Glass Production at an Early Islamic Workshop in Tel Aviv

*Ian C. Freestone,
Institute of Archaeology, UCL, 31-34 Gordon Square,
London WC1H 0PY, United Kingdom;
i.freestone@ucl.ac.uk

Ruth E. Jackson-Tal,
Institute of Archaeology, Hebrew University of Jerusalem,
Mount Scopus 91905, Israel;
rutheve.jackson-tal@mail.huji.ac.il

Itamar Taxel,
Department of Archaeology and Ancient Near Eastern Cultures,
Tel Aviv University; Ramat Aviv 6997801, Israel;
taxelita@post.tau.ac.il

Oren Tal,
Department of Archaeology and Ancient Near Eastern Cultures,
Tel Aviv University; Ramat Aviv 6997801, Israel;
orental@post.tau.ac.il

*Corresponding Author

Highlights

- First published example from Palestine of an early Islamic secondary workshop
- Co-existence of glass from three primary production centres
- Raw glass made in Egypt and glass made in Palestine available to the glassworkers
- At least 12 production events identified
- Importance of batch analysis for the interpretation of glass workshops

Glass Production at an Early Islamic Workshop in Tel Aviv

Ian C Freestone, Ruth E. Jackson-Tal, Itamar Taxel and Oren Tal

Abstract

A refuse deposit at HaGolan Street, Khirbet al-Ḥadra, northeastern Tel Aviv, is rich in debris deriving from an Islamic period glass workshop, dating to the 7th–8th centuries. Twenty-four samples of glass vessels, chunks and moils were analysed by electron microprobe. Glass used in the workshop derives from three primary sources: Egypt II, somewhere in inland Egypt, Beth Eli‘ezer, near Hadera, Israel and a third group which appears to represent a previously unknown Levantine primary production centre. Glass corresponding to at least twelve production events has been identified. While vessels made of Beth Eli‘ezer and Egypt II glass have previously been reported from the same context, this is the first time that they have been related to the products of a single workshop. It appears that glass from both primary production centres was available in the later 8th century, and that the glass workers at HaGolan St were obliged to balance the high working and fuel costs of the stiff low-soda Levantine glass against the better working properties but higher raw material costs of the high-soda glass from Egypt.

Keywords: Early Islamic glass, secondary workshop, production event, electron microprobe analysis

1. Introduction

It is generally agreed that the majority of glass used in the 1st millennium CE was made from sand and alkali in a small number of primary workshops in Palestine or Egypt, then distributed as raw chunks to many secondary workshops for remelting and shaping (Nenna et al., 1997; Degryse 2014). A number of glass compositional groups have been identified in the Mediterranean and beyond in Late Antiquity and the Early Islamic periods, and these appear to correspond to different primary workshops (Freestone et al., 2000; Foy et al., 2003). While the distribution of the raw glass offers important information about the ancient economy, our ability to interpret this material with confidence requires advances in our understanding of a wide range of issues, for example the definition of production groups, the attribution of these groups to source locations and their relative and absolute chronologies

Many of the available analyses of glass from Palestine are for raw glass from primary workshops, where precise dating is particularly problematic due to the absence of diagnostic artefacts. The analysed glass represents material neglected or even rejected by the glassmakers and may be not have been of the same quality as that distributed to secondary workshops. Furthermore, it is frequently retrieved from the walls or the floors of the furnaces and may have been contaminated. Therefore, in order to improve our understanding of eastern Mediterranean glass production and distribution, compositional data representative of the vessels made at the secondary production stage are required.

It has been observed that glass may undergo a number of compositional changes during vessel production, due to contamination, mixing and loss of volatile material at high temperatures (Tal et al., 2008; Paynter, 2008; Rehren et al., 2010). These changes need to be better understood if we are to use compositional data to understand the distribution of archaeological glass. In addition, these compositional effects can offer important evidence of processes in the glass workshop.

The converse to these issues is that elemental analysis may help to interpret archaeological material from deposits associated with glass workshops, allowing insights into processes such as supply of raw materials, types of vessels produced and scale and duration of production. Thus analyses of workshop material is valuable from a range of perspectives, and there is a need for more investigation of this type of assemblage.

The present paper presents new analytical data for Early Islamic glass and vessels and production material from Tel Aviv. The site is important as, with the exception of Raqqa, Syria (Henderson, 2013), which also made primary glass, secondary workshop material from the Early Islamic period has hardly been investigated in detail. The present material is from a refuse deposit and the relationships between the glass materials requires clarification through analysis. Key questions include the extent to which vessel cullet (waste glass) was used as a raw material to feed the production process; whether the vessels associated with the production debris represent products of the furnace; the likely duration of the production; and the source of the glass used.

The results of the analysis show distinctive elemental patterns which have not been frequently recorded and inform the issues of interest. Unusually, we have evidence for the use of two, or perhaps three, distinct types of natron glass in the same workshop, a phenomenon which to our knowledge has not previously been reported from this period and region. Furthermore, as will be seen, two of these glass types were made in very different locations, one in Egypt and the other in central Palestine.

2. Archaeological Context

Khirbet al-Ḥadra is located some 5 km east of the Mediterranean coastline and 0.3 km north of the Yarqon River in the northeastern section of Tel Aviv, presently within the boundaries of the Dan and Ramat HaḤayyal neighborhoods. In February 1970, ancient remains were discovered during development at 27 HaGolan Street (within the Ramat HaḤayyal neighborhood), and were subsequently excavated by the late J. Kaplan (1971, 21–22). A small ashlar-built structure, whose southern part was partially destroyed by a mechanical tool prior to the excavation, was the main excavated feature. Kaplan attributed two phases of use to this structure: first, as a mausoleum in the original phase dated to the Late Roman period (3rd or 4th century CE); and in the second phase, as a refuse deposit dated to the beginning of the Early Islamic period (7th–8th centuries CE). In addition to the pottery and stone finds recovered in this deposit, glass and especially secondary glass production refuse, were recorded. Our new and more comprehensive interpretation is largely based on Kaplan's archival file and the available finds we managed to recover.

The preserved section of the structure (Structure A) excavated in 1970 was a single square-shaped space (*ca*. 3.1 × 3.6 m, preserved to c. 3.25 m high), carved into the *kurkar* bedrock (fossilized dune sandstone) on the southern slope of the hill that formed part of the second *kurkar* ridge of the central coastal plain of Israel. The walls and floor were made of well-dressed rectangular *kurkar* ashlars (*ca*. 0.3 × 0.6 m), apparently in dry construction (Fig. 1). The gap created between the building's walls and the bedrock was filled with fieldstones and earth.

In order to level the bedrock, the ashlars of the floor were laid over a foundation layer (0.1 m thick) of lime mixed with ash. One of the ashlars near the northeast corner was carved in the form of a square-shaped, shallow basin probably to be used as a settling pit. The walls were made of ashlars imitating the header-and-stretcher technique, but some stretchers were divided between quasi-headers and stretcher courses. No evidence was found for a doorway or stairs that may have led into the structure.

The interior contained a series of earth layers, which differed one from the other by their thickness, colour and texture. Despite the clear stratigraphic division of the structure's interior deposits, the roughly homogenous mix of pottery and glass indicates that these deposits occurred within a relatively short period of time.

Elsewhere we have suggested identifying the first stage of this structure as a subterranean storage installation of a type known from other sites along the Sharon Plain and the Carmel coastal strip, commonly termed 'pools' or 'barns', normally dated to the Roman, Byzantine and Early Islamic periods (Tal et al., 2013).

2.1 Glass working remains

Numerous artefacts were found in the earth layers excavated in the ashlar-built structure (Structure A). As well as pottery sherds and a few small complete vessels, animal bones, fragments of marble slabs and a few stone and metal objects (Tal et al., 2013), these included the remains of secondary glass production, including furnace remains, primary raw glass chunks, vessel production remains and fragments of glass vessels that may have been produced in the furnace. Since the furnace was dismantled and dumped into this structure, its original form cannot be determined. The evidence nevertheless indicates the existence of a secondary glass workshop nearby. Given the heterogenic nature of this assemblage we see no direct connection between the remains of the secondary glass production and the other above-mentioned finds. Still, we cannot preclude the possibility that some of the marble slab fragments served as a working surface for marvering in the secondary glass production process.

Several fragmentary glazed (vitrified) and unglazed fired mud-bricks, c. 11 × 15 × 3 cm that formed part of the furnace were found (Fig. 2 and Fig. 3). Some of the bricks had negative straw impressions that were used as a tempering agent during their production. Among the fragmented bricks, some must have been from the furnace ceiling as indicated by vitrified drops. Similar bricks, occasionally mixed with fieldstones, have been found in furnaces at Late Roman Jalame (Weinberg, 1988), Late Byzantine Ramla (South) (Tal et al., 2008) and medieval Giv‘at Yasaf (Tell er-Ras/Somelaria) (Weinberg 1987), and brick-built furnaces are also known from western Europe (Foy and Nenna, 2001, 61–62).

Nine angular chunks (up to about 4 × 6 cm) of bluish-green and yellowish-brown (amber) glass, covered with a layer of silver weathering, were found, and probably represent the primary raw material brought to the site to produce vessels (Fig. 4). Alternatively, they could represent remelted material broken out of the furnace, but this is considered less likely as there seems to have been no obvious advantage in such a practice.

About 50 irregular lumps (up to 4 × 5 cm), of bluish and greenish glass covered with a thick layer of extremely porous limy/ashy material were found. These lumps may be waste or spillage from the mixing of raw glass in the furnace. They are likely to have fallen into the floor or firebox of the furnace and have become contaminated with calcareous ash (Fig. 5).

Fig. 1. The ashlar-built structure, looking northeast.

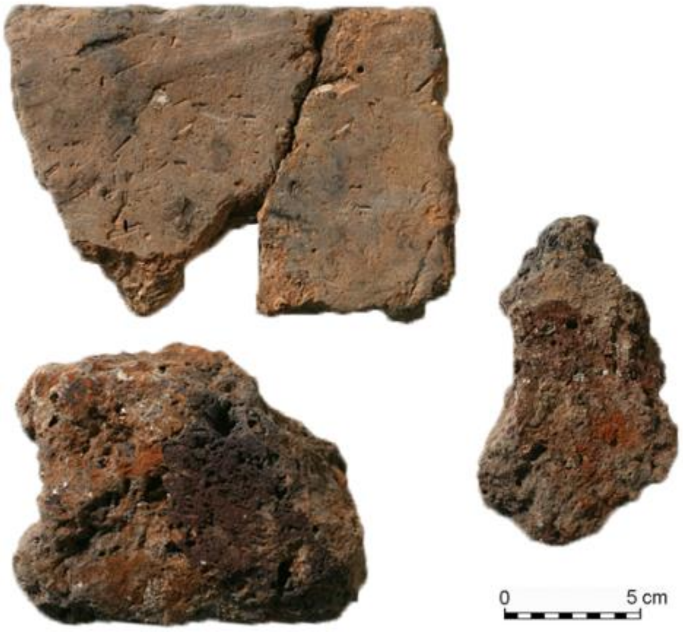

Fig. 2. Fragmentary unglazed fired mud-bricks from workshop furnace

Fig. 3. Fragmentary glazed (vitrified) and unglazed fired mud-bricks from workshop furnace.

Fig. 4. Raw glass chunks.

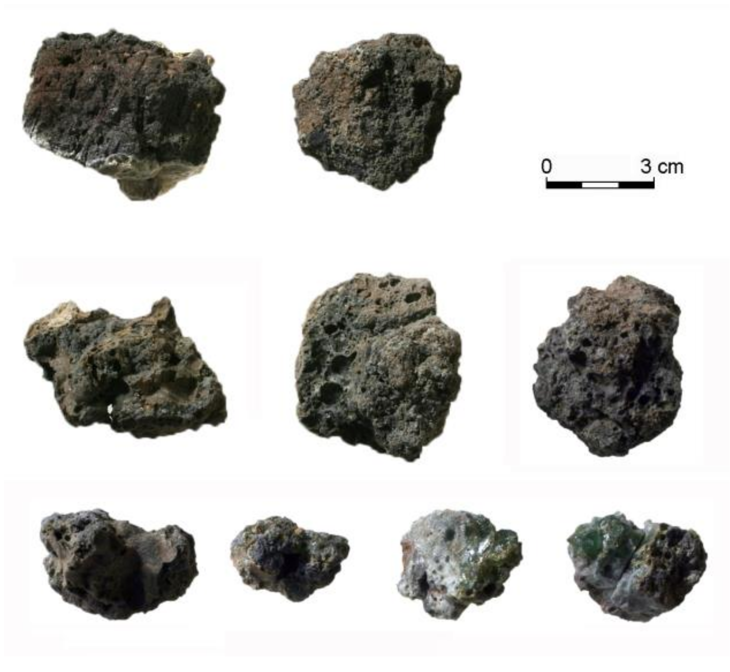

Fig. 5. Glass lumps.

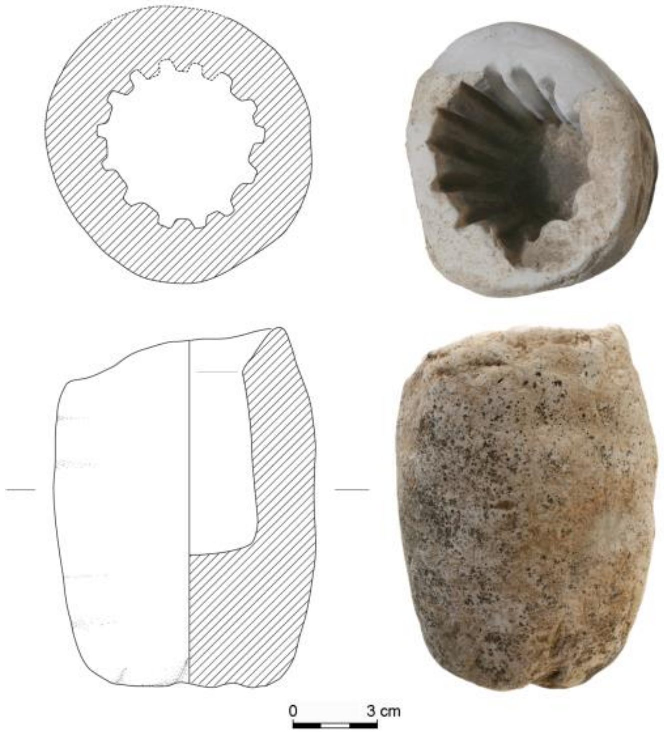

Fig. 6. A limestone mould for glass vessel blowing.

2.2. Vessel Production Remains

One of the most notable finds is a complete, cylindrical, cup-shaped dip mould, unevenly carved on the outside, with a wide rim and 14 inner vertical concavities on the inside (Fig. 6). It measures c. 13 cm high and 9 cm in its external diameter. It is made of relatively hard limestone and its thick walls (2 cm on average) and base (some 5 cm) were obviously intended to withstand the heat and pressure of molten glass without the glass adhering to it (cf. Stern, 1995, 45–46). To impress the pattern, the primary glass gather was blown into it, producing a ribbed vessel. The vessel was then removed and probably would have been inflated again by free blowing and tooled until the desired shape was achieved. The secondary inflation of the vessel would produce a larger, shallower and sparser rib design, parallel or twisted on the vessel walls (Gudenrath, 2001, 55, Figs. 44, 45).

Although dip moulds are known as early as the Early Roman period, they are more common in the Islamic period reflecting the large numbers of glass vessels decorated in this fashion (Whitehouse, 2001, 81–82). A terracotta ribbed dip mould is known from a context of the 3rd–4th century CE at Komarowa, Ukraine (Stern, 1995, 24, Fig. 8) and two metal dip moulds with other designs are attributed to the Early Islamic period yet their origin is unknown, perhaps from the Middle East (von Folsach and Whitehouse, 1993, Figs. 3, 6; Whitehouse, 2001, 82, nos. 10, 11). However, late antique stone moulds such as this one are rarely found in secure archaeological contexts. This mould can probably be dated more accurately to the 8th century CE, given the dating of most finds recovered with it (notably the pottery assemblage, which dates to around the late 8th/early 9th century CE, cf. Tal et al., 2013) and especially its stratigraphic position in the 'earliest' layer of discarded material/deposition. Hence its great importance. It is highly likely that the mould was used by the workers who produced secondary glass at the site. However, no mould-blown ribbed vessels were found among the glass fragments in this refuse.

Fig. 7. Moils.

Fig. 8. Working debris fragments: 1) cylindrical rod; 2–3) uneven glass pieces.

Eleven cylindrical or half-cylindrical moils made of colourless glass appearing bluish-green and yellow-tinged were found (Fig. 7). Moils are waste glass that remains around the end of the blowing tube after the vessel has been removed, usually by cracking off (Price, 1998, 333, note 4; Amrein, 2001, 22). They are typically cylindrical tubes with one end cut off straight and the other end left rounded and uneven. These moils (1.5–3 cm in diameter) testify to the use of blowing tubes for the production of glass at the site. The thin-walled vessels were probably colourless with a bluish-green and yellowish tinge; their moils appear in deeper colours because of their thickness.

Other working debris fragments are few and consist of a tiny cylindrical rod of light green glass and two rounded uneven glass pieces (Fig. 8). These objects are typical by-products from the making of glass vessels. The rod and glass pieces are perhaps the remains from the extraction of the primary gob of glass from the furnace or from the vessels formation. Similar finds were also discovered at Late Roman Jalame (Weinberg, 1988, 33–37, Pls. 3–6, Color Pl. 3a).

2.3 Glass Vessels

About 160 vessel fragments were found of which only 36 are indicative pieces (Fig. 9). They are made of colourless, bluish-green, yellow and yellow-brown (amber) glass covered with silver weathering and iridescence. A single bottle was found with a complete profile. The majority are bowls and bottles, but several jars, beakers, cup-shaped lamps and 'wine-glasses' were also found. The vessels are free-blown and mostly plain, apart from a complete bottle which is decorated with an applied circular plain stamp, as well as a wall fragment decorated with a wavy trail.

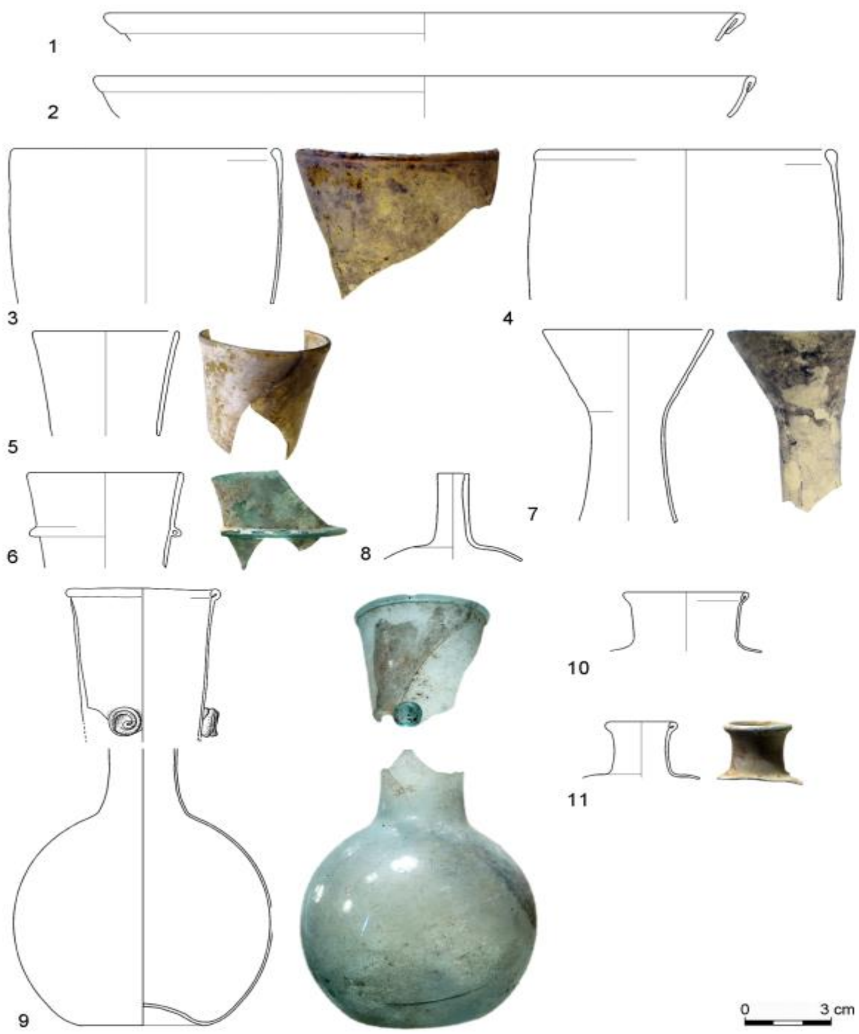

Fig. 9. Selection of glass vessels.

The vessels cannot be attributed securely to the glass production debris from the excavation evidence alone, although they were found alongside it. However, the repetitive appearance of one vessel type, a cup-shaped lamp with circular handle supports this assumption (Fig. 10). Although they might represent cullet brought for recycling, the analytical data presented and interpreted below provides a clear conclusion about the origin of the vessels and affirms their production in the workshop.

The indicative vessels can be dated to the Late Byzantine to Umayyad/early ‘Abbasid periods, 7th–8th centuries CE, according to similar well-dated contexts at Beth Shean (Hadad, 2005; Winter, 2011), Khirbat el-Thahiriya (Jackson-Tal, 2012) and Ramla (Gorin-Rosen, 2008; 2010; Gorin-Rosen and Katsnelson, 2005; Pollak, 2007; Jackson-Tal, 2008). They consist mostly of types indicating the stylistic continuation of the Byzantine-period glass vessels with few markers dated to the Umayyad and early ‘Abbasid periods.

Fig. 10. Circular handles of cup-shaped glass lamps.

3. Analysis, Results and Interpretation

Twenty-four samples were chosen to give a representation of colour and category of material, to include vessel wall fragments, handles, moils and chunks (Table 1). Some thin “colourless” glass vessels appeared blue-green when viewed in cross-section and are designated as such in Table 1. Small fragments were mounted in epoxy resin blocks, polished down to 0.25 µm and vacuum-coated with carbon. They were analysed using a JEOL JXA 8100 microprobe with three wavelength dispersive spectrometers, operated at 15 kV accelerating potential, beam current 50 nA, working distance of 10 mm and rastered at a magnification of x800. X-rays were collected for 30s on peak and 10s on each background. Standards were pure elements, oxides and minerals of known composition. Seven areas were analysed on each sample and the mean taken. Corning Museum

No.	Form	Colour	Group	Batch	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	FeO	SrO	Total
2	ves	am	A	1	12.28	0.39	2.57	75.87	0.06	0.01	0.60	0.33	6.56	0.09	0.01	0.42	0.11	99.29
11	ch	am	A	1	12.55	0.41	2.58	75.79	0.06	0.02	0.62	0.31	6.61	0.09	0.02	0.42	0.10	99.57
8	ves	am	A	1	12.20	0.41	2.59	75.96	0.06	0.01	0.59	0.33	6.46	0.08	0.01	0.40	0.08	99.18
1	ves	am	A	1	12.23	0.39	2.60	75.92	0.07	0.02	0.59	0.32	6.52	0.09	0.01	0.42	0.09	99.25
19	moil	b-g	B		12.60	0.36	3.21	74.15	0.07	0.05	0.82	0.39	7.59	0.05	0.01	0.27	0.12	99.68
17	moil	b-g	B		12.05	0.53	3.28	75.74	0.06	0.02	0.63	0.51	6.12	0.12	0.02	0.62	0.10	99.79
10	ves	b-g	B		12.13	0.45	3.34	75.45	0.06	0.03	0.57	0.52	6.30	0.10	0.02	0.47	0.11	99.55
14	ch	b-g	B		12.20	0.70	3.58	74.24	0.04	0.02	0.78	0.42	7.10	0.11	0.01	0.49	0.09	99.78
7	ves	b-g	B	2	12.37	0.69	3.59	73.13	0.06	0.07	0.61	0.44	7.69	0.11	0.01	0.54	0.12	99.43
21	han	b-g	B	2	12.55	0.71	3.59	72.97	0.06	0.06	0.63	0.45	7.72	0.11	0.01	0.51	0.10	99.47
24	han	b-g	B	2	12.45	0.70	3.60	73.15	0.07	0.06	0.62	0.45	7.67	0.12	0.02	0.52	0.10	99.52
22	han	b-g	B	2	12.58	0.69	3.60	73.05	0.06	0.07	0.63	0.45	7.70	0.10	0.02	0.51	0.11	99.57
23	han	b-g	B	2	12.39	0.71	3.63	73.15	0.07	0.05	0.63	0.45	7.72	0.11	0.02	0.53	0.10	99.56
3	ves	b-g	B	3	11.47	0.84	3.74	73.44	0.07	0.04	0.65	0.44	7.69	0.15	0.02	0.69	0.10	99.34
4	ves	b-g	B	3	11.43	0.85	3.76	73.59	0.06	0.03	0.63	0.45	7.68	0.14	0.02	0.73	0.07	99.45
5	ves	b-g	B	3	11.52	0.85	3.78	73.48	0.05	0.03	0.63	0.44	7.70	0.14	0.03	0.70	0.11	99.48
9	ves	b-g	B	3	11.50	0.85	3.81	73.39	0.05	0.03	0.64	0.45	7.72	0.15	0.02	0.74	0.10	99.45
15	moil	b-g	C	4	15.23	0.31	1.74	70.57	0.05	0.11	1.10	0.20	9.57	0.19	0.01	0.56	0.08	99.70
18	moil	b-g	C	4	15.23	0.31	1.74	70.48	0.04	0.10	1.11	0.19	9.59	0.20	0.01	0.57	0.07	99.65
6	ves	b-g	C		15.63	0.35	2.08	70.27	0.04	0.09	1.09	0.27	8.19	0.20	0.02	0.64	0.08	98.97
20	moil	b-g	C		14.11	0.36	2.24	70.35	0.06	0.10	0.98	0.25	10.10	0.24	0.01	0.67	0.08	99.55
13	ch	b-g	C		15.26	0.43	2.53	69.30	0.05	0.09	1.04	0.22	9.52	0.33	0.02	0.87	0.07	99.73
16	moil	b-g	C	5	14.50	0.56	2.69	69.48	0.08	0.07	1.05	0.26	9.76	0.34	0.02	0.92	0.11	99.85
12	ch	b-g	C	5	14.39	0.56	2.71	69.49	0.08	0.05	1.04	0.25	9.76	0.35	0.02	0.95	0.09	99.73
	Corning A Given				*14.30*	*2.66*	*1.00*	*66.56*	*0.13*	*0.16*	*0.10*	*2.87*	*5.03*	*0.79*	*1.00*	*0.98*	*0.10*	
	Corning A Analysed (n=13)				14.30	2.63	0.99	66.63	0.10	0.14	0.09	2.80	4.97	0.83	1.01	0.98	0.15	
	Corning B Given				*17.00*	*1.03*	*4.36*	*61.55*	*0.82*	*0.54*	*0.20*	*1.00*	*8.56*	*0.09*	*0.24*	*0.31*	*0.019*	
	Corning B Analysed (n=13)				16.91	1.02	4.48	61.89	0.76	0.50	0.16	1.03	8.59	0.12	0.25	0.30	0.07	

Table 1. Analyses of glasses by EPMA. Given values for Corning A and B from Brill (1999).
Also analyed and not detected in HaGolan samples Sb, Sn, Ba, Cu, Pb, Co.
ves=vessel fragment; ch = chunk; han=handle
am=amber; b-g = blue-green

Ancient Glass Standards A and B (Brill, 1999) were measured a number of times during the same analytical run, and results compare well with the given values (Table 1).

Results (Table 1) show that the glasses are all soda-lime-silica compositions, with the low MgO and K_2O characteristic of natron glass. No plant ash glass was identified. As alumina and lime contents reflect predominantly the composition of the glassmaking sand, they have been found to be helpful in interpreting glass origins. The HaGolan Street glass can be subdivided on this basis into three groups, labelled A-C (Fig. 11). Soda levels are relatively low, but they confirm a major division between Groups A and B with Na_2O below 13% on the one hand, and Group C with Na_2O above 14% on the other (Fig. 12). There is a general increase of chlorine with increasing soda, reflecting the dependence of chlorine solubility in the glass upon the soda content (Fig. 12).

In Fig. 11 we have added comparison data for glass from the Early Islamic primary production centre at Beth Eli‘ezer near Hadera (Freestone et. al., 2000 and unpublished data; previously termed “Levantine II”) and for the Egypt II groups (Gratuze and Barrandon, 1990; Bimson and Freestone, 1985). Group B is seen to coincide with the Beth Eli‘ezer products, and this interpretation is supported by its low soda content which is typical. Group C appears to represent Egypt II and again its moderate levels of soda are consistent with this. Group A does not overlap with either group, but on the basis of its low soda content, would appear to be more closely related to Group B (Fig. 12).

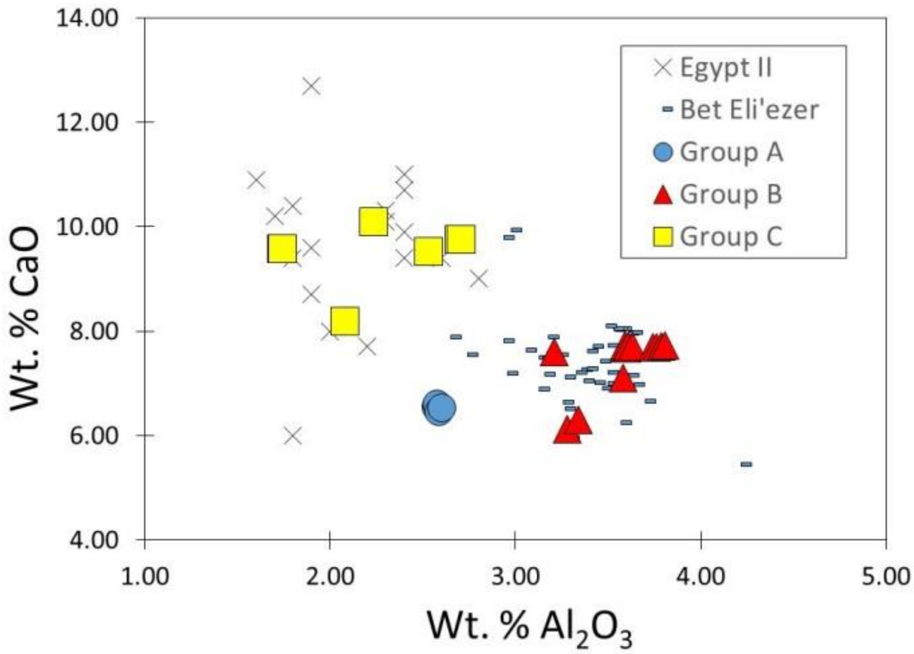

Fig. 11. Lime and alumina for Groups A-C with comparative data for Egypt II and Beth Eli‘ezer (for sources see text).

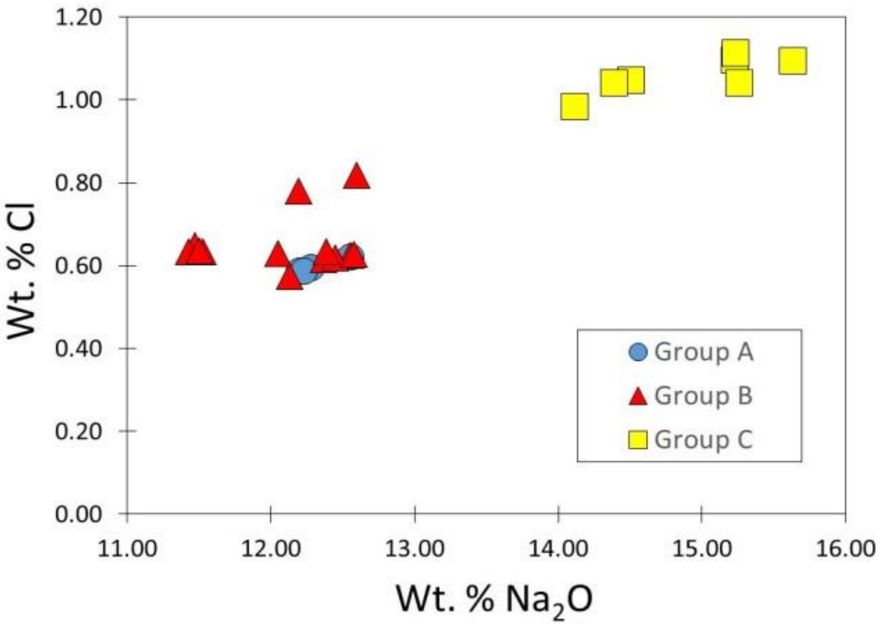

Fig. 12. Soda and chlorine contents for Groups A-C. The higher chlorine in Group C reflects its dependency on the higher soda content of the glass.

On the basis of the strontium content and isotopic composition of the Beth Eli‘ezer glass, Freestone et al. (2003) observed that it was made using Palestinian coastal sand, in which the lime occurred in the form of aragonitic shell fragments. On the other hand, Egypt II glass was made using a sand containing limestone, probably from inland Egypt. While the concentrations of Sr in the HaGolan Street glasses approach the limits of detection of our EPMA technique it is sufficiently precise to differentiate the glasses on the basis of their SrO/CaO ratios (Fig. 13) with group C having lower values than Groups A and B. This supports the interpretation that Group C is glass of Egyptian II type.

Foy et al. (2003) have noted that Egyptian glass generally has high TiO_2 relative to Levantine glass from the coastal strip of Palestine and the Al_2O_3/TiO_2 ratios in Fig. 13 again suggest that Group C is Egyptian. The strong correlation of TiO_2 and FeO and their characteristic ratios in Groups A and B as opposed to Group C, again suggests two distinct regions of production, with sand characterised by different heavy mineral assemblages. The data are compared in Fig. 14 with reference data obtained for Egypt II and a range of Levantine glasses (samples from Ashmunein, Beth Eli‘ezer, Apollonia and Beth Shean; unpublished LA-ICP-MS data of Freestone et al.) and show a good correspondence. Not only does this confirm the attribution of Groups B and C but also clearly indicates that Group A is Levantine, and was made on the Palestinian coastal plain, albeit from a different sand and in a different location from Group B.

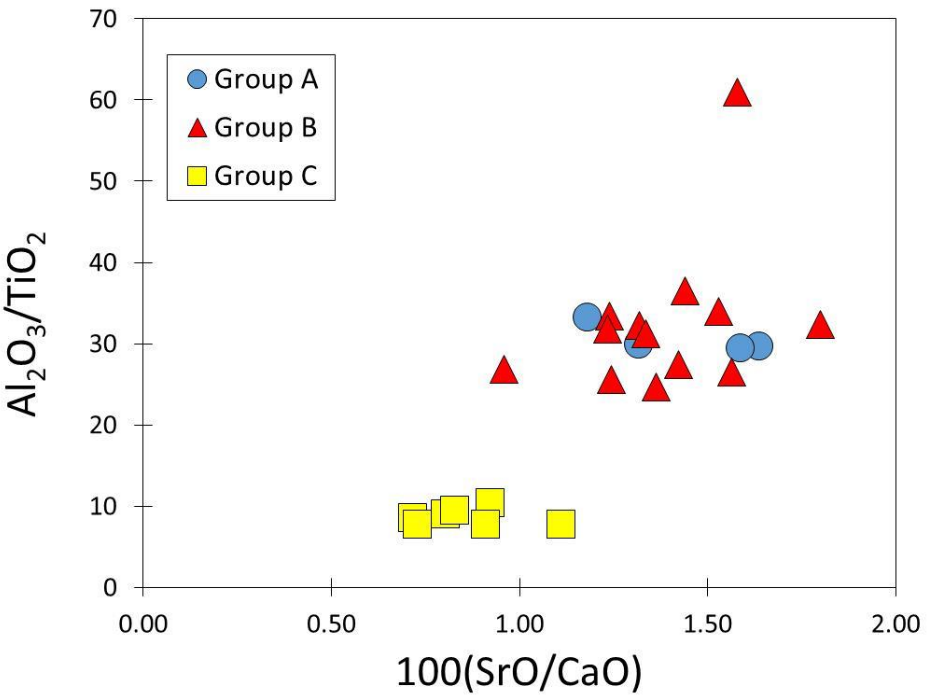

Fig. 13. SrO/CaO ratio showing different sources of lime for Groups A and B as opposed to Group C, with Al_2O_3/TiO_2 showing likely regional difference.

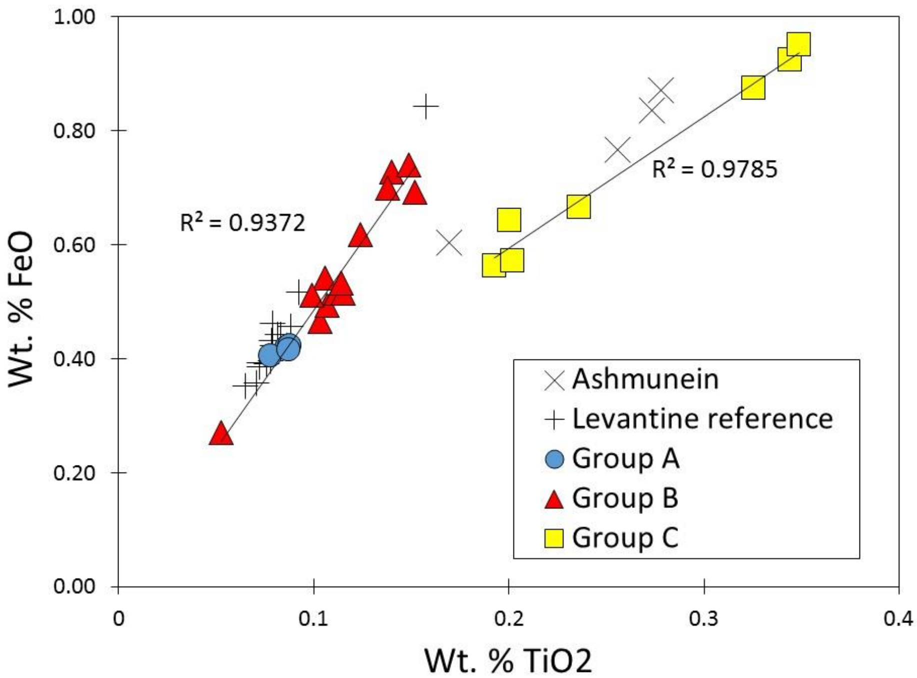

Fig. 14. Correlation between FeO and TiO_2 for Groups A and B as opposed to Group C, with ICP-MS reference data for Levantine tank furnaces and Tel el Ashmunein (Freestone et al, in progress). Trend lines and correlation coefficients for Groups B and C are shown.

In summary, the data indicate that the glass at HaGolan Street was derived from three sources: Group B from the Beth Eli‘ezer furnaces, Group A from an unknown Levantine source, and Group C from the Egypt II source, which appears to have originated in inland Egypt, but which has not yet been located. Chunk glass from all three compositional groups occurs on the site, suggesting that all were used as raw material in the workshop.

Although the use of vessel cullet is a possibility in any secondary workshop, we detect no evidence for this in the present case. The elements lead and copper, frequent contaminants during the recycling process (Freestone et al. 2002b) were not detected in any of the analysed glasses but this is to be expected as glasses coloured with these elements were uncommon in Palestine at this time. However, the glass analysed contains no added manganese. Manganese dioxide was commonly added to glass as a decolourant in the first millennium CE and occurs in some Egypt II and Levantine-type glass of the Byzantine and early Islamic periods. Its presence might be expected if recycling of old glass had been occurring. ICP-MS data (Freestone et al. 2000) indicate that the natural level of MnO in Levantine glass is approximately 200 ppm, and these are

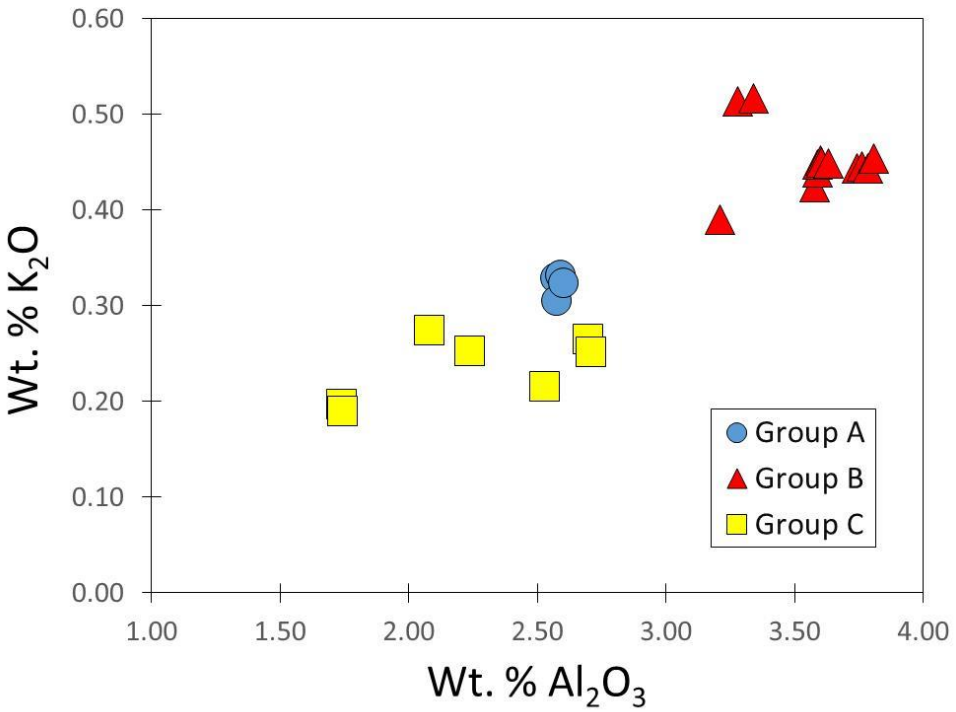

Fig. 15. Potash versus alumina implying an association of the two components in feldspars and/or clay minerals in the glass making sand.

the levels detected here, at around the limit of detection of our EPMA method. Finally, there is a general correlation between K_2O and Al_2O_3 in the glasses analysed (Fig. 15), which is a reflection of the association of these components in feldspar or clay minerals in the glassmaking sand (Tal et al., 2004). In other secondary workshop assemblages, for example the Late Byzantine workshop at Ramla (Tal et al., 2008; see also Rehren et al., 2010) we have observed elevated K_2O due to incorporation of ash during the melting process, as has been demonstrated in experimental replication of Roman glass working (Paynter, 2008). Under such circumstances, the K_2O-Al_2O_3 correlation is perturbed and K_2O shows a strong correlation with P_2O_5 (Tal et al., 2008, Rehren et al., op. cit.) which is not observed in the HaGolan Street glass. The absence of glass with elevated K_2O resembles the compositions seen in a primary workshop (Freestone et al. 2000, Tal et al., 2004) and appears to reflect the use of relatively pristine glass. Therefore as far as we are able to judge at the present time, recycling of old glass does not appear to have been a significant process at the HaGolan Street workshop, a conclusion which is fully consistent with the well-defined compositional groups which indicate limited mixing between Groups A, B and C.

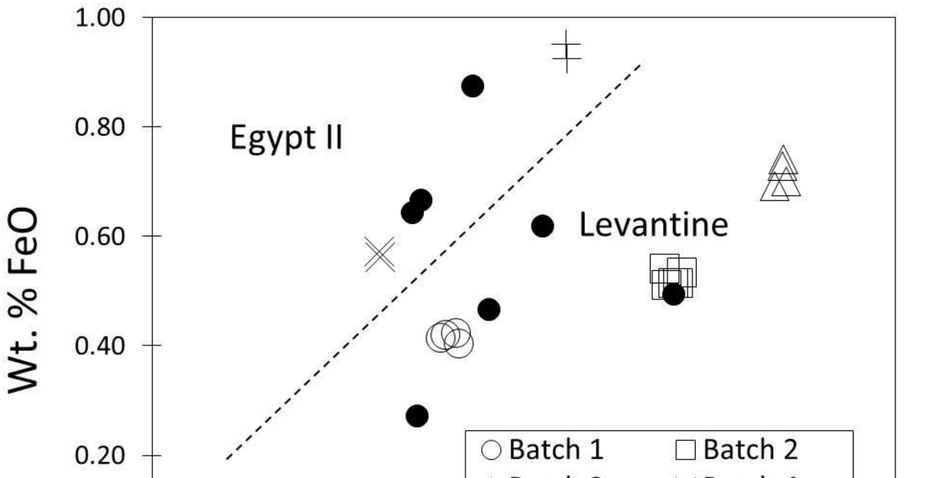

Fig. 16. Batch analysis of glass in terms of FeO and MgO. Five batches, each comprising more than one object are identified along with seven individuals. Note the different FeO/MgO ratios of Egyptian and Levantine glasses.

The possibility of identifying glass from single workshop batches has been explored by Price et al. (2005) and Freestone et al. (2009). It is argued that each production event or melt is characterised by its own particular mixture of raw materials which imparts a distinctive composition. In the present case it has been argued above that the glass being melted was primary material brought to the workshop direct from tank furnaces, but it appears that even single glass slabs were inhomogeneous, as indicated by the detailed investigation of the glass from the tanks at Beth Eli‘ezer (Freestone et al., 2000). Each charge at the secondary furnace would have comprised chunks removed from the primary production site with their own distinctive composition (Freestone et al., 2009). Glasses from different melting events will therefore differ in composition, while within a batch vessels have identical compositions, within analytical error.

The HaGolan data show five tight compositional batches, where all analysed elements are within two standard deviations of the mean. These are listed in Table 1 and shown graphically in terms of MgO and FeO in Fig. 16. In addition there are seven individual analyses which are not closely linked to any other, differing significantly in one or more components. Note that these groupings are also apparent (although not labelled) in plots of other elements, e.g. CaO vs Al_2O_3 (Fig. 11). It may therefore be inferred that there was a minimum of twelve glass working events at the HaGolan Street workshop.

4. Discussion

The presence of glass from two or potentially three different primary production centres might suggest that domestic glass, made at different times and places, was present and had become mixed with the workshop material. However, the evidence suggests that all three glasses were worked at HaGolan Street. In the first instance it is noted that the suggested date ranges for the products of Beth Eli‘ezer (7th–8th centuries CE: Freestone et al., 2000) and Egypt II (8th–9th centuries CE: Gratuze and Barrandon, 1990) allow an overlap of the two groups in the late 8th century CE. Furthermore, this is consistent with the 7th–8th centuries CE date inferred from the forms of the glass vessels. Although Group A does not match analysed material from Beth Eli‘ezer, its very low soda content suggests that it is relatively late (probably Umayyad), as Late Byzantine glasses from the region typically have higher Na_2O, in the range 13–16% (Tal et al., 2004; 2008; Freestone et al., 2008; Schibille et al., 2008). Therefore it is assumed that Group A is either Beth Eli‘ezer glass which has not been represented in the sample so far analysed from the site, or it represents a contemporary Early Islamic production from another locality in the same region.

All Groups A- C contain both vessel fragments and glass production waste or raw material in the form of moils and/or chunks, implying that three compositions were being worked on the site, as vessels and production material are unlikely to be associated in a domestic assemblage. In the case of Batch 1 (corresponding to Group A), there is a chunk and three vessel fragments within the same batch, so it seems irrefutable that the Batch 1 vessels were produced from raw glass on site. The other batches identified do not contain both vessels and working waste (Table 1), but the presence of vessel glass which can be grouped in batches in this way from a single deposit suggests workshop waste, rather than the simultaneous disposal of a number of sets of vessels from consumer contexts, which seems unlikely.

It seems probable that the total number of batches made at HaGolan Street was considerably more than the twelve identified here. Each moil represents a single vessel, and the size of a tank of glass in a secondary workshop (e.g. the tank at Beth Shean; Gorin-Rosen, 2000) suggests that the number of vessels blown from a batch of glass will have numbered in the tens or possibly hundreds. Thus, where a batch has been identified from a single moil or vessel fragment, this is likely to represent a small fraction of the vessels blown with the same composition, and loss rates due to putting the waste back into the furnace, along with other losses such as mechanical attrition of glass on the workshop floor, will have been very high. Hence no evidence will have been recovered for many production events. This inferred high wastage makes it all the more surprising that we have batches comprising four to five vessels. The explanation is likely to be that these represent activity towards the end of the life of the workshop. Therefore, the fact that the cup-shaped lamp with rounded handles is well represented in the assemblage (Fig. 10) does not necessarily imply that it was the main form produced in the workshop, but that it was made during one of the last phases of glass working, as all the handles analysed are from a single batch (Batch 2). The 8th century CE date of these vessels concurs with this assumption. This has clear implications for the interpretation of glass workshop assemblages and suggests that a programme of analysis is essential if they are to be properly interpreted.

Egypt II and Levantine glass have previously been reported from the same consumer context, e.g. at Raya, South Sinai (Kato et al., 2008) but to our knowledge this is the first time they have been shown to have been in use in the same workshop at about the same time. While we cannot prove that there was competition between Egyptian and Levantine producers to supply raw glass in the 8th century CE it appears that both types of glass were available to the same glassworkers. HaGolan is substantially further north than has been reported previously for Egyptian II glass, indicating the success of this material in the market at this time relative to Levantine glass. This may be a result of the higher soda and lower silica of Egypt II glass, which would have imparted a lower viscosity, a lower melting temperature and a longer working range, which are likely to have been preferred by the glass workers. A similar situation with respect to Egyptian and Palestinian glass seems to have occurred in earlier periods, for example in the 4th–5th centuries CE between Egyptian HIMT and Levantine I (e.g. Freestone et al., 2002a; 2002b; Foster and Jackson, 2009; Nenna, 2014). However, HIMT does not seem to have penetrated north into Syria-Palestine.

It is of interest that the three batches which have a good representation of vessel fragments are all Levantine glass. If they are assumed to represent the final products of the workshop, as suggested above, then Levantine glass is likely to have been procured in preference to Egyptian material at a late stage in the life of the workshop. Group A is probably also present here because of its amber colour, which was difficult to produce as it required especially reducing conditions in the primary glass making furnace to generate the ferri-sulphide chromophore (Schreurs and Brill, 1984; Arletti et al., 2011; Freestone and Stapleton 2015) and is likely to have been produced on an occasional basis. The Group A/Batch 1 material may therefore represent a consignment of coloured glass brought in for special use, or material that had been deliberately conserved because of its colour.

5. Conclusions

The importance of the HaGolan Street site assemblage lies in the rarity of analyzed and studied secondary glass production evidence in Syria-Palestine dated to the Early Islamic period. The elemental data allow an interpretation of production at the site which goes far beyond that attainable by straightforward archaeological study. It has been shown that the glass at HaGolan Street derived from three sources: Group A from an unknown Levantine source, Group B from the Beth Eli‘ezer furnaces, and Group C from the Egypt II source, which appears to have originated in inland Egypt, but has not yet been located. Vessel fragments and glass production waste or raw material in the form of moils and/or chunks glass from all three compositional groups occurs at the site, suggesting that all were used as raw material and worked in the workshop.

The suggested date ranges for the products of Beth Eli‘ezer (7th–8th centuries CE) and Egypt II (8th–9th centuries CE) allow an overlap of the two groups in the late 8th century CE. This is consistent with the 7th–8th centuries CE date inferred from the typological study of the glass vessels and the rare stone mould discovered with them. There appear to have been at least twelve melting episodes and the different batches identified represent activity towards the end of the life of the workshop. Furthermore, the recognition that the vessels which are well-represented in the assemblage represent a single batch of glass draws attention to the difficulties in interpreting glass workshop assemblages on the basis of typology alone, as the dominant forms are likely to represent the final products, rather than represent the life of the workshop.

In addition to allowing an interpretation of the production processes at our site, our analyses provide more general insights on the use of different raw glasses in the early Islamic period. For the first time we are able to document the use of Levantine and Egypt II glass to make vessels in the same workshop at about the same time, suggesting that the glassworkers could make a choice as to which raw material to use. Although the higher-soda Egypt II composition was characterised by properties which would have been preferred by the glass workers, the late stages of glass production at HaGolan Street appear to have used inferior Levantine glass, which was harder to work and presumably required more fuel and time to melt. Egyptian primary glass makers were located closer to the sources of natron and were able to include more in their glass than the glass makers of Beth Eli‘ezer. However, their raw glass had to be transported over a longer distance which would have added significantly to its cost. For the glass workers of HaGolan Street, there may have been a choice between expensive, better quality Egyptian glass, and inferior Levantine glass, which was produced at a more proximal location and therefore cheaper to acquire. The lower cost of the raw Levantine glass had to be balanced against the higher cost and effort it required to produce vessels.

Acknowledgements

The current study is supported by the Israel Science Foundation — Personal Research Grant (No. 118/12), headed by O. Tal. Drawings of the glass vessels were produced by the Computerized Archaeology laboratory (Institute of Archaeology, The Hebrew University in Jerusalem). Dr Harriet White and Mr Kevin Reeves (University College London) are thanked for their excellent laboratory support and Pavel Shrago and Itamar Ben-Ezra (Tel Aviv University, Institute of Archaeology) for their assistance in preparing the illustrations. We thank the referees for their thoughtful and helpful comments.

References

Amrein, H. 2001. *L'Atelier de verriers d'Avenches: L'Artisanat du verre au milieu du 1er siècle après J.-C.* Cahiers d'archeologie romande 87. Aventicum 11. Lausanne.

Arletti, R., Quartieri, S. and Freestone, I. C. 2013. A XANES study of chromophores in archaeological glass*. Applied Physics A* 111(1), 99–108.

Bimson, M. and Freestone, I. C. 1985. The discovery of an Islamic glass-making site in Middle Egypt, in *Annales du 10^{e} Congrès de l'Association Internationale pour l'Histoire du Verre*, 237–243.

Brill, R. H. 1999. *Chemical Analyses of Early Glasses*. New York.

Degryse, P. 2014. *Glass Making in the Greco-Roman World: Results of the ARCHGLASS Project.* Leuven.

Foster, H. and Jackson, C. M. 2009. The composition of 'naturally coloured' late Roman vessel glass from Britain and the implications for models of glass production and supply. *Journal of Archaeological Science* 36, 189–204.

Foy, D. and Nenna, M.-D. 2001. *Tout feu tout sable: Mille ans de verre antique dans le Midi de la France.* Marseille.

Foy, D., Picon, M., Vichy, M. and Thirion-Merle, V. 2003. Caractérisation des verres de la fin de l'Antiquité en Méditerranée occidentale: l'Émergence de nouveaux courants commerciaux, in Foy, D. and Nenna, M.-D. (eds.), *Échanges et commerce du verre dans le monde antique.* Monographies Instrumentum no. 24. Montagnac, 41–85.

Freestone I. C., Gorin-Rosen Y. and Hughes M. J. 2000. Composition of primary glass from Israel, in Nenna, M.-D. (ed.), *La Route du Verre: Ateliers primaires et secondaires de verriers du second millinaire av. J.-C. au Moyen-Age*, Travaux de la Maison de l'Orient Méditerranéen no. 33. Lyon, 65–84.

Freestone, I. C., Greenwood, R. and Gorin-Rosen, Y., 2002a. Byzantine and early Islamic glassmaking in the Eastern Mediterranean: Production and distribution of primary glass, in Kordas, G. (ed.), *Hyalos – Vitrum – Glass*, Athens, 167–174.

Freestone, I. C., Ponting, M. and Hughes, M. 2002b. The origins of Byzantine glass from Maroni Petrera, Cyprus. *Archaeometry* 44, 257–272.

Freestone I. C., Leslie, K. A., Thirlwall, M. and Gorin-Rosen, Y. 2003. Strontium isotopes in the investigation of early glass production: Byzantine and early Islamic glass from the Near East*. Archaeometry* 45, 19–32.

Freestone, I. C., Jackson-Tal, R. and Tal, O. 2008. Raw glass and the production of glass vessels at late Byzantine Apollonia-Arsuf, Israel. *Journal of Glass Studies* 50, 67–80.

Freestone, I. C., Price, J. and Cartwright, C. 2009. The batch: Its recognition and significance, in *Annales du 17^{e} Congrès de l'Association Internationale pour l'Histoire du Verre*, 130–135.

Freestone, I. C. and Stapleton, C. P. 2015. Composition, technology and production of coloured glasses from Roman mosaic vessels, in Bayley J., Jackson C. M. and Freestone I. C. (eds.), *Glass of the Roman World*. Oxbow, 62–77.

Gorin-Rosen, Y. 2000. The ancient glass industry in Israel: Summary of finds and new discoveries, in Nenna, M.-D. (ed.), *La Route du Verre: Ateliers primaires et secondaires de verriers du second millinaire av. J.-C. au Moyen-Age*, Travaux de la Maison de l'Orient Méditerranéen no. 33. Lyon, 49–64.

Gorin-Rosen, Y. 2008. Glass vessels from the Ramla excavations. Qadmoniot 135, 45–50 (in Hebrew).

Gorin-Rosen, Y. 2010. The Islamic glass vessels, in Gutfeld, O. *Ramla: Final Report on the Excavations North of the White Mosque*. Qedem 51. Jerusalem, 213–264.

Gorin-Rosen, Y. and Katsnelson, N. 2005. Glass finds from the salvage excavations at Ramla. *'Atiqot* 49, 101–114.

Gratuze, B. and and Barrandon, J.-N. 1990. Islamic glass weights and stamps: Analysis using nuclear techniques. *Archaeometry* 32, 155–162.

Gudenrath, W. 2001. A survey of Islamic glassworking and glass-decorating techniques, in Carboni, S. and Whitehouse, S. (eds.), *Glass of the Sultans.* New York, 46–67.

Hadad, S. 2005. *Islamic Glass Vessels from the Hebrew University Excavations at Bet Shean*. Qedem Reports 8. Jerusalem.

Henderson, J. 2013, *Ancient Glass: An Interdisciplinary Exploration*. Cambridge.

Jackson-Tal, R. E. 2008. Glass vessels, in Tal, O. and Taxel, I. *Ramla (South): An Early Islamic Industrial Site and Remains of Previous Periods*. Salvage Excavation Reports 5. Tel Aviv, 166–184.

Jackson-Tal, R. E. 2012. The early Islamic glass finds from Khirbet el-Thahiriya. *'Atiqot* 71, 57*–72*.

Kaplan, J. 1971. Museum of Antiquities of Tel Aviv-Yafo: Excavations 1970. *Museum HaAretz Bulletin* 13, 18–22.

Kato, N., Nakai, I. and Shindo, Y. 2009. Change in chemical composition of early Islamic glass excavated in Raya, Sinai Peninsula, Egypt: On-site analyses using a portable X-ray fluorescence spectrometer. *Journal of Archaeological Science* 36(8), 1698–1707.

Nenna, M.-D., 2014. Egyptian glass abroad: HIMT glass and its market, in Keller, D., Price, J. and Jackson, C. (eds), *Neighbours and Successors of Rome – Traditions of*

Glass Production and Use in Europe and the Middle East in the Later 1st Millennium AD. Oxford, 177–193.

Nenna, M.-D., Vichy, M. and Picon, M. 1997. L'Atelier de verrier de Lyon, du Ier siècle après J.-C., et l'origine des verres 'Romains'. *Revue d'Archéométrie* 21, 81–87.

Paynter, S., 2008. Experiments in the reconstruction of Roman wood-fired glassworking furnaces: Waste products and their formation processes. *Journal of Glass Studies* 50, 271–290.

Pollak, R. 2007. Excavations in Marcus Street, Ramla: The glass vessels. *Contract Archaeology Reports* 2, 100–133.

Price, J. 1988. Exhibits at Ballots: An Egyptian teracotta group showing Eros beside a glass furnace. *The Antiquaries Journal* 68(2), 317–319.

Price, J., Freestone I. C. and Cartwright C. R. C. 2005, 'All in a day's work?' The colourless cylindrical glass cups found at Stonea revisited, in Crummy, N. (ed.), *Image, Craft and the Classical World: Essays in Honour of Donald Bailey and Catherine Johns.* Monographies Instrumentum no. 29. Montagnac,163–169.

Rehren, Th., Marii, F., Schibille, N, Stanford, L. Swan, C. 2010. Glass supply and circulation in Early Byzantine Southern Jordan. In Drauscke J. and Keller D. (eds.), *Glass in Byzantium – Production, Usage, Analyses*. Mainz: RGZM 8, 65–82.

Schibille, N., Marii, F. and Rehren, T. 2008. Characterization and provenance of late antique window glass from the Petra church in Jordan. *Archaeometry* 50(4), 627–642.

Schreurs, J. and Brill, R. 1984. Iron and sulphur related colors in ancient glasses. *Archaeometry* 26, 199–209.

Stern, E. M. 1995. *The Toledo Museum of Art. Roman Mold-Blown Glass: The First through Sixth Centuries.* Rome.

Tal, O., Jackson-Tal, R. E. and Freestone, I. C. 2004. New evidence of the production of raw glass at late Byzantine Apollonia-Arsuf, Israel. *Journal of Glass Studies* 46, 51–66.

Tal, O., Jackson-Tal, R. E. and Freestone, I. C. 2008. Glass from a late Byzantine secondary workshop at Ramla (South), Israel. *Journal of Glass Studies* 50, 81–95.

Tal, O., Taxel, I. and Jackson-Tal, R. E. 2013. Khirbet al-Ḥadra: More on refuse disposal practices in early Islamic Palestine and their socio-economic implications. *Strata: Bulletin of the Anglo-Israel Archaeological Society* 31, 117–148.

von Folsach, K. and Whitehouse, D. 1993. Three Islamic molds. *Journal of Glass Studies* 35, 149–153.

Weinberg, G. D. 1987. A glass factory of Crusader times in northern Israel (preliminary report), *Annales du 10^e Congrès de l'Association Internationale pour l'Histoire du Verre*, 305–316.

Weinberg, G. D. 1988. The glass factory and manufacturing processes, in Weinberg, G. D. (ed.), *Excavations at Jalame: Site of a Glass Factory in Late Roman Palestine.* Columbia, 24–37.

Whitehouse, D. 2001. Mold-blown glass, in Carboni, S. and Whitehouse, D. (eds.), *Glass of the Sultans.* New York, 81–99.

Winter, T. 2011. The glass finds, in Bar-Nathan, R. and Atrash, W. *Bet She'an II. Beisān: The Theater Pottery Workshop*. IAA Reports 48. Jerusalem, 345–362.

List of Figure Captions

Fig. 1. The ashlar-built structure, looking northeast.

Fig. 2. Fragmentary unglazed fired mud-bricks from workshop furnace.

Fig. 3. Fragmentary glazed (vitrified) and unglazed fired mud-bricks from workshop furnace.

Fig. 4. Raw glass chunks.

Fig. 5. Glass lumps.

Fig. 6. A limestone mold for glass vessel blowing.

Fig. 7. Moils.

Fig. 8. Working debris fragments: 1) cylindrical rod; 2–3) uneven glass pieces.

Fig. 9. Selection of glass vessels.

Fig. 10. Circular handles of cup-shaped glass lamps.

Fig. 11. Lime and alumina for Groups A-C with comparative data for Egypt II and Beth Eli‘ezer (for sources see text).

Fig. 12. Soda and chlorine contents for Groups A-C. The higher chlorine in Group C reflects its dependency on the higher soda content of the glass.

Fig. 13. SrO/CaO ratio showing different sources of lime for Groups A and B as opposed to Group C, with Al_2O_3/TiO_2 showing likely regional difference.

Fig. 14. Correlation between FeO and TiO_2 for Groups A and B as opposed to Group C, with ICP-MS reference data for Levantine tank furnaces and Tel el Ashmunein (Freestone et al, in progress). Trend lines and correlation coefficients for Groups B and C are shown.

Fig. 15. Potash versus alumina implying an association of the two components in feldspars and/or clay minerals in the glass making sand.

Fig. 16. Batch analysis of glass in terms of FeO and MgO. Five batches, each comprising more than one object are identified along with seven individuals. Note the different FeO/MgO ratios of Egyptian and Levantine glasses.