	4.3	3.3	2.3	74.4	n. d.	0.7	6.5	1.4	1.9	5.2
MO-48	Piece	Colourless	2	4.5	3.3	2	74	n. d.	0.8	8.5	n. d.	2.4	4.5
MO-54	Piece	Colourless	2	5.2	3.4	2.7	71.7	n. d.	0.8	8.4	n. d.	2.3	5.5
MO-72	Piece	Colourless	2	6	3	2.4	75.1	n. d.	1.6	4.5	n. d.	2.3	5.1
MO-81	Piece	Colourless	2	5.4	2.1	3.3	73.7	0.9	0.6	5.3	n. d.	2.4	6.3
MO-59	Technological element	Green	3	1	2.3	1.4	83.1	n. d.	0.7	3.4	n. d.	1.9	6.2
MO-39	Technological element	Green	3	2.1	2.8	1.3	81.1	n. d.	0.6	5	n. d.	1.7	5.5
MO-26	Piece	Green	3	5.2	4	1.8	67.2	n. d.	0.9	10.3	n. d.	4.3	6.3
MO-41	Technological element	Colourless	3	1.6	2.9	1.4	78.7	n. d.	0.5	5.9	n. d.	2.6	6.3

MO-87	Piece	Colourless	3	3.5	2.6	2.3	73.1	n. d.	0.7	5.7	2.6	3.9	5.6
MO-43	Piece	Green	3	1.7	3.2	3	66.6	n. d.	0.4	13.1	n. d.	2.5	9.5
MO-89	Piece	Colourless	3	2.1	2.9	1.4	77.5	n. d.	0.3	3.7	1.2	2.7	8.2
MO-71	Piece	Dark green	3	2.2	2.3	1.1	79.2	n. d.	n. d.	4.3	3.8	1.7	5.4
MO-49	Piece	Green	3	2.1	3.6	1.5	75.7	n. d.	0.5	6.3	n. d.	2.9	7.4
MO-51	Piece	Dark green	3	4.3	3.4	1.5	74.7	n. d.	0.7	6.7	n. d.	2	6.7
MO-53	Piece	Dark green	3	2	4	1	73.6	n. d.	0.6	3.8	4.6	2.3	8.1
MO-80	Piece	Colourless	3	2.1	1.5	1.1	85.3	n. d.	0.7	2.9	n. d.	2.2	4.2
MO-65	Piece	Colourless	4	4.3	4.7	3.2	55.5	1.5	0.6	22.5	n. d.	1.7	6
MO-25	Piece	Dark green	4	1.5	6.4	3.8	56.9	1	0.2	23.9	1.5	1.4	3.4
MO-28	Piece	Colourless	4	3.3	5.6	2.5	56.1	0.8	0.7	24.1	n. d.	2.3	4.6
MO-30	Piece	Colourless	4	2.5	5	2.3	58.4	1	0.6	23.4	n. d.	1.8	5
MO-31	Piece	Colourless	4	3.2	4.5	2.7	57.2	1.4	0.7	21.6	n. d.	2.8	5.9
MO-32	Piece	Dark green	4	1.8	5.5	3	60.6	2	0.5	19.5	1.3	1.9	3.9
MO-100	Piece	Dark green	4	1.2	6.4	3.6	57.9	2.1	0.5	20.1	2.1	1.6	4.5
MO-101	Piece	Dark green	4	0.8	7.3	3	55.7	1.4	0.4	26.6	1.4	0.8	2.6
MO-102	Piece	Dark green	4	0.8	6.5	3.2	52	2.2	0.3	29	2.6	1.1	2.3
MO-104	Piece	Dark green	4	1.1	6.9	3.5	55.4	n. d.	n. d.	26.3	1.6	1.5	3.7
MO-106	Piece	Dark green	4	1	3.6	2.1	58.7	1.6	0.4	25.8	1.1	2.2	3.5
MO-107	Piece	Dark green	4	5.7	3.6	3.1	55	n. d.	0.9	24.9	1	2.3	3.5