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Late antique and early medieval glass from the northern Venetian lagoon: New data from the archaeological site of Jesolo

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ABSTRACT

Accurate microchemical characterisation was performed on a 4th-12th-century repertoire of coloured and colourless glass samples found in the archaeological excavation of Jesolo (ancient *Equilus*, northern Italy).

The research aimed to improve the state-of-the-art knowledge of early medieval glass, through the characterisation of a stratigraphically very well-dated and homogeneous glass collection, further representing a *unicum* in the area of the western upper Adriatic.

A representative sampleset of sixty-seven glass finds -including vessels, windows, *tesserae* and blocks of raw glass- was investigated by electron microprobe (EMPA) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). All samples are classified as soda-lime-silica glass made of impure sands and natron. In most cases, glass colour is imparted by iron naturally present in the sands, often counteracted by varying levels of manganese. The collection also includes numerous Co– and Cu-coloured glass. Colourless glass is Mn-decoloured or, to a lesser extent, Mn/Sb-decoloured. The proportion between fresh and recycled glass is almost equal. The provenance investigation has established that while Levantine imports are numerically limited, most materials can be traced back to the Egyptian area. Among the twelve samples assigned to the Levantine area, both Jalame-type and Apollonia-type glass has been identified in an almost equal percentage. Among Egyptian glass, a consistent group of 22 samples has been straightforwardly assigned to the HIMTa and, to a lesser extent, HIMTb groups. Both group 2.1 and 3.2 are clearly attested in almost equal amounts but individually less frequent than HIMT.

1. Introduction

From 2013 to 2016, following a field survey in 2011, an archaeological excavation has enabled to define the history of *Equilus*, a Late Antique mansion on the margin of the future city of Venice's lagoon, in the present-day town of Jesolo[1] [1]. Overall, it was possible to reconstruct a settlement sequence from the 1st century BCE to the contemporary age, divided into six periods. The glass assemblage studied here was recovered during excavations in the area north of the remains of the old Cathedral (Fig. 1A).

Glass samples have been investigated within the frame of the project Food & S.T.O.N.E.S., specifically aimed at studying the circulation of different types of early mediaeval goods in the Adriatic Sea.

The site shows continuous occupation over time, starting from the first centuries of the imperial age, when the area was a lagoon with only a few land strips emerging. Traces of earliest occupation are few and scattered but indicate the presence of settled areas and production facilities (the discovery of *Hexaplex Trunculus* shell mounds suggests purple production in the northern area in the Roman period).

The late Antique phases of frequentation have returned the most complete evidence. As of the 4th century the entire settlement is well legible. Small individual houses were built to the north for housing or craft purposes. To the south, on the other hand, a large quadrangular building was divided into two rows of juxtaposed rooms, some with structured hearths, facing a paved street (Fig. 1B). The remains of thresholds and hearths suggest that these rooms functioned as small self-

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contained lodgings, each with access from the street and equipped with a back room for the temporary accommodation of people passing through. Soon the building expanded with the addition of a third row of rooms at the rear. The latter are larger and the presence of some facilities, including a well, suggests residential and continuous use. Further south, where the remains of the Romanesque cathedral are preserved, the excavations performed in the second half of the 20th century uncovered the remains of a small 5th-century church. In the final years of the 5th century, these spaces were transformed into a burial area after a fire destroyed the mansion and ended its activity.

Ancient *Equilus* was a point of contact and exchange of an articulated lagoon communication system composed of water and land routes that provided connections from Ravenna to Aquileia.

The excavation testified to the vitality of these areas between the 4th and 6th centuries. Indeed, the site could rely on numerous resources found in the lagoon, some of primary importance, such as fishing and salt. *Equilus* undoubtedly had a primary role in the trade of regional products but also for wide-ranging trade from the Mediterranean basin, both from North Africa and the Near East.

The study of glass materials from this site represents an excellent opportunity to investigate the distribution channels in the upper Adriatic, at a time when the entire Mediterranean trade network is being redefined.

2. Materials

The glass objects from *Equilus*, from the late antique and early mediaeval periods, constitute a stratigraphically very well dated and homogeneous cluster, a *unicum* in the area of the western upper Adriatic. Comparable discoveries are few and recent sampling and analyses were not available.

The total number of glass fragments found at *Equilus* was about 2000, attributable to 620 individual objects.

Unfortunately, most fragments were not diagnostic and 1254 wall fragments could not be referred to specific types.

The samples were selected based on chronological and typological criteria to obtain a representative collection of the types that are most represented in the considered stratigraphy and that best represent the manufacturing techniques, colours and decoration techniques among this glass repertoire. Overall, the samples investigated here are 67, corresponding to 59 objects (Table 1, Fig. 1C).

Based on the chronological criterion, the samples were taken from the contexts dated to the late antique and early mediaeval phases of the village and the large building interpreted as a *mansio*. The sample set also includes 14 finds from the later period, difficult to read stratigraphically and therefore dated over a broad chronological horizon ranging from the 9th to the 12th century, *i.e.* a period for which there are few analytical data.

As for the typological criterion, it is worth underlining that the shapes are fairly standardised, thus providing a good indicator that the assemblages are consistent and that any residuality is very low. Overall, glass objects can be divided into several functional types: vessels for lighting (17 % of identifiable objects), ornamental objects (2 % of identifiable objects), glass for architectural use (mosaic *tesserae* and window panes: 16.5 % of identifiable objects) and tableware, which is the most represented category (64.5 % of identifiable objects). Included in the latter category are many shapes, open or closed, or parts of vessels that are well recognisable but cannot be fully reconstructed, even if some of these uncertain objects may also have served as lighting vessels. Specifically, among the most attested vessels are drinking glasses/cups

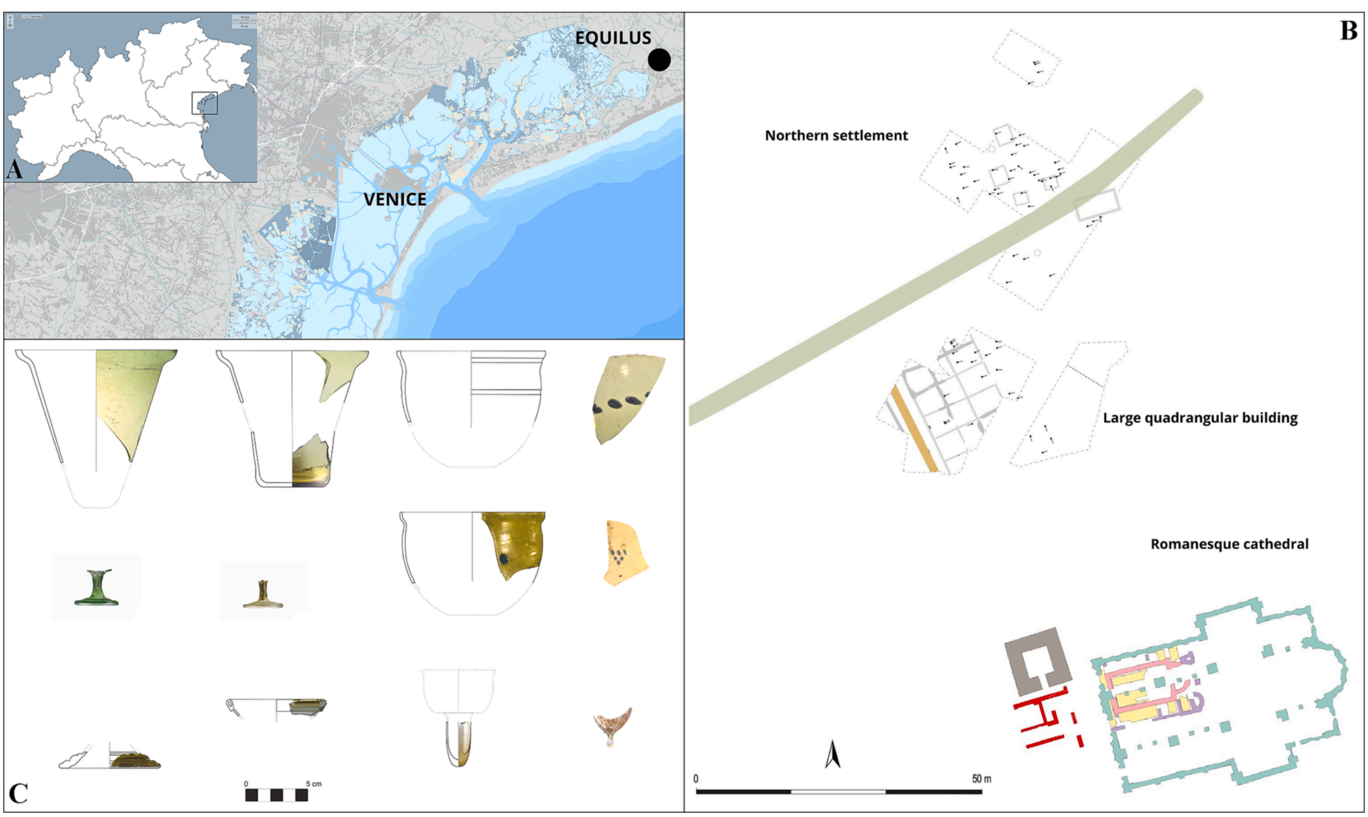

Fig. 1. A) Location of *Equilus* (credits: Laboratorio di Archeologia Medievale Ca' Foscari). B) The general plan of Jesolo excavations from 2013 to 2016. The large quadrangular building has been identified as a *mansio* (credits: Laboratorio di Archeologia Medievale Ca' Foscari). C) Glass typology. Representative shapes from *Equilus* (credits: Laboratorio di Archeologia Medievale Ca' Foscari).

Table 1
Findspot, colour, shape, typology and chronology of the 67 samples from Jesolo.

Inv.	Year	US	Colour	Shape	Typology	Cen.
JE7	2015	5002	Yellow	Window	–	7th
JE9	2015	5002	Colourless	Window	–	7th
JE10	2015	5002	Green-blue	Beaker	Is. 96 (rounded rim)	7th
JE10 bis	2015	6002	Colourless	Window	–	6th
JE11	2015	5002	Blue dark	Beaker/Cup	–	7th
JE14	2015	6002	Light green	Window	–	6th
JE17	2015	6002	Green-yellow	Multiple filament base	Is. 87 / Is. 120	6th
JE18b	2016	7003	Dark blue	Beaker	Is. 96 (cut rim)	End of 5th-beginning of 6th
JE18c	2016	7003	Colourless (slightly yellow)	Beaker	Is. 96 (cut rim)	End of 5th-beginning of 6th
JE20	2016	7003	Colourless (slightly green)	Ring-shaped base	–	End of 5th-beginning of 6th
JE22	2013	2026	Light yellow	Lamp-handle	Is. 134	End of 5th-beginning of 6th
JE24	2016	7035	Bluish grey	*Tessera*	–	9th-12th
JE25	2016	7035	Colourless	Cup? (open shape)	–	9th-12th
JE25 bis	2014	3002	Green olive	Beaker	Is. 96 (cut rim)	End of 5th-beginning of 6th
JE26	2016	7035	Yellow-green	Beaker/Cup	–	9th-12th
JE31b	2015	6018	Dark blue	Beaker	Is. 96 (cut rim)	6th
JE31c	2015	6018	Colourless	Beaker	Is. 96 (cut rim)	6th
JE40	2016	7062	Turquoise blue	*Tessera*	–	End of 4th-beginning of 5th
JE47	2016	7073	Grey	*Tessera*	–	9th-12th
JE49b	2015	6019	Dark blue	Beaker	Is. 96	End of 5th-beginning of 6th
JE49c	2015	6019	Colourless	Beaker	Is. 96	End of 5th-beginning of 6th
JE50	2015	4003	Colourless	Window	–	5th-6th
JE51	2015	6019	Light green	Window	–	End of 5th-beginning of 6th
JE51 bis	2016	7073	Olive green	Window	–	9th-12th
JE51 ter	2015	4003	Light green olive	Multiple filament base	Is. 87 / Is. 120	5th-6th
JE59	2016	7073	Light aqua blue	Cup? (open shape)	–	9th-12th
JE61	2015	4003	Dark yellow	Goblet	Is. 111	5th-6th
JE62	2016	7073	Light yellow	Beaker	Is. 96 (rounded rim)	9th-12th
JE64	2016	7073	Olive green	Beaker	Is. 96 (cut rim)	9th-12th
JE72	2015	6023	Aqua blue	Block	–	End of 5th-beginning of 6th
JE78	2016	7058	Dark green	Beaker/Cup	–	9th-12th
JE78 bis	2015	4019	Light yellow-green	Window	–	6th – 7th
JE79	2015	4019	Light yellow	Goblet	Is. 111	6th – 7th
JE80	2016	7058	Green	Multiple filament base	Is. 87 / Is. 120	9th-12th
JE83	2014	3056	Yellow	Goblet	Is. 111	End of 6th – 7th
JE86	2016	7058	Turquoise blue	*Tessera*	–	9th-12th
JE87	2016	7058	Colourless	Lamp	Uboldi III.2	9th-12th
JE89	2016	7066	Cobalt blue	Tessera	–	9th-12th
JE90	2014	3056	Light yellow	Lamp	Uboldi IV.2	End of 6th – 7th
JE90 bis	2016	7066	Olive green	Block	–	9th-12th
JE94	2015	6031	Aqua blue	Goblet	Is. 111	End of 6th – 7th
JE95	2015	6031	Light aqua blue	Goblet	Is. 111	End of 6th – 7th
JE103	2014	3071	Aqua blue	Block	–	5th
JE104	2014	3071	Aqua blue	Goblet	Is. 111	5th
JE108	2014	3071	Colourless	Beaker/Cup	–	5th
JE109	2014	3071	Colourless (slightly yellow)	Cup? (open shape)	–	5th
JE110	2013	1067	Light green	Goblet	Is. 111	5th
JE127c	2013	2037	Colourless	Beaker	Is. 96 (bottom)	5th
JE127b	2013	2037	Dark blue	Beaker	Is. 96 (bottom)	5th
JE129c	2013	2037	Colourless (slightly green)	Beaker	Is. 96 (cut rim)	5th
JE129g	2013	2037	Green	Beaker	Is. 96 (cut rim)	5th
JE134	2013	2037	Green	Beaker	Is. 96 (cut rim)	5th
JE141	2014	3084	Light green	Lamp	Uboldi III.2	5th
JE148	2014	3098	Aqua blue	Goblet	Is. 111	End of 5th-beginning of 6th
JE149	2014	3098	Green-yellow	Goblet	Is. 111	End of 5th-beginning of 6th
JE162c	2015	6074=6073	Colourless	Beaker	Is. 96 (cut rim)	End of 6th – 7th
JE162b	2015	6074=6073	Dark blue	Beaker	Is. 96 (cut rim)	End of 6th – 7th
JE199	2015	6081	Dark olive green	Block	–	End of 6th – 7th
JE225	2014	3174	Yellow	Goblet	Is. 111	5th
JE229	2015	6092	Light green	Window	–	6th
JE250c	2015	6100	Light green	Beaker	Is. 96	6th
JE250b	2015	6100	Dark blue	Beaker	Is. 96	6th
JE324b	2015	6187	Dark blue	Beaker	Is. 96 (cut rim)	End of 5th-beginning of 6th
JE324c	2015	6187	Colourless	Beaker	Is. 96 (cut rim)	End of 5th-beginning of 6th
JE395	2014	3302	Light yellow-green	Beaker	Is. 96 (cut rim)	5th
JE397	2014	3302	Light green	Beaker	Is. 96 (cut rim)	5th
JE408	2014	3302	Green	Multiple filament base	Is. 87 / Is. 120	5th

Abbreviations: Inv.=inventory noumber; US=stratigraphic unit; Cen.=century; Is.=Isings.

of type Isings[2] 96/106 (with cut or fire-rounded rims, some engraved with linear patterns or decorated with applied blue drops) and goblets of type Isings 111.

There is little evidence of closed types pertaining to *ampullae* or jugs and large open-shaped wares such as cups or plates. The bases resting on multiple trails were found on site and thus sampled; however, since the bodies of the vessels were never preserved, their attribution to open or

[2] For all references to the Isings typology, see [3].

closed types proved challenging. Among glass vessels, the majority were free-blown and a minority were cast or mould-blown.

Based on the typological study of the glass repertoire, sampling focused on tableware vessels assimilated to Isings type 96 or 106. They have been placed in a single category of vessels, given the difficulty in attributing sometimes very minute fragments, in which it is not clear whether the body had truncated-cone or globular development on a flattened base (JE49c; JE127c; JE250g). They certainly come in two variants: with a cut rim (JE18c; JE25bis; JE31c; JE64; JE129c; JE129g; JE134; JE162c; JE324c; JE395; JE397) or with a rounded, flame-finished rim (JE10; JE62). Their typical colours range from yellow-green to deeper green and are often decorated with blue drops applied to the body of the vessel, forming triangular groups or horizontal lines (JE18b; JE31b; JE162b; JE324b; JE49b; JE127b; JE250b). This is a multipurpose recipient, which sometimes had handles (as seen in Concordia finds [2]) and could also serve a lighting function.

An equally large group of samples belongs to stem-hollow goblets (Isings type 111), usually with flattened circular bases (JE61; JE79; JE83; JE94; JE95; JE104; JE110; JE148; JE149; JE225). The type Isings 111 appears to replace the Isings 96/106 beakers/cups from the 5th century onward and it is not excluded that it may also have served the function of illumination, perhaps as standing lamps. However, this function was also performed by vessels expressly made for this intended use, *i.e.* provided with handles (Isings 134: JE22) or funnel-shaped to be inserted into metal supports (Uboldi[3] IV.1 type: JE90) or even with a more expanded body and the peculiar teardrop-shaped termination (Uboldi III.2 type: JE87; JE141).

Among open-shaped wares, sampling focused on cups or plates (JE25; JE59; JE109) and walls presumably pertaining to these same types (JE11; JE26; JE78; JE108). Hypothetically, the bases resting on multiple trails (JE17; JE51ter; JE80; JE408) or ring-shaped bases (JE20) may resemble the above-mentioned cups/plates.

A substantial part of the sampleset is further represented by window panes (JE7; JE9; JE10 bis; JE14; JE50; JE51; JE51 bis; JE78 bis; JE229), mosaic *tesserae* (JE24; JE40; JE47; JE86; JE89) and glass blocks (JE72; JE90 bis; JE103; JE199).

The presence of production indicators is not sufficient to assume or disregard the presence of a secondary workshop at *Equilus*. However, the nature of the site as a place of transit, may suggest a role in the marketing of semi-finished products rather than production.

3. Methods

The measurements have been performed through electron microprobe analysis (EMPA) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). The quantitative determination of major and selected minor elements (Cu, Sb and Pb), as well as volatiles (Cl and S) was performed at the joined laboratory of the DST-UNIFI and CNR-IGG of Florence, using a JEOL Superprobe JXA-8230, equipped with five wavelength-dispersive spectrometers (WDS), under the following operating conditions: 15 kV, beam current at 10nA and beam diameter 10 µm. The peak counting time was of 10 s for Na, 15 s for MgO, Al_2O_3, SiO_2, K_2O, CaO, FeO, TiO_2, 30 s for P_2O_5, Cl, S and 40 s for MnO, Sb_2O_5, SnO_2, PbO and CuO. Matrix effects were corrected by ZAF algorithm. A selection of natural phases is used as primary standard for the elemental calibration (Astimex albite for Si and Na, plagioclase for Al, olivine for Mg, diopside for Ca, sanidine for K, apatite for P, celestine for S, tugtupite for Cl, barite for Ba and Smithsonian ilmenite for Ti and Fe). Synthetic reference material glass NIST-SRM1832 and three different Smithsonian Corning glasses (Corning-A NMNH 117218–4, Corning-B NMNH 117218–1 and Corning-D NMNH 117218–3 [5]) are used as specific secondary standards for the analytical quality control. Replicate measurements (10 to 25) on the above mentioned international reference standards show a good precision with a variation coefficient lower than 1 % for silica, up to 2 % for the other major elements and up to 5 % for minor elements. Accuracy is lower than 0.5 % for silica, up to 0.5 % for the other major elements, between 0.8 and 1 % for most minor elements while up to 2 % for Sb_2O_5 and PbO. The total R^2 is considerably lower than 1 for all the analysed standards.

The trace element content was determined by laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS at IGG-CNR, Pavia, Italy). The instrument combined an ablation microbeam, based on a Nd:YAG laser source (Brilliant, Quantel) operating at 266 nm (for details see [6]), and a quadrupole ICP-MS (Drc-e, Perkin Elmer). Forty masses were acquired; the laser was operated at 10 Hz of repetition rate, the power on the sample was 1.5 mW and the 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 [7] and using NIST SRM 610 and ^{29}Si as external and internal standards, respectively. Values were normalised to the weathered continental crust, based on [55].

4. Results

The collection is characterised by homogeneous glass fragments. The *tessera* JE40 is the only one showing fine bands of dark and light grey shades (Fig. S1A-B). Light bands include small (<10 µm), bright inclusions showing $CaSb_2O_6$ composition, with CaO ranging between 14 and 16 wt% and Sb_2O_5 between 78 and 86 wt% ($CaO/Sb_2O_5 = 0.16/0.19$ based on five measurements).

The separation between the colourless and blue portions of Ising 96 samples JE18, 31, 49, 127, 162, 250 and 324 (or green in JE129) is neat (Fig. S1C-D). In this case, however, it is not proper banding but rather two glasses superimposed on each other. Blue glasses differ in the dimension and frequency of bubbles and inclusions. For instance, the sample JE127 appears very homogeneous, with a few large bubbles and a limited number of inclusions (Fig. S1C). On the other hand, the sample JE324 shows numerous bubbles and numerous inclusions of variable dimensions (Fig. S1D), and the sample JE31 shows a few inclusions of large dimensions and many large bubbles. The inclusions are represented by aggregates of tiny copper crystals in sample JE129 or aggregates of iron (75–80 wt%), cobalt (1.3–19.9 wt%) and copper (0.5–8 wt %) in samples JE18, 31, 127, 162, 250 and 324.

Average glass composition is reported in Table 2 (EMPA; full dataset in Table S1) and Table S2 (LA-ICP-MS; full dataset in Table S3).

The composition of light and dark bands of sample JE40 (labelled as JE40 lb and JE40 db, respectively) have been provided separately. In addition, the average composition has been calculated (JE40 av.); however, these data should be considered with caution since it is not possible to estimate what overall volume each band corresponds to.

The glass collection can be described as soda-lime-silica glass. Al_2O_3 contents range between 2 and 4 wt% (Fig. S2), indicating the use of impure sand as the vitrifying agent of all glass samples [8].

MgO and K_2O contents are below 1.55 and 0.9 wt%, respectively. Higher values were found in the block JE72 (1.9 wt% K_2O) and the beaker JE129c (1.64 wt% MgO). Since the MgO-K_2O ratio is indicative of the type of flux used [9], it is possible to establish that mineral soda was used as the fluxing agent for all samples, except JE72 and JE129c (mixed alkalis or the enviroment may have affected these two latter samples). CaO levels ranging between 4.3 and 9.9 wt% must have stabilised the modified network. A significant presence of dolomite and K-feldspars can be excluded based on the low amounts of MgO and K_2O and the absence of appreciable correlations between them and CaO. The high Sr contents (above 350–810 ppm) may further indicate the presence of shells [10–11]. The latter may have been naturally present in the sand or deliberately added to the glass batch [12].

As for colouring and decolouring agents (Fig. S1B-D), FeO levels range between 0.3 and 3.7 wt%. In most colourless, yellow and green

[3] For all references to the Uboldi typology, see [4].

Table 2
The results achieved by EPMA on the glass collection from Jesolo. All values are provided as wt%.

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Cl	SO_3	CuO	PbO	Sb_2O_5	SnO_2	Total
JE7	n = 8	64.60	0.14	2.62	0.90	1.62	1.18	7.96	18.79	0.72	0.13	0.86	0.37	0.01	0.01	0.02	bdl	99.93
	sd	0.2	–	–	–	–	–	0.1	0.2	–	–	–	–	–	–	–	–	
JE9	n = 6	63.84	0.14	2.42	0.73	1.38	1.18	7.85	20.26	0.54	0.09	1.09	0.41	0.01	0.01	0.02	bdl	99.96
	sd	0.1	–	–	–	–	–	0.1	0.2	–	–	–	–	–	–	–	–	
JE10	n = 6	66.08	0.20	2.57	1.37	0.91	0.88	5.82	19.91	0.63	0.11	1.12	0.31	0.01	0.01	bdl	bdl	99.93
	sd	0.2	0.1	0.2	0.3	–	–	0.3	0.2	–	0.1	–	–	–	–	–	–	
JE10bis	n = 9	68.00	0.07	2.27	0.44	0.13	0.79	6.21	19.59	0.49	0.05	1.12	0.32	bdl	bdl	0.46	0.01	99.95
	sd	0.1	–	0.1	–	–	–	0.1	0.1	–	–	–	0.1	–	–	0.1	–	
JE11	n = 11	66.00	0.17	2.27	1.62	0.43	0.72	6.67	19.64	0.55	0.06	0.95	0.35	0.27	0.21	bdl	0.01	99.90
	sd	0.2	–	–	0.1	–	–	0.1	0.2	–	–	–	–	0.1	0.1	–	–	
JE14	n = 6	66.14	0.35	2.71	1.09	1.74	1.14	4.94	19.93	0.44	0.04	1.22	0.22	0.01	bdl	bdl	bdl	99.98
	sd	0.1	–	–	–	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE17	n = 6	68.40	0.06	2.93	0.29	0.04	0.46	8.74	16.90	0.86	0.10	1.05	0.11	bdl	bdl	bdl	bdl	99.94
	sd	0.4	–	–	–	–	–	0.4	0.1	–	–	–	–	–	–	–	–	
JE18c	n = 5	65.26	0.21	2.49	0.75	1.15	1.00	5.76	21.10	0.46	0.04	1.51	0.26	bdl	bdl	bdl	bdl	99.97
	sd	0.1	–	–	–	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE18b	n = 7	62.51	0.18	2.75	2.37	1.08	1.02	5.78	19.28	0.56	0.03	1.30	0.24	0.83	2.00	bdl	0.05	99.98
	sd	0.4	–	0.2	0.6	0.1	–	0.2	0.2	–	–	0.1	–	–	0.1	–	–	
JE20	n = 8	71.39	0.07	2.84	0.35	0.76	0.59	7.76	14.47	0.56	0.09	1.00	0.08	bdl	bdl	bdl	bdl	99.96
	sd	0.2	–	0.1	–	–	–	0.1	0.1	0.1	–	–	–	–	–	–	–	
JE22	n = 11	65.22	0.13	2.18	0.74	1.59	0.93	8.02	19.20	0.61	0.12	0.71	0.47	0.01	0.02	0.01	bdl	99.96
	sd	0.1	–	0.1	0.1	0.1	0.1	0.1	0.2	–	–	–	–	–	–	–	–	
JE24	n = 10	67.96	0.08	2.45	0.52	0.55	0.61	6.64	16.56	0.68	0.19	0.97	0.22	1.11	0.08	1.35	0.05	100.01
	sd	0.3	–	–	0.1	–	–	0.1	0.3	–	–	–	–	0.1	–	0.2	–	
JE25	n = 7	67.37	0.10	2.01	0.58	0.82	0.64	7.49	19.14	0.42	0.05	1.05	0.31	bdl	bdl	bdl	bdl	99.96
	sd	0.1	–	–	0.1	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE25bis	n = 12	67.72	0.50	2.98	3.44	1.51	0.96	5.69	15.45	0.53	0.15	0.80	0.22	0.01	bdl	bdl	bdl	99.96
	sd	0.2	–	–	0.1	0.1	–	0.1	0.2	–	–	–	–	–	–	–	–	
JE26	n = 6	66.76	0.49	2.96	1.71	1.83	1.20	5.86	17.51	0.43	0.03	0.97	0.22	0.01	bdl	bdl	bdl	99.97
	sd	0.2	–	–	–	–	–	–	0.1	–	–	–	–	–	–	–	–	
JE31c	n = 10	66.54	0.24	2.34	0.96	1.55	0.90	5.67	19.89	0.41	0.05	1.15	0.30	bdl	bdl	bdl	bdl	99.98
	sd	0.2	–	–	–	0.1	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE31b	n = 10	63.03	0.22	2.46	2.48	1.50	0.97	5.83	18.62	0.43	0.05	1.07	0.27	1.01	2.02	0.01	0.01	99.99
	sd	0.7	–	0.1	0.5	0.1	0.1	0.2	0.4	–	–	–	–	0.1	0.3	–	–	
JE40 db	n = 6	70.20	0.07	2.70	0.40	0.48	0.71	7.76	14.86	0.63	0.21	0.80	0.23	0.75	0.04	0.13	0.01	99.95
	sd	0.2	–	–	–	–	–	0.1	0.1	–	–	0.1	–	0.2	–	–	–	
JE40 lb	n = 7	69.15	0.07	2.69	0.45	0.51	0.72	7.85	14.79	0.65	0.21	0.74	0.30	1.02	0.05	0.69	0.07	99.95
	sd	0.3	–	0.1	–	–	–	0.1	0.1	–	–	–	0.1	0.1	–	0.2	–	
JE40 av.	n = 13	69.68	0.07	2.69	0.42	0.49	0.71	7.81	14.83	0.64	0.21	0.77	0.26	0.84	0.05	0.35	0.04	99.86
	sd	0.7	–	–	–	–	–	0.1	0.1	–	–	–	0.1	0.1	–	0.3	–	
JE47	n = 16	66.81	0.10	2.19	1.20	0.91	0.73	5.97	19.92	0.40	0.04	1.30	0.30	bdl	bdl	0.06	bdl	99.92
	sd	0.3	–	0.1	0.3	–	–	0.1	0.3	–	–	–	–	–	–	–	–	
JE49c	n = 7	66.66	0.11	2.18	0.55	1.19	0.94	6.47	19.94	0.31	0.03	1.41	0.22	bdl	bdl	bdl	bdl	100.00
	sd	0.3	–	0.1	–	–	–	0.1	0.1	–	–	0.1	–	–	–	–	–	
JE49b	n = 8	66.77	0.11	2.29	1.25	0.84	0.75	6.03	19.28	0.50	0.09	1.25	0.32	0.26	0.16	0.11	0.01	99.99
	sd	0.4	–	0.1	0.3	–	–	0.1	0.1	–	–	0.1	–	–	–	–	–	
JE50	n = 9	63.94	0.13	2.35	0.77	1.54	0.92	7.78	20.39	0.58	0.08	0.92	0.46	0.01	0.01	0.02	bdl	99.89
	sd	0.4	–	–	–	–	–	0.2	0.3	–	–	–	–	–	–	–	–	
JE51	n = 10	65.27	0.50	2.97	1.26	1.82	1.04	4.33	20.71	0.32	0.04	1.44	0.21	bdl	bdl	bdl	bdl	99.92
	sd	0.3	–	0.1	–	0.1	–	0.1	0.2	–	–	–	–	–	–	–	–	
JE51bis	n = 7	63.42	0.39	3.23	2.97	1.42	1.54	5.78	19.13	0.38	0.14	1.28	0.22	0.01	0.01	bdl	bdl	99.92
	sd	0.5	–	–	0.1	–	–	0.1	0.5	–	–	–	–	–	–	–	–	
JE51ter	n = 7	65.38	0.15	2.54	1.28	1.41	1.13	8.37	17.71	0.64	0.11	0.77	0.41	0.01	0.03	0.03	bdl	99.95
	sd	0.4	–	0.1	–	0.1	–	0.2	0.3	–	–	–	–	–	–	–	–	
JE59	n = 5	68.24	0.06	3.33	0.35	0.05	0.61	9.95	15.32	0.90	0.11	0.94	0.11	bdl	0.04	bdl	bdl	100.01
	sd	0.2	–	–	–	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE61	n = 6	64.56	0.16	2.62	0.87	1.68	1.16	7.57	19.11	0.78	0.15	0.85	0.39	0.01	0.01	0.01	bdl	99.93
	sd	0.2	–	0.1	–	–	–	–	0.2	–	–	–	–	–	–	–	–	
JE62	n = 14	65.19	0.15	2.68	0.93	1.55	1.10	8.08	18.21	0.61	0.07	0.91	0.37	0.01	0.01	0.08	bdl	99.97
	sd	0.2	–	–	0.1	0.1	–	0.1	0.2	–	–	–	–	–	–	–	–	
JE64	n = 13	63.99	0.57	3.19	1.82	2.24	1.20	5.88	19.21	0.48	0.09	0.93	0.30	0.04	0.04	bdl	0.01	99.98
	sd	0.3	–	0.1	–	0.1	–	0.1	0.2	–	–	–	–	–	–	–	–	
JE72	n = 11	69.92	0.11	3.01	0.66	0.19	0.84	7.33	14.36	1.90	0.10	0.85	0.16	0.08	0.30	0.11	0.08	99.99
	sd	0.2	–	0.1	–	–	–	0.1	0.3	0.4	–	–	–	–	–	–	–	
JE78	n = 8	66.26	0.36	3.08	1.83	1.29	1.05	6.76	17.44	0.62	0.11	0.89	0.21	0.01	0.02	bdl	bdl	99.91
	sd	0.2	–	–	0.1	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE78bis	n = 9	66.19	0.16	2.64	0.83	1.24	1.02	9.24	16.69	0.63	0.11	0.81	0.34	bdl	0.01	0.09	bdl	99.99
	sd	0.3	–	–	–	–	–	0.2	0.1	–	–	–	–	–	–	–	–	
JE79	n = 13	67.73	0.16	2.57	0.79	1.47	1.10	6.86	17.23	0.79	0.15	0.80	0.33	0.01	0.01	0.01	bdl	100.01
	sd	0.3	–	0.1	–	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE80	n = 10	66.48	0.23	2.45	0.88	1.53	0.95	5.99	19.46	0.58	0.05	1.12	0.25	0.01	bdl	0.01	bdl	99.97
	sd	0.2	–	0.1	–	0.1	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE83	n = 11	64.82	0.12	2.14	0.64	1.14	0.87	8.95	19.28	0.50	0.07	0.87	0.43	bdl	bdl	0.07	bdl	99.89
	sd	0.3	–	–	–	0.1	–	0.1	0.2	–	–	–	–	–	–	–	–	

(*continued on next page*)

Table 2 (*continued*)

		SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Cl	SO_3	CuO	PbO	Sb_2O_5	SnO_2	Total
JE86	n = 12	68.59	0.07	3.11	0.35	0.04	0.57	7.90	15.71	0.80	0.19	0.96	0.14	1.15	0.23	bdl	0.13	99.95
	sd	0.2	–	0.1	–	–	–	0.1	0.1	–	–	–	–	0.1	–	–	–	
JE87	n = 9	71.12	0.07	1.97	0.37	0.78	0.42	5.94	17.54	0.45	0.04	1.02	0.24	bdl	bdl	bdl	bdl	99.97
	sd	0.2	–	–	–	–	–	0.1	0.2	–	–	–	–	–	–	–	–	
JE89	n = 6	68.26	0.05	2.62	0.75	0.45	0.58	8.16	15.36	0.57	0.19	0.77	0.41	0.11	0.01	1.66	bdl	99.94
	sd	0.3	–	–	–	–	–	0.1	0.4	–	–	–	–	–	–	0.1	–	
JE90	n = 14	65.30	0.14	2.52	1.09	1.49	1.33	8.51	17.48	0.68	0.14	0.89	0.29	0.01	0.01	0.05	bdl	99.94
	sd	0.2	–	–	–	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE90bis	n = 9	62.88	0.50	3.26	3.25	1.94	1.45	6.48	18.19	0.59	0.20	0.91	0.31	0.02	0.04	bdl	bdl	100.02
	sd	0.2	–	–	0.1	0.1	–	0.2	0.1	–	–	–	–	–	–	–	–	
JE94	n = 9	70.57	0.06	2.94	0.35	0.02	0.72	6.98	16.54	0.58	0.05	1.00	0.11	bdl	bdl	bdl	bdl	99.91
	sd	0.2	–	0.1	–	–	–	0.2	0.2	–	–	–	–	–	–	–	–	
JE95	n = 9	67.30	0.10	2.82	0.63	0.25	0.88	7.94	17.23	0.60	0.11	0.99	0.24	0.22	0.34	0.37	0.02	100.01
	sd	0.2	–	0.1	–	–	–	0.1	0.2	–	–	–	–	–	–	–	–	
JE103	n = 6	67.47	0.17	3.96	1.03	0.23	1.28	8.21	14.95	0.92	0.19	0.73	0.14	0.10	0.46	0.04	0.10	99.98
	sd	0.4	0.1	0.6	0.3	–	0.1	0.4	0.2	–	0.1	–	–	–	–	–	–	
JE104	n = 6	71.48	0.10	2.86	0.42	0.04	0.66	7.02	15.58	0.60	0.09	0.86	0.14	0.01	0.04	bdl	0.02	99.93
	sd	0.5	–	0.1	0.1	–	0.1	0.2	0.4	–	–	–	–	–	–	–	–	
JE108	n = 7	66.59	0.05	2.02	0.97	0.89	0.91	6.91	18.92	0.44	0.05	1.03	0.35	bdl	0.01	0.78	bdl	99.92
	sd	0.3	–	–	0.4	0.1	0.1	0.1	0.5	–	–	0.1	–	–	–	0.2	–	
JE109	n = 9	66.57	0.12	2.44	0.67	1.34	0.94	6.66	19.38	0.59	0.07	0.75	0.43	bdl	bdl	bdl	bdl	99.96
	sd	0.2	–	–	–	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE110	n = 8	64.00	0.14	2.47	0.79	1.18	0.96	8.43	19.84	0.65	0.13	0.87	0.49	bdl	bdl	0.01	bdl	99.96
	sd	0.1	–	0.1	0.1	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE127c	n = 12	66.16	0.24	2.45	0.98	1.58	0.91	5.89	19.78	0.45	0.05	1.16	0.30	0.01	0.01	bdl	bdl	99.97
	sd	0.2	–	–	0.1	0.2	0.1	0.1	0.2	–	–	0.1	–	–	–	–	–	
JE127b	n = 10	63.28	0.23	2.69	3.64	1.62	1.01	5.91	18.35	0.48	0.05	1.03	0.29	0.66	0.79	bdl	bdl	100.01
	sd	0.3	–	0.1	0.1	–	–	0.2	0.2	–	–	–	–	–	–	–	–	
JE129g	n = 10	62.81	0.46	2.89	1.50	2.28	1.64	5.73	20.64	0.39	0.04	1.26	0.28	0.01	bdl	bdl	bdl	99.94
	sd	0.3	–	0.1	–	–	–	0.1	0.1	0.1	–	–	–	–	–	–	–	
JE129b	n = 10	58.32	0.42	2.75	1.45	2.00	1.55	5.52	19.56	0.50	0.13	1.04	0.34	6.10	0.23	0.01	0.03	99.94
	sd	0.3	–	0.1	–	0.1	–	0.1	0.1	–	–	–	–	0.2	–	–	–	
JE134	n = 11	65.91	0.49	2.54	1.21	1.91	0.95	6.04	19.11	0.42	0.05	1.00	0.30	0.01	bdl	bdl	bdl	99.96
	sd	0.2	–	–	–	0.1	–	0.1	0.2	–	–	–	–	–	–	–	–	
JE141	n = 8	65.50	0.12	2.21	0.66	1.15	0.83	7.58	19.89	0.56	0.08	0.89	0.47	0.01	0.01	bdl	bdl	99.97
	sd	0.2	–	–	–	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE148	n = 8	70.28	0.11	3.13	0.57	0.02	0.93	9.47	14.18	0.43	0.08	0.68	0.08	bdl	bdl	bdl	bdl	99.94
	sd	0.2	–	–	–	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE149	n = 13	65.42	0.15	2.41	0.97	1.47	1.11	7.98	18.41	0.66	0.12	0.86	0.34	0.01	0.02	0.02	bdl	99.94
	sd	0.2	–	0.1	–	–	–	0.1	0.2	–	–	–	–	–	–	–	–	
JE162c	n = 8	66.49	0.14	2.42	0.62	1.19	0.75	6.09	20.09	0.48	0.03	1.38	0.24	bdl	bdl	bdl	bdl	99.92
	sd	0.3	–	0.1	–	–	–	0.1	0.2	–	–	–	–	–	–	–	–	
JE162b	n = 8	64.37	0.14	2.58	1.91	1.14	0.90	6.08	19.40	0.48	0.04	1.32	0.24	0.64	0.69	bdl	bdl	99.95
	sd	0.3	–	0.1	0.1	0.1	0.1	0.3	0.2	0.1	–	–	–	–	–	–	–	
JE199	n = 10	63.69	0.56	3.40	3.74	2.13	1.41	5.75	17.39	0.48	0.17	1.00	0.21	0.02	0.01	bdl	bdl	99.98
	sd	0.4	–	0.1	0.1	0.1	0.1	0.1	0.2	–	–	–	–	–	–	–	–	
JE225	n = 11	65.67	0.13	2.47	0.82	1.79	1.10	8.16	17.75	0.72	0.13	0.79	0.36	0.01	0.02	0.02	bdl	99.94
	sd	0.2	–	–	–	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE229	n = 8	66.34	0.35	2.76	1.11	1.75	1.15	4.93	19.58	0.44	0.05	1.24	0.23	0.01	bdl	bdl	bdl	99.95
	sd	0.1	–	–	–	–	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE250g	n = 10	64.74	0.59	3.03	1.54	1.14	1.17	5.70	20.16	0.41	0.05	1.04	0.40	bdl	bdl	bdl	bdl	99.96
	sd	0.2	–	–	–	0.1	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE250b	n = 9	62.58	0.56	3.09	2.61	1.72	1.19	5.60	19.76	0.43	0.06	1.05	0.37	0.44	0.51	bdl	0.01	99.99
	sd	0.3	–	0.1	0.4	0.1	0.1	0.1	0.1	–	–	–	–	–	0.1	–	–	
JE324c	n = 7	69.02	0.12	2.14	0.66	1.28	0.66	5.36	18.77	0.48	0.03	1.16	0.22	bdl	bdl	bdl	bdl	99.91
	sd	0.1	–	–	–	0.1	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE324b	n = 6	66.65	0.14	2.29	2.91	1.01	0.74	5.45	17.57	0.58	0.05	1.05	0.19	0.54	0.76	bdl	0.01	99.94
	sd	0.1	–	–	0.1	–	–	–	0.2	–	–	–	–	0.1	0.1	–	–	
JE395	n = 9	67.44	0.21	2.31	0.85	1.81	1.06	5.19	19.22	0.34	0.04	1.30	0.18	bdl	bdl	bdl	bdl	99.93
	sd	0.1	–	–	–	0.1	–	0.1	0.1	–	–	–	–	–	–	–	–	
JE397	n = 10	67.62	0.05	3.03	0.28	0.03	0.49	8.49	17.81	0.87	0.06	0.90	0.35	bdl	bdl	bdl	bdl	99.97
	sd	0.2	–	0.1	–	–	–	0.3	0.1	–	–	–	–	–	–	–	–	
JE408	n = 10	65.49	0.31	2.63	1.11	1.75	1.04	5.18	20.46	0.35	0.04	1.33	0.24	0.01	bdl	bdl	bdl	99.93
	sd	0.3	–	0.1	0.1	0.2	–	0.1	0.1	–	–	–	–	–	–	–	–	

Abbreviations: b = blue, c = colourless; db = dark bands, lb = light bands; bdl = below detection limits; n = number of measurements; sd = standard deviation.

samples, FeO is below 1.5 wt%, while in blue and olive green samples, it shows the entire range of values. The highest FeO values are shown by the dark blue portions of the beakers JE18, 31, 127, 250 and 324, and the olive green glass of the beaker JE25bis, the window JE51bis and the block JE199.

FeO amounts are responsible for the final colour of naturally Fe-coloured, Fe-Mn coloured and high-Fe coloured glass (Table S4). Since the threshold limit used to identify natural MnO levels contents is set at 0.025 wt% [13–14], the classification as naturally Fe-coloured "fresh" glass is straightforward for samples JE94 and JE148 (with 0.02 wt% MnO) and probable for samples JE17 and 397 (with 0.03–0.04 wt% MnO).

In the Fe-Mn group, MnO levels range between 0.021 and 2.23 wt%. Manganese decolouring counteracts iron colouring action and a safe cut-off limit for manganese recycling and deliberate addition is not available.

Consequently, while naturally coloured glass should be surely "fresh" (unless we assume the recycling of an "equally fresh" glass), the other groups may hide the recycling of Mn-decoloured glass. In this regard, it is worth noting that although it is not unquestionably ascertained at which stage the manganese was introduced in the glass batch, the prevailing hypothesis is that it happened in the primary stage of production [15]. In any case, this shareable thesis does not exclude the recycling of Mn-decolourised cullets in secondary ateliers.

Further distinctions can be drawn based on Co, Cu, Sn, Sb and Pb amounts. Following Foster and Jackson [16], the levels of these colouring agents have been used as indicators of recycling and glass colouring. In this study, the threshold values for natural contribution from the sands have been set at below 50 ppm for Co, 100 ppm for Cu, 50 ppm for Sn, 65 ppm for Sb and 150 ppm for Pb. These values are derived from multiple studies performed on natural sands providing the following maxima: 50 ppm Co, 94 ppm Cu, 20 ppm Sn, 40 ppm Sb and 135 ppm Pb (values calculated in [17] from data provided by [11,18–24]).

Based on these cut-off limits and the assumption that manganese was added at the primary production step, 11 Fe-Mn coloured samples may be considered "fresh" while the remaining 19 are recycled.

In the high-Fe-coloured group, FeO levels ranging from 2.5 to 3.7 wt % should be intended as intentionally added or resulting from the recycling of a high-Fe glass. The maximum FeO value found in the HIMT reference group ([25]; *i.e.* the one richest in FeO) is 3.22 wt%. However, this high value has been measured in a single sample (sample # 32832), while in the others, FeO levels do not exceed 2.0 wt%. On the other hand, the average FeO content is 0.96 wt% (s.d. 1.66) in natron glass (database of 7188 samples from the literature) or 1.02 wt% (s.d. 1.62) if plant ash glass is included (database of 11,418 samples from the literature). Until the Egyptian sands and glass workshops are studied in detail, it is not possible to establish with certainty whether the FeO content in these samples is natural -indicating the use of particularly impure sands- or added -indicating a technological choice- or both (*e.g.*, mix of different sands/cullets).

Among the remaining coloured samples, blue and green glass is obtained by the deliberate addition of cobalt and/or copper. Since a few hundred ppm of cobalt are required to obtain a deep blue glass (0.006 CoO wt% in [26–27]) –even in the presence of high amounts of other colouring agents such as copper [28]– the 9 blue samples classified as artificially Co-coloured are tinted by the deliberate addition of cobalt. This group can be further divided based on the other chromophores: Co-Fe-Cu-Pb, with FeO $>$ 2 wt%; Co-Cu-Pb, with FeO $<$ 2 wt%; and Co-Sb with FeO $<$ 1 wt%. Such "mixed" compositions are relatively common in Roman and late Antique glass, during which blue glass can be characterised by high contents of iron, copper and other elements such as nickel, zinc, arsenic, tin and lead [29]. All these elements are associated with different sources from which cobalt can be extracted, concentrated and processed as the main product or recovered as a valuable by-product of the processing of other metals such as copper and silver (see, *e.g.*, [29–40]). Considering the numerous suitable sources and the possibility of further additions other than cobalt, it becomes difficult to establish which raw material was introduced in the glass batch unless glasses coloured with cobalt and copper were separately introduced. However, the high copper contents may also suggest that cobalt was recovered as a by-product of copper processing rather than from a primary cobalt source (*e.g.*, cobaltite, erythrite, asbolane). It should also be added that the nine samples of Co-coloured glass all have a CoO/NiO ratio between 4 and 20, *i.e.* compatible with their manufacturing period based on the ratios indicated in [29].

Moving on to Cu-coloured glass, it is interesting to observe that most samples are blue (Cu^{2+}), except for the green portion of sample JE129. In the blue samples, it is evident that Cu (evidently Cu^{2+}) was the only effective chromophore. Indeed, antimony formed Ca-antimonates in the JE40 sample. Overall, while the deliberate addition of intensely coloured cullets seems more reliable than primary colouring agents for JE24, 40 and 95, the addition of metal scraps could be appropriate for samples JE86 and 129 g.

The last three categories include decoloured glass. The most widespread type is represented by Mn-decoloured glass. This type of glass is common in Late Antique vessels and *tesserae* (esp. 4^{th}-7^{th} centuries AD) and typically shows MnO contents up to 2.4 wt% (av. 1.1 wt%, s.d. 0.63; see [41]). The reader is advised to note that even in this case, the classification as fresh glass presupposes the inclusion of manganese in the primary workshops.

Sb-decoloured glass is absent, while glass decoloured by manganese and antimony is scarcely represented. In the first group (Mn(/Sb)-dec.), antimony is present in concentrations so low as to be perhaps not effective, while in the second group (Sb/Mn-dec), it is perhaps the antimony to have played the major role. However, both types of glass are recognised as recycled products [42–43].

5. Discussion

5.1. Glass provenance

Glass provenance has been first assessed comparing the composition of Jesolo glass with the compositional range of thirty reference and compositional groups from the Levantine, Syrian and Egyptian areas (Table S5a-b). Following a distinction previously used for the provenance investigation of Apulian glass [44], the compositional groups that properly define the Egyptian HIMT glass (*i.e.* rich in iron, manganese and titanium) are labelled as "HIMT" and include six groups: HIMT *s.s.* [25], Foy's Group 1 [45], HIMT1 [16], HIMTa-b [46] and strong HIMT [47]. The compositional groups depleted in the same characterising elements but not so drastically to equal the low levels of Levantine products are labelled as "DIMT" (with D = depleted [44]). DIMT glass has been further distinguished into DIMT1, including Group 2.1 [45], weak HIMT [47], HLIMT [46] and CaO-rich HIMT [48], and DIMT2, including Group 3.2 [45] and HIMT2 [16]. For Group 3.2, the compositional values provided by [45,49,50] were separately considered. Regarding HIMT2, the inclusion in DIMT2 is motivated by its similarity to Group 3.2 but it is well known that it includes abundant recycled material. To clearly show the differences between the three macro-groups Levantine, HIMT and DIMT, the ternary diagram in Fig. 2 has been prepared, based on [51].

Summarising the results obtained in terms of compositional match (shown in Table S6), it is evident that some reference and compositional groups, such as the entire Egypt series, did not provide valuable comparison for Jesolo glass. Some samples are compatible with a single group; others, on the other hand, are comparable with several groups whose compositions are partly coincident and generally included in the same macro-group. Below, the results of the compositional comparison are discussed based on their attribution to the different reference macro-groups.

5.1.1. Levantine-Syrian macro-group

A small core of 12 samples can be assigned to this production area (JE17, 20, 40, 59, 72, 86, 89, 94, 95, 104, 148, 397; Fig. 3). The samples JE17, 89 and, to a lesser extent, JE95 are comparable to the 4^{th}-century glass from Jalame. Among these, the JE95 sample is a borderline case because it has characteristics compatible with the weak HIMT glass; however, the compositional similarity with the Levantine products is such as not to question the attribution of this goblet to Jalame-type glass.

The samples JE20 and 40 are compatible with the composition of both Jalame and Roman Mn glass. Conversely, the samples JE148 and 94 and, to a lesser extent, the samples JE104 and 86, are comparable to the 6^{th}-7^{th}-century glass from *Apollonia*.

Among these former nine samples, the compatibility with reference groups is confirmed even based on minor and trace elements (Fig. S3A, B). However, the presence of high amounts of colouring agents or recycling traces affects the provenance assignment of JE95, 40, 104 and 86, for which the indicated reference group should have, however,

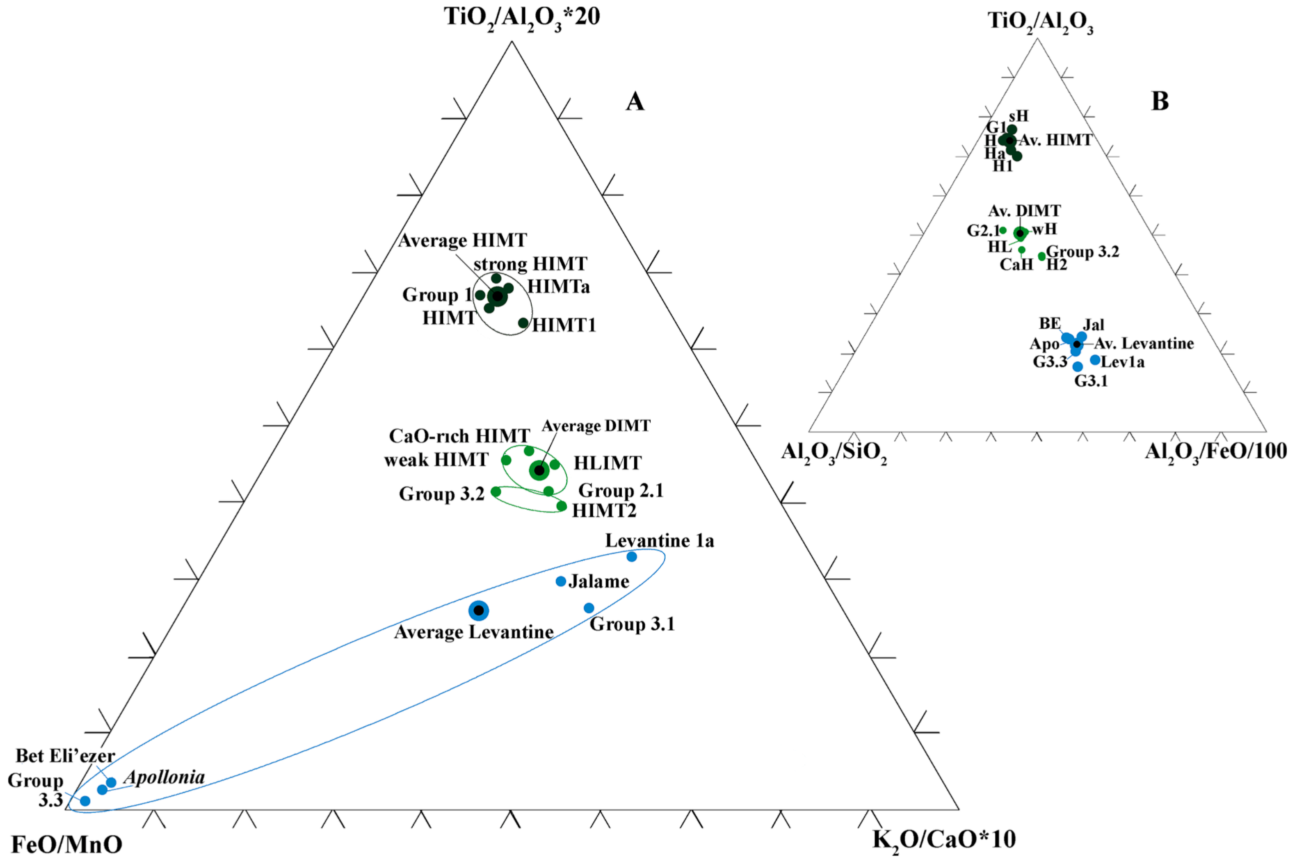

Fig. 2. The ternary diagrams visualise the distinction among Levantine (light blue), DIMT (green) and HIMT glass (dark green). These 3 broad macro-groups are clearly separated based on the TiO_2/Al_2O_3*20 - FeO-MnO - $K_2O/CaO*10$ (A) and TiO_2/Al_2O_3 – Al_2O_3/SiO_2 – $Al_2O_3/FeO/100$ ratios (see [51]). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

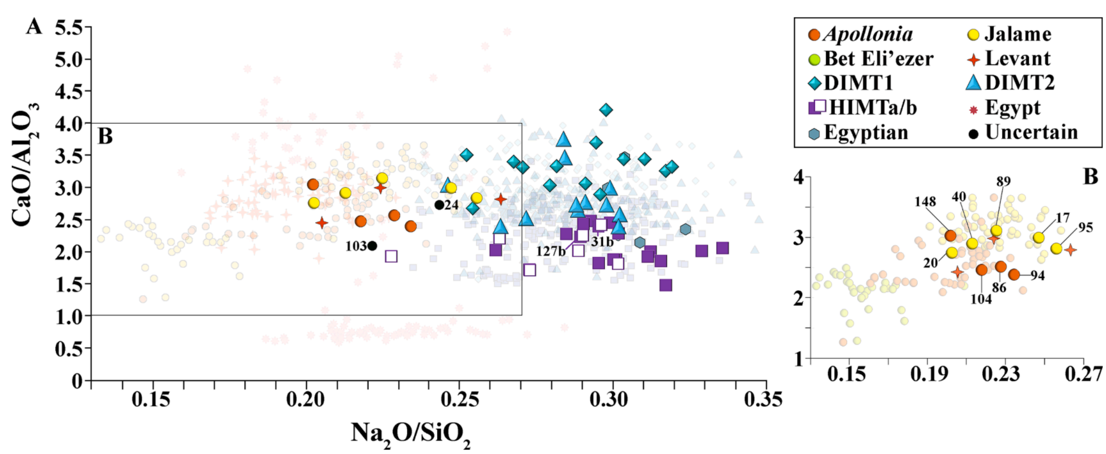

Fig. 3. The binary diagram Na_2O/SiO_2-CaO/Al_2O_3, significant for provenance assessment of Levantine glass (after [52]). A) The samples from Jesolo and the reference groups in background. The orange crosses indicate Jesolo finds generically attributed to the Levant. Samples marked "Egyptian" correspond to JE10, 11, 18b-c and 141. B) The area of distribution of Levantine products showing Jesolo glass assigned to *Apollonia* and Jalame reference groups. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

represented the base glass. In this respect, a representative example is provided by the sample JE86 which is compatible with the composition of *Apollonia* glass, except for high Cu, Sn, Pb amounts and MnO levels (0.04 wt%) slightly above the average value of the reference group. In this case -as well as for the other three samples, a significant addition of colourants to an *Apollonia*/Jalame glass seems more reliable than indicating a different provenance.

A similar problem also occurs for the last three samples (JE397, 59 and 72) which can however be assigned to the Levantine area. These samples cannot be reliably assigned to a specific compositional group, except for the sample JE59 shows consistent compositional similarities with the 8th-century Syrian group al-Raqqa type 3 (the dating would be compatible). The sample JE397 shows Na_2O contents (17.8 wt%) slightly higher than those of Jalame glass (max. 17.7 wt%) and a consistent similarity with the Dor glass (excluding TiO_2 lower amounts [53]). For the block JE72, both assignments to the Levantine or Syrian areas remain open (although dating suggests the Levant more reliable rather than al-Raqqa). It is also worth noting that the high K_2O contents measured in this block are similarly found in the Syrian group al-Raqqa type 4. This observation would therefore seem to support a Syrian provenance but it must be considered that potassium also represents an indicator of the intensity of recycling [54]. In this latter case, high K_2O contents support the classification of this block as a ("raw") material produced by multiple recycling rather than giving information on its provenance.

Minor and trace elements patterns of these three samples (Fig. S4C) fall within the range of the Jalame, *Apollonia* and al-Raqqa type 3 groups, thus proving ineffective in refining the assignment further.

5.1.2. HIMT macro-group

Before discussing the assignments, it is important to specify that the Egyptian provenance of the HIMT glass is supported by the compositional correspondence with the (few) Egyptian sands studied so far [56]. The location of the Egyptian workshops is not ascertained but two different areas were indicated as the most likely: Nilotic delta and North Sinai (*e.g.*, Ostracena, Pelusium [56]). However, we still do not know what was produced where, pending the characterisation of geographically and chronologically contextualised specimens.

A large group of 22 samples can be assigned to the Egyptian-HIMT macro-group (JE14, 25bis, 26, 31b, 31c, 51, 51bis, 64, 78, 80, 90bis, 127c, 127b, 129c, 129 g, 134, 199, 229, 250b, 250 g, 395, 408). Although they fall into different groups or combinations of groups, their assignment to the HIMT glass is straightforward in terms of major, minor and trace elements contents. The green portion of the beaker JE129g does not show a consistent correspondence with any of the compositional groups but the best match is found with HIMT glass.

Overall, this wide and numerous HIMT macro-group can be further distinguished between HIMTa and HIMTb, mainly based on FeO-TiO_2 ratio (Fig. 4).

All samples are classified as HIMTa if one considers the limits of HIMTb, as defined by the materials analysed by [46]. Conversely, using the threshold of 5.4 for the Fe_2O_3 to TiO_2 ratio proposed by [57], the samples JE25bis, 31b, 51bis, 78, 90bis, 127b and 199 are classified as HIMTb. However, the assignment of JE31b and 127b does not appear convincing since the increase in iron content is due to the addition of cobalt (and TiO_2 levels are very low). Moreover, their trace element pattern show much lower values than those of HIMTb glass (Fig. S4C). Therefore, these two samples have been indicated as HIMTa/b in all diagrams but the assignment to the HIMTa glass made for the colourless portions is preferable for the blue-coloured spots too. To conclude the observations deductible on the basis of major elements contents, it is also worth noting that the low Na_2O values of JE25bis are at the limit of the compositional group but similar to those of VS072 from Ciudad de Vascos [58], probably attributed to HIMTb.

The patterns of HIMTa samples' minor and trace elements delineate a further subdivision (Fig. S4). All samples fall within the broad compositional range of the HIMT glass but a small core of three samples (JE31c, 80 and 395; black lines in Fig. S4A) shows depleted REE patterns, falling within the compositional range of DIMT or even Jalame and *Apollonia* glass. In the literature, a limited number of HIMT specimens share a

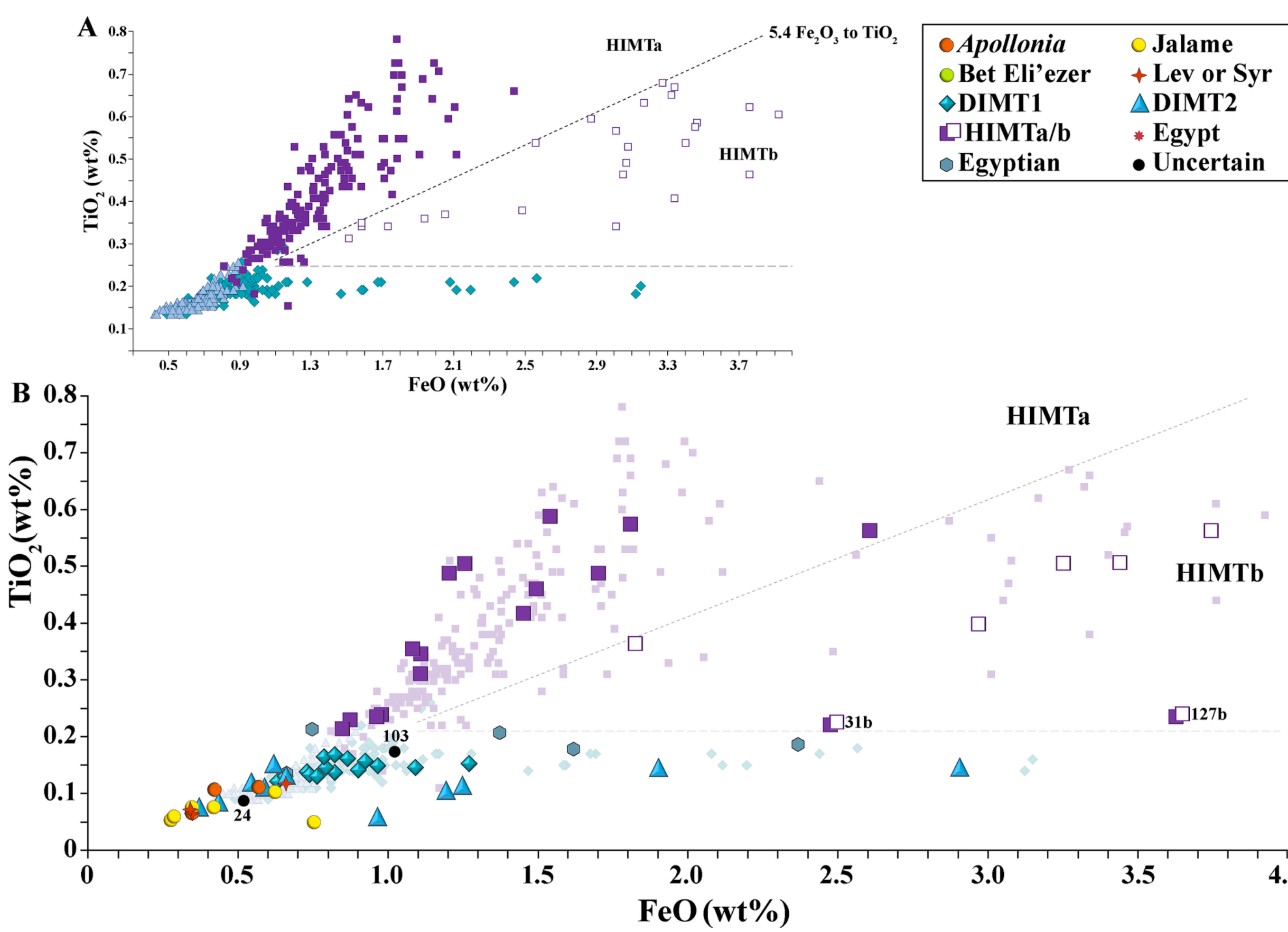

Fig. 4. Binary diagrams significant for provenance assessment and HIMTa/b distinction: FeO-TiO_2. A) The distribution of the Egyptian reference groups used for comparison. B) The samples from Jesolo and the reference groups in background. Samples marked "Egyptian" correspond to JE10, 11, 18b-c and 141.

similar composition in terms of major, minor and trace elements: no. 6919–12 K from London - Billingsgate Bath House (HIMTa in [59]); OU2_1 from Oudenburg (HIMT in [60]), PSAL 046 from *Portus Ilicitanus* (HIMTa in [57]) and SA07 from Salapia (HIMTa in [44]). In all comparable cases, the HIMT nature of the specimens is not doubted but the possibility that this REEs depletion is due to different sand or recycling with Levantine glass -even in those cases where it is not apparent- should be considered.

5.1.3. DIMT macro-group

Reference and compositional groups labelled as DIMT are considered of Egyptian origin based on their compositional similarity with HIMT glass. However, the abundance of recycled materials suggests considering only some fresh materials as representative of primary groups (see, *e.g.*, [61] on Group 3.2). Hafnium isotopes analyses performed by [62] have allowed to trace the Egyptian origin of two samples which can be assigned to the Group 2.1 high-Fe (J15-Of-27–1 S1) and, with more caution, to the Group Foy 2.1 (no. J14-Kg-3D-411), based on major and minor components. At the moment, however, these two analyses are surely informative but scarcely representative with respect to the abundance of the whole Group Foy 2.1, *i.e.* one of the compositional groups most represented from the Late Antiquity, inside which it is difficult to identify fragments of fresh glass.

The most convincing evidence for an Egyptian origin comes from the compositional comparison with HIMT glass based on the analysis of major, minor and trace components but certainly does not exclude that a single compositional group may correspond to more than one workshop or that the same workshop/area may have produced different glass corresponding to more than a single reference group.

Among Jesolo glass, eleven (/fourteen) samples are assigned to DIMT1 (Foy 2.1, weak HIMT, HLIMT and CaO-rich HIMT) and seven (/thirteen) samples are assigned to DIMT2 (Foy 3.2, HIMT2). The distinction was made on the basis of all the elements and is highlighted here by the diagrams in Fig. 5.

Within DIMT1, all samples are comparable to the Group 2.1. As can be seen in Table S6, the assignment considered the compositional range provided by [45] and the average (±2sd) provided in [50], separately. In this regard, it is worth observing that only three samples perfectly fit in the Group 2.1 established by [45] even if the samples bearing traces of recycling are omitted from the calculation of the compositional range (JE7, 62, 149). The same considerations cannot be made concerning the values provided by [50] since the samples used for calculating the average are not specified (and the standard deviations are very large).

However, to create a confidence scale within the assignments, the samples JE7, 62 and 149 reach the highest level, followed by JE61, 78bis, 90, 110 and 225 and by JE9, 50 and 51ter. Nevertheless, it is worth noting that the minor and trace elements pattern of sample JE110 shows Zr and Hf values even lower than those measured in DIMT2 and Levantine glass, thus weakening its assignment to this group (Fig. S5). For the last three samples, the assignment is more uncertain. The base

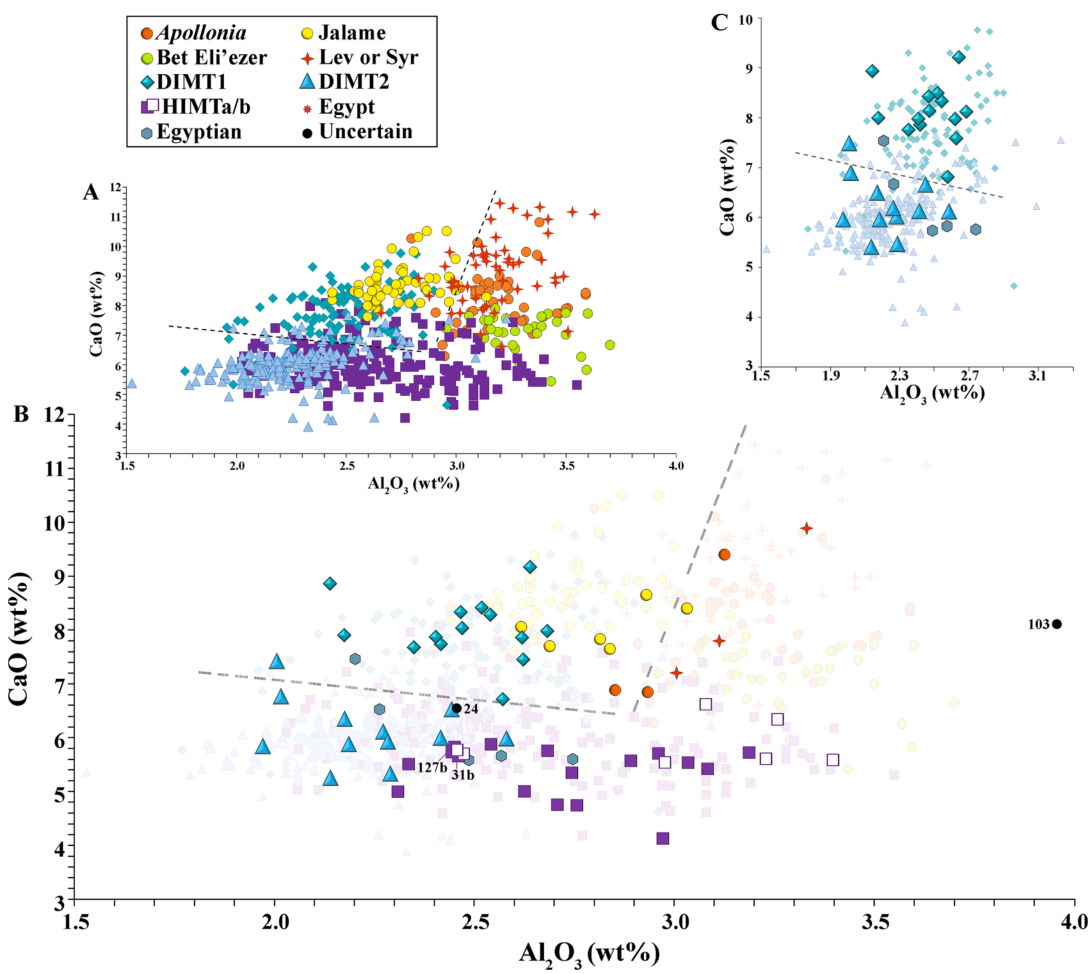

Fig. 5. Binary diagrams significant for provenance assessment: Al_2O_3-CaO. A) The distribution of the reference groups used for comparison. B) The samples from Jesolo and the reference groups in background. The orange crosses indicate Jesolo finds assigned to the Levantine-Syrian area. Samples marked "Egyptian" correspond to JE10, 11, 18b-c and 141. C) DIMT1 and DIMT2 distribution areas. Only Jesolo samples assigned to these two macro-groups are shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

glass of JE22, 79 and 83 is of type 2.1 but some parameters seem more compatible with other groups. For example, the sample JE79 could be distinguished based on relatively higher SiO_2 and lower CaO levels, characteristic of HIMT2. Similarly, JE22 shows Al_2O_3-SiO_2 and MgO-K_2O ratios compatible with both Group 2.1 and 3.2. Moreover, it is interesting to note that MgO contents of samples JE22 and 83 (as well as those of JE50, 78bis and 110) are relatively lower than those typically found in Group 2.1 glass while compatible with Group 3.2 glass composition.

The differences noted above result in various possible assignments, which often indicate recycling. This seems to be the case of this group which includes only recycled materials that can still be associated with the Egyptian area based on their compositional signature. Despite MnO amounts varying between 1.14 and 1.79 wt% and Sb levels ranging between 74 and 624 ppm, none of these samples can be assigned to the Roman Mn-Sb compositional group as to the Mn-Sb technological group. The difference is that while the former results from mixing Roman Mn with Roman Sb, the latter only considers the absolute contents of manganese and antimony regardless of the possible attribution to the compositional groups mentioned above. On the other hand, the high Sb contents characterising the Roman Sb primary group further support the recycled nature of this group of samples.

As regards DIMT2, the compatibility with the compositional ranges provided by the various authors for Group 3.2 has been verified (Table S6). Applying the distinction introduced by [49], all 7 samples falling within the compositional range of this group (JE10bis, 25, 47, 49c-b, 87, 324c) can be classified as “low Sr” or “main group” (Fig. 6).

As for the level of reliability of the various assignments, the JE49c and 87 samples are certain assignments, followed by JE25 and 324c. The remaning three samples are similarly assigned to the Group 3.2 although showing some notable anomalies such as the high iron contents of JE47 and 49b (*i.e.* the blue portion of JE49c) and the low TiO_2/Al_2O_3 ratio of JE10bis. For this latter sample, while a classification as Roman Mn-Sb glass proved incompatible based on several major and minor elements contents, the mixture with a Roman Sb glass may seem reliable. Overall, the samples assigned to Group 3.2 define a more homogeneous subgroup than DIMT1 and the anomalies observed in the samples JE10bis, 47 and 49b can be easily explained by the addition/recycling of “foreign” components such as antimony, cobalt and copper.

Straightforward assignment of an additional six samples (JE108, 109, 141, 162c, 324b, 162b) to Group 3.2 is hampered by the presence of significant compositional anomalies that can be either explained by the mixing of different glasses or by the the addition of de/colouring agents. In detail, while the majority of the characterising features are compatible with the Group 3.2, the Al_2O_3/SiO_2 ratio and the Al_2O_3 contents in JE109 and 162c, the CaO/Sr and TiO_2/Al_2O_3 ratios in JE108 and JE141 and the trace element pattern of JE108 and JE162c are typical of Group 2.1. For these 3 samples, therefore, the assignment is to the DIMT2 macro-group -which remains the most convincing- rather than to a single reference group.

Lastly, the blue portions of the beakers JE162 and 324 show particularly high iron levels, reaching the typical values of Group 2.1 high Fe. Moreover, zirconium contents are slightly higher and, in JE162b, the Al_2O_3/SiO_2 ratio also falls within the Group 2.1 compositional range (due to relatively higher contents of Al_2O_3). In this case, therefore, not all the differences can be clearly explained by the addition of colouring agents and the attribution to DIMT2 - suggested by the colourless portion - remains uncertain, especially concerning JE162b.

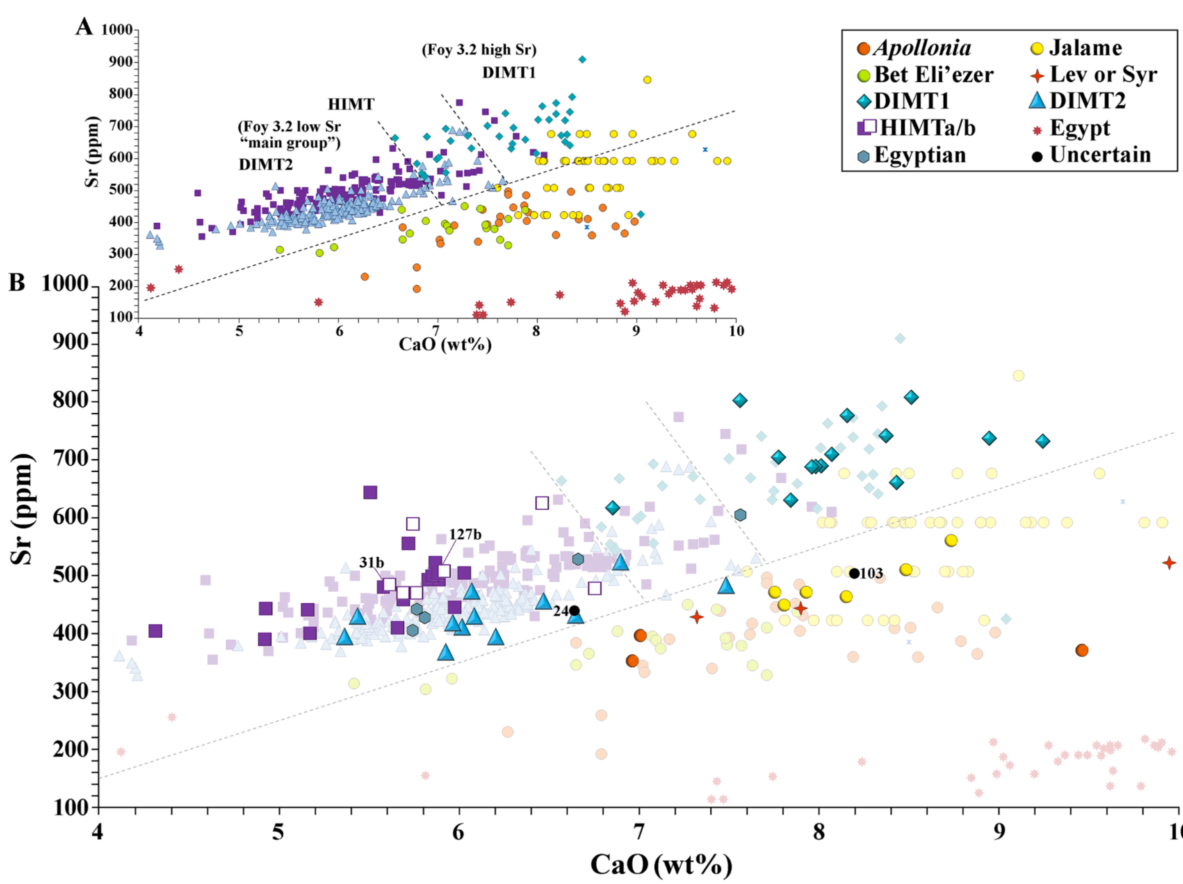

Fig. 6. Binary diagrams significant for provenance assessment: CaO-Sr. A) The distribution of the reference groups used for comparison. B) The samples from Jesolo and the reference groups in background. Samples marked “Egyptian” correspond to JE10, 11, 18b-c and 141. The separation lines for DIMT1 and DIMT2 leave an intermediate space where both groups plot. Furthermore, it should be noted that, in this diagram, the diffusion area of group 2.1 coincides with that of group 3.2 “high Sr”, casting some doubts on the consistency of the latter variant.

5.1.4. Unassigned samples

The last six samples left to be discussed were probably produced starting from materials of different origins. The samples JE10, 11 and 18c-b shows characteristics of both HIMT and, more consistently, of DIMT1 glass (JE18c also of DIMT2); JE103 shows characteristics of both Levantine (Roman Mn) and Egyptian glass (DIMT1); and, lastly, JE24 is a Roman Mn-Sb glass mixed with a coloured glass. Therefore, while an Egyptian area of origin may be hypothesised for JE10, 11 and 18c-b, the provenance issue remains open for JE103 and 24. These two samples also show an enriched and a rather depleted minor and trace element pattern, respectively (Fig. S5).

6. Conclusions

The collection of sixty-seven glass samples from Jesolo represents a rather heterogeneous natron-based glass repertoire in colours and provenances (Table 3). The incidence of Levantine products is rather low compared to the preponderant role played by Egyptian products. The numerical values supporting this statement are 12 finds (=18 %) from the Levant and 53 (=82 %) from Egypt (22 HIMT, 27 DIMT and 4 DIMT/HIMT).

As for Levantine glass, the 6 samples classified as Jalame-type and Roman Mn are typologically heterogeneous (one base on multiple filament, one beaker, one goblet, one base and two *tesserae*). Only one Mn-decoloured fragment (JE20) is classified as fresh glass but two other coloured glasses could be considered naturally Fe-coloured if a slightly higher MnO cut-off limit (0.03–0.04 wt%) is accepted. The two *tesserae* and the goblet appear recycled; however, only the *tessera* JE89 has evidence that can safely track recycling. Glass dating spans from the 4th to the 6th century and it is perhaps interesting to note that the only sample datable to a much later period (9th-12th) is the recycled and Co-coloured *tessera* JE89. *Apollonia*-type glass is less represented than that of Jalame. Three out of four samples are taken from aqua blue goblets (two fresh and one recycled) dated back to the 5th and 5th-6th centuries -*i.e.* prior to or approximately contemporary with the activity of *Apollonia* furnaces (6th-7th century CE)- and the turquoise blue *tessera* JE86 is dated to the 9th-12th centuries.

Glass of Levantine or Syrian provenance includes an aqua blue cup and an aqua blue block. The identification of Syrian glass is problematic and further complicated by the fact that compatible samples are recycled and one of them has higher MgO levels than those accepted for natron glass. Moreover, while the dating of JE59 would be compatible with that of the 8th century al-Raqqa glass, that of JE72 proved unreliable being two centuries earlier. However, it should be noted that the fragment comes from a rather disturbed phase of spoliation. Therefore, it cannot be ruled out that it was mistakenly attributed to an earlier phase than the real one.

Compared to the overall picture available for the northern Adriatic area (*i.e.* Aquileia, Classe, Ravenna and Comacchio) between the 4th and 7th centuries, these findings are in line with the lower influx of Levant glass compared to Egyptian products. The presence of raw glass (block JE72) between this core of materials is particularly interesting because it testifies to the arrival of non-shaped Levantine materials. It is even more interesting to note that the block appears to be produced from glass recycling rather than raw materials. This aspect is further supported by the analysis of the block JE103 whose recycling intensity does not allow to recognise any preferential compositional signature despite a greater similarity with Levantine glass.

As for Egyptian glass, HIMT glass is the most abundant group and, considering that it is the most attested along the western Adriatic coast (personal data), it is not surprising that as much as 33 % of the entire Jesolo repertoire can be associated with this production. HIMT products include colourless, green and dark blue glass. Decolouration was obtained by manganese while glass colouring was due to iron or copper for green and cobalt for blue. Typologically, HIMT glass is mainly represented by beakers but bases on multiple filaments, windows and (2) blocks are also present. From a typological standpoint, it is worth noting that contrary to the bases on multiple filaments, beakers and blocks -also present in Levantine glass- the windows are made only with HIMTa/b and DIMT1/2 glass.

The blocks are both assigned to the compositional group HIMTb, *i.e.* a lesser testified HIMT variant whose products have been found in Bulgaria (Dichin), Egypt (Bubastis, north Sinai, Tebtynis), France (Gémenos - Saint-Jean-de-Garquier, Marseille - Bourse), Greece (Thessaloniki), Italy (Aquileia, Aiano-Torraccia, Brescia, Carvico, Classe, Cosenza, Fumolo-Grado, Milano, Napoli, Padova, Pedemure San Biagio, San Genesio, San Giusto, Siena, Torcello), Jordan (Petra), Slovenia (Korinjski hrib), Turkey (Sagalassos), Spain (Ciudad de Vascos, Portus Ilicitanus), Tunisia (Carthage, Nabeul), perhaps United Kingdom (Temple of Sulis Minerva) and even in shipwreck's cargoes such as the shipwreck Redoute Béar (Port-Vendres). Therefore, the distribution of HIMTb glass reaches the entire Mediterranean up to internal Europe and perhaps the United Kingdom. However, according to the available information, its abundance in Italian sites is higher than in other countries. In this regard, it may also be interesting to note that its trade (quantitatively) involved, above all, the northern Adriatic coast.

Overall, DIMT glass is quantitatively testified like HIMT glass but the percentages decrease considering the frequency of the single groups. DIMT1 glass includes six goblets, two lamps, four windows, one base on multiple trails and one beaker, all made with recycled glass. The samples are coloured by iron and cover the entire chronological range from the 5th to the 12th century, although most of them are dated between the 5th and the 7th centuries. Including samples of uncertain attribution, DIMT2 glass includes four beakers, one lamp, three walls, two cups (?), one window and one *tessera*. Numerous samples are decoloured by Mn or, to a lesser extent, through the combination of manganese and antimony. The colours are due to the iron naturally present in the sand or added cobalt. Unlike DIMT1, DIMT2 mostly includes fresh glass (or presumed to be so).

From a technological point of view, in addition to the considerations made for the raw glass blocks, it is worth noting that Sb-decoloured glass is missing. This lack appears somewhat in contrast to the abundance of Egyptian products but can perhaps be explained on a chronological basis. The Roman Sb group mainly includes 3rd-century materials, although attested from the 1st to the 4th century. Considering that Jesolo glass is dated from the 5th century, Roman Sb glass may no longer be available on the market but used for recycling.

Changing the observation point from technology to chronology, the evolution that is possible to grasp at Jesolo appears significant, especially concerning recycling and the overwhelming dominance of Egyptian products in all the explored periods.

Among the twelve coloured finds dated between the 4th and 5th centuries, the percentage of fresh and recycled/added glass is similar if the Fe-Mn type is considered primary otherwise, only one sample can be considered fresh. Colourless glass is mainly Mn-decoloured (3 samples) but also Sb/Mn-decoloured (1 sample). Provenance investigation has identified four samples as Levantine/Syrian products, seven Egyptian HIMTa and five DIMT.

Among the nineteen coloured finds dated between the 5th and 6th centuries, the percentage of (presumably) fresh glass is still similar to that of recycled/added glass. The two naturally Fe-coloured samples from the Levant belong to this period where HIMTb glass with high-Fe also appears. Several beakers made with Mn-decoloured glass and decorated with a cobalt-coloured blue drop are also dated to this period. Among the seven colourless finds, five were Mn-decoloured, while the combination of manganese and antimony (recycling) was used for two colourless windows. The provenance survey divided the materials as follows: 4 Levantine-type glass, 7 HIMTa, 1 HIMTb, 5 DIMT1, 5 DIMT2 and 2 of uncertain provenance.

Among the thirteen samples dated between the 6th and the 7th centuries, only three samples could be classified as fresh. Colourless glass includes 1 Mn-decoloured sample and one of the Sb-Mn type and

Table 3
Summary table of the results obtained.

Sample no.	Shape	Cent.	Colour	Colour classification	F/R/A[†]	Provenance investigation Major elements contents	Provenance investigation Minor and trace elements contents	Provenance area	Correspondence
JE17	Fil	6	GY	Nat.? Fe-col.	F?	Jalame	Jalame-*Apollonia*	Levant	Jalame
JE89	Tes	9–12	cB	Co-Sb (↑Mn,Cu, Pb)	R	Jalame	Jalame-*Apollonia*	Levant	Jalame
JE95	Gob	6–7	laB	Cu-Fe-Sb-Pb (↑Mn,Sn)	R?	Jalame, wH	Jalame-*Apollonia*	Levant	Jalame (base glass)
JE40	Tes	4–5	tB	Cu-Fe-Sb (↑Mn, Pb)	A	Jalame, Roman Mn	Jalame-*Apollonia*	Levant	Jalame (/Roman Mn) (base glass)
JE20	Bas	5–6	CsG	Mn-dec.	F	Jalame, Roman Mn	Jalame-*Apollonia*	Levant	Jalame-Rom Mn
JE148	Gob	5–6	aB	Nat. Fe-col	F	*Apollonia*	Jalame-*Apollonia*	Levant	*Apollonia*
JE94	Gob	6–7	aB	Nat. Fe-col	F	*Apollonia*, Jalame	Jalame-*Apollonia*	Levant	*Apollonia*
JE104	Gob	5	aB	Fe-Mn (↑Cu,Sn, Pb)	R	*Apollonia*, Bet Eli'ezer, Roman Mn	Jalame-*Apollonia*	Levant	*Apollonia* (base glass)
JE86	Tes	9–12	tB	Cu-sn-Pb (↑Mn)	A/R?	*Apollonia*, Jalame, Raqqa 3	Lev(/DIMT)	Levant	Apollonia (base glass)
JE397	Bek	5	lG	Nat.? Fe-col.	F?	Jalame, *Apollonia* [~Dor]	Jalame-*Apollonia*	Levant	–
JE72[#]	Blo	5–6	aB	Fe-Mn-Pb (↑Cu, Sn,Sb)	R	*Apollonia*, Jalame, Raqqa 3	DIMT(/Lev)	Levant (including Syria)	–
JE59	Cup?	9–12	laB	Fe-Mn (↑Pb)	R	Raqqa 3, Jalame, *Apollonia*	Lev	Levant (including Syria)	–
JE14	Win	6	lG	Fe-Mn	F?	HIMT1	HIMTa	Egypt - HIMT	HIMTa
JE26	Bek/Cup	9–12	YG	Fe-Mn	F?	G1, sH, HIMT1, HIMTa	HIMTa	Egypt - HIMT	HIMTa
JE31c	Bek	6	C	Mn-dec.	F	HIMT1, wH	HIMTa(/Levant)	Egypt - HIMT	HIMTa
JE134	Bek	5	Gr	Fe-Mn	F?	G1, sH, HIMT1, HIMTa	HIMTa	Egypt - HIMT	HIMTa
JE229	Win	6	lG	Fe-Mn	F?	G1, sH, HIMT1, HIMTa	HIMTa	Egypt - HIMT	HIMTa
JE408	Fil	5	Gr	Fe-Mn	F?	G1, HIMT1	HIMTa	Egypt - HIMT	HIMTa
JE395	Bek	5	lYG	Fe-Mn	F?	HIMT1	HIMTa(/Levant)	Egypt - HIMT	HIMTa
JE80	Fil	9–12	Gr	Fe-Mn	F?	HIMT1, weak H	HIMTa(/Levant)	Egypt - HIMT	HIMTa
JE51	Win	5–6	lG	Fe-Mn	F?	HIMT1	HIMTa	Egypt - HIMT	HIMTa
JE250g	Bek	6	lG	Fe-Mn	F?	HIMT1	HIMTa	Egypt - HIMT	HIMTa
JE64	Bek	9–12	oG	Fe-Mn (↑Cu,Sn, Pb)	R	G1, HIMT1, HIMTa	HIMTa	Egypt - HIMT	HIMTa
JE129c	Bek	5	C	Mn-dec.	F	Group 1	HIMTa	Egypt - HIMT	HIMTa
JE127c	Bek	5	C	Mn-dec.	F	HIMT1, wH	HIMTa	Egypt - HIMT	HIMTa
JE250b	Bek	6	dB	Co-Fe-Cu-Pb (↑Mn,Sn)	A/R?	G1, sH	HIMTa	Egypt - HIMT	HIMTa
JE129g	Bek	5	Gr	Cu-Pb (↑Mn,Sn)	A/R?	(HIMT)	HIMT	Egypt - HIMT	HIMTa
JE31b	Bek	6	dB	Co-Fe-Cu-Pb (↑Mn,Sn)	A/R?	HIMTb	HIMTa	Egypt - HIMT	HIMTa*(b)
JE127b	Bek	5	dB	Co-Fe-Cu-Pb (↑Mn,Sn)	A/R?	HIMTb	HIMTa	Egypt - HIMT	HIMTa*(b)
JE25bis	Bek	5–6	oG	HFe(/Mn)	A/R?	HIMTb	HIMTb (/a)	Egypt - HIMT	HIMTb
JE51bis	Win	9–12	oG	HFe(/Mn)	A/R?	G1, HIMTb	HIMTb (/a)	Egypt - HIMT	HIMTb
JE78	Bek/Cup	9–12	dG	Fe-Mn (↑Cu,Pb)	R	HIMT1, HIMTa-b	HIMTb (/a)	Egypt - HIMT	HIMTb
JE90bis	Blo	9–12	oG	HFe(/Mn, ↑Cu, Pb)	A-R	G1, HIMTb	HIMTb (/a)	Egypt - HIMT	HIMTb
JE199	Blo	6–7	doG	HFe(/Mn, ↑Cu, Pb)	A-R	HIMTb	HIMTb (/a)	Egypt - HIMT	HIMTb
JE62	Bek	9–12	lY	Fe-Mn (↑Sb)	R	G2.1*, G2.1**, wH, HLIMT,CaH	DIMT1	Egypt - DIMT1	Foy 2.1
JE7	Win	7	Y	Fe-Mn (↑Sb,Pb)	R	G2.1*, G2.1**, wH, HLIMT, CaH, HIMT1	DIMT1	Egypt - DIMT1	Foy 2.1
JE149	Gob	5–6	GY	Fe-Mn (↑Sb,Pb)	R	G2.1*, G2.1**, wH, HLIMT, CaH	DIMT1	Egypt - DIMT1	Foy 2.1
JE225	Gob	5	Y	Fe-Mn (↑Sb,Pb)	R	G2.1*, G2.1**, wH, HLIMT, CaH	DIMT1	Egypt - DIMT1	Foy 2.1
JE90	Lam	6–7	lY	Fe-Mn (↑Sb)	R	G2.1*, G2.1**, wH, CaH	DIMT1 - HIMT	Egypt - DIMT1	Foy 2.1
JE110	Gob	5	lG	Fe-Mn (↑Sb)	R	G2.1*, G2.1**, wH, HLIMT, CaH	DIMT2 (/Levant)	Egypt - DIMT1	Foy 2.1
JE61	Gob	5–6	dY	Fe-Mn (↑Sb)	R		DIMT1	Egypt - DIMT1	Foy 2.1

(*continued on next page*)

Table 3 (*continued*)

Sample no.	Shape	Cent.	Colour	Colour classification	F/R/A†	Provenance investigation Major elements contents	Provenance investigation Minor and trace elements contents	Provenance area	Correspondence
						G2.1*, G2.1**, wH, HLIMT, CaH, HIMT1			
JE78bis	Win	6–7	lYG	Fe-Mn (↑Sb,Pb)	R	G2.1*, G2.1**, wH, HLIMT, CaH	DIMT1 - HIMT	Egypt - DIMT1	Foy 2.1
JE51ter	Fil	5–6	loG	Fe-Mn (↑Sb,Pb)	R	G2.1*, G2.1**, CaH	DIMT1 - HIMT	Egypt - DIMT1	Foy 2.1
JE9	Win	7	C	Mn(/Sb)-dec. (↑Pb)	R	G2.1*, G2.1**, HLIMT	DIMT1	Egypt - DIMT1	Foy 2.1
JE50	Win	5–6	C	Mn(/Sb)-dec. (↑Pb)	R	G2.1*, HLIMT, G3.2***	DIMT1 (/HIMT)	Egypt - DIMT1	Foy 2.1
JE79	Gob	6–7	lY	Fe-Mn (↑Sb)	R	G2.1**, wH, HIMT2	DIMT1	Egypt – DIMT(1?)	Foy 2.1 (base glass)
JE22	Lam	5–6	lY	Fe-Mn (↑Pb)	R	G2.1**, wH, HLIMT, CaH	DIMT1	Egypt – DIMT(1?)	Foy 2.1 (base glass)
JE83	Gob	6–7	Y	Fe-Mn (↑Sb)	R	G2.1**, wH, CaH	DIMT1 (/HIMT)	Egypt – DIMT(1?)	Foy 2.1 (base glass)
JE49c	Bek	5–6	C	Mn-dec.	F	G3.2*, HIMT2	DIMT2 (/Levant)	Egypt – DIMT2	Foy 3.2 low Sr
JE87	Lam	9–12	C	Mn-dec.	F	G3.2*, G3.2**	DIMT2 (/Levant)	Egypt – DIMT2	Foy 3.2 low Sr
JE25	Cup?	9–12	C	Mn-dec.	F	G3.2*, G3.2**, HIMT2, wH, CaH	DIMT2 (/Levant)	Egypt – DIMT2	Foy 3.2 low Sr
JE324c	Bek	5–6	C	Mn-dec.	F	G3.2*, G3.2**, HIMT2, wH	DIMT2 (/Levant)	Egypt – DIMT2	Foy 3.2 low Sr
JE47	Tes	9–12	Gy	Fe-Mn (↑Sb)	R	G3.2*** (high Fe)	DIMT2 (/Levant)	Egypt – DIMT2	Foy 3.2 low Sr (base glass)
JE49b	Wal	5–6	dB	Co-Cu-Pb (↑Mn, Sn,Sb)	A/R?	HIMT1 (DIMT2 high Fe)	DIMT2 (/Levant)	Egypt – DIMT2	Foy 3.2 low Sr (base glass)
JE10bis	Win	6	C	Sb/Mn-dec.	R	(DIMT2)	DIMT2 (/Levant)	Egypt – DIMT2	Foy 3.2 low Sr (base glass)
JE109	Cup?	5	C	Mn-dec.	F	G3.2***, HIMT2, wH	DIMT2 (/Levant)	Egypt – DIMT2	(Foy 3.2 + G2.1?)
JE162c	Bek	6–7	C	Mn-dec.	F	G3.2***, HIMT2	DIMT2 (/Levant)	Egypt – DIMT2	(Foy 3.2 + G2.1?)
JE141	Lam	5	lG	Fe-Mn	F?	G2.1**, wH, CaH, G3.2**, G3.2***, HIMT2	DIMT1/2	Egypt – DIMT2	(Foy 3.2 + G2.1?)
JE108	Bek/Cup	5	C	Sb/Mn-dec. (↑Pb)	R	G3.2**, G3.2***	DIMT2 (/Levant)	Egypt – DIMT2	(Foy 3.2 + G2.1/RomSb?)
JE324b	Bek	5–6	dB	Co-Fe-Cu-Pb (↑Mn,Sn)	A/R?	(DIMT1-HIMT)	DIMT1/2	Egypt – DIMT2?*	(Foy 3.2 + G2.1/colouring agents?)
JE162b	Bek	6–7	dB	Co-Cu-Pb (↑Mn)	A/R?	HIMT1 (DIMT1 high Fe)	DIMT1/2	Egypt – DIMT2?*	(Foy 3.2 + G2.1/colouring agents?)
JE10	Bek	7	GB	Fe-Mn	F?	HIMT1 (DIMT1)	DIMT1-HIMT	Egypt-DIMT1/HIMT	Mixed?
JE11	Bek/Cup	7	dB	Co-Cu-Pb (↑Mn, Sb)	A/R?	(DIMT1, HIMT)	DIMT1-HIMT	Egypt-DIMT1/HIMT	Mixed?
JE18c	Bek	5–6	CsY	Mn-dec.	F	HIMT2 (DIMT1)	DIMT1/2	Egypt-DIMT1/HIMT	Mixed?
JE18b	Bek	5–6	dB	Co-Fe-Cu-Pb (↑Mn,Sn)	A/R?	(HIMT-DIMT)	DIMT1	Egypt-DIMT1/HIMT	Mixed?
JE103	Blo	5	aB	Fe-Mn-Pb (↑Cu, Sn,Sb)	R	(Roman Mn, DIMT1)	DIMT1 (/Levant)	Levant-Egypt (DIMT1)	Mixed?
JE24	Tes	9–12	GyB	Cu-Sb (↑Mn,Sn, Pb)	R?	Roman Mn-Sb	DIMT2 (/Levant)	Levant-Egypt (DIMT2)	Mixed?

†This column reports the results shown in the column “Fresh/Rec.” of Table S4, based on the amounts of FeO, MnO, Co, Cu, Sn, Sb and Pb. However, when the provenance assignment suggests the blending of multiple types of glass, the possibility of recycling becomes implied even if the sample is marked otherwise. # characterised by MgO or K2O values above the limits of the natron field. ° by association with colourless glass. Abbreviations: a = aqua; B = blue;Bas = Base; Bek = Beaker; Blo = Block; C = Colourless; Cs = colourless slightly; d = dark; F = fresh; Fil = filament; G = group; Gob = goblet; Gr = green; l = light; Lam = Lamp; Lev = Levantine; oG = olive green; R = Recycled; t = turquoise; Tes = tessera; wal = wall; Win = window; Y = yellow. Groups abbreviations: G1, G2.1* and G3.2* by Foy et al. (2003); G2.1** and G3.2** by Schibille (2022); G3.2*** by Cholakova and Rehren (2018); Raq = al-Raqqa”; H1 = HIMT1; H2 = HIMT2; Ha = HIMTa; Hb = HIMTb; HL = HLIMT; wH = weak HIMT; sH = strong HIMT.

coloured glass includes a naturally Fe-coloured goblet from Apollonia. The provenance investigation has confirmed the trend observed in the previous period showing only few products arriving from the Levant (two samples). Among Egyptian glass, the HIMTa is absent while the HIMTb is still testified by a dark olive green block. DIMT2 is infrequent (two samples) while DIMT1 prevails over all other groups (six samples). Two further samples can be assigned to the Egyptian area without being able to provide a more specific assignment.

Lastly, glass dated to the 9^{th}-12^{th} centuries does not seem to testify to the arrival of glass types different from those attested in previous periods, with the exception perhaps of the Syrian products. Colourless glass is only represented by Mn-decoloured 3.2-type glass. Conversely, coloured glass includes 3 HIMTa, 3 HIMTb, 1 DIMT1, 1 DIMT2, 3 Levantine and 1 of uncertain provenance.

Finally, it should be noted that the evaluation of the extent of recycling depends very much on the consideration of Mn-decoloured and Fe-Mn glass as primary or recycled. In the first case, the percentages are 37 % fresh, 42 % recycled and 21 % recycled or intentionally added (with de/colouring agents); in the second case, the naturally Fe-coloured samples are only 2 (or 4) in the whole repertoire.

CRediT authorship contribution statement

Elisabetta Gliozzo: Conceptualization, Investigation, Methodology, Data curation, Formal analysis, Writing – original draft, Visualization, Writing – review & editing. **Margherita Ferri:** Conceptualization, Writing – original draft, Visualization, Writing – review & editing. **Eleonora Braschi:** Validation, Writing – review & editing. **Silvia Cadamuro:** Writing - review & editing. **Alessandra Cianciosi:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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Appendix A. Supplementary data

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