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ORIGINAL PAPER

Colourless glass from the Palatine and Esquiline hills in Rome (Italy). New data on antimony- and manganese-decoloured glass in the Roman period

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Abstract A collection of 21 glass samples (18 colourless and 3 light aqua blue) found in recent excavations performed at the Palatine and Esquiline hills in Rome has been investigated by means of SEM-EDS, EMPA and LA-ICP-MS. The glass was recovered in the "Baths of *Helagabalus*" and the *Horti Lamiani*. The collection included cups and bowls widely attested in Rome and Ostia from the late second to the first half of the third century AD. The analyses assigned this collection to the RC/LAC-MnSb groups (Roman and Late Antique colourless glass with both antimony and manganese) which seemed closely related to the Levantine area.

Keywords Colourless glass · Baths of *Helagabalus* · *Horti Lamiani* · Imperial Rome · EMPA · LA-ICP-MS · RC-Sb · LAC-Sb · RC-MnSb · LAC-MnSb

The archaeological background and research objectives

The glass vessels selected for archaeometric study come from two recently investigated archaeological contexts in Rome (Fig. 1).

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The former (PNE) is the complex known as "Baths of *Helagabalus*", situated on the north-east slope of the Palatine Hill (Saguì 2013; Saguì et al. 2014; Saguì and Cante 2015). The site has been occupied from the early Iron Age to the Middle Ages. During the Imperial age, it was characterized by the construction of two large buildings, which follow one another in a short interval of time. Dated to the Hadrianic period (117–138 AD), the first one comprises a series of utilitarian rooms (*horreum*), overlooking the road connecting the Colosseum with the *Forum*. The Hadrianic complex was completely destroyed in the Severan period (end of the second-early third century AD), in order to build a new and different structure, with rooms arranged around a central rectangular courtyard. The glass samples (PNE 1-10, 12; 20-21) belong to forms dating to the last decades of the second century AD and probably used within the Hadrianic *horreum* (Lepri 2013).

The second archaeological context is located in the southern sector of the Esquiline hill, in the area corresponding to the ancient *Horti Lamiani* and the present Piazza Vittorio (PV). The site was named after *L. Aelius Lamia*, a consul living under the reign of the emperor *Augustus*, responsible for the creation of these gardens. The area became part of the imperial ownership probably under *Tiberius* and certainly from the reign of *Caligula*, who built his urban *villa* there. The *horti* instead became a private property of the Emperor possibly under *Alexander Severus* (222–235 AD) (Cima and Talamo 2008; Barbera 2013; Alagia 2014).

The most recent investigations carried out in this area under the direction of Dr. Serlorenzi (Soprintendenza Speciale per i Beni Archeologici di Roma) yielded an important archaeological sequence from the late Republican period to the twentieth century AD. The main discovery is represented by a new sector belonging to this complex, centred around a large hall

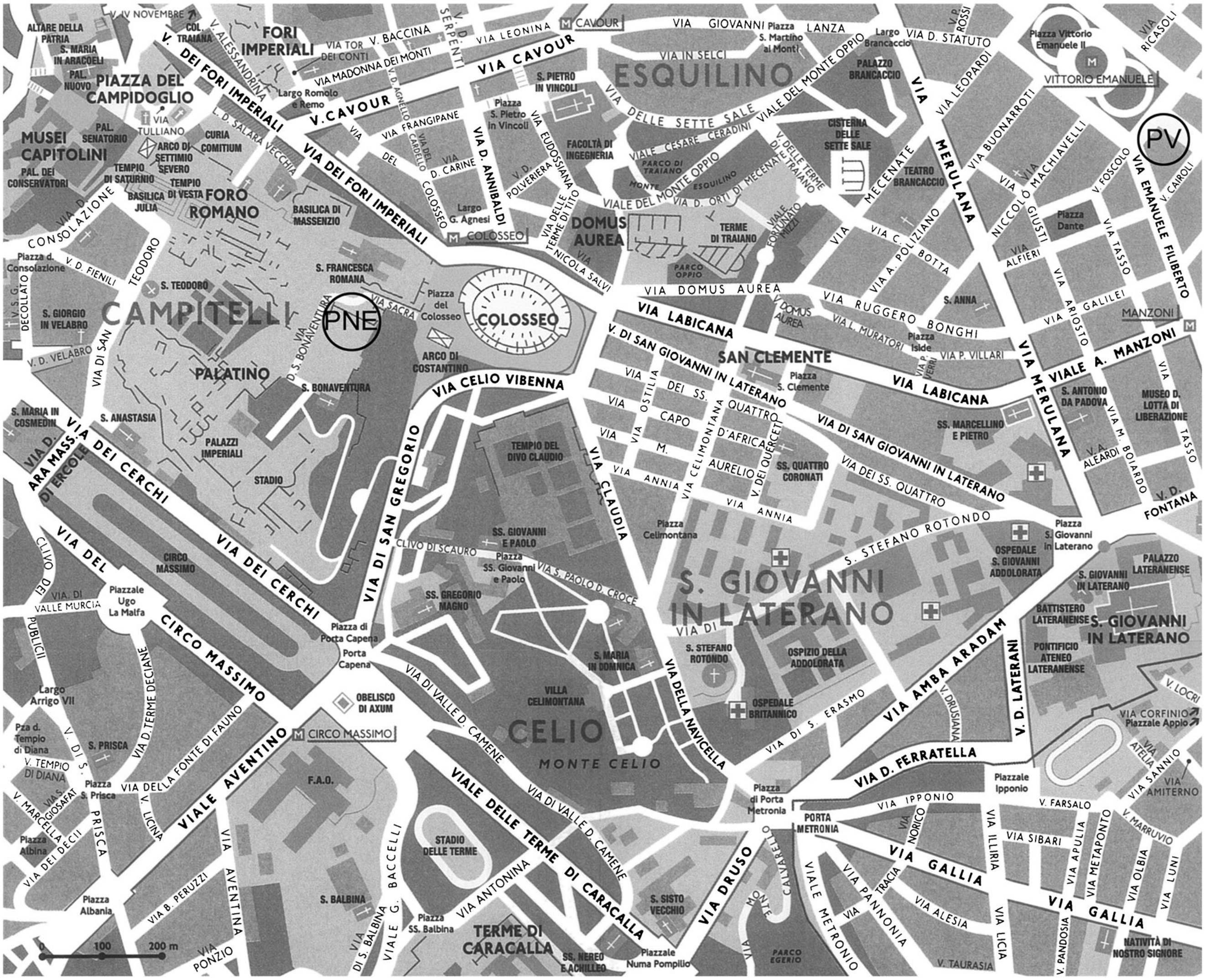

Fig. 1 Map of Rome (detailed view) with the location of the two archaeological contexts investigated

of the Middle Imperial age (Barbera et al. 2010). The glass analysed here (PV 13-19, 22) comes from late second century AD deposits, found in an open area corresponding to the archaeological sector named "Aula Cortile Grande" and related to the building activities of the hall.

Based on current knowledge of colourless glass, this research is aimed at characterising glass vessels with two main objectives: (1) the material characterisation and (2) the provenance assessment. In the first case, the nature of network formers, fluxes and stabilising agents is a matter for investigation. The identification of decolouring agents is further examined, in order to understand whether it was their addition or the use of a pure white sand which affected the final aspect of glass vessels. These results will be of further help in provenance determination, the latter being addressed by comparing the bulk chemical compositions of the sample set to the known reference groups on colourless glasses.

Materials

A set of 21 glass vessels (Table 1; Figs. 2 and 3) was selected for archaeometric investigation. The morphological types are known from other contexts of Rome and Ostia dating to the Middle Imperial age, a period in which most vessels seem to be made of colourless glass.

The first group of fragments is representative of the most frequent types in both contexts: cups and bowls of common use sharing many technical features. All colourless (PNE 1-4, 6, 8-10, 12; PV 13-17, 19) and aqua-blue (PNE 5, 7; PV 18) specimens are free-blown glass with very thin walls; the rim is fire-worked, often with a rough upper part of the outer surface perhaps caused by a wheel, and triangular-shaped in some specimens more or less sharp-edged. In Rome and Ostia, the presence of these forms from the late second to the first half of the third century AD seems highly significant (Lepri 2013, pp. 142–143). For instance, many similar and coeval vessels

Table 1 Sample list

	SIte	Colour
Baths of *Helagabalus*	PNE 1	Colourless
	PNE 2	Colourless
	PNE 3	Colourless
	PNE 4	Colourless
	PNE 5	Aqua blue
	PNE 6	Colourless
	PNE 7	Aqua blue
	PNE 8	Colourless
	PNE 9	Colourless
	PNE 10	Colourless
	PNE 12	Colourless
	PNE 20	Colourless
	PNE 21	Colourless
Horti Lamiani	PV 13	Colourless
	PV 14	Colourless
	PV 15	Colourless
	PV 16	Colourless
	PV 17	Colourless
	PV 18	Aqua blue
	PV 19	Colourless
	PV 22	Colourless

unearthed at the archaeological site of Vigna Barberini (Palatine Hill, very close to the Baths of *Helagabalus*) were recently published (Foy 2014, in particular p. 21 f.fol.).

These types are also very common in some Late Antonine (160–190 AD) contexts in Ostia (the north-east area of the *Terme del Nuotatore*), whose glass findings still remain unpublished. They are characterised by several dimensional variants, which are consistent with the existence of sets made of these types of vessels.

Their presence in *Gallia Narbonensis* (Foy 2014, *ibid.*) makes the provenance issue even more complex, although the important role played by the Italic workshops is beyond any doubt.

In this regard, further data will be provided by the study of glass collections from *Vigna Barberini* and from *Gallia Narbonensis*, which are currently being investigated by Foy (2014, p. 13, note 1 and p. 24), within the broader project on the first to fourth century AD Roman colourless glass.

The second group of samples investigated here includes fragments of colourless goblets type Isings 86, characterised by a weathered milky surface (PNE 20-21; PV 22). In particular, two of them are vessels decorated by circular-shaped appliqués, made by stamping the decoration on a drop of ductile glass (i.e. not yet cooled). One appliqué (PNE 20) depicts a male bust in profile and a similar one, with a bearded male profile, was found in the same context. These items probably belonged to the same vessel (Lepri 2013, pp. 144–148 and p. 159, fig. 5.4-5). The third goblet (PV 22) is decorated with rounded-shaped appliqués, reproducing a shell in negative.

Both decorations are typical of vessels dating from the late second to the third centuries AD. The former decoration is generally considered to be derived from or inspired by coins, in fact, the presence of male and female profiles, surrounded by a crown of small points or by a raised edge, sometimes also accompanied by letters, recalls the representation of several members of the Antonine's and Severans' dynasties on coins of that period. Specimens with this kind of decoration are known from the Italian peninsula, from *Gallia*, *Germania Inferior* and from collections, although the majority of finds seems to be concentrated in Rome.

Also, the shell decoration belongs to the same repertoire and shows morphological and technical variants. The appliqués of the investigated goblet can be directly referred to those decorating a colourless flask, placed in a second century AD burial, within the Roman cemetery of Noli (Savona, Italy) (Pastorino 2007).

Since colourless glass is generally considered to be used for high-quality tableware, the present work is also an attempt to investigate the possible differences between decorated and plain ware with respect to their chemical composition, among vessels made by the same technique of the free blowing.

Experimental

Scanning electron microscopy (SEM-EDS)

Commonly used for imaging samples, scanning electron microscopy (SEM) was used for textural observations, mainly performed in backscattered electrons. The instrument was a Philips XL 30 SEM equipped with an EDAX-DX4 energy dispersive spectrometer (EDS) operating at 20 kV. For chemical microanalyses, a variety of natural phases (albite, almandine, biotite, chlorite, Cr-diopside, diopside, kadeite, kaersutite, olivine, plagioclase, pyrope, rhodonite, sanidine) and synthetic glass materials (NIST 1831) was used as primary and quality control standards. For SEM observations, a small fragment of glass was cut, mounted in resin, polished and carbon coated.

Electron micro probe analysis (EMPA)

The major and minor element concentrations were estimated in all samples by electron microprobe analysis (CNR, Firenze, Italy). The instrument was a JEOL Superprobe JXA-8600 (University of Florence, working with the following operative settings: 15 kV, beam current at 15 μA, beam diameter 1–5 μm. A variety of natural phases (bustamite, stibnite, cuprite, galena, metallic cobalt and Sn) and synthetic glass materials (NIST 1831) was used as primary and quality control standards. PAP software was used for correction. Precision was

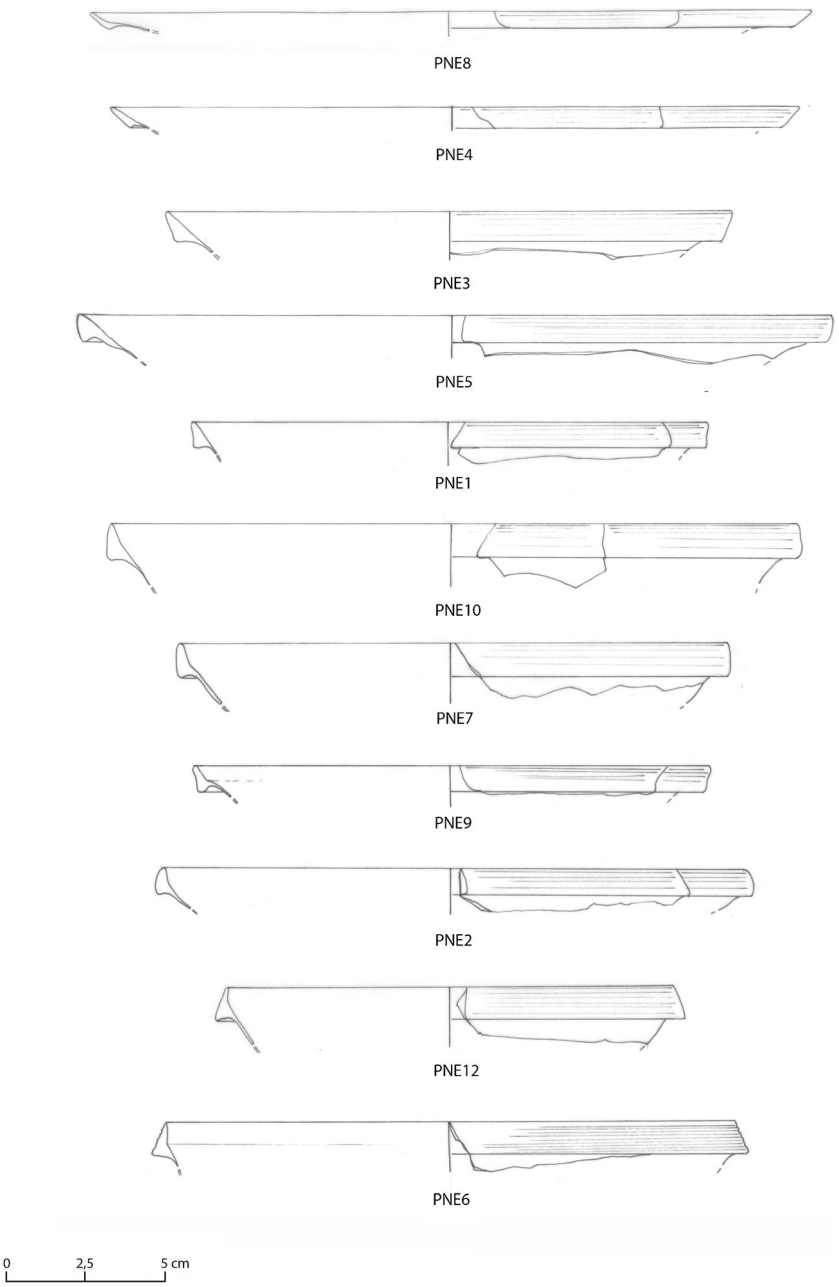

Fig. 2 Drawings of the specimens analysed

within 1 % for major elements, about 3–4 % for minor elements and about 8 % for trace elements. Accuracy was ≤ 1 % for SiO_2, Na_2O, CaO, MgO, K_2O, and MnO; equal to 2.5 % for Al_2O_3; 3.4 % for Fe_2O_3; below 15 % for Cu, Pb and Sb. Generally 5–7-point microanalyses were performed per sample, and mean and standard deviations were calculated.

Laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS)

The trace element content of glasses was determined by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS at CNR, Pavia, Italy). The instrument combines an ablation microbeam based on a Nd/YAG laser source (Brilliant, Quantel) operating at 266 nm (for details, see Tiepolo et al. 2003), and a quadrupole ICP-MS (Drc-e, Perkin Elmer). Thirty-four masses from ^{7}Li to ^{238}U were acquired; the laser was operated at 10 Hz of repetition rate, the power on the sample was 1.5 mW and spot size was set at 40 μm. Accuracy was assessed on the USGS BCR-2 reference glass (analysed as an unknown in each analytical run) and was better than 20 % at the sub ppm level. Data reduction was carried out with the software package GLITTER (van Achterbergh et al. 2001) and using NIST SRM 610 and ^{29}Si as external and internal standards, respectively. The obtained values were normalised

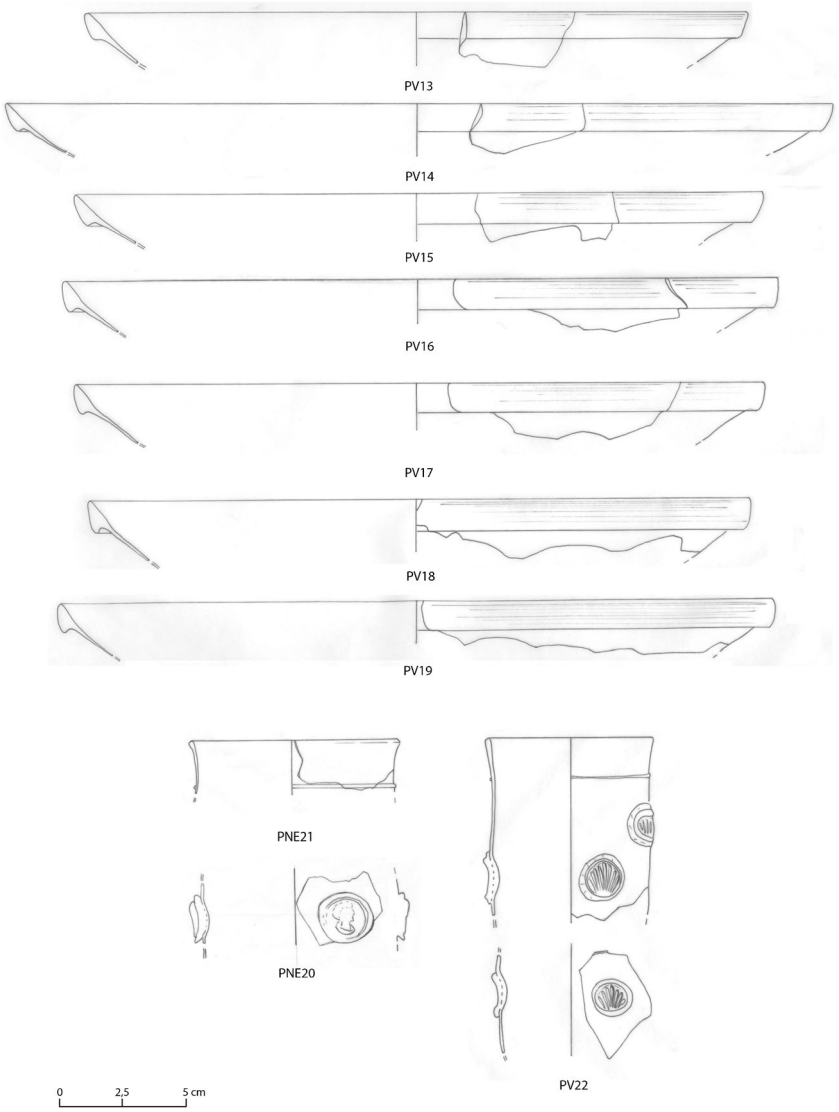

Fig. 3 Drawings of the specimens analysed

against the average composition of the weathered upper continental crust (Kamber et al. 2005).

Results

From a textural point of view, all PNE and PV samples are exceptionally homogeneous, never showing relics or newly formed phases. Compositional bands are absent as well. The external surfaces sometimes show a thin alteration layer, mainly characterised by the loss of Na_2O and K_2O and the increase of SiO_2 and Al_2O_3 with respect to the bulk composition.

The major and minor element concentrations ascribe the investigated samples to the soda-lime-silica glass type (Table 2). The contents of the oxides are rather similar among colourless and aqua blue glass; the only exception being represented by SiO_2, whose amounts vary between 68 and 78 wt%. SiO_2 and Al_2O_3 contents (ranging between 2.4 and 3.1 wt%) suggest the use of a siliceous sand as the network former. CaO ranges between 5.1 and 6.3 wt%, being the major stabilizing agent. The MgO and K_2O contents are rather low, sometimes even lower than those generally indicated for the use of natron as a flux. In any case, the use of natron is ascertained for both colourless and aqua samples. Excluding sample no. 18, the Fe_2O_3 contents range between 0.38 and 0.85 wt%, indicating thereby that this component has not been deliberately added. In colourless glass, MnO amounts are always lower than those of Fe_2O_3 and range between 0.05 and 0.47 wt%, being below 0.2 wt% in 4 samples only. Contrary to the low amounts of Fe_2O_3 and MnO, Sb_2O_3 contents are relatively high in all samples, ranging from 0.21 to 0.37 wt% (i.e. from 1754 to 3091 ppm).

Minor and trace element contents (Table 3) are overall low in both colourless and aqua blue samples, except for Pb, which

Table 2 Major and minor element content (wt%) in colourless and aqua blue samples, determined by EMPA

Samples	Na_2O		MgO		Al_2O_3		SiO_2		K_2O		CaO		TiO_2		MnO		Fe_2O_3		Sb_2O_3		TOT
	n=3	sd	*n*=3	sd	*n*=3	sd	*n*=3	sd	*n*=3	sd	*n*=3	sd	*n*=3	sd	*n*=3	sd	*n*=3	sd	*n*=3	sd	
Colourless																					
1	20.21	1.77	0.45	0.08	2.53	0.15	68.54	1.55	0.47	0.11	5.80	0.23	0.072	0.025	0.21	0.05	0.58	0.13	0.23	0.01	99.09
2	19.94	1.46	0.44	0.06	2.50	0.16	69.60	1.68	0.54	0.08	5.68	0.13	0.072	0.038	0.26	0.18	0.47	0.22	0.31	0.08	99.81
3	20.04	1.70	0.45	0.09	2.48	0.21	69.57	1.24	0.48	0.09	5.69	0.21	0.074	0.020	0.33	0.12	0.38	0.10	0.27	0.10	99.76
4	19.85	2.01	0.52	0.07	2.58	0.11	68.67	1.76	0.55	0.06	6.12	0.30	0.083	0.011	0.26	0.28	0.66	0.25	0.30	0.01	99.59
6	20.29	1.38	0.46	0.04	2.52	0.12	68.46	0.99	0.53	0.15	5.76	0.27	0.074	0.034	0.25	0.04	0.45	0.01	0.28	0.07	99.07
8	20.12	1.47	0.44	0.04	2.50	0.14	69.35	1.18	0.53	0.11	5.65	0.26	0.075	0.009	0.41	0.14	0.75	0.01	0.32	0.01	100.15
9	19.28	1.76	0.56	0.06	2.66	0.10	68.81	1.77	0.61	0.11	6.32	0.28	0.093	0.016	0.39	0.32	0.79	0.13	0.24	0.06	99.75
10	19.74	0.91	0.51	0.05	2.37	0.16	69.01	0.89	0.57	0.08	6.04	0.25	0.083	0.003	0.47	0.26	0.85	0.18	0.22	0.07	99.86
12	19.66	0.32	0.43	0.09	2.47	0.15	69.95	0.35	0.53	0.09	5.61	0.25	0.074	0.079	0.21	0.03	0.65	0.10	0.37	0.12	99.95
13	19.55	0.60	0.47	0.07	2.57	0.10	69.80	0.88	0.60	0.12	5.91	0.22	0.078	0.008	0.32	0.12	0.67	0.20	0.24	0.07	100.21
14	19.06	0.63	0.42	0.08	2.63	0.17	70.79	0.44	0.50	0.08	5.44	0.16	0.077	0.000	0.23	0.11	0.57	0.04	0.25	0.06	99.97
15	20.54	2.09	0.49	0.04	2.53	0.20	67.96	1.91	0.51	0.00	6.20	0.28	0.075	0.060	0.34	0.02	0.55	0.06	0.27	0.00	99.47
16	20.07	1.77	0.46	0.03	2.47	0.15	68.66	1.89	0.56	0.03	6.07	0.15	0.072	0.011	0.25	0.08	0.54	0.04	0.28	0.01	99.43
17	19.84	1.51	0.47	0.09	2.41	0.15	69.32	1.55	0.56	0.02	5.91	0.26	0.073	0.084	0.46	0.06	0.73	0.02	0.24	0.03	100.01
19	19.39	0.31	0.45	0.08	2.71	0.16	69.56	0.66	0.58	0.11	5.86	0.42	0.072	0.013	0.13	0.10	0.70	0.05	0.25	0.00	99.70
20	18.59	0.82	0.31	0.08	2.15	0.12	72.43	0.49	0.31	0.09	5.10	0.25	0.055	0.087	0.18	0.13	0.41	0.07	0.26	0.00	99.80
21	18.83	0.78	0.39	0.06	2.41	0.11	71.52	0.66	0.39	0.09	5.19	0.26	0.063	0.095	0.05	0.11	0.58	0.15	0.21	0.06	99.63
22	18.16	0.19	0.36	0.06	2.29	0.26	72.54	0.79	0.40	0.08	5.28	0.73	0.057	0.090	0.16	0.07	0.71	0.01	0.35	0.02	100.31
n=18	19.62	0.63	0.45	0.1	2.49	0.13	69.70	1.32	0.51	0.08	5.76	0.34	0.07	0.009	0.27	0.11	0.61	0.13	0.27	0.0	99.75
Aqua blue																					
5	18.55	1.08	0.55	0.03	2.74	0.20	69.54	0.88	0.61	0.10	6.31	0.16	0.081	0.014	0.66	0.07	0.75	0.01	0.22	0.06	100.01
7	11.36	1.14	0.53	0.07	2.68	0.19	78.12	1.52	0.62	0.01	5.11	0.33	0.077	0.055	0.65	0.09	0.73	0.12	0.24	0.02	100.12
18	18.88	0.79	0.42	0.05	3.06	0.11	69.14	0.64	0.91	0.05	5.43	0.70	0.077	0.063	0.39	0.04	1.25	0.08	0.34	0.03	99.90
n=4	16.94	3.7244	0.53	0.0793	2.78	0.1962	71.41	4.4825	0.70	0.1427	5.90	0.7643	0.08	0.0066	0.57	0.125	0.88	0.2492	0.25	0.06	100.03

Cu and Sn contents were both below the detection limits

Table 3 Trace element contents (ppm) in colourless and aqua blue samples, determined by LA-ICP-MS

Sample		Li	Be	B	Sc	V	Cr	Co	Ni	Zn	Rb	Sr	Y
1	*n*=3	4.58	0.25	204.44	6.16	8.83	6.48	1.69	3.6	29.02	8.52	349.7	5.57
	sd	0.11	–	2.57	0.70	0.80	2.41	0.07	0.5	1.58	0.08	5.4	0.25
2	*n*=3	4.39	<1.00	219.17	3.76	8.73	6.04	2.01	3.4	32.55	8.75	345.6	5.17
	sd	0.49	–	2.72	0.40	0.86	1.29	0.05	0.6	–	0.51	1.7	0.16
3	*n*=3	4.29	–	214.72	3.87	9.12	8.71	2.14	3.8	25.49	8.57	352.8	5.52
	sd	0.97	–	2.69	1.04	1.01	1.20	0.05	1.2	7.06	0.03	11.3	0.06
4	*n*=3	4.91	–	211.17	3.30	11.15	9.16	2.28	5.0	30.36	9.00	386.6	5.69
	sd	0.16	–	14.34	0.13	0.19	0.64	0.15	0.5	2.50	0.45	7.0	0.45
5	*n*=3	4.90	–	202.16	2.07	14.71	11.04	4.49	6.0	23.42	15.93	402.3	5.75
	sd	0.62	–	17.30	0.70	1.13	2.17	0.68	0.7	3.88	2.00	23.8	0.59
6	*n*=3	5.22	<1.00	211.77	3.99	9.05	8.83	2.13	4.2	25.22	8.73	354.6	5.47
	sd	0.65	–	9.47	0.50	0.35	2.04	0.23	0.4	1.39	0.30	2.5	0.16
7	*n*=3	2.91	3.72	126.25	4.73	12.95	14.31	2.15	3.0	41.19	42.96	375.2	3.69
	sd	2.97	2.96	127.29	0.16	1.65	7.18	2.27	2.9	–	44.34	57.4	3.63
8	*n*=3	4.73	1.06	208.52	3.57	8.92	9.50	2.08	3.1	19.99	9.42	346.5	5.64
	sd	0.70	0.03	4.21	0.13	1.24	1.80	0.05	0.6	11.61	0.42	1.9	0.37
9	*n*=3	5.69	1.10	220.37	3.08	11.22	10.87	2.67	5.1	32.46	12.21	398.9	6.15
	sd	0.22	–	6.69	0.54	0.83	2.60	0.19	0.9	12.06	0.31	6.1	0.16
10	*n*=3	4.73	1.07	216.06	2.51	10.84	10.68	2.34	4.1	30.96	9.52	384.9	5.73
	sd	1.22	0.33	8.89	0.72	1.80	2.12	0.15	0.2	4.03	0.02	2.2	0.06
12	*n*=3	3.94	–	214.80	3.14	10.70	10.14	2.00	4.3	36.94	10.78	345.5	5.36
	sd	0.11	–	5.84	0.18	0.14	1.09	0.04	1.1	5.58	1.45	2.4	0.26
13	*n*=3	4.75	0.99	198.85	2.70	10.68	12.43	2.25	4.8	25.77	26.11	371.9	6.10
	sd	0.34	–	1.87	0.53	1.24	0.04	0.18	0.8	11.70	1.65	0.1	0.14
14	*n*=3	4.60	1.42	220.19	3.45	9.50	6.98	1.84	4.3	29.08	10.43	341.5	5.52
	sd	0.24	0.70	2.23	0.70	0.43	2.24	0.28	0.5	2.90	0.45	0.9	0.42
15	*n*=3	4.87	0.88	201.26	3.07	8.86	8.89	1.91	5.9	29.86	10.78	378.9	5.79
	sd	0.58	–	7.33	0.42	0.23	1.31	0.10	1.7	6.82	0.01	3.8	0.06
16	*n*=3	4.57	–	208.97	2.82	9.56	8.81	2.39	4.0	24.44	10.47	372.5	5.86
	sd	0.67	–	3.43	1.19	0.86	2.09	0.08	1.0	7.50	0.16	0.4	0.13
17	*n*=3	5.19	0.92	204.58	2.31	9.04	8.31	2.28	4.6	34.00	10.07	366.6	5.78
	sd	0.21	–	17.44	0.40	0.83	0.78	0.27	1.1	1.46	0.81	0.4	0.13
18	*n*=3	5.14	1.47	224.34	2.54	9.19	10.92	2.14	2.3	30.29	11.27	345.2	5.60
	sd	0.83	–	14.40	0.35	0.54	0.49	0.16	0.9	5.58	0.11	3.3	0.25
19	*n*=3	3.80	–	197.09	2.53	10.87	10.09	2.47	5.4	26.71	10.10	372.7	5.83
	sd	0.24	–	7.59	1.18	0.13	3.48	0.16	1.1	–	1.03	1.6	0.34
20	*n*=3	2.04	1.48	249.96	2.58	4.26	7.38	1.00	2.0	28.90	4.45	298.6	4.56
	sd	1.36	0.47	26.11	0.50	2.03	2.10	0.22	1.1	2.46	0.85	11.3	0.55
21	*n*=3	4.04	–	280.41	1.70	5.60	8.66	1.23	2.6	22.34	5.61	309.5	5.52
	sd	0.00	–	12.90	0.36	1.32	1.24	0.07	1.0	–	0.30	0.1	0.07
22	*n*=3	3.48	–	212.72	2.41	5.24	7.80	1.24	2.8	31.51	6.40	305.2	5.03
	sd	0.47	–	12.61	0.36	0.00	1.35	0.27	0.7	–	0.45	4.9	0.01
	Average	4.46	1.32	211.19	3.17	9.68	9.23	2.23	4.1	29.59	12.01	360.5	5.53
	sd	0.84	0.83	26.51	0.97	2.51	1.99	0.81	1.2	5.43	8.13	31.4	0.55

Sample		Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb
1	*n*=3	50.75	1.555	0.10	164.12	5.87	10.64	1.361	5.04	1.06	0.32	0.81	0.149
	sd	1.48	0.156	0.00	1.31	0.08	0.04	0.046	0.13	0.09	0.01	0.14	0.004
2	*n*=3	49.85	1.502	0.12	155.20	5.93	9.98	1.274	5.46	1.05	0.33	1.22	0.147
	sd	1.12	0.044	0.04	4.82	0.25	0.21	0.083	0.56	0.13	0.08	0.05	0.088

Table 3 (continued)

3	*n*=3	49.35	1.483	0.10	165.08	5.92	9.97	1.277	5.20	1.01	0.29	0.85	0.127
	sd	1.17	0.045	0.01	0.57	0.04	0.30	0.084	0.19	0.21	0.12	0.13	0.014
4	*n*=3	54.44	1.522	0.12	170.83	6.22	10.80	1.316	5.74	0.99	0.35	0.99	0.153
	sd	0.86	0.018	0.01	2.15	0.13	0.05	0.005	0.21	0.24	0.02	0.00	0.019
5	*n*=3	53.09	1.700	0.24	198.13	6.81	11.45	1.370	5.89	1.39	0.37	1.34	0.168
	sd	5.99	0.085	0.01	10.91	0.29	0.67	0.171	0.54	0.33	0.07	0.43	0.052
6	*n*=3	49.56	1.492	0.10	161.65	5.57	10.32	1.320	5.27	1.05	0.36	0.94	0.139
	sd	0.15	0.303	0.02	0.98	0.27	0.28	0.080	0.15	0.01	0.04	0.33	0.058
7	*n*=3	63.22	2.070	0.78	254.86	3.88	7.16	0.868	3.96	0.86	0.22	0.55	0.109
	sd	11.53	0.255	0.77	85.42	3.52	6.39	0.781	3.66	0.48	0.18	0.32	0.060
8	*n*=3	50.26	1.392	0.14	162.17	6.03	10.49	1.349	5.26	1.18	0.31	1.19	0.123
	sd	1.32	0.090	0.01	0.65	0.18	0.01	0.087	0.03	0.13	0.16	0.12	0.008
9	*n*=3	59.81	1.782	0.20	179.77	6.71	11.82	1.486	5.84	1.27	0.28	1.05	0.177
	sd	1.30	0.057	0.01	1.68	0.12	0.58	0.076	0.14	0.09	0.08	0.19	0.015
10	*n*=3	54.95	1.656	0.14	170.94	6.37	11.02	1.385	5.32	1.26	0.31	0.97	0.109
	sd	1.40	0.021	0.02	4.44	0.13	0.15	0.023	0.25	0.25	0.02	0.07	0.008
12	*n*=3	50.67	1.467	0.15	158.56	5.95	10.58	1.343	5.83	1.15	0.30	0.96	0.159
	sd	0.33	0.018	0.02	1.64	0.03	0.23	0.052	0.25	0.06	0.07	0.06	0.071
13	*n*=3	53.74	1.730	0.37	179.63	7.72	13.35	1.584	6.41	1.36	0.37	1.07	0.163
	sd	1.82	0.127	0.03	3.20	0.04	0.49	0.206	0.33	0.11	0.07	0.06	0.048
14	*n*=3	51.89	1.402	0.14	162.22	6.14	10.20	1.305	5.39	0.84	0.26	0.85	0.116
	sd	1.58	0.068	0.02	0.66	0.40	0.13	0.057	0.40	0.29	0.01	0.12	0.057
15	*n*=3	50.79	1.530	0.14	172.30	6.28	11.03	1.364	6.11	1.19	0.31	1.03	0.138
	sd	0.27	0.001	0.00	0.41	0.01	0.31	0.091	0.08	0.35	0.16	0.17	0.005
16	*n*=3	49.19	1.532	0.15	171.57	6.47	10.87	1.332	5.79	1.03	0.30	0.94	0.153
	sd	1.10	0.048	0.01	3.42	0.02	0.04	0.081	0.50	0.05	0.03	0.01	0.062
17	*n*=3	48.23	1.413	0.13	167.32	6.30	10.41	1.221	5.64	0.99	0.33	0.94	0.172
	sd	0.11	0.236	0.02	0.31	0.25	0.61	0.057	0.00	0.13	0.10	0.42	0.014
18	*n*=3	51.55	1.620	0.14	162.53	6.07	10.29	1.290	5.66	1.20	0.32	0.84	0.183
	sd	0.82	0.014	0.01	0.87	0.08	0.18	0.027	0.16	0.28	0.10	0.02	0.045
19	*n*=3	48.82	1.540	0.14	170.49	6.17	11.12	1.360	5.00	1.19	0.38	1.03	0.187
	sd	0.96	0.185	0.01	1.63	0.03	0.59	0.095	0.23	0.25	0.03	0.08	0.044
20	*n*=3	38.02	0.925	0.02	128.39	4.66	8.52	0.948	5.20	1.04	0.19	0.88	0.228
	sd	2.86	0.283	0.02	5.19	0.58	0.29	0.157	0.76	0.13	0.06	0.30	0.066
21	*n*=3	42.82	1.230	0.05	134.74	5.07	9.03	1.055	4.99	0.94	0.30	1.07	0.160
	sd	0.04	0.088	–	2.39	0.26	0.09	0.105	0.11	0.18	0.02	0.15	0.002
22	*n*=3	40.26	0.998	0.07	139.52	5.25	8.91	1.184	4.87	1.05	0.28	1.02	0.129
	sd	0.16	0.199	0.01	0.91	0.06	0.12	0.009	0.31	0.25	0.05	0.36	0.037
	Average	50.78	1.514	0.17	169.82	6.03	10.45	1.295	5.46	1.11	0.31	0.99	0.151
	sd	5.62	0.248	0.15	25.87	0.82	1.28	0.165	0.54	0.15	0.05	0.17	0.029

Sample		Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Pb	Th	U
1	*n*=3	0.936	0.198	0.540	0.169	0.351	0.0649	1.37	0.101	110.52	1.012	1.158
	sd	0.019	0.024	0.049	–	0.004	0.0160	0.10	0.033	3.92	0.073	0.052
2	*n*=3	0.858	0.201	0.415	0.213	0.421	0.0673	1.27	0.079	107.61	1.030	1.098
	sd	0.070	0.022	0.033	–	0.023	0.0407	0.04	–	4.24	0.078	0.008
3	*n*=3	0.932	0.192	0.614	0.198	0.420	0.0654	1.20	0.112	105.29	1.015	1.174
	sd	0.138	0.007	0.168	–	0.041	0.0033	0.01	–	2.40	0.069	0.018
4	*n*=3	1.049	0.174	0.600	0.266	0.636	0.0830	1.35	0.147	112.44	1.123	1.180
	sd	0.206	0.002	0.025	0.168	0.025	0.0085	0.09	0.091	15.44	0.008	0.050
5	*n*=3	0.887	0.209	0.586	–	0.461	0.0860	1.24	0.187	410.24	1.246	1.092
	sd	0.197	0.053	0.280	–	0.086	0.0111	0.18	0.019	16.50	0.253	0.085
6	*n*=3	0.914	0.205	0.593	<0.156	0.588	0.1001	1.29	0.102	106.51	1.041	1.100
	sd	0.134	0.016	0.169	–	0.223	0.0395	0.09	0.006	0.33	0.016	0.042
7	*n*=3	0.589	0.132	0.266	<0.105	0.289	0.0720	1.74	0.227	208.92	1.438	0.910
	sd	0.349	0.083	0.233	–	0.216	–	0.23	–	64.25	0.140	0.404
8	*n*=3	0.939	0.187	0.457	–	0.504	0.1050	1.30	–	96.90	1.053	1.189
	sd	0.060	0.062	0.016	–	0.064	0.0028	0.02	–	0.13	0.096	0.066
9	*n*=3	0.966	0.209	0.527	0.177	0.719	0.0771	1.36	0.125	138.67	1.348	1.190
	sd	0.073	0.014	0.052	–	0.112	0.0261	0.24	0.013	2.11	0.042	0.078
10	*n*=3	1.013	0.187	0.640	–	0.502	0.0950	1.43	0.104	101.96	1.150	1.156
	sd	0.026	0.017	0.120	–	0.068	0.0042	0.05	–	0.41	0.078	0.064
12	*n*=3	0.867	0.208	0.494	0.201	0.425	0.0815	1.56	0.165	100.85	1.074	1.180
	sd	0.036	0.033	0.183	–	0.180	0.0318	0.33	–	4.07	0.113	0.008

Table 3 (continued)

13	*n*=3	1.022	0.213	0.474	–	0.354	0.1045	1.41	0.137	161.34	1.651	1.145
	sd	0.107	0.049	0.064	–	0.053	0.0078	0.22	–	0.59	0.080	0.018
14	*n*=3	1.029	0.174	0.533	0.261	0.579	0.0895	1.25	0.135	98.63	1.097	1.091
	sd	0.178	0.000	0.038	–	0.002	0.0134	0.25	–	1.48	0.030	0.049
15	*n*=3	0.877	0.223	0.634	–	0.591	0.0789	1.43	0.102	132.02	1.223	1.118
	sd	0.078	0.029	0.042	–	0.066	0.0115	0.18	–	1.53	0.040	0.019
16	*n*=3	0.877	0.188	0.563	–	0.500	0.0680	1.23	0.080	126.53	1.076	1.130
	sd	0.023	0.011	0.135	–	0.089	0.0014	0.04	–	1.32	0.006	0.093
17	*n*=3	0.980	0.167	0.526	0.161	0.586	0.0710	1.09	0.114	120.37	1.116	1.104
	sd	0.310	0.011	0.098	–	0.050	0.0212	0.16	0.003	1.03	0.042	0.004
18	*n*=3	0.975	0.191	0.527	0.263	0.569	0.0865	1.36	0.125	101.65	1.077	1.223
	sd	0.088	0.040	0.110	–	0.185	0.0404	0.11	–	1.78	0.033	0.075
19	*n*=3	0.947	0.193	0.454	–	0.517	0.0845	1.24	0.185	117.46	1.151	1.080
	sd	0.245	0.033	0.156	–	0.033	0.0163	0.17	–	0.83	0.030	0.004
20	*n*=3	0.672	0.184	0.503	0.264	0.466	0.0810	0.82	0.102	8.86	0.675	1.095
	sd	0.125	0.049	0.127	–	0.097	0.0021	0.17	–	0.21	0.106	0.076
21	*n*=3	0.842	0.187	0.610	–	0.429	0.0705	0.89	0.081	8.24	0.825	0.978
	sd	0.206	0.018	0.047	–	0.207	0.0262	0.15	–	0.04	0.013	0.025
22	*n*=3	0.730	0.196	0.497	–	0.500	0.0625	0.75	0.099	11.26	0.727	0.940
	sd	0.026	0.020	0.086	–	0.153	0.0035	0.13	0.025	0.30	0.049	0.074
	Average	0.911	0.191	0.532	0.217	0.505	0.0814	1.28	0.125	128.75	1.113	1.119
	sd	0.126	0.019	0.088	0.043	0.110	0.0131	0.23	0.039	93.42	0.218	0.088

Three measurements were performed each sample [sd = standard deviation]. Significant figures are to the second decimal place for minor elements, whereas values for trace and ultra-trace elements are significant to the third or fourth decimal place, following standardisation and experimental conditions

is generally around or above 100 ppm (except for samples 20–22). The strong positive correlation between Hf and Zr is rather constant around a 0.025 average value. Similarly, the contents of Rb are correlated to those of K (K/Rb ratio = average value of 0.044). The geochemical behavior of Y and that of the heavy REEs (Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu) is very similar and averagely opposed to that of light REEs. These features are particularly evident in the aqua blue sample no. 7, which shows the highest values of Be, B, Cr, Zn, Rb, Zr, Nb, Cs, Ba, Hf and Ta, and the lowest values of La, Ce, Pr, Nd, Gd, Tb, Dy, Ho, Er, Yb and U. Lastly, the colourless sample no. 20 may be distinguished from the rest of the group, showing the highest values of Tb and the lowest values of Li, V, Co, Ni, Rb, Sr, Zr, Nb, Cs, Ba, Eu and Th.

Discussion

Based on major element contents, both colourless and aqua blue glass would be derived from the mixing of sand and natron together. The high contents of Pb in colourless glass may indicate the use of recycled materials but it can be also related to the addition of antimony (Paynter 2006; Jackson and Paynter 2015).

As for decolouring agents, the fact that both Mn and Sb are present seems to suggest that their combined action has been effective in neutering the colouring effect of iron. On the other hand, the unnecessary presence of both components may provide an indication of the recycling of previously decolourised cullets.

As for provenance, the present collection has been compared with several known reference groups and especially with a total of 792 measurements performed on colourless glass and available in literature. From the reference collection, naturally colourless glass was excluded, as well as those analyses where manganese and antimony contents were not both provided by the authors. For the scope of comparison, the collected materials have been divided into six main groups, based on their MnO and Sb contents:

(1) RC-Sb. Roman colourless glass decolourised by Sb, including items dated between the first century BC and the third century AD, with MnO<0.2 wt% and Sb> 500 ppm;
(2) RC-Mn. Roman colourless glass decolourised by Mn, including items dated between the first century BC and the third century AD, with Mn>0.2 wt% and Sb< 20 ppm;
(3) RC-MnSb. Roman colourless glass with both Mn and Sb, including items dated between the first century BC and the third century AD, with Mn>0.2 wt% and Sb> 20 ppm;
(4) LAC-Sb. Late Antique colourless glass decolourised by Sb, including items dated between the fourth and the sixth centuries AD, with MnO<0.2 wt% and Sb> 500 ppm;
(5) LAC-Mn. Late Antique colourless glass decolourised by Mn, including items dated

Table 4 Mean and standard deviation value of the 6 colourless glass groups used here for comparison, based on 792 analysed samples

Group	RC-Sb	RC-Mn	RC-MnSb	LAC-Sb	LAC-Mn	LAC-MnSb
n=	423	50	83	54	58	124
SiO_2	71.3	69.6	69.8	70,7	67.1	69.1
sd	1.8	2.0	1.8	1,8	1.7	1.5
Al_2O_3	1.9	2.5	2.2	2.0	2.4	2.1
sd	0.2	0,2	0.2	0.3	0.3	0.3
TiO_2	0.1	0,1	0.1	0.1	0.2	0.1
sd	0	0	0	0	0.1	0
CaO	5.5	7.8	6.3	5.9	7.6	6.5
sd	0.8	0.8	1.0	0.7	1.3	0.9
MgO	0,4	0.6	0.6	0.5	1.0	0.6
sd	0,1	0.2	0.2	0.1	0.6	0.3
Na_2O	18,9	16.3	18.6	18.7	17.1	18.8
sd	1.7	1.7	1.6	1.4	1.9	1.3
K_2O	0.4	0.6	0.6	0.5	0.7	0.6
sd	0.1	0.2	0.1	0.2	0.4	0.2
Fe_2O_3	0,4	0.3	0.5	0.4	1.0	0.6
sd	0,1	0.2	0.2	0.1	0.5	0.1
MnO	0	1.1	0.6	0.1	1.2	0.7
sd	0	0.4	0.4	0.1	0.5	0.4
Sb	4749	1	3112	3531	2	2158
sd	2476	4	2249	1126	4	1746
Fluxes	423 N	50 N	109 N	54 N	8 N, 28 PA, 7 M	124 N
Country	4 Albania, 18 Egypt, 78 Italy, 5 Jordan, 4 Morocco, 25 Netherlands, 4 Switzerland, 285 UK	4 Albania, 6 Egypt, 3 Israel, 17 Italy, 10 Lebanon, 6 Morocco, 1 Switzerland, 3 UK	3 Belgium, 2 Egypt, 16 Italy, 3 Lebanon, 4 Morocco, 1 Netherlands, 6 Switzerland, 2 Tunisia, 46 UK	24 Italy, 2 Turkey, 28 UK	23 Albania, 5 Egypt, 24 Italy, 3 Jordan, 1 Lebanon, 2 Turkey	1 Albania, 57 Italy, 4 Jordan, 3 Turkey, 59 UK
Colour	408 C, 15 Cs	44 C, 6 Cs	63 C, 20 Cs	54 C	48 C, 6 Cg, 4 Cs	122 C, 2 Cs
Technique	26 EMPA, 5 EMPA + LA-ICP-MS, 230 ICP-AES, 4 ICP-MS + ICP-OES, 55 ICPS, 5 XRF, 69 XRF + EMPA, 25 XRF + ICP-MS, 4 XRF, EPMA, LA-ICP-MS	10 EMPA, 10 ICP-MS, 6 ICP-MS + ICP-OES, 3 LA-ICP-MS, 3 SEM-WDS/ EDS, 1 XRF, 15 XRF,EMPA, 2 XRF, EMPA + LA-ICP-MS	3 EMPA, 24 ICP-AES, 3 ICP-MS, 4 ICP-MS/ICP-OES, 22 ICPS, 3 SEM-EDS + LA-ICP-MS, 2 XRF, 20 XRF + EMPA, 1 XRF, EPMA, LA-ICP-MS	6 EMPA, 20 EMPA + LA-ICP-MS, 28 ICP-AES	5 AAS, 28 EMPA, 23 EMPA + LA-ICP-MS, 2 XRF	14 EMPA, 48 EMPA + LA-ICP-MS, 59 ICP-AES, 1 XRF, 2 XRF + EMPA
Reference	Arletti et al. 2006a, 2008, Foster and Jackson 2010, Gallo et al. 2013, Gliozzo et al. 2013, Huisman et al. 2009, Jackson 2005, Neri and Verità 2013, Paynter 2006, Rosenow and Rehren 2014, Schibille 2011a, Schibille et al. 2012, Silvestri et al. 2005, 2008	Arletti et al. 2008, 2010a, Bertini et al. 2011, Fischer and McCray 1999, Gallo et al. 2013, Gliozzo et al. 2013, Rosenow and Rehren 2014, Schibille 2011a, Silvestri et al. 2005, 2008, Thirion-Merle 2005	Arletti et al. 2008, 2010a, Foster and Jackson 2010, Foy et al. 2003, Gallo et al. 2013, Gliozzo et al. 2013, Huisman et al. 2009, Jackson 2005, Neri and Verità 2013, Paynter 2006, Rosenow and Rehren 2014, Silvestri et al. 2008, Thirion-Merle 2005, Van Der Linden et al. 2009	Arletti et al. 2010b, Foster and Jackson 2010, Neri and Verità 2013, Schibille 2011b, Silvestri et al. 2005, al. 2011, Verità et al. 2008	Fiori et al. 2004, Rosenow and Rehren; Schibille 2011a; Schibille and McKenzie 2014, Schibille et al. 2012, Silvestri et al. 2005, 2011	Arletti et al. 2010a, Fiori et al. 2004, Foster and Jackson 2010, Neri and Verità 2013, Schibille 2011a, Schibille and McKenzie 2014, Schibille et al. 2012, Silvestri et al. 2011, Verità et al. 2008

For each group has been specified: (a) how many samples are included in the group (n=); (b) the type of flux (N = natron; PA = plant ash; M = mixed alkali); (c) the country where they have been found; (d) which colour have been indicated by authors (C = colourless; Cs = colourless slightly yellowish/ greenish/etc.; Cg = colourless gold leaf); (e) which analytical technique has been used for measurements; (f) the references

between the fourth and the sixth centuries AD, with Mn>0.2 wt% and Sb<20 ppm;

(6) LAC-MnSb. Late Antique colourless glass with both Mn and Sb, including items dated between

the fourth and the sixth centuries AD, with Mn> 0.2 wt% and Sb>20 ppm.

When the chronologies indicated by authors were covering broader time spans than those established for the Roman and the Late Antique period, the oldest chronology has been taken into account. For instance, a sample dated from the third to the fifth century AD is included in the Roman groups; based on the same criterion, a sample dated from the fourth to the seventh century is assigned to the Late Antique groups. A detailed discussion of the results obtained from this collection of bibliographic data is beyond the scope of this article and is therefore postponed to a forthcoming paper; however, mean and average values of these six groups are provided in Table 4, together with other descriptive features such as fluxes, findsites, colours, references and analytical techniques. As regards the latter, it is worth pointing out that different analytical techniques, carried out in different laboratories, can introduce errors which cannot be estimated; however, data appear consistent and outliers are very rare as it appears clear from Figs. 4, 5, 6, 7 and 8.

The binary diagram SiO_2-Na_2O provided in Fig. 4 shows that all PNE and PV samples are comparable to the RC-Sb, RC-Mn/Sb, LAC-Sb and LAC-Mn/Sb groups, while they are clearly different from Mn-decolourised glass groups (RC-Mn and LAC-Mn). The RC-Sb and the LAC-Sb groups are very similar to each other as are the RC-Mn/Sb with the LAC-Mn/Sb. Conversely, the RC-Mn and the LAC-Mn do not seem closely correlated; in fact, the former is SiO_2 richer and Na_2O poorer than the latter.

Despite the fact that they are not colourless glass groups, the composition of the Levantine and the HIMT glass have been compared to the investigated collection, but common features of some significance were not found. In this regard, it is worth remembering that the Levantine group is defined by 9 glass collections (Brill 1988; Freestone et al. 2000; Foy et al. 2003; Schibille et al. 2008; Foster and Jackson 2009), which include materials of Syrian–Palestinian origin, dated between the first and the eighth century AD. Conversely, the later HIMT group is defined by five glass collections (Mirti et al. 1993; Foy et al. 2003; Foster and Jackson 2009; Freestone 1994), which includes materials mainly dated between the fourth and the seventh century AD, likely originating from northern Sinai and Egypt (Freestone et al. 2005; Nenna 2014). For the sake of clarity, the average composition of Levantine, HIMT and colourless glass groups are provided in Table 5.

Al_2O_3 contents (Fig. 5) in PNE and PV samples are higher than those of both RC-Sb and LAC-Sb glass, but comparable to all other colourless groups. Conversely, CaO contents (Fig. 5) are perfectly compatible with the Sb-decoloured groups (RC-Sb, LAC-Sb) as well as with glass where both manganese and antimony are present (RC-Mn/Sb and LAC-Mn/Sb). Levantine glass is clearly separate from both PNE

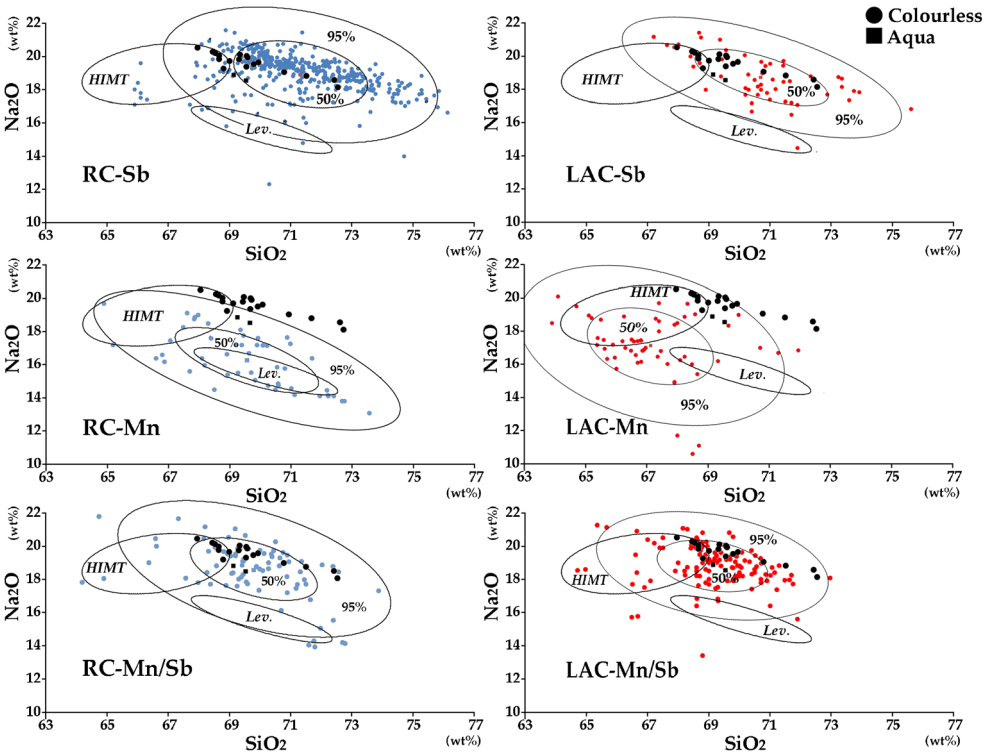

Fig. 4 SiO_2-Na_2O binary diagrams showing the composition of the investigated samples (*black dots*) compared to that of reference groups (*blue dot* for Roman glass, *red dot* for Late Antique glass). The Levantine and HIMT fields have been drawn based on Gliozzo et al. (2013). For the colourless glass groups, both the 95 % and the 50 % prediction ellipses have been drawn

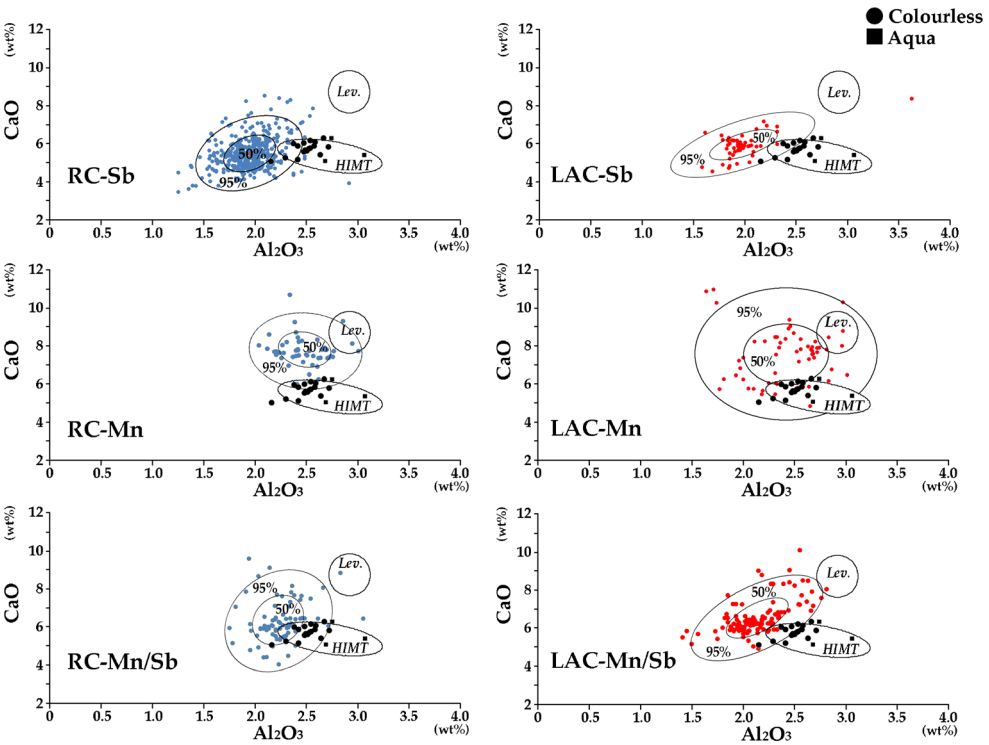

Fig. 5 Al_2O_3-CaO binary diagrams showing the composition of the investigated samples (*black dots*) compared to that of reference groups (*blue dot* for Roman glass, *red dot* for Late Antique glass). The Levantine and HIMT fields have been drawn based on Gliozzo et al. (2013). For the colourless glass groups, both the 95 % and the 50 % prediction ellipses have been drawn

and PV samples which are instead constantly included in the HIMT field..

In addition to clearly indicating the use of natron for all PNE-PV samples, the MgO-K_2O binary diagram provided in Fig. 6 further shows that the vast majority of the colourless glass considered for comparison (768 samples over a total of 792) is natron-based. It is interesting to observe that all Sb-decoloured glass, i.e. both the present collection and the reference data, concentrates just outside the bottom-left corner of the natron field while Mn-decoloured glass overall shows higher levels of K_2O and, to a lesser extent, higher MgO contents.

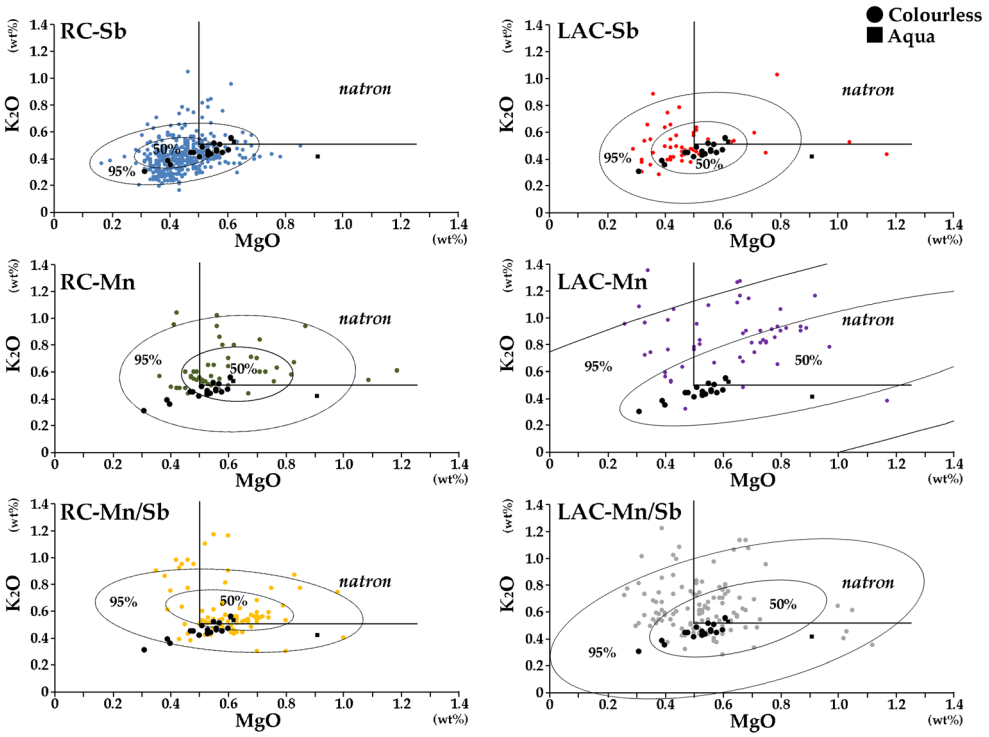

Fig. 6 MgO-K_2O binary diagrams showing the composition of the investigated samples (*black dots*) compared to that of reference groups (*blue dot* for Roman glass, *red dot* for Late Antique glass). For the colourless glass groups, both the 95 % and the 50 % prediction ellipses have been drawn

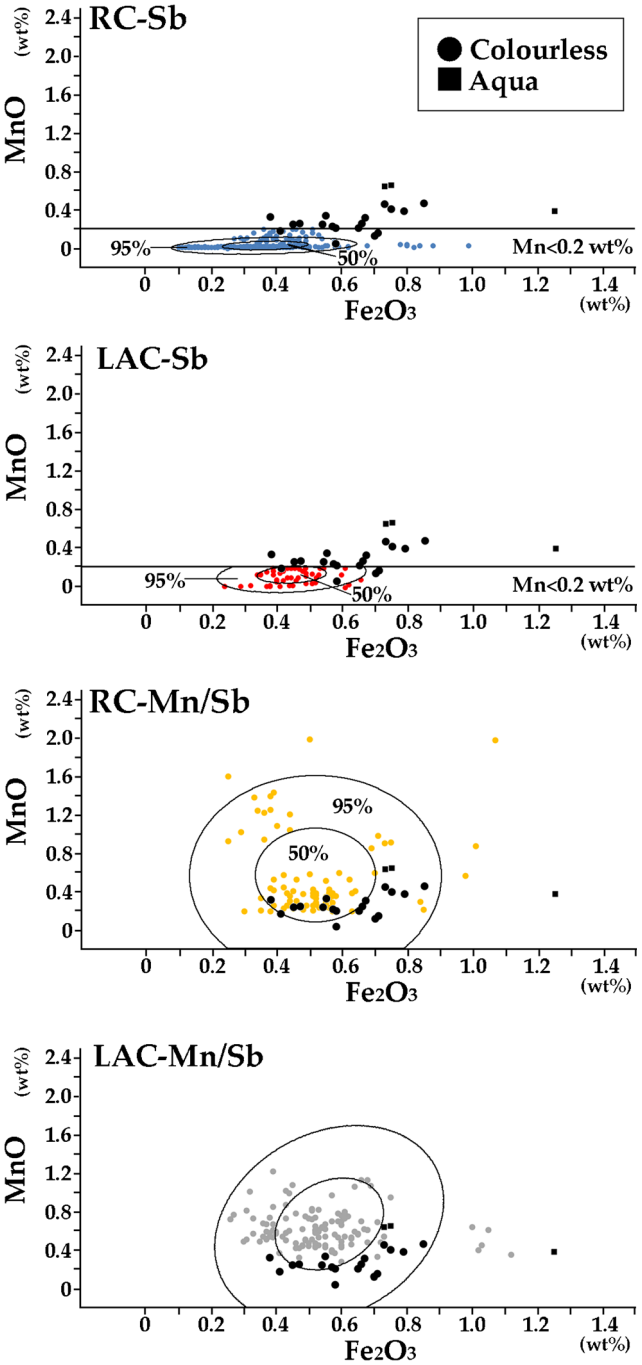

Fig. 7 Fe_2O_3-MnO binary diagrams showing the composition of the investigated samples (*black dots*) compared to that of the RC-Sb, LAC-Sb, RC-MnSb and LAC-MnSb reference groups (*blue, red, yellow and gray dots*). For the colourless glass groups, both the 95 % and the 50 % prediction ellipses have been drawn

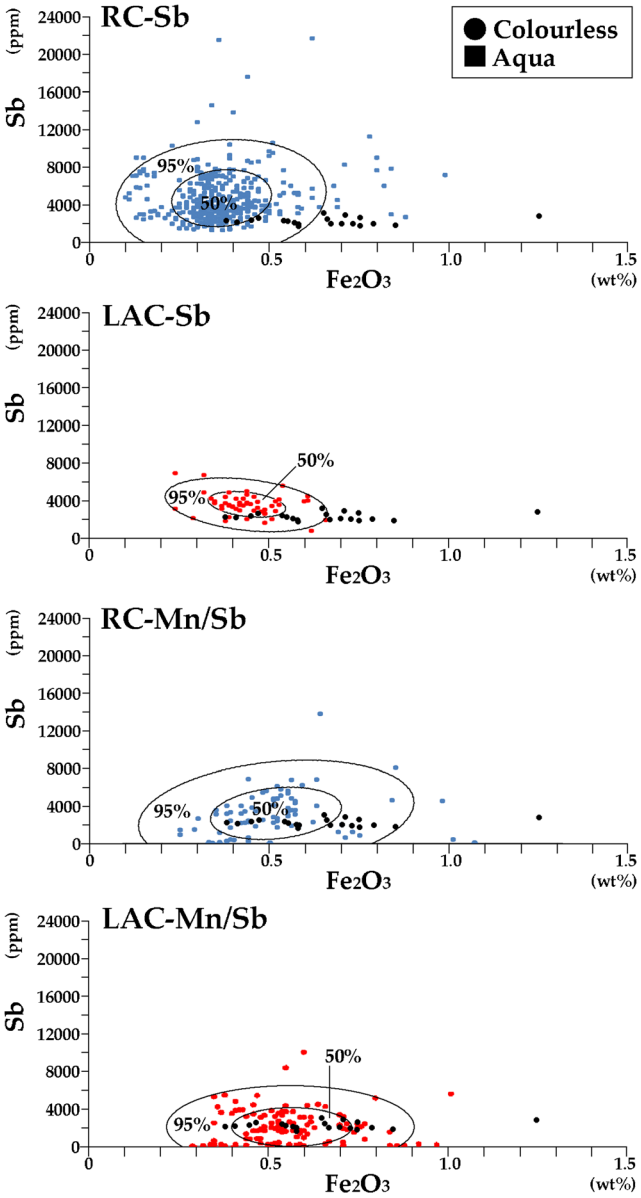

Fig. 8 Fe_2O_3-Sb binary diagrams showing the composition of the investigated samples (*black dots*) compared to that of the RC-Sb, LAC-Sb, RC-MnSb and LAC-MnSb reference groups (*blue dot* for Roman glass, *red dot* for Late Antique glass). For the colourless glass groups, both the 95 % and the 50 % prediction ellipses have been drawn

MnO and Fe_2O_3 contents in PNE-PV samples never exceed 1 wt%, except for aqua blue sample no. 18. In Fe_2O_3-MnO binary diagrams (Fig. 7), almost all investigated samples lie just above the RC/LAC-Sb groups (which have MnO contents fixed at below 0.2 wt%), overlapping the broader fields of the RC/LAC-MnSb groups. Similarly, in binary diagram Fe_2O_3-Sb (Fig. 8), the PNE-PV samples overlap the RC/LAC-MnSb group fields while the correspondence with the RC/LAC-Sb fields is only partial.

Summing up, the compositional comparison between the PNE-PV samples and the colourless glass available in literature shows that the majority of samples investigated here are similar to the Roman and Late Antique glass groups containing both antimony and manganese and, to a lesser extent, to those decoloured by antimony only. A small group of vessels (19–22) showed instead lower amounts of MnO (below 0.2 wt%) and could be compared to the RC/LAC-Sb groups, especially in relation to SiO_2, Na_2O, MgO, K_2O and MnO amounts.

Table 5 Mean and standard deviation values of the Levantine and HIMT glass groups [n = stands for number of analyses]

Group	Levantine	HIMT
n=	152	396
SiO_2 (wt%)	69.9	67.8
sd	1.8	2.1
Al_2O_3 (wt%)	2.9	2.4
sd	0.2	0.3
TiO_2 (wt%)	0.08	0.24
sd	0.02	0.16
CaO (wt%)	8.7	6.0
sd	0.9	0.6
MgO (wt%)	0.6	0.9
sd	0.1	0.2
Na_2O (wt%)	15.6	19.4
sd	1.2	1.1
K_2O (wt%)	0.8	0.5
sd	0.2	0.1
Fe_2O_3 (wt%)	0.4	1.1
sd	0.1	0.6
MnO (wt%)	0.6	1.3
sd	0.6	0.5

With respect to the Levantine and the later HIMT coloured glass groups, a comparison based on major element composition does not seem conclusive. In PNE-PV samples, SiO_2 and TiO_2 contents are similar to those of the Levantine glass, Na_2O, Al_2O_3 and CaO are similar to those of the HIMT glass, Fe_2O_3 contents can be compared sometimes to the Levantine while some other times to the HIMT glass, while MnO contents are even lower than the average value provided for the Levantine group.

Comparing minor and trace element data to the average values of both Levantine and HIMT glass (as reported by Schibille 2011b), it is possible to observe a greater similarity of the investigated samples with the Levantine glass and a neat distinction in relation to HIMT glass, mainly based on Zr and Ba values (Fig. 9). Personal data further show that only Hf values are in the range of the Levantine materials while greatly lower if compared to the HIMT glass. Although the depletion in rare earth and trace elements generally indicates the use of a mature sand where heavy minerals are quantitatively very low, the possibility that the REE pattern is "altered" by contaminants introduced via antimony must be also taken into account.

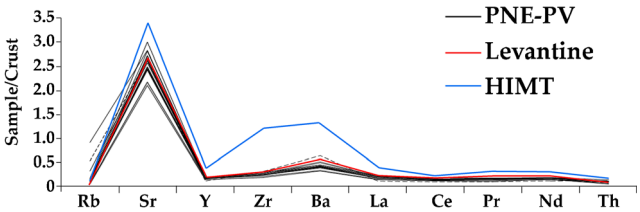

Fig. 9 REE pattern of the investigated samples and reference materials. All values have been normalised to the upper continental crust (Kamber et al. 2005). Levantine and HIMT glass patterns from Schibille (2011b)

Conclusions

The sample set is rather homogeneous both texturally and compositionally, even though the few aqua blue samples here investigated showed slightly higher iron contents, while a colourless (no. 20) and an aqua blue sample (no. 7) were slightly different from the rest of the group, based on lower and higher trace element contents, respectively.

The majority of the investigated colourless samples were found to be closely comparable to Roman and Late Antique colourless glass in which both antimony and manganese are present, here temporarily named RC-MnSb and LAC-MnSb glass groups; the only exceptions being their averagely higher Al_2O_3 contents with respect to these wider glass groups.

Three goblets type Isings 86 (PNE 20-21 and PV 22) and one cup (PV 19) showed MnO amounts lower than 0.2 wt% and also the overall values obtained for the other major element contents were similar to those of both RC-Sb and LAC-Sb groups.

As far as provenance, it has been noted that among major elements, some (esp. SiO_2, TiO_2 and MnO) were more similar to the Levantine glass while others (esp. Na_2O, Al_2O_3 and CaO) were compatible with the later HIMT reference group. However, the REE pattern seems to rule out the possibility of a HIMT and thus Egyptian provenance in favour of a Levantine one. Assuming thus a Levantine origin of the sand, we could hypothesise that a greater amount of Na_2O and thus of the natron flux was used for the production of this SiO_2-rich colourless glass. The higher Al_2O_3 contents could possibly be explained by the use of a different (and perhaps geographically close) sand. In that case, the CaO contents may either be typical of this *ad hoc* sand or intentionally added, based on technological constraints: an increase of vitrifying and fluxing agents corresponding to a relative increase of the stabilizing agent.

Lastly, despite an overall analysis of Roman colourless glass is beyond the scope of this research, it is definitely helpful to observe that the RC-Sb, LAC-Sb, RC-MnSb and LAC-Mn/Sb groups include mostly vessels and *tesserae* but also windows, moils, chips, rods, trails, chunks and lumps. Although further investigation will be required, it does not seem that colourless glass was preferentially used for a specific category of objects or rather for a glass production addressing a specific level of society. Also, among the investigated vessel collection, the glass composition of uncommon and high quality items such as the three goblets type Isings 86 (PNE 20-21, PV 22) is closely comparable to that of a cup of common use (PV 19).

References

Alagia D (2014) Topografia degli Horti Lamiani. Riconsiderazioni di un tema archeologico. Scienze dell'Antichità 20.1:247–266

Arletti R, Ciarallo A, Quartieri S, Sabatino G, Vezzalini G (2006) Archaeometrical Analyses of Game counters from Pompeii. In: M. Maggetti, B. Messiga (eds) Geomaterials in Cultural Heritage, Special Publication, Geological Society of London, 257, 175–186

Arletti R, Vezzalini G, Biaggio Simona S, Maselli Scotti F (2008) Archaeometrical studies of Roman Imperial age glass from Canton Ticino. Archaeometry 50:606–626

Arletti R, Vezzalini G, Benati S, Mazzeo Saracino L, Gamberini A (2010a) Roman window glass: a comparison of findings from three different Italian sites. Archaeometry 52:252–271

Arletti R, Giacobbe C, Quartieri S, Sabatino G, Tigano G, Triscari M, Vezzalini G (2010b) Archaeometrical investigation of Sicilian Early Byzantine glass: chemical and spectroscopic data. Archaeometry 52:99–114

Barbera M (2013) Gli Horti Lamiani: topografia e organizzazione del complesso, alla luce dei vecchi e nuovi scavi. In: Caligola. La trasgressione al potere, Cat. Mostra Nemi, Museo delle Navi Romane, 2013, Roma, pp. 179–188

Barbera M, Barrano S, de Cola G, Festuccia S, Giovannetti L, Menghi O, Pales M (2010) La villa di Caligola. Un nuovo settore degli *Horti Lamiani* scoperto sotto la sede dell'ENPAM a Roma, http://www.fastionline.org/docs/FOLDER-it-2010-194.pdf

Bertini M, Shortland A, Milek K, Krupp EM (2011) Investigation of Iron Age north-eastern Scottish glass beads using element analysis with LA-ICP-MS. J Archaeol Sci 38:2750–2766

Brill RH (1988) Scientific investigations. In: Weinberg (ed) Excavations at Jalame: site of a glass factory in late Roman Palestine, Columbia, 257–294

Cima M, Talamo E (2008) Gli *horti* di Roma antica, Quaderni capitolini, 2, Milano

Fiori C, Vandini M, Mazzotti V (2004) I colori del vetro antico, Padova:Il Prato

Fischer A, McCray WP (1999) Glass Production Activities as Practised at Sepphoris, Israel (37 BC–AD 1516). J Archaeol Sci 26:893–905

Foster HE, Jackson CM (2009) The composition of 'naturally coloured' late Roman vessel glass from Britain and the implications for models of glass production and supply. J Archaeol Sci 36:198–204

Foster HE, Jackson CM (2010) The composition of late Romano-British colourless vessel glass: glass production and consumption. J Archaeol Sci 37:3068–3080

Foy D (2014) Deux types de coupes et d'assiettes du IIe siècle soufflées dans un verre incolore: Des productions de Méditerranée occidentale? J Glass Stud 56:13–27

Foy D, Picon M, Vichy M, Thirion-Merle V (2003) Caractérisation des verres de la fin de l'Antiquité en Méditerranée occidentale: l'émergence de nouveaux courants commerciaux. In: D. Foy, M.-D. Nenna (eds.), Échanges et commerce du verre dans le monde antique, Actes du Colloque de l'AFAV, Aix-en-Provence et Marseille (7-9 Juin 2001), Monographies Instrumentum 24, Éditions Monique Mergoil, pp 41–85

Freestone IC (1994) Appendix: chemical analysis of 'raw' glass fragments. In: Hurst (ed) Excavations at Carthage, II. British Academy Monographs in Archaeology, 4, 290. Oxford University press

Freestone IC, Gorin-Rosen Y, Hughes MJ (2000) Primary glass from Israel and the production of glass in late Antiquity and the early Islamic period. In: Nenna (ed), La route du verre, 33, 65–83

Freestone IC, Wolf S, Thirlwall M (2005) The production of HIMT glass: elemental and isotopic evidence, Annales du 16e Congrès de l'Association internationale pour l'histoire du verre (London, 2003), pp 153–157

Gallo F, Silvestri A, Molin G (2013) Glass from the Archaeological Museum of Adria (North-East Italy): new insights into Early Roman production technologies. J Archaeol Sci 40:2589–2605

Gliozzo E, Santagostino Barbone A, D'Acapito F (2013) Waste glass, vessels and window-panes from Thamusida (Morocco): grouping natron-based blue-green and colourless Roman glasses. Archaeometry 55:609–639

Huisman DJ, De Groot T, Pols S, Van Os BJH, Degryse P (2009) Compositional variation in roman colourless glass objects from the Bocholtz burial (The Netherlands). Archaeometry 51:413–439

Jackson CM (2005) Making colourless glass in the Roman period. Archaeometry 47:763–780

Jackson CM, Paynter S (2015) A great big melting pot. Exploring patterns of glass supply, consumption and recycling in Roman Coppergate, York. Archaeometry. doi:10.1111/arcm.12158

Kamber BS, Greig A, Collerson KD (2005) A new estimate for the composition of weathered young upper continental crust from alluvial sediments, Queensland, Australia. Geo Cosmo Acta 69:1041–1058

Lepri B (2013) Il vetro della media età imperiale nelle stratigrafie delle "Terme di Elagabalo". In C. Panella, L.Saguì (eds) Valle del Colosseo e pendici nord-orientali del Palatino. Materiali e contesti 2, Roma, pp 139–160

Mirti P, Casoli A, Appolonia L (1993) Scientific analysis of Roman glass from *Augusta Praetoria*. Archaeometry 35:225–240

Nenna M-D (2014) Egyptian glass abroad: HIMT glass and its market. In: D. Keller, J. Price, C. Jackson (eds), Neighbours and successors of Rome, Oxbow Books, pp 177–193

Neri E, Verità M (2013) Glass and metal analyses of gold leaf tesserae from 1st to 9th century mosaics. A contribution to technological and chronological knowledge. J Archaeol Sci 40:4596–4606

Pastorino AM (2007) Tomba 5. Il corredo. In: A. Frondoni (ed), Il tesoro svelato : storie dimenticate e rinvenimenti straordinari riscrivono la storia di Noli antica: Noli, Sale espositive della Fondazione Culturale S. Antonio, Genova, pp 98–99

Paynter S (2006) Analyses of colourless Roman glass from Binchester, County Durham. J Archaeol Sci 33:1037–1057

Rosenow D, Rehren T (2014) Herding cats - Roman to Late Antique glass groups from Bubastis, northern Egypt. J Archaeol Sci 49:170–184

Saguì L (2013) Area delle "Terme di Elagabalo": tre millenni di storia alle pendici del Palatino. In: Panella C (ed) Scavare nel centro di Roma. Storie Uomini Paesaggi, Roma, pp 132–151

Saguì L, Cante M (2015) Archeologia e architettura nell'area delle "Terme di Elagabalo", alle pendici nord-orientali del Palatino. Dagli isolati giulio-claudii alla chiesa paleocristiana. Thiasos 4:37–75

Saguì L, Cante M, Quondam F (2014) Le "Terme di Elagabalo". I risultati delle ultime indagini. Scienze dell'Antichità 20(1):211–230

Schibille N (2011a) Supply routes and the consumption of glass in first millennium CE Butrint (Albania). J Archaeol Sci 38:2939–2948

Schibille N (2011b) Late Byzantine mineral soda high alumina glasses from Asia Minor: A new primary glass production group. doi:10.1371/journal.pone.0018970

Schibille N, McKenzie J (2014) Glass tesserae from Hagios Polyeuktos, Costantinople: their early Byzantine affiliations. In: Keller D, Price J, Jackson C (eds) Neighbours and successors of Rome. Oxbow Books, Oxford, pp 114–127

Schibille N, Marii F, Rehren T (2008) Characterization and provenance of late antique window glass from the Petra church in Jordan. Archaeometry 50:627–642

Schibille N, Degryse P, O'hea M, Izmer A, Vanhaecke F, Mckenzie J (2012) Late Roman glass from the 'Great temple' at Petra and Khirbet Et-Tannur, Jordan—technology and provenance. Archaeometry 54:997–1022

Silvestri A, Molin G, Salviulo G (2005) Roman and Medieval glass from the Italian area: bulk characterization and relationships with production technologies. Archaeometry 47:797–816

Silvestri A, Molin GM, Salviulo G (2008) The colourless glass of Iulia Felix. J Archaeol Sci 35:331–341

Silvestri A, Tonietto S, Molin G (2011) The palaeo-Christian glass mosaic of St. Prosdocimus (Padova, Italy): archaeometric characterisation of 'gold' tesserae. J Archaeol Sci 38:3402–3414

Thirion-Merle V (2005) Le Verres de Beyrouth et les verres du Haut Empire dans le monde occidental: Etude archéométrique. J Glass Stud 47:37–53

Tiepolo M, Bottazzi P, Palenzona M, Vannucci R (2003) A laser probe coupled with ICP-double focusing sector-field mass spectrometer for in situ analysis of geological samples and U-Pb dating of zircon. Can Mineral 41:259–272

van Achterbergh E, Ryan CG, Jackson SE, Griffin WL (2001) Data reduction software for LA-ICP-MS. In: Sylvester, P. (ed.), Laser-ablation-ICPMS in the Earth Sciences: Principles and Applications, vol. 29. Mineralogical Association of Canada, pp 239-243

Van Der Linden V, Cosyns P, Schalm O, Cagno S, Nys K, Janssens K, Nowak A, Wagner B, Bulska E (2009) Deeply coloured and black glass in the northern provinces of the Roman Empire: differences and similarities in chemical composition before and after AD 150. Archaeometry 51:822–844

Verità M, Arena MS, Carruba AM, Santopadre P (2008) Materiali vitrei nell'opus sectile di Porta Marina (Ostia antica). Bollettino Isitituto Centrale Restauro 16–17:78–94