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# STUDIES ON THE RENAISSANCE VENETIAN *ROSETTA* BEADS THROUGH CHEMICAL ANALYSES AND RECIPES OF MURANESE GLASSMAKERS

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## ABSTRACT

The term *rosette* (little roses) first appeared in reference to glass beads and cane slices in Venetian documents dated 1482. The term has indicated chevron glass beads and cane slices applied to glass objects (*millefiori* decoration). These beads were obtained from segments of drawn glass canes presenting in their section consecutive circular and star-pattern polychrome layers. The invention of the *rosetta* beads is attributed to Maria Barovier, daughter of the famous Muranese glassmaker Angelo. The production of these canes in Murano has continued almost uninterrupted to the present day and not only in Venice.

This study reports on quantitative chemical analyses (micro X-ray fluorescence or wavelength dispersive X-ray microanalysis) of the individual colored layers of five genuine Venetian archaeological *rosetta* beads and fragments of canes dated sixteenth to early seventeenth century. The analyses evidence that the base-glass composition as well as colorants and the opacifier are in the tradition of Renaissance Venetian glass. They correspond to a recipe for *rosetta* cane reported in a treatise of an unknown Muranese. In contrast, three recipes for *rosetta* cane of a treatise dated to the second half of the eighteenth century evidence a quite different scenario: new raw materials and a new opacifier.


The term *rosette* (little roses) indicates special glass beads (star-chevron) made in Venice since the end of the fifteenth century. They are made from segments of drawn hollow canes shaped using specially constructed star molds and presenting in section consecutive circular or star-pattern polychrome glass

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*Correction Notice: at the time of online publication, Marco Verità's name was mistakenly listed with an acute accent rather than a grave accent. This error has been corrected for the print version of this volume.*

layers. Slices of *rosetta* canes were also incorporated into clear glass to form blown or massive objects.[1]

The term *rosette* first appeared in Venetian documents dated 1482 (*paternostri a rosete*),[2] and glass objects decorated with *rosette* (beads, knife and dagger handles, blown objects) made in the furnace of Maria and Giovanni Barovier (children of the famous glassmaker Angelo) are listed in an inventory dated 1496.[3] Furthermore, the Archivio di Stato di Venezia (State Archive of Venice) has preserved a document dated 1487 that allows Maria Barovier to continue creating her "beautiful and unusual works, not blown, diligently produced in her own small furnace."[4] On the basis of these documents, the invention of the *rosetta* cane is credited to Maria.

To make the *rosetta* cane the glassmaker picks up a gather of molten glass (its color will form the central layer of the cane) on a pontil rod, shapes the glass by rolling it back and forth on a marver, and presses the glass into a ribbed mold. The first gather is then coated with molten glass of a contrasting color, rolled on a marver, and then pressed in a mold. These processes are repeated until the desired number of glass layers is obtained. Then, an assistant attaches a pontil to the free end of the *paraison* (a partially inflated gather at the end of a blowpipe) and together with the glassmaker they walk in opposite directions, stretching and elongating the *paraison* into a cane of glass until it is the required diameter.[5] The cane is cut into short segments, which are transformed into beads by shaping the ends into the form of hexagonal truncated pyramids (**Fig. 1a**), or the segments (**Fig. 1b**) are picked up with molten glass to decorate blown and massive objects (**Fig. 2**).[6]


FIG 1. (a) Examples of Renaissance rosetta beads from the Venetian area. Diam. 20–30 mm. Samples not analyzed; (b) Fragments (cross sections) of Renaissance *rosetta* canes from the Venetian area; probably production wastes. Diam. about 20 mm. Samples not analyzed. (Photos: Gianni Moretti)

1 Zecchin 1989, 214.
2 Zecchin 1987a, 58.
3 Zecchin 1989, 211–212.
4 *Opera sua pulchra inconsueta et non sufflata, in quadam sua fornace parvula ad hoc studiose confecta* (Zecchin 1989, 213).
5 Moretti 1985.
6 Hollister 1981; Stocco 2024.


FIG 2. Two fragments of Renaissance blown objects decorated with *rosetta* slices from the Venetian area. Samples not analyzed. (Photo: the authors)

*Rosetta* beads gave an extraordinary boost in the sixteenth century to the production of beads in Venice and to their export to West Africa and the Americas, where they were highly valued commodities. Additionally, *rosetta* beads were possibly manufactured in the Low Countries[7] and France.[8] Their manufacture has continued on Murano to the present day.

R*osetta* beads have largely been studied from the point of view of their form, shape, diffusion, and trade. They vary in the number of layers, colors, and points of the stars.[9] However, this bead type has received less attention from archaeometrists. Chemical analyses of *rosetta* beads from the Americas,[10] Low Countries,[11] Portugal,[12] and Germany[13] were published, but in general only semi-quantitative compositions are reported. Furthermore, as far as the authors are aware, analyses of genuine Renaissance Venetian *rosetta* beads are not available today. The possibility of analyzing five *rosetta* fragments found in archaeological excavation in the Venetian area presented an opportunity to fill this gap, albeit partially. The individual colors were analyzed separately by punctual X-ray techniques—energy dispersive X-ray micro-fluorescence spectrometry (μEDXRF) and electron probe microanalysis (EPMA)—and the samples were studied from the point of view of their glass composition, coloring techniques, and glassmaking technology.

The results attest that the base glass of the *rosetta* samples is of soda-lime-silica type. Their base-glass composition compared with a dataset of chemical analyses of genuine Renaissance Venetian glass objects matches *vitrum blanchum* and

7 Francis 1988; Hulst and others 2012; Van der Storm and Karklins 2021.

8 Karklins and Bonneau 2019.

9 Karklins 1985; Kos 1994; Bailo 1903; Moretti 2005; Rodrigues 2007; Francis 2008; Blair, Pendleton, and Francis 2009; Karklins 2012.

10 Loewen and Dussubieux 2021; Hawkins and Walder 2022.

11 Karklins and others 2001.

12 Lima and others 2012.

13 Gradmann and others 2013.

common glass compositions.[14] Similarly, colorants and opacifiers are in the tradition of Renaissance Venetian glass.

Results were also compared with recipes specific for *rosetta* cane found in eighteenth-century treatises of Venetian glassmakers. These recipes evidence a quite different scenario: alongside traditional recipes (soda-lime-silica glass and lead-tin calx as opacifier), new glass compositions, new raw materials, and a new opacifier differing from the Renaissance Venetian glassmaking tradition were used.

## MATERIALS AND METHODS

Hundreds of fragments of *rosetta* canes, beads, and (less abundant) decorated objects were found in archaeological excavations in the Venetian area. Nevertheless, most of these remains were found in occasional excavations and, despite their certain origin, a precise dating of them is not possible. Furthermore, permission for analysis of fragments has not been granted except for five *rosetta* archaeological fragments found in Fusina, a location at the edge of the Venetian lagoon, where the embankment of the river Brenta was reinforced with waste from ceramic and glass furnaces of Venice and Murano from the fifteenth century until the embankment was abandoned in 1610, when the course of the Brenta was changed.[15]

The diameters of the five fragments (beads: MV, PG3; canes: PG1, PG2, RB) vary between 8 mm (RB) and 28 mm (PG1). All the samples consist of seven concentric layers with the same color sequence (from outside: blue, white, red-brown, white, natural green, white, natural green). The white and red-brown are opaque and the other colors are translucent. In the sample RB, the natural green layers are replaced by light blue (cyan) layers. As far as the authors are aware, these samples are representative of the majority of the Renaissance Venetian *rosetta* remains. Other rarer patterns—for instance, canes where the blue layer is replaced by an emerald-green layer—were also found (see **Figure 1a**).[16]

Small fragments were cut with a diamond wheel from the samples, embedded in acrylic resin, and polished down to 3 μm grade with diamond paste. Optical micrographs of the polished cross sections of three of the analyzed samples are reported in **Figure 3**.

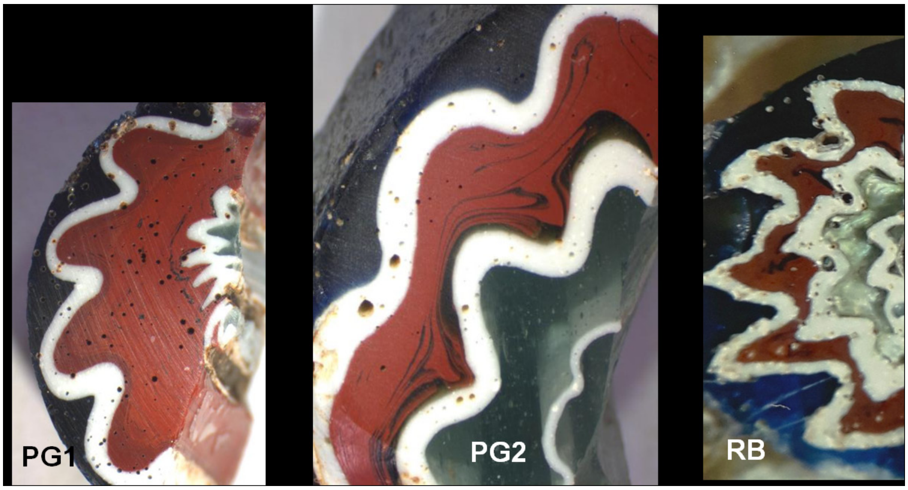


FIG 3. Optical micrographs of the polished cross sections of three analyzed samples (not to scale). Diam. (sample): PG1, 28 mm; PG2, 17 mm; RB, 8 mm. (Photo: the authors)

14 Verità and Biron 2021.
15 Canal 2013.
16 Bailo 1903.

The samples were analyzed for their quantitative chemical composition through punctual techniques to allow analysis of the individual colors separately. Two samples (PG1, PG2) were analyzed by µEDXRF at the LAMA laboratory of the Iuav University, Venice, using a Bruker M4 Tornado spectrometer. The other samples were analyzed by an electron probe X-ray microanalysis wavelength dispersive Cameca SX-50 at the Stazione Sperimentale del Vetro, Murano, Venice. Analytical conditions, data processing, calculated accuracy, and detection limits are reported elsewhere (µEDXRF,[17] EPMA[18]). Each color was analyzed from three different points on each sample and the average values considered. The average composition, including crystals and glass phase, was measured for the white glass.

## RESULTS

The quantitative chemical composition of the individual glass colors of the five *rosetta* samples are reported in wt % of the oxides in **Table 1a**.

### Base glass

The base-glass (the transparent glass to which colorants and opacifiers were added) composition was calculated by subtracting from the compositions in **Table 1a** the concentration of colorants, opacifiers, and related elements (copper, lead, tin, cobalt, nickel, arsenic, bismuth) and recalculating to 100% the other glass components (**Table 1b**). From this calculation iron was excluded for red glass, since it was intentionally added to improve the coloring process ($Fe_2O_3$ 3–7%). The higher iron content of the light-blue glass ($Fe_2O_3$ 1.08%) of sample RB is also related to the coloring process, while the higher iron content of the blue glass is probably related to the presence of this element in the cobalt ore used to color the glass.

The base glass of the samples is of the soda-lime-silica type. The potassium ($K_2O$ 1.7–3.6%), magnesium (MgO 3.4–4.1%), chlorine (Cl 0.6–1%), and phosphorous ($P_2O_5$ 0.2–0.4%) contents indicate that they were melted using soda plant ash as a flux and a silica source. The content of the main components and of alumina is variable in a restricted range ($SiO_2$ 63.3–68.8%; $Na_2O$ 12.7–15.4%; CaO 8–12%; $Al_2O_3$ 1–1.9%). Instead, the base-glass compositions of the four colors within each sample are almost identical to each other (for instance, sample RB: $SiO_2$ 63.5–65.8%, $Na_2O$ 12.7–14.0%, CaO 10.7–12.0%, $Al_2O_3$ 1.2–1.3%; and sample PG3: $SiO_2$ 63.3–65.6%, $Na_2O$ 12.8–13.9%, CaO 9.8–10.3%, $Al_2O_3$ 1.6–1.9%).

The base glass of the samples shows a strong similarity with Venetian glass composition. Three basic recipes for glassmaking were in use in Venice during the Renaissance. The glass used for most common objects was characterized by a natural green-to-yellow hue and in general was melted from raw materials not specially selected. *Vitrum blanchum* had been made since the fourteenth century by melting a batch of nearly equal amounts of a selected silica source (silica pebbles from the Ticino river) and soda plant ash imported from the Levant. This glass decolorized with manganese had a more or less pronounced gray hue. Around the middle of the fifteenth century, Venetian glassmakers invented *cristallo*, a colorless glass famed for its remarkable clarity and homogeneity, similar to rock crystal.[19]

17 Tesser and others 2020.
18 Verità and others 1994.
19 Verità 2021.

TABLE 1A. Quantitative chemical composition in wt % of the oxides of the glass colors forming the *rosetta* samples. Opaque white and red glass: average composition (crystals and glassy phase). Traces of zinc (ZnO 0.07%) were found in the red glass of sample RB. Searched for and not detected: Sb, Cr, Ba.

| SAMPLE | COLOR | GLASS TYPE | $SiO_2$ | $Al_2O_3$ | $Na_2O$ | $K_2O$ | CaO | MgO | $SO_3$ | $P_2O_5$ | Cl | $TiO_2$ | $Fe_2O_3$ | MnO | CuO | PbO | $SnO_2$ | CoO | NiO | $As_2O_3$ | $Bi_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PG1 | natural green | COM | 64.2 | 1.69 | 13.7 | 2.87 | 10.2 | 3.52 | 0.23 | 0.33 | 0.82 | 0.070 | 0.79 | 0.74 | | 0.22 | 0.59 | | | | |
| PG1 | blue | COM | 63.5 | 1.57 | 12.8 | 2.60 | 9.40 | 3.59 | 0.17 | 0.24 | 0.87 | 0.069 | 1.14 | 0.76 | 0.04 | 0.47 | 1.54 | 0.199 | 0.073 | 0.82 | 0.17 |
| PG1 | red-brown | COM | 58.0 | 1.42 | 12.1 | 1.65 | 8.30 | 3.06 | 0.06 | 0.28 | 0.73 | 0.053 | 3.36 | 0.57 | 1.15 | 4.24 | 4.80 | 0.041 | 0.012 | 0.15 | |
| PG1 | white | COM | 47.2 | 1.05 | 11.2 | 2.20 | 6.40 | 2.42 | 0.23 | 0.18 | 0.56 | 0.026 | 0.48 | 0.23 | | 14.2 | 13.5 | | | 0.10 | |
| PG2 | natural green | VB | 67.7 | 1.02 | 14.9 | 2.03 | 8.46 | 3.89 | 0.22 | 0.33 | 0.80 | 0.055 | 0.51 | 0.06 | | 0.02 | 0.02 | | | | |
| PG2 | blue | VB | 63.8 | 1.03 | 14.4 | 1.86 | 8.15 | 3.92 | 0.18 | 0.27 | 0.95 | 0.059 | 0.76 | 0.05 | 0.17 | 0.34 | 2.60 | 0.360 | 0.20 | 0.36 | 0.47 |
| PG2 | red-brown | VB | 58.8 | 1.01 | 13.3 | 1.45 | 7.54 | 3.48 | 0.09 | 0.25 | 0.90 | 0.049 | 3.39 | 0.10 | 2.96 | 3.10 | 3.50 | 0.019 | | 0.05 | |
| PG2 | white | VB | 50.3 | 0.75 | 11.2 | 1.58 | 5.93 | 2.84 | 0.14 | 0.15 | 0.66 | 0.025 | 0.40 | 0.08 | | 13.0 | 12.8 | | | 0.11 | |
| PG3 | natural green | COM | 63.8 | 1.85 | 13.4 | 3.35 | 9.90 | 3.85 | 0.15 | 0.35 | 0.80 | 0.120 | 0.60 | 1.67 | | 0.10 | 0.10 | | | | |
| PG3 | blue | COM | 63.7 | 1.55 | 12.4 | 3.15 | 9.50 | 3.75 | 0.16 | 0.38 | 0.70 | 0.100 | 1.05 | 0.66 | 0.15 | 1.00 | 1.20 | 0.110 | 0.05 | 0.25 | 0.18 |
| PG3 | red-brown | COM | 59.5 | 1.75 | 12.8 | 3.15 | 9.30 | 3.75 | 0.17 | 0.35 | 0.72 | 0.100 | 7.00 | 0.68 | 0.50 | 0.15 | 0.10 | | | | |
| PG3 | white | COM | 51.0 | 1.35 | 11.2 | 2.90 | 8.30 | 3.10 | 0.19 | 0.35 | 0.70 | 0.094 | 0.65 | 0.75 | | 12.2 | 7.20 | | | | |
| MV | natural green | VB | 67.6 | 1.16 | 13.7 | 1.99 | 9.54 | 3.74 | 0.25 | 0.33 | 0.60 | 0.040 | 0.58 | 0.50 | | | | | | | |
| MV | blue | VB | 67.0 | 1.30 | 13.5 | 2.20 | 8.45 | 3.50 | 0.25 | 0.30 | 0.60 | 0.030 | 1.10 | 0.50 | 0.12 | 0.20 | 0.10 | 0.130 | 0.08 | 0.40 | 0.25 |

(Contd.)

| SAMPLE | COLOR | GLASS TYPE | $SiO_2$ | $Al_2O_3$ | $Na_2O$ | $K_2O$ | CaO | MgO | $SO_3$ | $P_2O_5$ | Cl | $TiO_2$ | $Fe_2O_3$ | MnO | CuO | PbO | $SnO_2$ | CoO | NiO | $As_2O_3$ | $Bi_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MV | red-brown | VB | 59.2 | 1.20 | 12.0 | 1.75 | 7.50 | 3.10 | 0.20 | 0.28 | 0.50 | 0.030 | 3.00 | 0.25 | 0.45 | 6.50 | 4.00 | | | | |
| MV | white | VB | 51.5 | 0.80 | 11.2 | 1.60 | 6.80 | 2.80 | 0.20 | 0.28 | 0.60 | 0.050 | 0.35 | 0.22 | | 14.0 | 9.50 | | | 0.10 | |
| RB | light blue | VB | 64.0 | 1.20 | 12.4 | 2.40 | 11.0 | 3.45 | 0.20 | 0.28 | 0.75 | 0.070 | 1.05 | 0.55 | 1.70 | 0.45 | 0.50 | | | | |
| RB | blue | VB | 63.6 | 1.15 | 13.2 | 2.50 | 10.3 | 3.25 | 0.22 | 0.31 | 0.65 | 0.060 | 0.95 | 0.50 | 0.12 | 0.40 | 0.70 | 0.800 | 0.19 | 0.60 | 0.50 |
| RB | red-brown | VB | 60.5 | 1.10 | 12.9 | 2.40 | 10.2 | 3.45 | 0.17 | 0.30 | 0.70 | 0.070 | 5.70 | 0.55 | 0.70 | 0.60 | 0.70 | | | | |
| RB | white | VB | 52.7 | 1.05 | 11.5 | 2.20 | 10.0 | 3.35 | 0.18 | 0.25 | 0.65 | 0.050 | 0.63 | 0.48 | | 11.0 | 6.0 | | | | |

TABLE 1B. Base-glass composition in wt% of the oxides calculated by subtracting the concentration of colorants, opacifiers and related elements to the analyses of Table 1a and recalculating to 100% the other glass components.

| SAMPLE | COLOR | GLASS TYPE | $SiO_2$ | $Al_2O_3$ | $Na_2O$ | $K_2O$ | CaO | MgO | $SO_3$ | $P_2O_5$ | Cl | $TiO_2$ | $Fe_2O_3$ | MnO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PG1** | natural green | COM | 64.7 | 1.70 | 13.8 | 2.89 | 10.3 | 3.55 | 0.23 | 0.33 | 0.83 | 0.071 | 0.79 | 0.74 |
| **PG1** | blue | COM | 65.7 | 1.63 | 13.2 | 2.69 | 9.72 | 3.71 | 0.18 | 0.25 | 0.90 | 0.072 | 1.18 | 0.78 |
| **PG1** | red-brown | COM | 67.3 | 1.65 | 14.0 | 1.91 | 9.63 | 3.55 | 0.08 | 0.32 | 0.85 | 0.061 | | 0.66 |
| **PG1** | white | COM | 65.5 | 1.45 | 15.4 | 3.05 | 8.87 | 3.36 | 0.32 | 0.25 | 0.78 | 0.046 | 0.67 | 0.32 |
| **PG2** | natural green | VB | 67.7 | 1.02 | 14.9 | 2.03 | 8.46 | 3.89 | 0.22 | 0.33 | 0.80 | 0.055 | 0.51 | 0.06 |
| **PG2** | blue | VB | 66.8 | 1.08 | 15.1 | 1.95 | 8.54 | 4.11 | 0.19 | 0.28 | 1.00 | 0.062 | 0.80 | 0.05 |
| **PG2** | red-brown | VB | 67.6 | 1.16 | 15.3 | 1.67 | 8.66 | 4.00 | 0.10 | 0.29 | 1.03 | 0.056 | | 0.11 |
| **PG2** | white | VB | 67.9 | 1.01 | 15.1 | 2.13 | 8.00 | 3.84 | 0.19 | 0.20 | 0.90 | 0.033 | 0.54 | 0.11 |
| **PG3** | natural green | COM | 63.9 | 1.85 | 13.4 | 3.36 | 9.92 | 3.86 | 0.15 | 0.35 | 0.80 | 0.120 | 0.60 | 1.67 |
| **PG3** | blue | COM | 65.6 | 1.60 | 12.8 | 3.24 | 9.78 | 3.86 | 0.16 | 0.39 | 0.72 | 0.103 | 1.08 | 0.68 |
| **PG3** | red-brown | COM | 64.5 | 1.90 | 13.9 | 3.41 | 10.1 | 4.06 | 0.20 | 0.38 | 0.78 | 0.108 | | 0.74 |
| **PG3** | white | COM | 63.3 | 1.68 | 13.9 | 3.60 | 10.3 | 3.85 | 0.24 | 0.43 | 0.87 | 0.117 | 0.81 | 0.93 |
| **MV** | natural green | VB | 67.6 | 1.16 | 13.7 | 1.99 | 9.53 | 3.74 | 0.25 | 0.33 | 0.60 | 0.040 | 0.58 | 0.50 |
| **MV** | blue | VB | 67.9 | 1.32 | 13.7 | 2.23 | 8.56 | 3.55 | 0.25 | 0.30 | 0.61 | 0.030 | 1.11 | 0.51 |
| **MV** | red-brown | VB | 68.8 | 1.40 | 14.0 | 2.03 | 8.72 | 3.60 | 0.24 | 0.33 | 0.58 | 0.035 | | 0.29 |
| **MV** | white | VB | 67.4 | 1.05 | 14.7 | 2.09 | 8.90 | 3.66 | 0.26 | 0.37 | 0.79 | 0.065 | 0.46 | 0.29 |
| **RB** | light blue | VB | 65.7 | 1.23 | 12.7 | 2.47 | 11.3 | 3.54 | 0.21 | 0.29 | 0.77 | 0.072 | 1.08 | 0.56 |
| **RB** | blue | VB | 65.8 | 1.19 | 13.7 | 2.59 | 10.7 | 3.36 | 0.23 | 0.32 | 0.67 | 0.062 | 0.98 | 0.52 |
| **RB** | red-brown | VB | 65.5 | 1.19 | 14.0 | 2.60 | 11.0 | 3.74 | 0.20 | 0.32 | 0.76 | 0.076 | | 0.60 |
| **RB** | white | VB | 63.5 | 1.26 | 13.8 | 2.65 | 12.0 | 4.03 | 0.22 | 0.30 | 0.78 | 0.060 | 0.76 | 0.58 |

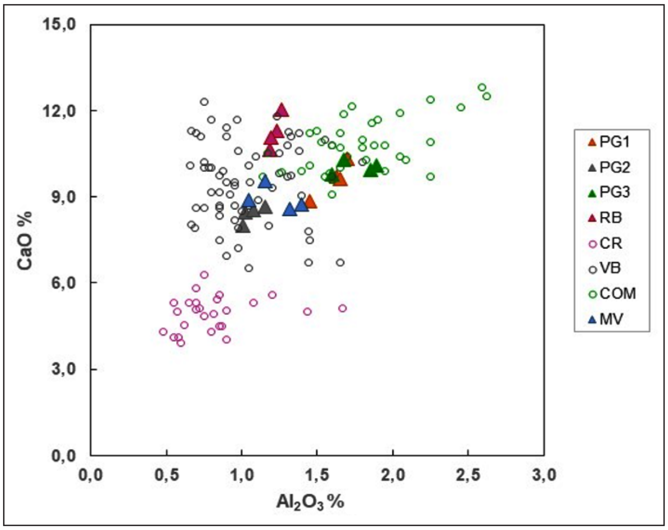


FIG 4. Diagram of the calcium versus aluminium concentrations of the base glass of the *rosetta* samples (colored triangles) compared with a dataset of Renaissance Venetian glass distinguishing *cristallo* (light gray line circles), *vitrum blanchum* (dark line circles), and common glass (green line circles) compositions. (Graphic: the authors)

The base-glass compositions of the samples were compared in binary diagrams (**Fig. 4**) to a dataset of Venetian glass (Lagoon dataset[20]) of about 200 analyses of genuine Renaissance Venetian transparent glass samples. The CaO plotted against the $Al_2O_3$ of the *rosetta* samples (triangles: orange PG1; gray PG2; green PG3; red RB; blue MV) fall in the same area as for *vitrum blanchum* (gray circles) and common glass (green circles). Similar plots are found for magnesium, silica, and sodium concentrations. The CaO and $Al_2O_3$ plots for samples PG1, RB, and PG3 are in the range for the composition of Venetian *vitrum blanchum*, while those for the samples PG2 and MV are closer to common glass. None of the base-glass compositions of the *rosetta* samples resembles the Venetian *cristallo* composition (pink circles).

## Colorants and opacifiers

The translucent natural green glass present in four samples is colored by iron involuntarily introduced as a contaminant of the raw materials (natural color). The manganese addition was intended to obtain the desired green hue rather than to decolorize glass. This aspect is evident in sample PG2, where the traces of manganese found (MnO 0.06%), clearly insufficient to decolorize the iron content ($Fe_2O_3$ 0.51%), correspond to an involuntary addition through the silica source or the glass cullet.

The translucent light-blue color that replaces the natural green layers in sample RB was obtained by adding copper (CuO 1.7%) and iron ($Fe_2O_3$ 1.05%). Pure oxidized copper was used; in fact, no elements indicating the use of bronze or of metallurgical byproducts were found.

As regards the blue glass, zaffre was used as a colorant, a cobalt ore that was powdered, calcined, and mixed with quartz sand and then traded in this form. The low potassium content ($K_2O$ 2–3.2%), similar to the other colors of the *rosetta* samples, excludes the use of smalt, a blue pigment consisting of a potassium silicate glass, rich in cobalt.[21] Variable amounts of tin ($SnO_2$ 0.1–2.6%) and lead (PbO 0.2–1.0%) were also detected in the blue layers in which no cassiterite crystals were observed. No relation was found between the two elements, suggesting that some tin could have entered the

20 Verità and Biron 2021.
21 Freestone and Tatton-Brown 2005.

glass composition as white glass cullet opacified by lead-tin calx and some as a secondary component of the zaffre. The cobalt ore brought nickel, copper, bismuth, and arsenic (elements not detected in the other colors), as well as iron ($Fe_2O_3$ 0.80–1.18% in blue glass; 0.51–0.79% in natural green glass). These elements (bismuth and arsenic in particular) are characteristic of the cobalt ore extracted in Germany that had been in use in Venice as well as in other European countries since 1520–1530 as a blue colorant for glass, glazes, and enamels.[22]

The opaque white glass was obtained by adding lead and tin to the base glass. Once added to the soda-lime-silica glass, the lead dissolved during melting, yielding soda-lime-lead-silica glass in which microcrystals of cassiterite ($SnO_2$) are found.[23] The amount of tin is variable ($SnO_2$ 6–13.5%), indicating different levels of opacification. The Pb/Sn ratio is close to one for the PG1 and PG2 samples and close to 1.5 for the other samples. Until the middle of the fifteenth century, white opaque glass (*lattimo*) was produced in Venice for small applications on blown glass, for the preparation of mosaic tesserae, and for enamels. Around the middle of the fifteenth century, Venetian glassmakers improved their *lattimo* for producing luxury blown glassware in order to imitate the very expensive porcelain items arriving from China. According to the recipe books of Venetian glassmakers and the analyses available, sixteenth-century *lattimo* was made by adding a lead-tin calx to *cristallo* or *vitrum blanchum* glass. For instance, the treatise *Trattatelli* (recipe 24 in the first book and 9 in the second)[24] describes the formation of the opacifier as a white calx floating on the melt of comparable amounts of metallic lead and tin. Giovanni Darduin's book (for instance, recipe 35) prescribes melting a batch made of 12 parts *cristallo* frit, 22 parts lead-tin calx, and a small amount of manganese.[25] Several other of Darduin's recipes report the production of *lattimo* by using lead-tin calx.[26]

The red-brown glass was colored and opacified by copper (CuO 0.45–3%) in the form of metallic microparticles. The separation of coloring particles during the cooling of the melt was achieved by addition of iron ($Fe_2O_3$ 3–7%) in a reduced form.[27] Significant and comparable amounts of lead (PbO 0.6–6.5%) and tin ($SnO_2$ 0.7–4.8 %) were found in the red glass, except for sample PG3 (PbO and $SnO_2$ less than 0.2%), indicating that lead-tin calx was also added to the batch. It is interesting to observe that some recipes for red-brown (*rosso in corpo*) glass of the Renaissance Venetian treatises indicate the addition of lead-tin calx (for instance, Montpellier 120 and Darduin 155), others don't (for instance, Montpellier 110 and Darduin 156).[28] The manuscripts do not explain why lead-tin calx was added or not. Nevertheless, the addition of tin in a reduced form acts as a strong reducer and helps the color formation.[29] In Darduin's manuscript the lead-tin calx is prepared at a high temperature to give a white calx (*bianca*, more oxidised) or at a lower temperature to give

22 Verità and Zecchin 2015a; Verità and Biron 2021; Molera and others 2021; Verità and Zecchin 2015b.

23 Verità, Zecchin, and Tesser 2018; Matin 2019.

24 Milanesi (1864) 1968.

25 Zecchin 1986, 128.

26 Verità, Zecchin, and Tesser 2018.

27 Bandiera and others 2021.

28 Montpellier: Zecchin 1987b, 266, recipe 120; 265, recipe 110; Darduin: Zecchin 1986, 187, recipes 155, 156.

29 Bandiera and others 2021.

a gray calx (*berettina*, less oxidised).[30] The *Anonimo* manuscript recommends using gray calx to make transparent ruby red (*rosechiero*), a process that requires a reduced glass melt.[31]

## RECIPES

To better understand the technology used in Murano in preparing and coloring glass for the *rosetta* cane, research was carried out on the recipes of the Venetian glassmakers. In the Renaissance treatises, recipes for the individual colors are found, but not specifically for the base glass and coloring of all the layers of *rosetta* canes. However, four recipes for *rosetta* canes have been found in two unpublished treatises of Venetian glassmakers belonging to private collections.[32]

The first one (indicated below as *Treatise 1*) is a notebook that belonged to an unknown Muranese glassmaker (**Fig. 5**). The manuscript is not precisely dated; it belongs to a group of fourteen recipe books which are transcriptions, probably in the second half of the eighteenth century, of older recipes.[33]

The second treatise (indicated below as *Treatise 2*) is a collection of various recipes, some dated between 1754 and 1781. In this manuscript three undated recipes for *rosetta* cane are found. They probably belonged to the Muranese family Ferrari, owners of a glassworks specialized in production of the *rosetta* cane and beads.[34]

Discussion of these recipes enhances our understanding of the development of *rosetta* beads' glass composition.

### Treatise 1

One detailed recipe of this treatise instructs how to prepare the base glass and colorants "as used in the past" (*come usava anticamente*) for production of *rosetta* canes. The base glass is melted from a batch of 100 pounds of soda ash imported from the Levant, 50 pounds of purified soda ash, and 160 pounds of silica (finely ground Ticino pebbles). Once ready, the melt is poured in water and the glass grit (*cotizzo*) is collected and dried. The resulting soda-lime-silica base glass can be classified as Venetian *cristallo*; the same base glass (i.e., having the same composition) is used for all the colors. The use of *cristallo* as the base glass for colors (especially for blue) is frequently reported in Venetian recipes—Neri in his book (recipe 49) explains that the best blue glass (*meraviglioso*) is obtained by coloring a *cristallo* base glass.[35]

The *cotizzo* is then mixed with colorants and remelted. Opaque white glass is prepared by adding lead-tin calx and a small amount of manganese to avoid any green hue; and opaque red-brown (*rosso in corpo*) is produced by adding copper oxide, two iron compounds (steel and flakes from beating a hot iron on an anvil), and lead-tin calx. Recipes are also provided for five translucent colors: yellow, colored with iron and manganese; green, with copper and iron; blue, with cobalt in the form of zaffre; light blue, with copper and zaffre; and purple, with manganese.

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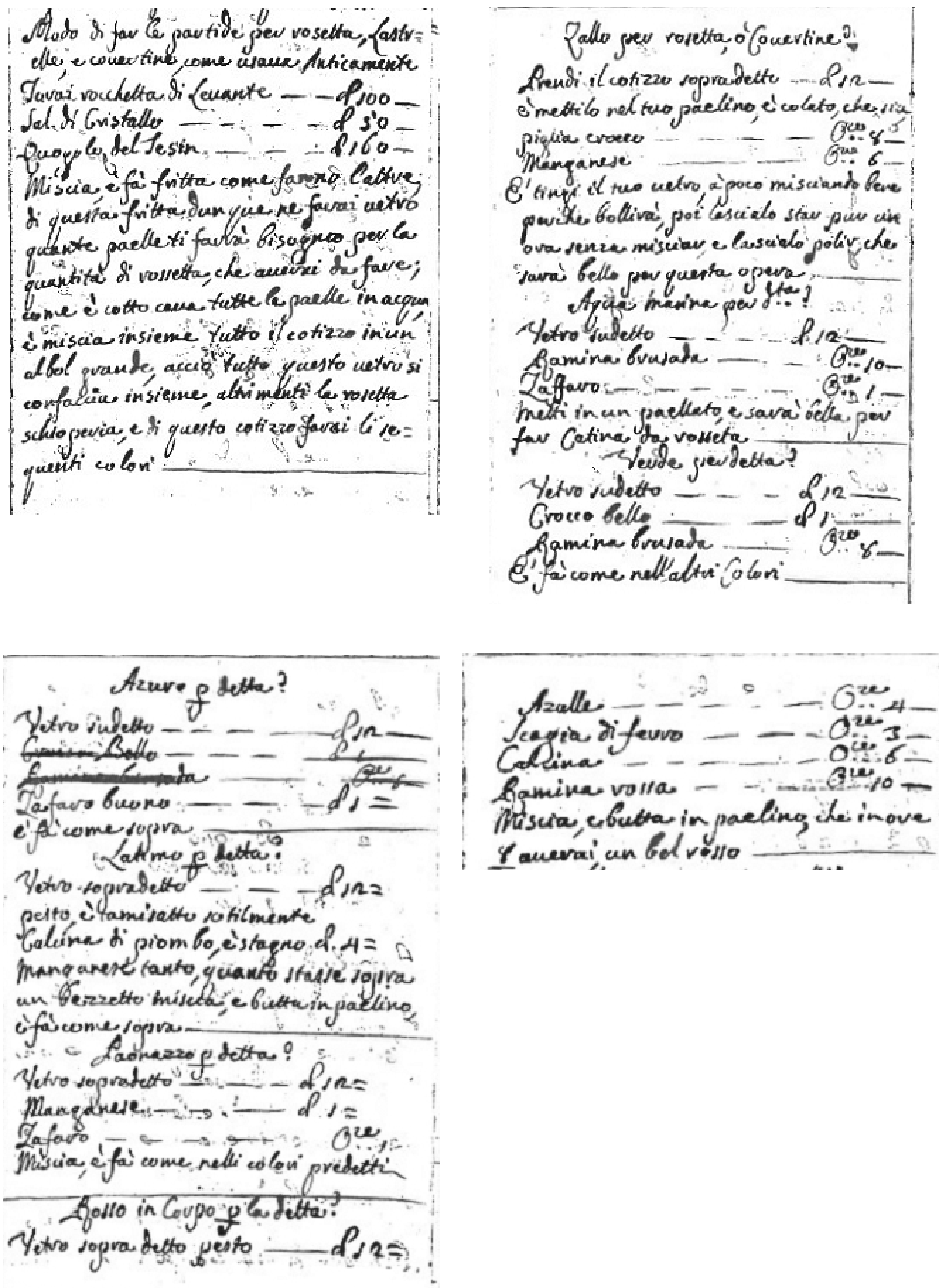
30 Zecchin 1986, 161–162, recipe 97.
31 Moretti and Toninato 2001, recipe 32.
32 Toninato 1982; Toninato and Moretti 1992.
33 Toninato and Moretti 1992.
34 Zecchin 1998, 39. The first recipe refers to very large (*stragrande*) *rosetta* beads.
35 Neri (1612) 2001.


Modo di far le partide per rosetta, Lattesine, e couertine, come usava Anticamente
Tavai rocchetta di Levante — d 100 —
Sal di Cristallo — d 50 —
Quogolo del Tesin — d 160 —
Miscia, e fà fritta come fanno Lattive; di questa fritta dunque ne farai vetro quante paelle ti farà bisogno per la quantità di rosetta, che averai da fare; Come è cotto cava tutte le paelle in acqua è miscia insieme tutto il cotizzo in un albol grande, acciò tutto questo vetro si confalia insieme, altrimenti la rosetta schioperia, e di questo cotizzo farai li seguenti colori

Giallo per rosetta, ò Couertine:
Prendi il cotizzo sopradetto — d 12 —
è mettilo nel tuo paelino, è coloto, che sia
pigia crocco — Onze 4
Manganese — Onze 6 —
E tingi il tuo vetro, à poco misciando bene perche bollirà, poi lascialo star per un'ora senza misciar, e lascialo polir, che sarà bello per questa opera
Aqua marina per d.:
Vetro sudetto — d 12 —
Ramina brusada — Onze 10 —
Zaffaro — Onze 1 —
Metti in un paelleto, e sarà bella per far Catina da rosetta
Verde per detta:
Vetro sudetto — d 12 —
Crocco bello — d 1 —
Ramina brusada — Onze 8 —
E fà come nell'altri Colori

Azuro p detta:
Vetro sudetto — d 12 —
Zafaro buono — d 1 =
è fà come sopra
Lattimo p detta:
Vetro sopradetto — d 12 =
pesto, è tamisatto sotilmente
Calcina di piombo, è stagno d. 4 =
manganese tanto, quanto stasse sopra un Pezzetto miscia, e butta in paelino
è fà come sopra
Paonazzo p detta:
Vetro sopradetto — d 12 =
Manganese — d 1 =
Zafaro — Onze 1
Miscia, è fà come nelli colori predetti
Rosso in Coupo p la detta:
Vetro sopra detto pesto — d 12 =

Azalle — Onze 4 —
Scaglia di ferro — Onze 3 —
Calcina — Onze 6 —
Ramina rossa — Onze 10 —
Miscia, e butta in paelino, che in ove 4 averai un bel rosso

FIG 5. Recipes for base glass (*cotizzo*) and colors for *rosetta* cane (Treatise 1). (Photo: the authors)

A summary of the recipes limited to the four colors used in the analyzed samples is reported in **Table 2**. Except for the quality of the base glass (*vitrum blanchum* in the analyzed samples; *cristallo* in the recipe), some clear correspondences are found between the recipe and the results of the analyses. In particular, the base-glass composition is the same for all the colors of each analyzed sample, and colorants used in the recipe correspond to the results of the analyses; lead-tin calx was used to color the opaque white glass, and copper, iron, and a certain amount of lead-tin calx to obtain the red-brown color.

| | | GLASS COMPONENTS | | | | COLORANTS | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **COLOR** | **RECIPE** | **glass grit *cotizzo*** | **saltpeter** | **silica** | **litharge** | **zaffre** | **calcined copper** | **lead-tin calx** | **arsenic** | **manganese** | **iron flakes** | **steel** |
| **blue** | **1** | 48 | | | | 4 | | | | | | |
| | **2abc** | 48 | 36.5 | 73 | 94* | 10 | | | | | | |
| **light blue** | **1** | 44 | | | | 3.7 oz. | 3 | | | | | |
| | **2a** | 44 | 35 | 70 | 60 | 4 oz. | 10 | | | | | |
| **red-brown** | **1** | 200 | | | | | 14 | 8 lb. 4 oz. | | | 4 lb. 2 oz. | 5 lb. 6 oz. |
| | **2abc** | 200 | | | | | 4 | 40 | | | 2 lb. 6 oz. | 2 |
| **white** | **1** | 48 | | | | | | 16 | | traces | | |
| | **2abc** | 46 lb. 8 oz. | 35 | 70 | 93 lb. 4 oz. | | | | 16** | | | |

TABLE 2. Recipes for base glass and colors of *rosetta* canes from eighteenth-century treatises of Venetian glassmakers.

Unless otherwise specified, quantities are indicated in pounds. Transcription limited to the colors of the analyzed samples.

(*) Blue 2b: 85 pounds, 6 ounces of litharge instead of 94 pounds; minor differences also for saltpeter, silica, and zaffre

(**) White 2b: 17 pounds of arsenic instead of 16

## Treatise 2

The first recipe explains how to prepare six colors (recipe 2a: opaque white and red-brown, translucent light blue, blue, green, and black) and the other two how to prepare four colors (recipe 2b: white, red-brown, blue, and green; recipe 2c: white, red-brown, blue, and black). The number of colors used in a cane, the number of layers, and the sequence of colors are not specified.

In these recipes the base glass is different. It is made of one part *cotizzo* (its composition is not specified, but it is likely that it was of the soda-lime-silica type observed in most Venetian recipes) with four to five parts of a mixture of *nitro* (saltpeter, $KNO_3$), *retrigerio* (litharge, PbO), and *terra* (silica, $SiO_2$). The proportions of these components are reported in **Table 2**. Saltpeter was first used to produce the new potash-lead-silica glass patented in 1674 by George Ravenscroft in London. The first Muranese recipes using saltpeter and litharge are dated to the last years of the seventeenth century; the earliest, dated 1693 (no. 214), is found in the Darduin treatise.[36] The melting of this batch leads to a very complex base glass whose composition, calculated from the batch components, shows low alkali content ($Na_2O$ 3–4%; $K_2O$ 7–8%) and a quite high lead content (PbO 35–40%).

The addition of saltpeter and litharge differs in some colors, leading to distinctive base-glass compositions. For instance, saltpeter and litharge do not enter the composition of the opaque red-brown glass (this is understandable, since saltpeter is a strong oxidizer able to hinder the formation of the metallic copper particles that

36 Zecchin 1986, 218.

produce the red-brown color) and the red-brown recipes are similar to the recipe of *Treatise 1*. For the same reason, saltpeter and litharge are not used in the recipe for black glass colored with manganese. An attempt to make black glass with saltpeter and litharge had nevertheless been made (recipe 2c), but the final comment of the glassmaker was negative: *Questo negro non riuscì buono* (This black didn't work out well). Finally, more litharge is added to the recipe for white glass than the recipes for blue and aqua glasses (see **Table 2**).

The colorants for blue, light blue, green, and red-brown are the same as in *Treatise 1*, while a major difference concerns the white glass. A new colorant-opacifier (lead arseniate microcrystals) replaces the traditional tin oxide introduced as lead-tin calx. Several recipes for a new white glass made with arsenic, saltpeter, and lead, dated 1693 or later, are found at the end of the Darduin treatise. By varying the opacifier concentration, an opalescent glass (*girasole*, sunflower) or a very intense opaque white glass (*smalto*) were made. Since the beginning of the eighteenth century, the new white glass opacifier was preferred to the traditional lead-tin calx by Venetian glassmakers, probably because of its better properties (small crystals homogeneously dispersed) and the lower cost.[37]

## GLASS FIT (COMPATIBILITY OF GLASSES)

The recipe for the base glass of *Treatise 1* deserves special comment. The *cotizzo* is prepared following a particular procedure. Given the limited capacity of the crucibles at that time, the amount of *cotizzo* needed to prepare colors for *rosetta* cane was too large for a single melting. Therefore, the recipe instructs that the melt of several pots (*quante paelle ti farà bisogno*) be poured in water. Then, all the *cotizzo* produced is carefully mixed and the homogenized mixture is used to melt each color; without this precaution, the *rosetta* cane will break (*altrimenti la rosetta schioperia*). This is a simple and effective way to ensure that the base glass of all the colors has the same composition. A similar procedure is found in recipe XVII of the *Anonimo* treatise:[38] all the colors for a polychrome glass cane must be melted using the same base glass; otherwise, the resulting object breaks spontaneously (*vetri fatti con composizioni diverse non si uniscono bene e sono pericolosi*). Certainly, a similar problem concerned the opaque white glass whose composition greatly differs from the composition of the other colors. We don't know how this problem was solved. One possibility was to modify the lead-to-tin ratio of the calx, but there is no documentary evidence of this.

The origin of this problem lies in the fit (physical compatibility) of the colors forming the cane. The compatibility or "fit" of two glasses fused together is solely a function of their thermal expansion and viscosity. The chemical composition of the glass strongly influences these two physical properties. When two glasses without fit are fused together, a permanent stress is created at their interface, and if the resulting strain is high, the object breaks. To avoid spontaneous fractures, their softening temperature and thermal expansion must be the same.[39] This corresponds to the indications of the recipe of *Treatise 1* and what was observed in the analyses: the base-glass composition for all the colors forming a cane is the same.

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37 Verità, Zecchin, and Tesser 2018.
38 Moretti and Toninato 2001.
39 Schwoerer 2013.

The situation is different with regard to the recipes 2a, b, c, where the base-glass compositions differ from color to color, mainly for the red. We can't explain these differences. However, we must take into account that glasses having different viscosities can be compatible if the difference in their thermal expansions compensates for the strain introduced by the gap in their viscosity. For instance, if the viscosity differences result in tension between the two glasses and the expansion differences result in an equal amount of compression between the two glasses, the two stresses cancel each other out.[40]

## CONCLUSIONS

This study reports the results of the quantitative chemical analyses of the colored glass layers of five genuine Renaissance Venetian *rosetta* glass fragments dated the first half of the sixteenth to the beginning of the seventeenth century.

A dataset of chemical composition of the colors of *rosetta* canes made in Venice from their invention, at the end of the fifteenth century, to the nineteenth century does not exist. The analyses of five genuine Renaissance Venetian *rosetta* glass fragments are a first contribution in this direction.

The base-glass composition is of the soda-lime-silica type (soda ash glass). Compared with a dataset of Renaissance Venetian glass, their composition corresponds to that of *vitrum blanchum* and common glass. The same base-glass composition was found for the four glass colors of each sample, confirming the special attention given by the Muranese glassmakers to avoid problems of glass fit and of mechanical breakage of the canes.

The glass coloring techniques correspond to those of the Renaissance Venetian tradition. Elements associated with the cobalt ore used to color blue glass correspond to the zaffre in use after 1520–1530.

Recipes expressly made for *rosetta* canes were found in two treatises of Venetian glassmakers. They attest, alongside the production following the traditional compositions, the use of new raw materials, a new opacifier, and a variety of colors.

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40 Schwoerer 2013.

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