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The 17th Century Glasshouse at Shinrone, Co. Offaly, Ireland

Caimin O'Brien[1], Jean Farrelly[2] and Sarah Paynter[3]

Summary

An upstanding 17th century wood-fired glass furnace survives at Shinrone, County Offaly, Ireland. Two seasons of excavation have been carried out at the glasshouse by Caimin O'Brien and Jean Farrelly, and samples of glass working waste and products were recovered. Glass working waste recovered as surface finds from the site of another glasshouse, contemporary with Shinrone and situated nearby at Glaster, Lusmagh, were also obtained for comparison. This report summarises the analytical results for the glass working waste from Shinrone and Glaster, together with a brief summary of the historical research and excavations undertaken by Caimin O'Brien and Jean Farrelly.

Keywords

Glass
Post Medieval
Technology

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Introduction

The post-medieval glass industry in England has been the subject of an increasing number or archaeological and scientific studies since the 1960's, which are comprehensively described by Crossley (1990). Documentary and archaeological evidence suggests that, prior to the 16th century, most of the green glass for windows and vessels used in Britain was produced in France and Germany. However records indicate that glass was being produced in certain areas of England, such as the west of the Weald and in Staffordshire. A number of furnaces dating to the medieval period have been excavated including 13th/14th-century and mid-16th century furnaces at Little Birches, Staffordshire (Welch, 1997), a 14th-century furnace at Blundens' Wood, Surrey (Wood, 1965), a furnace at Knightons, Surrey, dating to 1550 (Wood, 1982), and a furnace at Bagot's Park, Staffordshire dating to about 1530 (Crossley, 1967).

In 1567, Jean Carré, a merchant from Antwerp and a partner, Anthony Becku, obtained a patent for the manufacture of window glass in England. Glass workers from Lorraine and Normandy came to England to work the furnaces, bringing with them a different glass-working tradition (Kenyon, 1967; Godfrey, 1975). Among those who came in 1568 were Thomas and Balthazar de Hennezes, Esquiers, glassmakers from the Vosges, in Lorraine and there is a record of their intention to 'transport ourselves to the saide countrie of England, and there cause to be builded and edifyed two ovens to make great glas' (Grazebrook, 1877, 170-1). The glass produced by these glassmakers had a different quality to English medieval glass, being harder, brighter and less susceptible to weathering. Analyses have since shown that this glass is compositionally distinct from earlier glass, and this is discussed later in this report. The immigrants included the glass-making families of the de Hennezells and the de Bigaults, anglicised to Hensey or Henzey and Bigo respectively; members of these families subsequently relocated from England to Ireland.

In 1615, Sir Robert Mansell was awarded a monopoly on all types of glass making in England, and the use of wood fuel in glass-making in England was prohibited. As a result the designs of glass furnaces were rapidly adapted to use mineral fuel. One such furnace was run by Sir William Clavell and his partner Abraham Bigo, who had worked for many years in Staffordshire (Godfrey, 1975, 93). They were licensed to produce vessel glass for sale in the south-western counties but the furnace was demolished in 1623 by the Mansell monopoly, after glass was sold in breach of these restrictions and because of rent arrears (Godfrey, 1975, 101, 121). This furnace, at Kimmeridge in Dorset, has been excavated and published (Crossley, 1990, 233; Crossley, 1987).

Subsequently Bigo left for Ireland (Figure 1), where he leased land from Laurence Parsons of Birr Castle on 9th October, 1623, and arranged to buy wood for his glasshouse. It was a condition that Bigo should not 'set up any glass house or glasswork on any other land, or buy wood of any other for his glasswork but only of me'. In 1627, Abraham surrendered the lease to his son, Philip who was also associated, in the 1659 census, with a glasshouse in the townland of Glaster, near Lusmagh, in Co. Offaly (Figure 2) (Pender, 1939, 443). A large fragment of glass-furnace structure was recovered from a field wall in Glaster, along with fragments of glass found while fieldwalking. Material from the Glaster glasshouse, which is also likely to date to the early 17th century, was included in this study. Later in this report the glass from Glaster, where the glasshouse may have been run by Philip Bigo, is compared to that produced at Kimmeridge by his relative, Abraham Bigo.

Another glass-working family of French descent, the Henzeys, are listed as landowners in Co. Offaly in the 17th century at Banagher, Lusmagh and Shinrone (ibid. 441, 443). Ananias Henzey (listed as Ananias Henley), brother of Staffordshire glassworkers Joshua and Paul Henzey, owned the land around the Shinrone glasshouse site and is likely to have operated the furnace (Figure 2). Therefore useful parallels can be drawn between glassmaking at the Shinrone furnace and at glasshouses of slightly earlier date in Staffordshire. In 1670 Ananias Henzey set up a glass-house near the new town of Portarlington which was founded in c.1660 (see Figure 2). The Calendar of State Papers for November 1670 state that Hensey was 'failing in his art of making glass' due to 'some disappointment in the melting of his metal' (Westropp, 1920, 33) despite the fact that he had 'practised it in another place these twenty years past'. Ananias Henzey died in 1690 and is buried at Old Swinford, West Midlands, England (Grazebrook, 1877, 52).

In 1638/9 the exportation and manufacture of glass in Ireland was prohibited (Westropp 1978, 32) and in 1641 another Bill prohibited the felling of trees as a fuel supply for glass furnaces in Ireland (*ibid.,* 36). The archaeomagnetic date obtained for the furnace at Shinrone, indicates that it was last fired between 1610 and 1660 (at the 98% confidence level) and between 1620-1650 (at the 68% confidence level) (McCann and Gould, 1999). Therefore glass production at Shinrone is likely to have commenced around 1610, favoured by the monopoly in England, and ceased around 1640 with the bill enforcing a change in the fuel used in Ireland and the subsequent introduction of coal-fired furnaces.

Glass compositional types

In Europe in the medieval period, glass was produced using the ashes of plants as one of the raw materials and consequently this type of glass is commonly referred to as forest glass. These glasses have characteristic compositions as a result of the use of plant ash, tending to contain significant quantities of phosphorus as well as magnesia, lime and potash. However the relative amounts of these elements present varies greatly depending on a large number of factors, including the type of plant used, the region from which the plant derived, the time of year when the plant was collected, the part of the plant burnt and the temperature used for ashing (Smedley *et al*, 2001; Sanderson and Hunter, 1981; Turner, 1956; Stern and Gerber, 2004).

Recent analyses of medieval and early post-medieval glass from production sites in England have demonstrated that there are many different compositional types, which can be largely distinguished by variations in the concentrations of lime (CaO) and alkalis (potash K_2O and soda Na_2O) that they contain. At sites including Little Birches in Staffordshire (Mortimer, 1997; Welham, 2001) Blundens Wood in Surrey (Welham, 2001) and Idehurst North and South in the Weald (Dungworth and Clark, 2004), the forest glass produced contained high concentrations of potash and so has been referred to as 'potash glass'. The furnaces thought to have been producing potash glass range from 13th/14th century to mid 16th century in date.

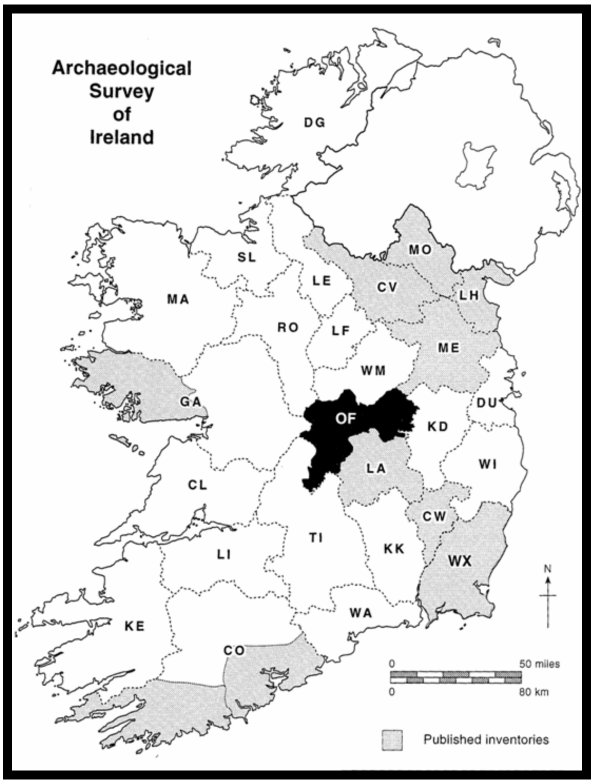

Figure 1: Location of County Offaly (OF) in the Republic of Ireland

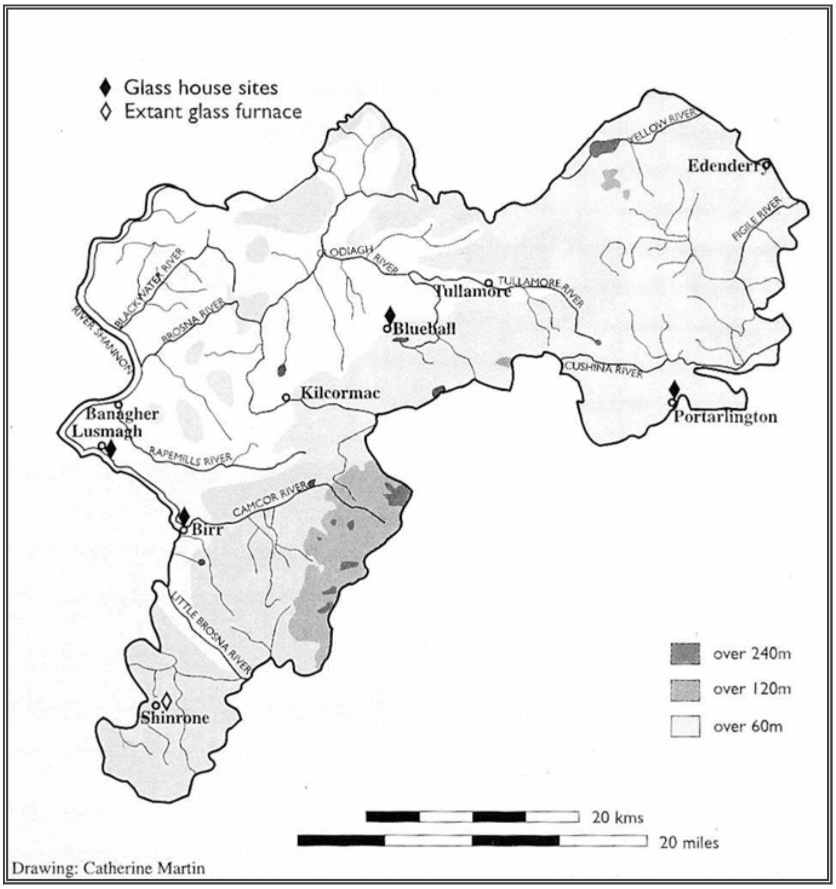

Figure 2: Location of glasshouse sites within County Offaly, including Birr, Lusmagh, Shinrone and Portarlington, all mentioned in this report (drawing by Catherine Martin).

A second type of glass identified at sites such as Kimmeridge in Dorset (Crossley, 1987), Sidney Wood in Surrey (Welham, 2001), Hutton in Yorkshire (Crossley and Aberg, 1972) and Tanland Copse in Sussex in the Weald (Dungworth and Clark, 2004), contains less potash but higher concentrations of lime and so has been referred to as high-lime, low-alkali glass (HLLA) (Mortimer, 1997). In England the transition from potash to HLLA glass takes place in the latter half of the 16th century, coinciding with the arrival of glass workers from France (Kenyon, 1967; Crossley, 1990) mentioned previously. The furnaces producing HLLA glass are all late 16th to early 17th century in date.

Other types of glass, in addition to the potash and HLLA types, have also been identified in the 16th/17th century period. Glasses with concentrations of lime and potash intermediate between these two types, which Mortimer has referred to as 'composition x' (Mortimer, 1997), appear to have been produced at sites such as St. Weonards in Herefordshire (Bridgewater, 1963), Cattail Pool and Bagot's Park in Staffordshire (Mortimer, 1997; Mortimer, 1993) and Knightons in Surrey (Welham, 2001). The furnaces producing this type of glass again date from the late 16th onwards; those listed here date from the late 16th century to the early 17th century.

The HLLA, potash and intermediate glass types generally contain a small amount of soda. However at some sites, for example at Rosedale in Yorkshire (Crossley and Aberg, 1972), Bickerstaffe (Hurst, 1968) and Haughton Green, both in Lancashire (Hurst, 1968; Vose, 1994), the glass produced contained higher amounts of soda (in excess of 3.5wt%). These glasses are sometimes referred to as 'mixed alkali' glasses and these sites again date to the late 16th and early 17th century.

The glass produced at Shinrone and Glaster is compared with these different compositional types later in this report.

The furnace

The Shinrone furnace was built from sandstone and comprised two sieges, each about 0.7m high with one on either side of the fire trench. Two ceramic pots holding the glass would have stood on each siege; in some places the imprints of the pots were still visible. Each end of the fire trench finished with an arch, from which the vaulted superstructure had been constructed (Figures 3 and 4). The vault of the furnace is approximately 3.3m high and the walls are around 0.8m thick. The side walls, now missing, were probably constructed from quartz-tempered handmade clay bricks as large numbers were found around the site, some with glazed surfaces similar to the rest of the furnace interior. These walls could have been demolished and rebuilt in order to remove or replace the crucibles (glass pots). Working or gathering holes, two in each side, for removing glass from the pots and reheating glass as it was worked, would have been incorporated into these brick-built walls. Although no evidence for the size of the gathering holes was found at the Shinrone furnace, a square cover for a working-hole found at Bagot's Park, Staffordshire, the site of an early 16th-century furnace (Crossley, 1967), was 0.2m across.


Figure 3: View of Shinrone furnace from the East during excavation

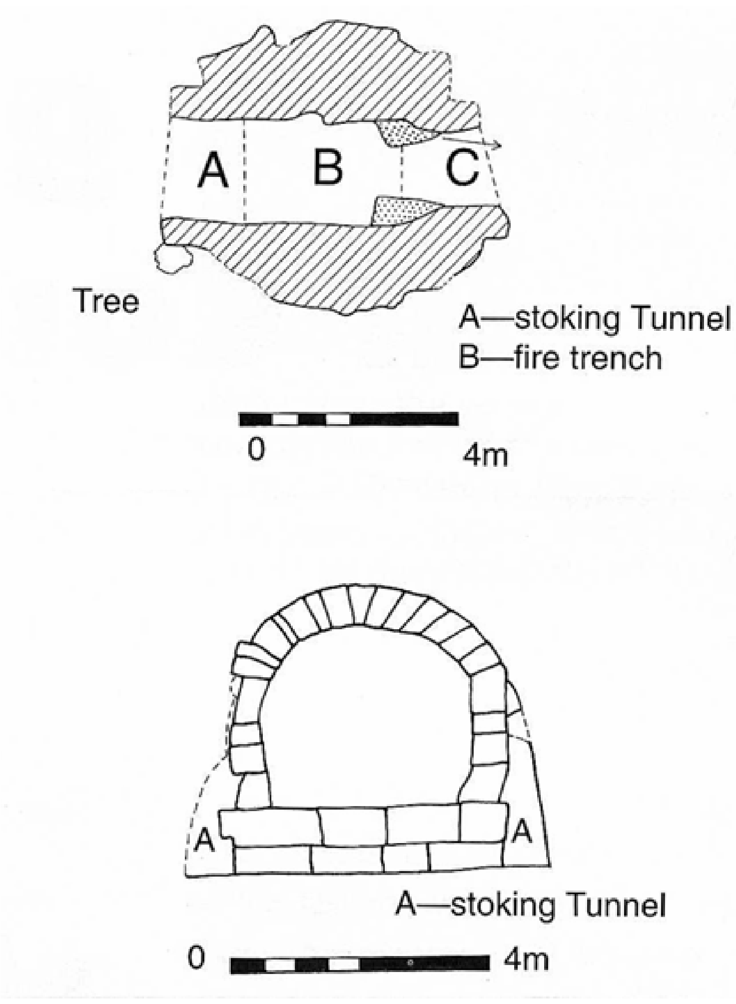

Figure 4: Plan and elevation of the glasshouse with flue running from north-east (on the left) to south-west (on the right)

The Shinrone furnace had no chimney but there were five holes high in the surviving walls of the furnace, each about 180mm wide, three in one face of the vault and two in the other. Comparisons can be drawn with post-medieval, wood-fired pottery kilns with domed superstructures, for which experimental replicas have been constructed containing a series of small vent holes in the dome, but no chimney, and these have operated successfully (Crossley, 1990, 272). The vents allow smoke to escape and give better control of the atmosphere within the kiln or furnace. The flue at Shinrone was slightly narrower at one end (the south-west end shown to the right of Figure 4) than the other, 1m wide as opposed to 1.8m wide, suggesting directionality in its use, and was 5.5m long.

Archaeological investigation

Two short seasons of excavation, a total of six weeks, were undertaken at Shinrone by Caimin O'Brien and Jean Farrelly (Figure 5). The glass furnace is situated on an eastern-facing slope of a north-south ridge, and would have been contained within an open-sided building measuring approximately 16m north-south by 10m east-west with a slate roof (Farrelly and O'Brien, 2000 and 2003). This furnace represents the final phase of glassmaking on site.

In the vicinity of the furnace, immediately beneath the surface, there was a large scatter of debris including furnace and crucible fragments and bricks. Below the debris were areas of internal flooring consisting of small stones in a mortared floor. Immediately north of the firing trench was an area of fire-reddened clay, which was archaeomagnetically dated. At the other end of the fire trench were two circular, shallow, flat-bottomed pits within a portion of the mortared floor. These may have acted as supports for circular barrels used by the glassmakers, for example to collect waste glass or as water containers.

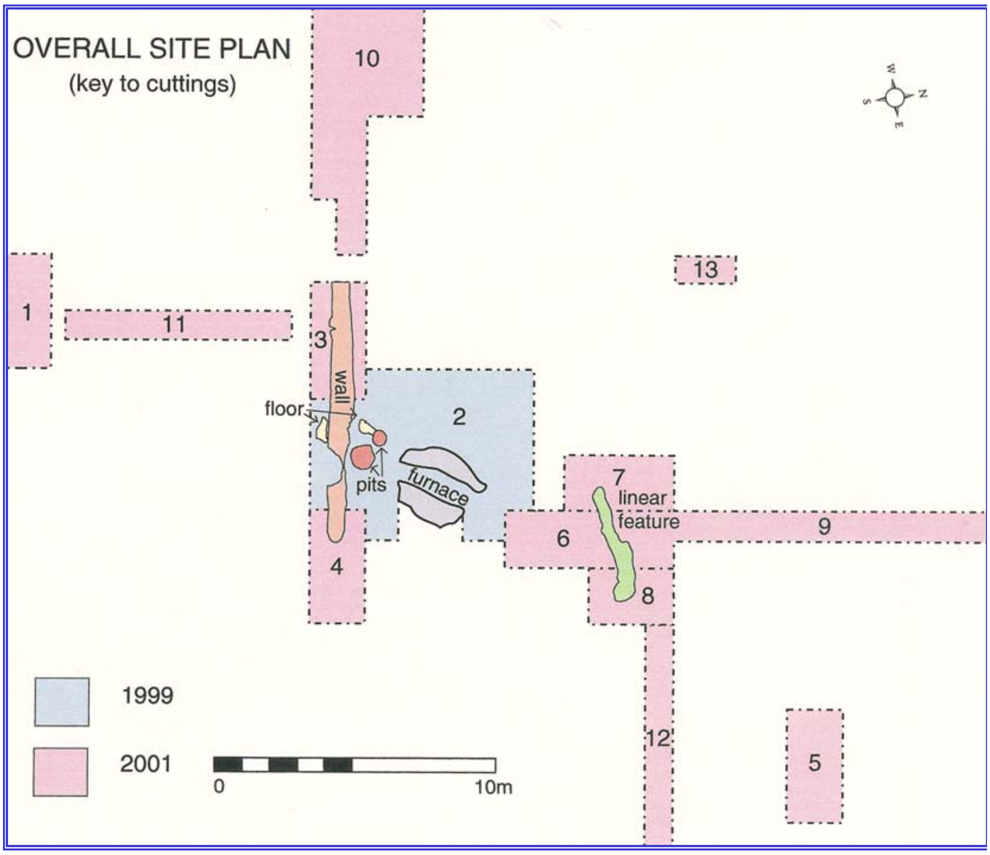

Figure 5: Site plan showing the areas excavated at Shinrone

South-west of the furnace, and upslope, the stratigraphy was over 1m deep. The stone foundation of a wall was discovered in cutting 2 in the first season of excavation, and was followed later in cuttings 3 and 4. The wall foundation appears to be the last phase of activity on the site, contemporary with the upstanding furnace. This wall is likely to have been a sidewall of the glasshouse as there is evidence of collapsed rubble and roof slates on the external south side of the wall. The foundation was cut into an earlier build up of fire-reddened clay, possibly re-deposited, and also partially ran along the edge of a pit full of debris, including crucible, brick and furnace fragments, which belong to an earlier phase of activity and possibly an earlier furnace. This pit was sealed with a layer of mortar. Beneath the fire-reddened clay were thin layers of charcoal-rich sandy soil containing window glass sherds. In trench 11, a stone feature running east-west, parallel with the wall and at a level contemporary with the wall foundation, was uncovered. Cutting 10 was not fully resolved but many scattered stones were uncovered 0.25 m beneath the surface, suggestive of a collapsed wall. The site appears to extend 16m west of the upstanding furnace.

East and north of the furnace, down slope, the stratigraphy was very shallow. An irregular linear feature running east-west was found in cutting 6, terminating in cuttings 7 and 8; this may have been a slot trench for a wooden fire-screen. Cuttings 9 and 12 contained a layer of stones and debris beneath the surface and a layer of mortar beneath, which may have been an area of hard internal flooring. In cutting 9 to the north of the glasshouse the internal mortared floor surface simply terminates where it meets a cobbled surface, possibly an external yard. Further to north-east, cutting 5 was archaeologically sterile. Although there was evidence for at least one sidewall to the south of the furnace, mentioned previously, no wall foundations were found to the north and east, which suggests that the building may have been open on these sides. The area to the north-west was largely unexcavated.

Finds assemblage

The finds assemblage from Shinrone comprised possible glass-working waste, glass products and fragments of glass-working structures recovered from various contexts (Appendix, Table 5) during two seasons of excavation at the furnace site. The assemblage was separated into categories on the basis of appearance, including colour, weathering characteristics and shape, by Jean Farelly. The categories included two types of pale green window glass (one with iridescent weathered surfaces), vessel glass, lumps and dribbles of glass, bottle glass, droplets of transparent blue glass, crucible fragments and furnace fragments. In addition a number of glass surface finds from the site of the Glaster furnace some 25km north of Shinrone, were also analysed. The glass in this assemblage consisted entirely of dribbles and lumps plus one crucible sherd and a fragment of refractory clay with one glazed surface; the latter was probably too thick to be a crucible sherd and so may be from a furnace structure.

Methods

Ten or more examples from most of the categories described above were sampled for examination and analysis using a scanning electron microscope with an energy dispersive spectrometer (SEM-EDS). The conditions used for analysis were an accelerating potential of 25kV, a beam current of 1.5nA and a counting time of 150s. Standard glasses of known composition were also analysed using SEM-EDS and the good agreement of the known and measured compositions is illustrated in the Appendix, Table 6. On the basis of the analytical results for glass standard D, the most similar to the glasses discussed in this report, an SEM-EDS analysis would be anticipated to be within about 20% relative of the Na_2O content, 5% of the MgO and Al_2O_3 content, 2% of the SiO_2, K_2O and CaO content, 12% of the P_2O_5 and MnO content and 18% of the Fe_2O_3 content. The detection limits for most elements measured by SEM-EDS were 0.1%, but 0.2% for P_2O_5 and SO_3 and 0.3% for Na_2O, BaO, SnO_2 and Sb_2O_5.

Results

The samples fell into several different compositional groups. The average compositions for each group are given in Tables 1 and 2 with the full data in the Appendix, Tables 7-13.

Glass waste and products made at Shinrone

The *dribbles* and *lumps* of glass from Shinrone all had similar compositions, which matched the composition of the *pale green window glass with iridescence* and the majority of the *pale green vessel* fragments from the site (see Table 1 for the average compositions and the Appendix, Tables 7 and 8 for the full data). Therefore both windows and vessels were made at Shinrone. The glass was of the HLLA type, produced from the late 16th century in England. Seven of the samples (three window glass fragments and four lumps of glass) contained slightly higher concentrations of soda and magnesia (Figures 7 and 8), and less silica, than the other samples but were similar in other respects.

Glass waste made at Glaster
All of the *dribbles* and *lumps* of glass from the Glaster furnace site had similar compositions and were HLLA type glass (average compositions in Table 2 and full data in the Appendix, Table 12). The Glaster glass was very similar to the glass made at Shinrone but they can be distinguished because the Glaster glass contains very slightly lower concentrations of manganese, phosphorus (Figure 6), aluminium and iron oxides (Figure 9); this is discussed later in this report.

Glass from Shinrone but made elsewhere
The average compositions for each of these groups are given in Table 1 and the full data are in the Appendix, Table 9.

The *pale green window glass (without iridescence)* from the Shinrone excavations was compositionally distinct from the glass made at the site, containing higher concentrations of magnesia and significantly higher levels of soda (Figure 8) but less manganese. This mixed alkali glass was not produced at Shinrone and had a more stable composition, so has not weathered to any visible extent.

All of the *bottle* glass samples were similar in composition and were HLLA glasses. However they contained more alumina, iron oxide (Figure 9) and often magnesium (Figure 7) and barium, but less potash (Figure 8) and often phosphorus, relative to the glass made at Shinrone. The higher iron content and greater thickness of these fragments accounts for their strong colour. They were not produced at Shinrone and both the composition and typology suggest that they are likely to post-date glass production at the site.

Four fragments of *pale olive vessel glass* from the site were found to be compositionally similar to the bottle glass, although they contained slightly less iron (Figure 9), manganese and barium. This glass is also distinct from the Shinrone glass and was not made at the site.

Table 1: Average compositions (wt%) and standard deviation of different types of waste from Shinrone, measured by EDS. Data from Tables 7-11. Figures in brackets: (number of samples / number of analyses)

Group	Type of waste		Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3	BaO
Glass waste made at Shinrone	Dribbles and lumps	Av	1.67	2.46	1.88	61.76	1.52	0.63	3.95	24.81	0.15	0.24	0.86	bd
	(24/72)	StDev	0.51	0.24	0.32	1.62	0.10	0.14	0.38	1.13	0.04	0.05	0.18	-
Glass products made at Shinrone	Pale green vessel	Av	1.56	2.55	2.07	62.23	1.54	0.73	3.96	24.01	0.15	0.24	0.88	bd
	glass (12/38)	StDev	0.22	0.17	0.16	0.69	0.10	0.11	0.22	0.38	0.04	0.04	0.12	-
	Pale gr'n window with	Av	1.91	2.71	2.11	61.74	1.75	0.55	3.73	24.12	0.14	0.27	0.85	bd
	iridescence (10/31)	StDev	0.80	0.37	0.62	2.03	0.46	0.19	0.27	0.52	0.07	0.17	0.23	-
Glass products from Shinrone but made elsewhere	Pale green window	Av	7.91	4.53	2.47	68.97	1.04	0.22	4.00	9.83	0.11	0.04	0.82	bd
	made elsew're (10/30)	StDev	0.87	1.62	0.61	1.54	0.35	0.17	1.36	2.34	0.07	0.04	0.29	-
	Bottles (10/28)	Av	1.61	3.41	5.37	59.09	0.57	0.47	1.86	24.46	0.31	0.19	2.33	0.34
	made elsewhere	StDev	0.44	0.87	1.13	1.31	0.45	0.08	0.55	1.19	0.10	0.06	0.59	0.29
	Pale olive vessel made	Av	2.55	3.87	4.06	60.05	0.87	0.46	1.27	24.94	0.24	0.07	1.57	bd
	elsewhere (4/13)	StDev	0.61	0.21	0.35	1.11	0.08	0.19	0.60	1.27	0.06	0.02	0.16	-
Shinrone crucibles and related waste	Crucible fabric (5/15)	Av	bd	0.36	22.37	71.44	0.23	0.04	1.90	0.36	2.43	0.01	0.69	bd
		StDev	-	0.05	1.73	1.84	0.06	0.03	0.26	0.04	0.36	0.01	0.15	-
	Crucible grog (2/5)	Av	bd	0.37	27.97	66.07	0.19	0.02	1.78	0.39	2.16	0.01	0.77	bd
		StDev	-	0.07	6.29	6.80	0.07	0.02	0.32	0.08	0.50	0.02	0.25	-
	Crucible glaze (5 both	Av	1.76	0.61	17.92	61.43	0.28	0.03	10.65	4.73	1.80	0.06	0.67	bd
	sides / 30)	StDev	0.50	0.37	3.77	2.40	0.23	0.03	2.17	4.46	0.43	0.06	0.71	-
	Vesicular brown waste	Av	2.82	0.35	18.33	68.06	0.13	1.27	5.75	0.82	1.87	0.02	0.55	bd
	(1/4)	StDev	0.24	0.04	0.37	1.20	0.09	0.96	0.41	0.45	0.39	0.01	0.06	-
Shinrone furnace materials and related waste	Furnace fragment	Av	bd	0.26	5.28	88.72	0.30	0.08	1.88	0.03	0.08	0.33	2.97	bd
	fabric (1/3)	StDev	-	0.13	1.66	2.25	0.07	0.10	0.39	0.02	0.05	0.06	0.38	-
	Furnace fragment	Av	1.41	0.63	4.84	78.96	0.33	0.05	8.30	2.95	0.31	0.18	2.00	bd
	glaze (2/5)	StDev	0.18	0.29	0.39	2.04	0.09	0.04	0.70	1.64	0.09	0.01	0.19	-
	Pale blue glassy	Av	1.61	0.53	4.64	79.31	0.25	0.02	7.92	3.82	0.20	0.17	1.47	bd
	droplets (9/27)	StDev	0.68	0.19	0.79	2.61	0.10	0.03	1.47	1.81	0.06	0.08	0.42	-

bd = below detection limit

Table 2:Average compositions (wt%) and standard deviation of different types of waste from Glaster, measured by EDS. Data from Tables 12-13. Figures in brackets: (number of samples / number of analyses).

Group	Type of waste		Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3	BaO
Glass waste made at Glaster	Dribbles and lumps (18/3)	Av	1.25	2.05	1.35	63.31	1.05	0.55	4.56	25.11	0.13	0.10	0.50	bd
		StDev	0.16	0.15	0.23	1.00	0.07	0.07	0.28	0.79	0.03	0.04	0.11	-
Glaster crucibles and related waste	Crucible fabric (1/3)	Av	bd	0.29	18.13	76.67	0.24	bd	1.20	0.27	2.32	bd	0.59	bd
		StDev	-	0.03	1.65	1.85	0.08	-	0.07	0.02	0.06	-	0.07	-
	Crucible grog (1/3)	Av	bd	0.29	19.01	76.17	0.26	bd	1.14	0.22	2.20	bd	0.51	bd
		StDev	-	0.08	3.05	3.26	0.01	-	0.08	0.03	0.17	-	0.01	-
	Crucible glaze (1 on one side /3)	Av	1.33	1.09	9.49	65.82	0.16	bd	8.44	12.06	1.08	bd	0.48	bd
		StDev	0.05	0.06	0.22	0.36	0.04	-	0.13	0.56	0.01	-	0.11	-
Glaster structural refractory clay and related waste	Structural refractory clay (1/3)	Av	bd	0.23	10.76	85.71	0.21	bd	0.88	0.28	1.08	bd	0.46	bd
		StDev	-	0.02	0.61	0.83	0.05	-	0.08	0.07	0.06	-	0.08	-
	Structural refractory clay grog (1/3)	Av	bd	0.27	19.18	75.25	0.21	bd	1.54	0.37	2.21	bd	0.62	bd
		StDev	-	0.05	1.38	1.23	0.02	-	0.15	0.05	0.09	-	0.10	-
	Structural refractory clay glaze (1/3)	Av	1.41	0.40	7.40	77.04	0.19	bd	10.15	1.96	0.84	bd	0.47	bd
		StDev	0.19	0.11	0.67	0.57	0.04	-	0.18	0.67	0.02	-	0.09	-

bd = below detection limit

Table 3: Composition of oak ash according to Turner, 1956, normalised.

Na_2O	MgO	SiO_2	P_2O_5	SO_3	K_2O	CaO
3.9	3.9	2.0	5.8	2.0	9.5	72.5

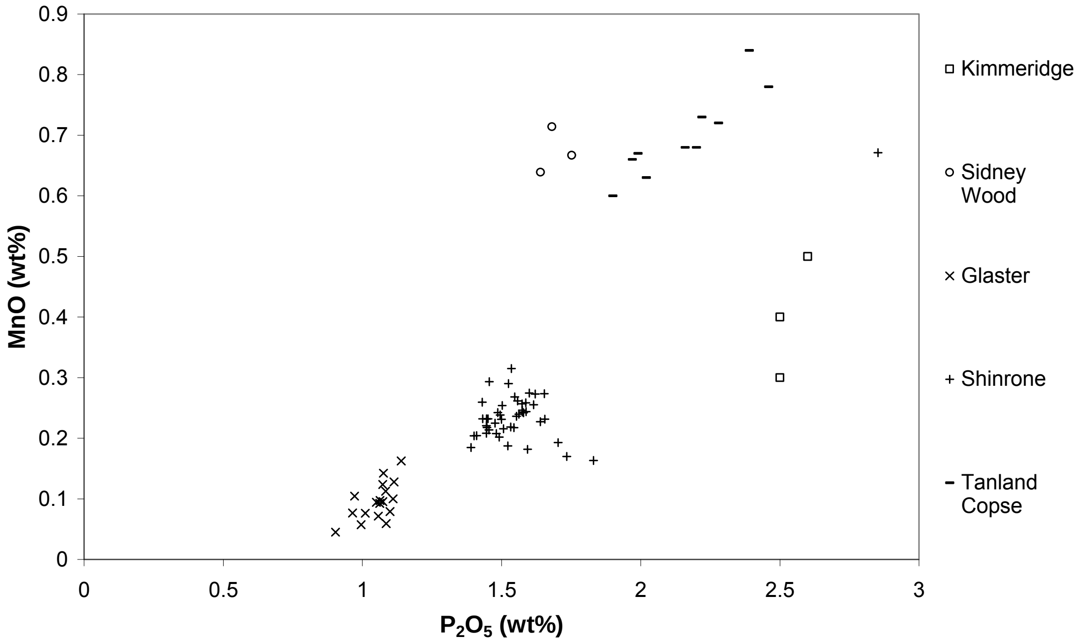

Figure 6: Manganese versus phosphorus oxide for late 16th / early 17th-century HLLA glasses from England and Ireland, using data from this study and from Kimmeridge (Crossley, 1987), Tanland Copse (Dungworth and Clark, 2004) and Sidney Wood (Welham, 2001).

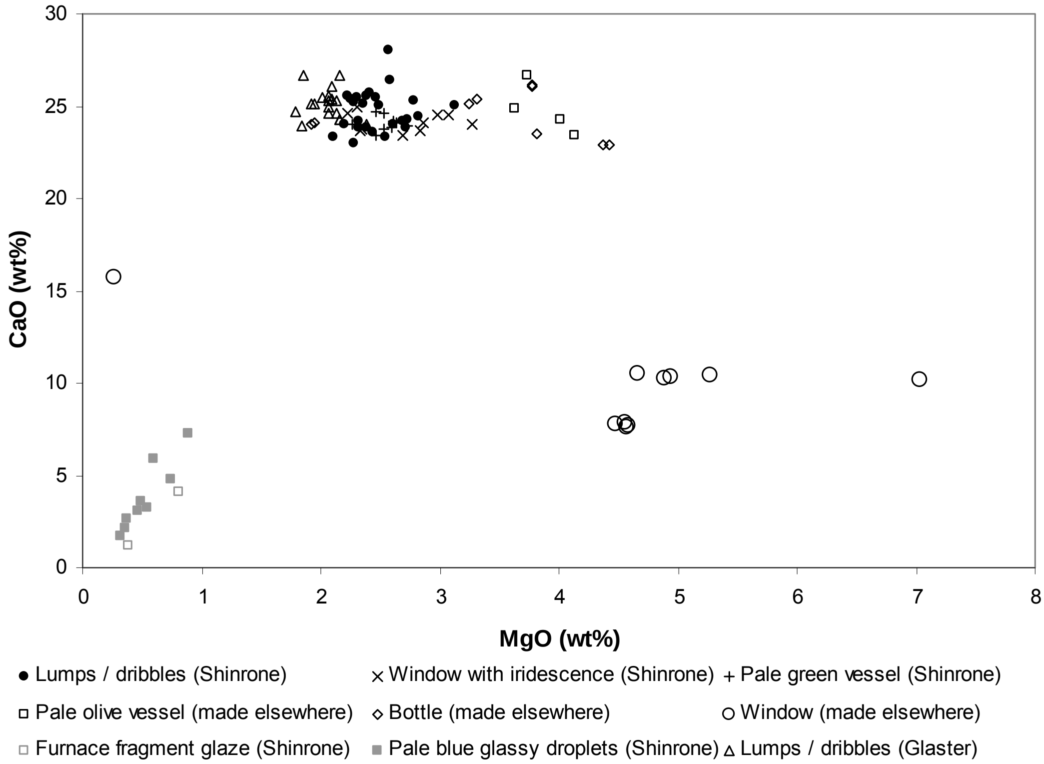

Figure 7: Lime versus magnesia for the Shinrone and Glaster assemblages

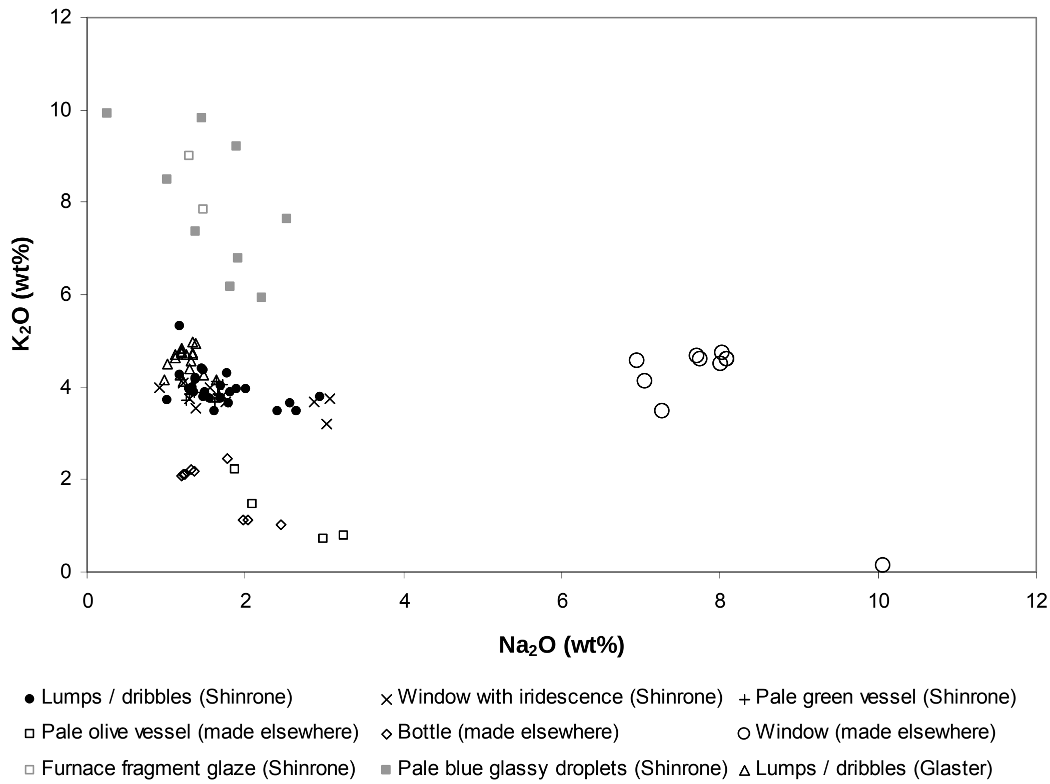

Figure 8: Potash versus soda for the Shinrone and Glaster assemblages

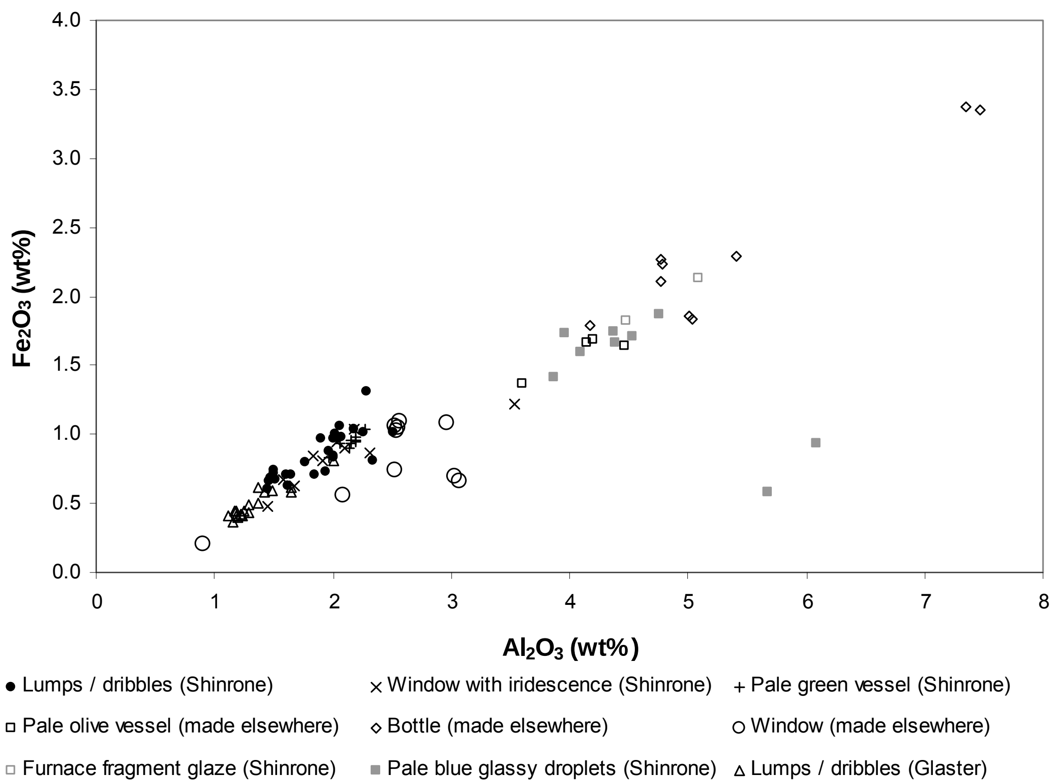

Figure 9: Iron oxide versus alumina for the Shinrone and Glaster assemblages

Furnace materials and related waste from Shinrone

The average compositions of all of these groups of samples are given in Table 1 and the full data are in the Appendix, Table 11. The furnace was constructed from sandstone, and analysis showed that *furnace fragments* contained around 90wt% silica. This material was well suited for construction of the glass house as it would have excellent temperature resistance. The blue, transparent glaze on the surface of the furnace fragments was rich in potash but contained little magnesia or lime. It matches the composition of the *pale blue glassy droplets*. This glassy material was produced unintentionally through the reaction of the silica-rich sandstone used to construct the furnace with potash-rich ashes and vapour (Misra *et al*., 1993) from high temperature dissociation of potassium carbonate in the ashes of the wood fuel. Over time, droplets of glaze have accumulated and fallen from the furnace roof onto the working surface below. The blue colour of the droplets is caused by a small amount of iron in the glass, derived from the sandstone. This type of material is also observed in wood-fired pottery kilns in China, where it is known as 'kiln sweat' (Wood, 1999).

Crucibles and related waste from Shinrone and Glaster

Large sherds of used *crucible*, including rims, were recovered during the excavations, though no bases were found. From these sherds, the vessel diameter at the rim was estimated as 0.5m and the imprint of a crucible base on one of the sieges was 0.4m diameter. The crucible walls were about 25mm thick. A number of samples had microstructures indicative of very high temperatures, where a large proportion was heavily vitrified despite the refractory properties of the material. Analysis showed that the crucible clay comprised about 20wt% alumina, 70wt% silica and small amounts of titania, potash and iron oxide. The same type of clay appears to have been used for the crucibles at Glaster, although more samples from Glaster are required to confirm this. The high titania content clearly distinguishes this refractory clay from those used in many English glasshouses of the 16th century and later, with the exception of the crucibles from Kimmeridge (Briggs in Crossley, 1987, 372), which were compositionally very similar to the ones from Shinrone and Glaster. The Kimmeridge crucibles contained 78% silica, 20% alumina, 1.5% potash and 2% titania and were made of a hard white, ungrogged clay, which Williams (in Crossley, 1987) suggested may have been pipeclay from the Dorset Bagshot Beds, of the type mentioned by Merrett (Cable, 2004). Other potential sources of crucible clay are mentioned in historical records, for example an early 17th-century manuscript for a glasshouse, probably at Ballynagerah Co. Waterford, states that 'fine white or sky colour clay' for the glass pots was obtained 'from Fethard', probably in Co. Wexford (Westropp, 1920, 26). Another record at about the same time, relating to the glasshouse at Birr in the King's County, states that the clay for the crucibles 'came from the north'.

The clay used in the construction of the Shinrone crucibles had been tempered with rounded quartz grains, and also contained particles of grog (ground up, previously fired ceramic). Analysis of the grog particles in each case indicated that these were made from the same type of refractory clay as the rest of the crucible. The addition of quartz and grog temper would have modified the properties of the clay in several beneficial ways. When clay dries the lubricating water that gives it plasticity is lost, and is accompanied by shrinkage. The presence of temper, which has no drying shrinkage, facilitates even drying and reduces the overall shrinkage and warping of the clay (Hamer and Hamer, 1997; Kingery and Vandiver, 1986). Temper is also useful in preventing the catastrophic failure of pottery during firing, particularly for thick or large objects, such as crucibles. Dry, but unfired, clay still contains chemically combined water and when the temperature rises during firing, this water boils and increases in volume. If the water is unable to escape then the pot can fail dramatically due to the build up of pressure. However the small channels and cracks that develop in a tempered pot during drying, due to the differential shrinkage of the temper and clay, allow the steam to escape, even from the clay furthest from the surfaces (Varndell and Freestone, 1997, 32-37; Tite, 1999). The presence of small voids and cracks in a ceramic structure can also help to prevent the growth of larger catastrophic cracks, thereby increasing the toughness of the ware (Tite, 1999). It is clear that as much care and expertise was required in the selection, preparation and use of raw materials for crucibles as was needed for the glass heated in them.

‘Glazes’ were present on both sides of the crucible sherds examined but their appearance and composition were variable and none of them had been intentionally produced. All of the glaze layers contained elevated concentrations of oxides such as alumina and titania, as they resulted from the interaction and dissolution of the crucible fabric with the vapour and ash produced by the wood fuel used in the furnace. The glazes, both on the inner and outer surfaces of the crucible shreds, were potash-rich like the glazes on the furnace structure. None of them had compositions representative of the glass that the crucibles had originally contained. However on some fragments one of the glaze layers was found to be richer in lime towards the surface in some places, as a result of the lime-rich glass that had been in contact with the crucible during use. The glazes often had matt, opaque patches due to the precipitation of crystalline phases at the surface.

The single fragment of crucible from the Glaster site again contained grog and quartz grains (Table 2 and Appendix, Table 13). A second piece of the same fired refractory clay from the Glaster site was considerably thicker than the other crucible fragments. It had only one original surface, on which a thick transparent glaze had formed, and contained both grog and a large quantity of quartz temper. The size and shape of the fragment and the large quantities of quartz present indicate that this may not be a crucible sherd, but rather a fragment of furnace structure made using the same refractory clay as used for the crucibles.

Analysis of a fragment of *vesicular brown waste* from the excavations showed that it was compositionally similar to the crucibles but with increased concentrations of alkalis (potash and soda). Lumps of quartz were occasionally present and some calcium sulphate was identified (Table 1 and Appendix, Table 10). This waste was produced through the reaction of the refractory clay used for the crucibles, and possibly some parts of the furnace structure, with alkalis, predominantly from the wood fuel used, rather than from the glass being made. The waste had accumulated on the sieges around the imprint of the crucible bases. To vitrify, this refractory material would have required exposure to high temperatures for long periods.

Discussion

Possible raw materials, and their proportions, used for glass production at Shinrone and Glaster

Potash and HLLA glasses were produced using ashes from plants, which can vary greatly in their composition as mentioned previously. The early 17th-century glasshouse at Ballynagerah, in Co. Waterford, listed ashes from the tanyard and castle grates together with kelp and fern ashes plus other unspecified types in their accounts (Westropp, 1920, 25-27). The ashes were combined with silica derived predominantly from sand and possibly quartz pebbles. Another contemporary record states that sand for glass-making in Irish glasshouses came from England and that alkali was obtained locally from the ash tree (Westropp, 1920, 31). Glass workers also collected waste glass (cullet) to add to their glass batches. Other factors, such as the temperature and duration of firing, and any additional stages involved in raw material preparation and glass production, such as fritting and refining, may also have affected the composition of the glass produced. In light of all of these variables, it is significant that the analytical results indicate that the glass produced at Shinrone had a consistent composition (see Table 1). The same is true of the glass produced at Glaster (see Table 2).

The consistency of the glass compositions indicates that the furnace conditions were accurately controlled, that great care was taken over the selection and preparation of the raw materials and cullet, and that an ample supply of the same raw materials was probably available throughout the glass-working period at Shinrone. It is known that Abraham Bigo’s glasshouse lease included the condition that all of the wood for his glasshouse should be bought from the overlord of Birr Castle. Therefore it is likely that the Shinrone and Glaster furnaces each had relatively plentiful supplies of wood for ashing, and that in both cases the wood for ashing was obtained predominantly from a single source.

The woodland in the Shinrone area, as in all of Co. Offaly, was mainly oak. For example, in 1537 there was a proposal to repair the castle at Trim, Co. Meath with several hundred great oaks to be felled in the forest of Offaly (Butler 1843, 78). Analytical data are available for oak ash (Turner, 1956; Sanderson and Hunter, 1981) and the data from Turner are reproduced in Table 3. Although these data do not include manganese, the results of Sanderson and Hunter (1981) indicate that several weight percent of manganese can also be present. These data are only used as a guide to the contribution of the ash to the glass, because of the compositional variability of ash and also because not all of the elements in the ash are in a form that can be easily incorporated into the glass (Turner, 1956). (For example, the reaction of the chlorides, NaCl and KCl, and sulphates with the glass batch is limited, and both are poorly soluble in molten glass). The ratios of elements present in the oak ash are approximately comparable to those in the Shinrone glass, and therefore locally-grown oak is likely to have been the predominant source of ash used at Shinrone. However the compositions of other types of wood ash, including birch and poplar (Turner, 1956; Sanderson and Hunter, 1981; Stern and Gerner, 2004) would probably be similar to oak (providing that the plants grew in the same geological environment) and cannot be discounted. Beech ash is also similar but beech is not a native species in Ireland; it was introduced into the country on a small scale at the end of the 17th century, only becoming widespread in the 19th century (McCracken 1971, 39, 135). It is possible that small amounts of other types of ash may have been used as well, for example adding alkali-rich kelp ash would increase the proportion of soda present slightly.

The proportions of raw materials used to produce the Shinrone glass, calculated using the normalised and oxidised composition of ash shown in Table 3, would be about 35wt% ash to 65wt% sand. However, in its original form a large proportion of the ash would have been in the form of carbonates and compounds containing absorbed water (Stern and Gerber, 2004) rather than oxides. The compositional data of Sanderson and Hunter (1981) suggest that less than half of the ash contributes to the glass composition and the rest is lost, for example as water and carbon dioxide during heating. Taking this into account the proportions by weight actually used by the glass makers could have been nearer to 1:1 ash and sand, or slightly more ash than sand.

Differences in the composition of HLLA glass from different sites

The glass produced in Ireland at Shinrone and Glaster is broadly similar to the HLLA glass produced in England at the late 16th- and early 17th-century sites mentioned previously. This suggests that similar furnace conditions and raw materials were used, which might be expected given that these furnaces share an association with glass-making families of French descent. However the Irish glass can be differentiated from the English equivalents because it contains lower concentrations of phosphorus (<1.8% P_2O_5) and manganese (<0.31% MnO) (see Figure 6). It is unlikely that the differences are due to treatment of the plant ash, such as leaching with water, since the glass compositions each contain both soluble (eg. potash) and insoluble (eg. lime) components from the ash. Sanderson and Hunter (1981) showed that it would be difficult to distinguish between the ashes of species such as oak and beech because of the similarities between the results taking into account the large variability in ash composition for each species. However they found that the manganese values for the ash from both species was strongly correlated with those of plants from each of the sites included in their study (data for phosphorus were not provided). Therefore the low manganese and probably the phosphorus values for the Glaster and Shinrone glass may be predominantly attributable to the geology of the region where the plants for ashing were grown, in both cases Carboniferous Limestone (Hallissy, 1979), rather than the species used.

As the compositional differences between the glass from Shinrone and the glass made at Glaster are so small, they are most likely to be a result of the use of wood and sand from different locations (although geologically similar as discussed above), perhaps near to each furnace and consequently with slightly different compositions. The difference between the concentrations of manganese and phosphorus in the Shinrone and Glaster glass is also likely to be related to the plant ash used. Both the plant ashes and the sand used are likely to have contained aluminium and iron compounds in varying amounts (Sanderson and Hunter, 1981) influencing the proportions of these elements present (see Figure 9).

Estimating the operating temperature of the Shinrone furnace

The glass waste and glass products from Shinrone are homogeneous and amorphous and so are likely to have been heated to above the liquidus temperature of the mixture in order to produce an inclusion-free melt. The viscosity of the glass would have increased as it cooled until, at a certain temperature, it was low enough for the glass to be easily shaped whilst viscous enough to hold its form.

A variety of different methods can be used to estimate the temperatures required for producing and working glass. One method is to use a phase diagram, which is a representation of the equilibrium state between different phases in a system, showing the influence of variables such as temperature and composition (Levin *et al*., 1964). Although phase diagrams provide a useful guide to liquidus temperatures, large errors can be introduced when considering multi-component systems. Archaeological glasses have complex compositions that have to be simplified, by combining oxides with similar properties and ignoring others, before they can be represented on a phase diagram.

Mathematical models can also be used to estimate the viscosity (Lakatos *et al*, 1972) or liquidus temperature (Cable and Smedley, 1987) of a sample of known composition. The models have been developed to fit experimental data gathered for glasses of varying composition. Again, archaeological glasses are generally more complex than allowed for by models, and so some simplification of the composition is necessary. Also, if the composition of the archaeological glass falls outside the compositional range of the experimental glasses used to form the model, the results are unlikely to be reliable.

Because of these difficulties the most accurate indications of the temperatures required to produce archaeological glasses are often provided by experiment. Cable and Smedley (1987) determined the liquidus temperatures of samples of HLLA archaeological glass as well as replicated glasses with HLLA compositions. Smedley *et al*. (2001) determined the rate of melting, at different temperatures, for replicated potash glasses. Welch (1997), Dungworth (2003) and Crossley (1987, 372) estimated the maximum temperature of use for crucibles from Little Birches (potash), Silkstone (HLLA) and Kimmeridge (HLLA) by monitoring changes with temperature of thermal expansion, microstructure and shape respectively.

The temperatures likely to have been attained at Shinrone and Glaster have been estimated by comparison with experimental data gathered for glasses of similar composition (see Table 4) and waste products associated with those glasses. The melting temperature of the glass-working waste (for example the lumps and dribbles) and also of the glass products from Shinrone is estimated to be in the region of 1260-1290°C, and therefore the temperature attained in the furnace may have exceeded this slightly. By comparison with crucibles of similar composition from Silkstone (Dungworth, 2003) and Kimmeridge (Crossley, 1987), which were tested to destruction, the Shinrone crucibles would probably have started to loose their strength and shape at about 1550-1600°C. The same crucibles were examined for evidence of the temperatures that they experienced during use, and the estimates were1300-1325°C for Silkstone and 1300-1350°C for Kimmeridge.

Estimating the quantities of raw materials required for glass production at Shinrone

In the following discussion, an attempt has been made to estimate the amount of wood required to supply sufficient ash for each firing at the Shinrone furnace. For this, comparisons with furnaces in England from the late 16th century onwards have been made, on the basis that similar French glass-working traditions were practiced in England at this time to those employed at Shinrone in the early 17th century. However the estimate is very approximate because of the great variability in the yield and composition of wood ash.

The Shinrone crucibles were approximately 0.4m wide at the base, the rim diameter was estimated at 0.5m and the crucible thickness was about 25mm. At Kimmeridge (Crossley, 1987) the crucibles were of a roughly comparable size with a base diameter of 0.32-0.37m and a rim diameter varying from 0.4 to 0.43m. The crucible height was about 0.47m and their thickness about 30mm. Therefore in the following calculations, the height of the Shinrone crucibles has also been estimated as about 0.47m, although it was not possible to reconstruct any of the Shinrone crucibles to their full height.

The Shinrone crucible was approximated to a cylinder with a diameter of 0.4m and, assuming that the crucibles were not filled to the brim, the volume of glass in each crucible produced from raw materials, was estimated as $0.4 \times \pi (0.4 / 2)^2 = 0.05\text{m}^3$.

The density of the glass was estimated at about 2200kg/m^3 (Mazurin *et al.*, 1987). Therefore the mass of glass produced per crucible was estimated as 2200 x 0.05 = 110kg.

By comparing the composition of the Shinrone glass with data for oak ash, it was estimated previously that 35% of the glass mass was derived from plant ashes (0.35 x 110 = 38.5kg).

Table 4: Experimental data for the liquidus of HLLA glass from the literature, (T exp = liquidus temperature indicated by crystallisation, T DTA = liquidus temperature determined by differential thermal analysis, see Cable and Smedley, 1987)

Sample	**Na_2O**	**MgO**	**Al_2O_3**	**SiO_2**	**P_2O_5**	**SO_3**	**K_2O**	**CaO**	**TiO_2**	**MnO**	**Fe_2O_3**	**BaO**	**Texp**	**T DTA**	**Reference**
10071	0.12	2.45	1.55	62.8	1.39	0.11	6.31	24.5	0.14	0.08	0.28	bd	1350	1310	Stern and Gerber, 2004
10074	0.28	3.36	2.56	61.8	2.37	0.07	5.99	20.2	0.19	1.65	0.71	0.21	1350	1320	
Hutton	1.3	2.5	2.2	62.6	2.0	0.3	5.9	21.2	ns	0.38	0.8	ns	1288	1265	Cable and Smedley, 1987
Rosedale	4.9	4.7	3.2	59.0	2.1	0.2	4.2	17.9	ns	0.29	1.6	ns	1200	1180	
Kimmeridge	3.9	4.0	2.2	60.3	1.9	0.34	3.2	21.3	ns	0.32	1.3	ns	1245	1240	
Shinrone	1.67	2.46	1.88	61.76	1.52	0.63	3.95	24.81	0.15	0.24	0.86	bd	-	-	This study

ns= not sought, bd = below detection limit

However the weight of ash actually added would have been considerably more than this, because about half the weight of the ash would be lost on heating, for example as water and carbon dioxide (Stern and Gerber, 2004; Misra *et al*., 1993). From the data of Sanderson and Hunter (1981) it has been estimated that around 42wt% of the ash added contributes to the glass composition, and therefore the amount of ash required per crucible is ~ 38.5 / 0.42 = 92kg.

Of the wood burned, only 0.5% ash is produced for oak, according to Turner (1956), therefore the amount of wood burned for ash per crucible would be 92 / 0.005 = 18.3 tonnes. As four crucibles were used at Shinrone, this equates to about 70 tonnes of wood per firing (not including the fuel for the furnace).

Although very approximate, this estimate illustrates the vast quantities of wood required simply for ashing in order to produce four crucibles of glass. Wood was also required to fuel the furnace and, since the ash from the fuel was probably recovered as much as possible for use in the glass batch, it is difficult to consider the two requirements separately (Godfrey, 1975). Ash could also be obtained already prepared. However the large estimate above suggests that the deciding factor in the amount of wood consumed may have been the quantity of ash required for the batch rather than the fuel demands of the furnace.

Conclusions

The Shinrone wood-fired glass house produced window and vessel glass of the high-lime, low-alkali type in the early 17th century. The glass was produced using a mixture of sand and plant ashes, of a species most likely oak from the surrounding woodlands. The consistency of the glass composition indicates that great care was taken in the selection of the raw materials and the control of the furnace operating parameters, and also that a plentiful supply of wood, from the same source, was probably available for ashing throughout the lifetime of the glasshouse. The furnace would have reached temperatures of at least 1260-1290°C in order for the glass to completely melt. Refractory materials were used to construct the furnace (sandstone and quartz-tempered brick) and for the crucibles (quartz and grog-tempered fire clay). The refractory clay is similar to the one utilised for crucibles at Kimmeridge by Abraham Bigo.

The furnace had a single flue suitable for use with wood billets, which produce a long flame (Crossley, 1990). The narrowing of the flue towards one end may suggest some directionality in the way it was used. There was no chimney but five small vents in the furnace roof would have facilitated control of the fuel burning rate, and hence the temperature, as well as allowing smoke to escape thereby influencing the furnace atmosphere. Potash-rich vapour, resulting from the disassociation of potassium carbonate in the fuel ash, reacted with the crucible surfaces and the interior walls of the furnace, causing the surfaces to glaze and ultimately resulting in droplets of transparent blue glaze falling from the furnace roof and walls; droplets of this 'kiln sweat' were found during the excavations.

The Glaster glasshouse also produced HLLA glass, operated at similar temperatures and used the same type of fireclay in the construction of the crucibles and possibly some of the furnace structure. Slight differences were observed between the compositions of the Glaster and Shinrone glass, due to differences in the source of raw materials used. The glass from these two Irish sites could be distinguished from the HLLA glass made at English sites in the late 16th to early 17th centuries, by the low manganese and phosphorus content of the Irish material. This is a result of the composition of the plant ash used and reflects predominantly the geology where the plants grew, and possibly the type of species used, at different furnace sites.

The French families associated with the Shinrone and Glaster furnaces also have links with glass making sites in England, such as at Kimmeridge, in Dorset, and in Staffordshire. Therefore there is potential to compare further, and in more detail, the technology and materials used at these, and other, glass furnace sites in late 16th and early 17th England. The excellent survival at Shinrone provides a unique opportunity to investigate the workings of post-medieval wood-fired glasshouses, which can be exploited in future research.

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Appendix

Table 5: Context descriptions

Context	Cutting	Description
1	1	Surface layer
2	1	Immediately under surface
4	2	Immediately under surface – top soil layer
5	2	Beneath C 4 – stoney layer with mortar, crucible and furnace frags.
7	1	Beneath C 2 – silty clay layer with some window glass
9	2	Immediately under surface and over C 12 and C 13 – probably layer of collapse material from furnace
10	2	Stony later immediately beneath surface with crucible frags.
12	2	Lighter clay under but possibly contemporary with C 9
13	2	Immediately outside (to NE) stoking tunnel – cinder layer
14	2	Immediately outside stoking tunnel – fire-reddened clay beneath C 13
18	2	Under C 5 – contains large quantities of furnace debris, crucible frags etc.
19	2	Top layer of loose soil in fire trench of furnace
20	2	Beneath C 19 in fire trench of furnace – 'coal' flecked layer
21	2	Beneath C 10 – fine grey silty sand layer which appears to contain ash
22	2	Beneath C 5 – reddish brown layer with frags of mortar, brick and fire-baked clay
27	3	Fire-reddened silty sand immediately below surface
29	2	Under C 5 – similar and possibly contemporary with C 22 but not reddened.
30	2	Under C 4 (top soil) – brown clayey silt with glass, brick and mortar frags
31	1	Beneath C 2 - natural sand layer disturbed by animal and root action
34	1	Fill of pit cut into C 2 and C 31
39	2	Beneath C 29 – brown soil with flecks of fire-reddened clay
46	4	Under surface and top soil – stoney layer with patches of compact mortar
60	6	Directly under surface – stoney layer with furnace and brick frags
82	3	Coarse yellow sand – lowest statigraphic level, immediately above natural
89	3	Fine black sand with window glass – below C 27 and above C 82

Table 6: Known compositions (bold Italics) versus compositions measured by EDS (normalised, bold) for Corning glass standards. Known compositions from Brill, 1999. bd = below detection limit

Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3	CoO	CuO	ZnO	SnO_2	Sb_2O_5	BaO	PbO
	13.55	2.53	1.04	67.22	0.23	0.22	2.87	5.13	0.81	1.08	1.04	0.22	1.44	bd	bd	1.82	0.61	bd
A	13.53	2.51	0.97	67.19	bd	bd	2.94	5.30	0.90	1.05	1.22	0.22	1.35	0.13	bd	1.94	0.47	bd
	13.75	2.39	0.94	66.84	bd	0.25	2.94	5.28	0.85	1.08	1.11	0.20	1.39	0.17	bd	1.88	0.59	0.12
	13.53	2.62	0.90	66.97	0.29	bd	2.87	5.17	0.78	1.08	1.21	0.20	1.27	0.13	bd	2.11	0.50	bd
Average	**13.59**	**2.51**	**0.96**	**67.05**	**bd**	**bd**	**2.91**	**5.22**	**0.83**	**1.07**	**1.14**	**0.21**	**1.36**	**0.13**	**bd**	**1.93**	**0.54**	**bd**
StDev	0.11	0.09	0.06	0.18	-	-	0.04	0.08	0.05	0.02	0.09	0.01	0.07	0.04	-	0.13	0.07	-
Known	***14.3***	***2.66***	***1***	***66.93***	***0.13***	***0.1***	***2.87***	***5.03***	***0.79***	***1***	***1.09***	***0.17***	***1.17***	***0.044***	***0.19***	***1.75***	***0.56***	***0.12***
	16.57	1.05	4.01	61.68	0.95	0.65	1.01	8.77	0.20	0.30	0.39	bd	2.89	0.31	bd	0.60	bd	0.51
	16.58	0.98	4.09	61.82	0.94	0.60	1.00	8.91	0.12	0.29	0.40	bd	3.14	0.20	bd	0.45	bd	0.33
B	16.37	0.93	4.09	62.14	0.83	0.66	1.03	8.99	0.12	0.23	0.44	bd	3.11	0.32	bd	0.28	bd	0.35
	16.21	1.09	4.17	61.92	1.03	0.67	1.13	9.02	0.08	0.23	0.32	bd	2.96	0.37	bd	0.21	bd	0.47
	16.40	1.10	4.14	61.79	0.88	0.54	1.01	8.71	0.13	0.21	0.39	bd	3.04	0.35	bd	0.51	bd	0.46
Average	**16.43**	**1.03**	**4.10**	**61.87**	**0.92**	**0.62**	**1.04**	**8.88**	**0.13**	**0.25**	**0.39**	**bd**	**3.03**	**0.31**	**bd**	**0.41**	**bd**	**0.43**
StDev	0.15	0.07	0.06	0.17	0.07	0.05	0.06	0.14	0.04	0.04	0.05	-	0.10	0.06	-	0.16	-	0.08
Known	***17***	***1.03***	***4.36***	***61.73***	***0.82***	***0.5***	***1***	***8.56***	***0.089***	***0.25***	***0.34***	***0.046***	***2.66***	***0.19***	***0.04***	***0.46***	***0.12***	***0.61***
	1.27	3.86	5.17	55.51	4.23	bd	11.30	14.73	0.38	0.57	0.47	bd	0.48	0.29	bd	1.15	bd	0.17
D	1.04	4.08	5.08	55.18	4.18	0.33	11.40	14.77	0.45	0.56	0.60	bd	0.57	0.23	bd	1.00	0.30	0.19
	0.98	3.98	5.09	55.44	4.17	0.32	11.37	15.05	0.46	0.55	0.53	bd	0.41	0.12	bd	0.99	0.35	0.19
	1.19	3.98	5.14	55.44	4.37	0.25	11.33	14.85	0.33	0.50	0.43	bd	0.54	0.12	bd	1.00	0.45	bd
Average	**1.12**	**3.97**	**5.12**	**55.39**	**4.24**	**0.27**	**11.35**	**14.85**	**0.40**	**0.54**	**0.51**	**bd**	**0.50**	**0.19**	**bd**	**1.04**	**0.34**	**0.15**
StDev	0.14	0.09	0.04	0.15	0.09	0.07	0.04	0.14	0.06	0.03	0.07	-	0.07	0.08	-	0.07	0.09	0.07
Known	***1.2***	***3.94***	***5.3***	***54.82***	***3.93***	***0.3***	***11.3***	***14.8***	***0.38***	***0.55***	***0.52***	***0.023***	***0.38***	***0.1***	***0.1***	***0.97***	***0.51***	***0.48***

Table 7: SEM-EDS analyses (normalised) for glass waste from Shinrone, results for 3 separate areas on each sample

Type	Cutting	Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
	3	C89	2.85	3.05	2.00	59.79	1.51	0.51	3.85	25.20	0.16	0.22	0.84
			2.96	3.15	2.11	59.66	1.49	0.62	3.74	24.84	0.15	0.24	0.88
			3.02	3.16	1.89	59.91	1.53	0.46	3.77	25.16	0.13	0.19	0.76
	3	C89	1.58	2.54	2.24	57.73	1.56	0.66	3.75	28.03	0.14	0.36	1.29
			1.70	2.58	2.34	57.41	1.55	0.74	3.79	28.13	0.19	0.24	1.31
			1.80	2.57	2.29	57.47	1.51	0.72	3.75	27.91	0.19	0.35	1.35
	3	C27	1.58	2.39	2.10	59.89	1.65	0.81	4.41	25.52	0.18	0.25	1.10
			1.42	2.46	2.05	59.67	1.65	0.78	4.31	26.00	0.17	0.30	1.05
			1.35	2.38	2.04	60.10	1.67	0.77	4.42	25.77	0.17	0.27	1.03
	3	C27	1.47	2.30	2.11	61.11	1.60	0.70	4.18	25.20	0.16	0.22	0.90
			1.28	2.37	1.97	61.24	1.55	0.71	4.16	25.22	0.18	0.25	1.00
			1.37	2.41	2.06	61.14	1.62	0.75	4.15	24.99	0.22	0.26	1.00
	3	C27	2.01	2.79	2.04	60.56	1.51	0.61	3.93	25.18	0.16	0.23	0.95
Lumps			2.03	2.79	1.96	60.31	1.45	0.59	3.96	25.38	0.17	0.27	1.03
			1.99	2.76	2.06	60.14	1.53	0.67	3.99	25.37	0.14	0.22	1.04
	7	Surface	1.61	2.37	1.55	63.78	1.38	0.71	3.43	24.06	0.04	0.28	0.65
			1.68	2.39	1.52	63.88	1.52	0.82	3.46	23.64	0.10	0.21	0.72
			1.53	2.38	1.46	63.62	1.56	0.91	3.54	23.86	0.22	0.24	0.66
	7	Surface	1.64	2.23	1.44	61.18	1.43	0.60	3.93	26.33	0.09	0.24	0.82
			1.78	2.32	1.53	62.21	1.44	0.59	4.05	25.06	0.12	0.24	0.66
			1.67	2.36	1.54	62.07	1.43	0.56	4.09	25.13	0.17	0.22	0.76
	3	C27	1.17	2.28	2.09	61.38	1.45	0.78	3.98	25.30	0.19	0.27	1.03
			1.27	2.24	2.05	61.40	1.55	0.77	3.98	25.22	0.09	0.27	0.97
			1.46	2.29	2.07	61.39	1.51	0.72	3.96	25.16	0.21	0.23	0.95
	4	C46	1.91	2.35	1.46	61.80	1.44	0.40	4.02	25.58	0.10	0.22	0.68
			1.94	2.43	1.49	62.04	1.43	0.20	3.92	25.50	0.13	0.18	0.70
			1.86	2.36	1.49	62.02	1.37	0.39	3.93	25.53	0.13	0.21	0.67

Table 7: Continued

Type	Cutting	Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Lumps (pale olive)	4	C46	1.40	2.22	1.50	61.58	1.58	0.64	4.37	25.73	0.08	0.17	0.68
			1.50	2.19	1.52	61.57	1.52	0.62	4.38	25.56	0.11	0.27	0.73
			1.53	2.26	1.48	61.55	1.55	0.67	4.34	25.47	0.17	0.22	0.76
	5	Surface	2.43	2.83	1.72	61.51	1.39	0.50	3.61	24.65	0.17	0.25	0.87
			2.73	2.84	1.81	61.42	1.50	0.57	3.76	24.04	0.19	0.31	0.75
			2.56	2.77	1.79	61.55	1.40	0.50	3.59	24.63	0.09	0.23	0.77
	5	Surface	2.44	2.66	1.89	61.86	1.48	0.76	3.52	24.11	0.12	0.17	0.97
			2.59	2.70	1.89	61.60	1.56	0.84	3.42	24.03	0.15	0.23	1.00
			2.21	2.71	1.93	61.78	1.40	0.73	3.49	24.32	0.20	0.28	0.94
	10	Surface	1.32	2.27	1.92	63.14	1.40	0.76	4.19	24.00	0.14	0.14	0.70
			1.25	2.07	2.07	63.42	1.34	0.71	4.27	23.75	0.17	0.18	0.75
			1.57	2.26	1.84	62.68	1.43	0.58	4.17	24.23	0.23	0.24	0.75
	10	Surface	2.77	2.77	1.99	60.77	1.46	0.97	3.49	24.29	0.16	0.25	1.00
			2.36	2.71	2.05	61.43	1.50	0.85	3.51	24.30	0.19	0.22	0.88
			2.80	2.72	2.00	61.13	1.41	0.85	3.46	24.19	0.09	0.18	1.02
Dribbles	2	C5	1.76	2.49	1.58	61.74	1.58	0.60	3.61	25.60	0.15	0.18	0.69
			1.81	2.43	1.61	61.97	1.46	0.59	3.63	25.43	0.09	0.22	0.70
			1.82	2.47	1.64	62.03	1.29	0.60	3.73	25.26	0.10	0.26	0.74
	2	C20	1.39	2.18	1.45	65.19	1.51	0.56	3.78	22.96	0.11	0.16	0.65
			1.85	2.42	1.47	64.58	1.46	0.67	3.70	22.90	0.16	0.19	0.50
			1.42	2.25	1.44	64.69	1.61	0.63	3.77	23.14	0.08	0.21	0.65
	2	C20	1.18	2.51	2.29	63.01	1.65	0.68	3.89	23.33	0.17	0.28	1.04
			1.45	2.58	2.23	62.91	1.52	0.76	3.91	23.26	0.14	0.24	1.01
			1.46	2.55	2.26	62.83	1.57	0.63	3.88	23.37	0.22	0.23	1.01
	2	C29	1.24	2.16	2.51	62.46	1.71	0.55	3.92	23.89	0.14	0.26	1.02
			1.36	2.38	2.54	62.22	1.56	0.68	3.95	23.83	0.17	0.25	1.07
			1.30	2.41	2.48	62.40	1.59	0.53	3.95	23.95	0.17	0.26	0.96

Table 7: Continued

Type	Cutting	Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Dribbles	2	C29	1.45	2.56	1.98	60.34	1.57	0.70	3.76	26.25	0.15	0.21	0.87
			1.37	2.56	1.97	60.47	1.52	0.59	3.81	26.39	0.17	0.23	0.91
			1.58	2.63	1.93	60.28	1.41	0.57	3.77	26.49	0.13	0.25	0.86
	2	C29	1.22	2.30	1.67	61.74	1.81	0.68	4.23	25.29	0.10	0.19	0.68
			1.28	2.20	1.63	61.81	1.62	0.72	4.29	25.53	0.10	0.09	0.70
			1.01	2.25	1.62	61.94	1.79	0.58	4.27	25.40	0.17	0.22	0.74
	2	C18	1.60	2.34	1.43	63.28	1.60	0.64	3.90	24.15	0.06	0.27	0.65
			1.45	2.32	1.54	63.43	1.55	0.51	3.91	24.21	0.10	0.26	0.65
			1.45	2.30	1.41	63.36	1.54	0.65	3.89	24.27	0.15	0.19	0.69
	2	C13	1.40	2.48	2.18	61.00	1.60	0.63	4.02	25.17	0.19	0.24	1.04
			1.33	2.51	2.19	61.21	1.49	0.64	3.99	25.12	0.22	0.24	1.01
			1.27	2.47	2.14	61.31	1.59	0.69	3.92	24.94	0.19	0.31	1.05
	2	C39	1.21	2.29	2.34	61.94	1.47	0.43	5.27	23.50	0.21	0.35	0.82
			1.09	2.56	2.38	61.70	1.46	0.35	5.35	23.59	0.20	0.28	0.85
			1.22	2.46	2.31	61.80	1.44	0.37	5.30	23.71	0.20	0.25	0.76
	2	C2	0.93	2.10	1.68	65.19	1.57	0.48	3.72	23.29	0.15	0.23	0.63
			1.23	2.12	1.58	65.16	1.60	0.43	3.66	23.17	0.20	0.26	0.60
			0.86	2.10	1.62	65.17	1.57	0.34	3.72	23.55	0.14	0.24	0.64

Table 8: SEM-EDS analyses (normalised) for glass products made at Shinrone, results for 3 separate areas on each sample

Type	Cutting	Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Vessel glass (pale green)	2	C13	1.68	2.47	2.17	61.87	1.61	0.86	4.09	23.73	0.17	0.26	0.96
			1.89	2.67	2.18	61.41	1.69	0.83	3.93	23.99	0.11	0.19	0.97
			1.58	2.64	2.23	61.81	1.63	0.75	4.14	23.79	0.12	0.23	0.92
	3	C27	1.51	2.48	2.09	63.07	1.41	0.78	3.84	23.37	0.21	0.25	0.98
			1.39	2.50	2.01	63.01	1.63	0.74	3.92	23.49	0.12	0.18	0.86
			1.54	2.42	2.08	62.73	1.64	0.80	3.91	23.35	0.08	0.28	0.95
	3	C27	1.19	2.22	1.82	63.95	1.40	0.60	4.29	23.50	0.08	0.18	0.73
			1.48	2.39	1.67	63.53	1.38	0.46	4.24	23.71	0.12	0.20	0.63
			1.43	2.25	1.75	63.38	1.42	0.52	4.40	23.76	0.19	0.23	0.63
	3	C27	1.38	2.50	2.22	61.69	1.59	0.72	3.87	24.67	0.17	0.24	0.94
			1.26	2.47	2.16	61.72	1.53	0.76	3.90	24.77	0.22	0.26	0.95
			1.43	2.61	2.19	61.48	1.60	0.81	3.86	24.54	0.14	0.27	1.04
	3	C27	1.68	2.72	2.26	61.43	1.62	0.80	4.10	23.81	0.14	0.25	1.02
			1.56	2.78	2.32	61.33	1.68	0.84	4.15	23.85	0.17	0.22	1.09
			1.64	2.70	2.26	61.43	1.67	0.75	4.12	24.01	0.15	0.23	1.00
	3	C27	1.67	2.66	2.22	61.83	1.60	0.83	3.78	24.13	0.12	0.24	0.88
			1.74	2.65	2.06	61.88	1.57	0.81	3.81	24.08	0.10	0.29	0.91
			1.61	2.60	2.12	61.77	1.63	0.91	3.82	24.17	0.15	0.29	0.90
	3	C27	1.74	2.59	2.17	61.68	1.56	0.77	3.84	24.23	0.15	0.23	0.97
			1.48	2.60	2.12	61.95	1.65	0.77	3.83	24.26	0.17	0.29	0.89
			1.75	2.64	2.15	61.80	1.56	0.83	3.84	24.08	0.13	0.26	0.93
	3	C27	1.62	2.35	1.94	62.87	1.42	0.80	3.69	24.02	0.16	0.26	0.87
			1.82	2.26	1.96	62.96	1.30	0.67	3.57	24.05	0.18	0.26	0.89
			1.39	2.20	2.02	63.05	1.64	0.74	3.76	23.97	0.19	0.18	0.75
	3	C27	1.13	2.35	2.13	62.10	1.53	0.58	3.85	24.78	0.07	0.28	1.02
			1.45	2.47	2.23	61.62	1.57	0.77	3.87	24.71	0.11	0.28	0.82
			1.33	2.56	2.24	61.46	1.56	0.77	3.84	24.74	0.19	0.25	1.04

Table 8: Continued

Type	Cutting	Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Vessel (pale green)	3	C27	1.16	2.52	2.15	63.18	1.46	0.72	3.71	23.62	0.26	0.26	0.92
			1.17	2.48	2.17	62.75	1.68	0.71	3.72	23.86	0.16	0.34	0.88
			1.43	2.57	2.15	62.68	1.45	0.74	3.70	23.72	0.11	0.27	1.08
Window glass (pale green with iride-scence)	1	C2	1.08	2.41	1.50	64.22	1.79	0.62	3.68	24.12	0.04	0.16	0.37
			1.30	2.25	1.62	64.22	1.76	0.50	3.75	23.71	0.04	0.07	0.59
			1.51	2.35	1.23	64.34	1.95	0.54	3.86	23.20	0.16	0.26	0.46
	1	C7	1.21	2.35	1.93	63.30	1.64	0.58	4.10	23.68	0.22	0.18	0.81
			1.13	2.39	1.95	63.29	1.58	0.54	4.07	23.77	0.21	0.19	0.76
			1.29	2.28	1.88	63.46	1.56	0.54	4.07	23.75	0.12	0.17	0.87
	1	C7	1.28	2.23	1.68	63.09	1.40	0.59	3.58	25.09	0.13	0.21	0.60
			1.51	2.25	1.61	63.10	1.45	0.49	3.59	24.93	0.13	0.28	0.63
			1.34	2.43	1.73	63.03	1.50	0.61	3.45	24.88	0.12	0.17	0.66
	1	C34	1.64	2.75	2.15	62.08	1.64	0.64	3.59	24.20	0.11	0.31	0.91
			1.68	2.93	2.21	61.46	1.57	0.82	3.80	23.92	0.05	0.28	1.26
			1.92	2.90	2.18	61.34	1.68	0.68	3.70	24.15	0.26	0.24	0.95
	2	C4	3.14	3.17	3.42	57.99	2.77	0.15	3.22	23.85	0.14	0.73	1.15
			3.27	3.38	3.52	57.67	2.85	0.10	3.13	23.70	0.20	0.70	1.30
			2.87	3.35	3.63	57.19	2.88	0.21	3.13	24.22	0.23	0.66	1.29
			2.81	3.19	3.54	57.69	2.96	0.04	3.27	24.29	0.19	0.59	1.14
	2	C4	2.80	2.93	2.04	60.55	1.49	0.54	3.66	24.68	0.15	0.19	0.94
			2.99	3.10	1.99	60.29	1.50	0.59	3.60	24.51	0.20	0.24	1.00
			2.83	3.18	2.09	60.12	1.49	0.65	3.78	24.53	0.19	0.18	0.90
	2	C5	1.48	2.61	2.08	62.50	1.55	0.75	4.04	23.60	0.20	0.24	0.86
			1.46	2.71	2.08	62.68	1.64	0.66	3.98	23.35	0.19	0.29	0.95
			1.72	2.74	2.16	62.62	1.54	0.69	3.92	23.35	0.16	0.20	0.89
	2	C13	1.01	2.16	1.57	63.26	1.86	0.43	4.01	24.72	0.09	0.19	0.66
			0.78	2.30	1.61	63.55	1.55	0.59	4.01	24.39	0.00	0.26	0.71
			0.96	2.22	1.56	63.36	1.71	0.62	3.93	24.67	0.03	0.13	0.64

Table 8: Continued

Type	Cutting	Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Window glass (pale green with iride-scence)	2	C14	2.87	3.01	1.83	60.70	1.49	0.61	3.81	24.37	0.14	0.27	0.86
			3.17	2.98	1.78	60.24	1.39	0.74	3.68	24.74	0.19	0.17	0.84
			3.15	2.97	1.88	60.32	1.58	0.57	3.76	24.47	0.05	0.18	0.83
	2	C22	1.81	2.70	2.32	62.21	1.49	0.59	3.75	23.67	0.13	0.29	0.84
			1.51	2.88	2.21	62.48	1.27	0.79	3.79	23.73	0.27	0.26	0.70
			1.82	2.92	2.41	61.55	1.62	0.72	3.86	23.52	0.12	0.15	1.07
Vessel glass (pale olive)	10	Surface	1.86	2.74	1.83	62.17	1.48	0.62	4.29	23.83	0.15	0.20	0.70
			1.80	2.73	1.85	62.42	1.43	0.60	4.27	23.74	0.17	0.22	0.69
			1.71	2.66	1.84	62.36	1.47	0.58	4.32	23.93	0.15	0.18	0.71
			1.73	2.75	1.85	62.16	1.41	0.56	4.30	24.02	0.23	0.24	0.74
			1.79	2.92	1.90	62.09	1.45	0.60	4.25	23.85	0.15	0.24	0.77
	5	Surface	1.82	2.71	2.07	61.60	1.61	0.84	3.86	24.20	0.14	0.27	0.82
			1.69	2.43	1.98	62.61	1.49	0.84	3.92	23.88	0.13	0.18	0.75
			1.93	2.69	1.97	61.94	1.50	0.79	3.84	23.98	0.13	0.21	0.95

Table 9: SEM-EDS analyses (normalised) for glass from the Shinrone excavations but made elsewhere, results for at least 3 separate areas on each sample, bd = below detection limit

Type	Cutting	Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3	BaO
Bottle	1	Surface	1.28	3.86	4.82	56.87	1.32	0.53	2.23	26.23	0.24	0.20	2.28	bd
			1.44	3.75	4.72	57.18	1.38	0.42	2.18	26.10	0.27	0.17	2.26	bd
			1.24	3.72	4.78	57.25	1.36	0.38	2.26	26.15	0.26	0.21	2.27	bd
	1	Surface	1.56	3.80	4.73	56.98	1.32	0.40	2.20	25.83	0.33	0.27	2.29	0.30
			1.19	3.77	4.80	57.19	1.27	0.52	2.19	26.13	0.22	0.22	2.22	bd
			1.33	3.73	4.80	56.99	1.24	0.51	2.18	26.18	0.28	0.29	2.19	bd
	1	Surface	1.20	4.38	5.01	60.85	0.26	0.37	2.13	22.89	0.28	0.21	1.81	0.60
			1.25	4.45	5.01	60.48	0.31	0.51	2.10	22.81	0.26	0.27	1.88	0.67
			1.23	4.45	5.02	60.48	0.21	0.39	2.11	22.94	0.28	0.31	1.88	0.71
	1	Surface	1.82	3.75	4.12	60.00	0.77	0.48	2.52	23.65	0.22	0.19	1.82	0.68
			1.71	3.85	4.26	59.95	0.69	0.57	2.46	23.67	0.17	0.23	1.70	0.73
			1.76	3.85	4.12	60.19	0.82	0.52	2.43	23.32	0.29	0.16	1.85	0.70
	1	Surface	1.05	4.41	5.09	60.76	0.10	0.29	2.13	23.02	0.27	0.20	1.93	0.75
			1.20	4.41	4.95	60.58	0.21	0.38	2.08	23.01	0.33	0.26	1.91	0.69
			1.36	4.27	5.08	60.92	0.17	0.44	2.07	22.78	0.26	0.23	1.67	0.75
	1	C31	1.09	3.28	4.76	60.03	0.26	0.37	2.11	25.41	0.24	0.20	2.20	bd
			1.18	3.33	4.84	59.66	0.32	0.46	2.14	25.44	0.35	0.20	2.00	bd
			1.37	3.30	4.70	59.74	0.32	0.38	2.12	25.29	0.30	0.17	2.14	bd
	2	C4	1.89	1.97	7.55	58.49	0.24	0.55	1.09	24.20	0.44	0.12	3.36	bd
			2.03	1.91	7.43	58.53	0.15	0.49	1.16	24.18	0.53	0.20	3.38	bd
			2.02	1.98	7.42	58.80	0.09	0.53	1.14	24.01	0.55	0.16	3.31	bd
			1.45	3.85	4.18	59.86	0.80	0.46	2.48	23.98	0.20	0.19	1.76	0.78
	2	C4	2.68	3.22	5.41	58.73	0.69	0.64	1.04	24.98	0.31	0.06	2.22	bd
			2.38	3.19	5.35	58.69	0.64	0.65	1.06	25.31	0.27	0.13	2.24	bd
			2.29	3.32	5.47	58.89	0.52	0.52	0.95	25.14	0.27	0.08	2.40	bd
	2	C4	2.05	1.92	7.41	58.90	0.15	0.47	1.10	23.91	0.43	0.14	3.37	bd
			1.97	1.91	7.35	58.70	0.22	0.54	1.16	23.97	0.33	0.17	3.39	bd
			2.06	1.92	7.28	58.77	0.14	0.43	1.12	24.29	0.51	0.10	3.37	bd

Table 9: Continued

Type	Cutting	Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
	1	C2	7.07	5.08	2.63	68.46	1.03	0.23	4.28	10.36	0.11	0.02	0.73
			6.85	5.45	2.66	68.30	1.04	0.41	4.06	10.26	0.00	0.10	0.85
			7.24	5.30	2.28	68.39	1.01	0.33	4.08	10.57	0.09	0.00	0.63
	1	C7	8.37	4.42	2.48	69.89	1.20	0.14	4.50	7.77	0.12	0.03	1.06
			8.15	4.47	2.60	69.71	1.23	0.17	4.69	7.78	0.11	0.06	0.99
			7.76	4.54	2.56	69.93	1.28	0.28	4.61	7.73	0.15	0.05	1.10
	1	C7	8.11	4.31	2.44	70.31	1.13	0.04	4.66	7.84	0.00	0.01	1.07
			7.90	4.74	2.49	69.72	1.36	0.15	4.68	7.73	0.10	0.02	1.05
			8.12	4.71	2.62	69.67	0.96	0.07	4.82	7.57	0.29	0.09	1.07
	1	C34	8.23	4.29	2.47	69.92	0.94	0.26	4.50	7.84	0.08	0.08	1.12
			7.79	4.56	2.51	70.32	0.89	0.06	4.45	7.96	0.21	0.00	1.25
			8.00	4.82	2.71	69.53	1.34	0.06	4.58	7.84	0.15	0.00	0.92
Window glass (pale green)	2	C4	6.80	4.68	2.94	67.95	1.20	0.10	4.49	10.44	0.00	0.09	1.10
			7.35	4.66	2.82	67.87	1.03	0.03	4.56	10.45	0.12	0.05	1.06
			6.73	4.64	3.11	67.90	1.20	0.01	4.63	10.53	0.03	0.05	1.07
	2	C13	9.86	0.29	0.94	72.06	0.15	0.50	0.14	15.76	0.12	0.00	0.15
			10.30	0.33	0.73	71.78	0.16	0.55	0.15	15.71	0.07	0.00	0.18
			10.05	0.19	1.02	71.99	0.00	0.63	0.16	15.59	0.08	0.00	0.30
	2	C14	7.59	4.85	2.99	67.29	0.99	0.31	4.67	10.44	0.16	0.00	0.69
			7.57	4.88	3.01	67.67	0.89	0.11	4.72	10.15	0.14	0.04	0.74
			8.00	4.95	3.09	66.92	1.05	0.25	4.59	10.25	0.13	0.06	0.65
	2	C14	7.10	6.89	2.00	67.93	1.23	0.36	3.53	10.17	0.18	0.02	0.58
			7.07	6.93	2.26	67.65	1.34	0.40	3.48	10.13	0.14	0.05	0.54
			7.65	7.26	2.01	66.70	1.53	0.45	3.39	10.14	0.09	0.17	0.55
	2	C5	8.26	4.54	2.53	70.03	1.20	0.10	4.55	7.58	0.16	0.00	1.03
			8.04	4.57	2.56	70.06	1.24	0.13	4.57	7.60	0.13	0.08	1.03
			8.00	4.62	2.54	69.65	1.28	0.22	4.65	7.74	0.17	0.09	1.04

Table 9: Continued

Type	Cutting	Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Vessel glass (pale olive)	2	C22	7.89	4.98	3.14	66.79	1.18	0.13	4.52	10.45	0.00	0.02	0.61
			7.98	5.01	3.01	67.09	1.04	0.26	4.49	10.12	0.16	0.00	0.72
			7.40	4.81	3.06	67.64	1.07	0.00	4.75	10.45	0.07	0.06	0.64
	2	C4	1.98	3.74	4.09	58.66	0.88	0.30	1.51	26.77	0.20	0.05	1.66
			1.89	3.75	4.23	58.77	0.89	0.38	1.40	26.62	0.28	0.09	1.66
			2.38	3.72	4.14	58.60	0.92	0.12	1.48	26.62	0.26	0.10	1.66
			2.08	3.66	4.11	58.57	0.89	0.25	1.57	26.78	0.37	0.09	1.63
	2	C4	2.78	4.01	3.63	61.29	0.80	0.58	0.72	24.45	0.30	0.07	1.37
			3.07	4.05	3.59	61.14	0.73	0.66	0.74	24.25	0.22	0.04	1.38
			3.14	3.96	3.58	61.31	0.78	0.55	0.71	24.23	0.26	0.11	1.36
			2.96	4.00	3.43	61.38	0.85	0.55	0.67	24.50	0.23	0.03	1.27
	2	C12	3.15	4.06	4.41	60.80	1.00	0.35	0.81	23.39	0.20	0.09	1.72
			3.21	4.14	4.53	60.64	1.00	0.33	0.82	23.41	0.18	0.06	1.59
			3.36	4.19	4.46	60.73	0.82	0.34	0.77	23.43	0.16	0.07	1.62
	2	C19	1.76	3.58	4.20	59.42	0.91	0.76	2.24	25.08	0.26	0.10	1.64
			2.19	3.69	4.22	59.39	0.87	0.67	2.18	24.74	0.29	0.08	1.68
			1.69	3.63	4.17	59.95	0.82	0.63	2.19	24.92	0.20	0.06	1.75

Table 10: SEM-EDS analyses (normalised) for crucibles and related waste from Shinrone, results for at least 3 separate areas on each sample, bd = below detection limit

Sample	Cutting	Context	Area	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Crucible 99E191: 58	2	C21	Fabric (bulk)	bd	0.36	20.29	72.93	0.24	0.09	2.10	0.34	2.53	0.01	1.00
				bd	0.28	20.88	73.25	0.33	0.00	1.66	0.30	2.48	0.00	0.81
				bd	0.37	19.81	73.85	0.21	0.04	2.05	0.30	2.66	0.00	0.67
			Glaze top	1.46	0.34	16.23	63.43	0.14	0.01	13.81	2.33	1.74	0.01	0.43
				1.64	0.96	12.20	61.46	0.34	0.00	12.10	9.01	1.37	0.16	0.75
				1.83	0.35	15.81	62.65	0.20	0.00	13.36	3.20	1.85	0.11	0.63
			Glaze bottom	1.13	1.07	10.43	64.14	0.74	0.02	8.12	12.12	0.98	0.12	1.05
				1.18	0.40	15.19	63.85	0.38	0.06	10.78	2.12	1.63	0.04	4.31
				0.89	1.84	4.88	62.87	1.29	0.07	5.15	21.37	0.51	0.20	0.84
Crucible 99E191: 11B	2		Fabric (bulk)	bd	0.35	22.27	71.13	0.25	0.07	1.96	0.38	2.66	0.01	0.83
				bd	0.39	23.57	69.73	0.30	0.08	1.87	0.40	2.77	0.00	0.90
				bd	0.36	22.19	71.29	0.23	0.00	1.79	0.37	2.93	0.01	0.76
				0.32	0.40	24.42	68.82	0.28	0.03	2.11	0.42	2.59	0.0	0.63
				bd	0.24	22.76	71.38	0.13	0.01	1.84	0.29	2.55	0.00	0.58
				bd	0.40	23.86	69.80	0.17	0.00	1.92	0.32	2.70	0.02	0.63
			Fabric (grog)	0.31	0.44	31.48	62.11	0.20	0.00	2.18	0.52	1.68	0.04	1.05
				bd	0.45	36.27	57.66	0.14	0.02	1.93	0.36	1.92	0.00	0.97
				bd	0.28	28.43	64.74	0.25	0.01	1.87	0.36	3.00	0.00	0.82
			Glaze bottom	1.02	0.80	18.75	62.01	0.34	0.07	7.90	6.03	2.13	0.09	0.78
				1.05	0.64	19.16	61.88	0.27	0.00	8.66	5.20	2.36	0.02	0.75
				0.93	0.53	19.11	63.77	0.21	0.00	8.61	4.09	2.22	0.03	0.51
				1.49	0.64	20.60	61.87	0.26	0.02	8.30	3.99	1.92	0.04	0.87
				1.43	0.63	20.45	61.55	0.24	0.02	8.20	4.58	2.17	0.04	0.70
				1.37	0.59	21.11	61.27	0.38	0.05	8.15	4.36	2.10	0.01	0.58
			(spot anal)	0.86	1.90	18.42	51.99	0.50	0.00	3.18	19.52	2.01	0.23	1.40
			Glaze top	2.10	0.26	19.17	62.21	0.12	0.00	13.08	0.35	2.31	0.04	0.26
				1.99	0.24	20.01	62.08	0.10	0.00	12.52	0.07	2.50	0.00	0.34
				1.96	0.34	18.41	61.85	0.20	0.00	13.09	1.36	2.10	0.03	0.49

Table 10: Continued

Sample	Cutting	Context	Area	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Crucible 99E191: 11B	2		Glaze top	2.41	0.33	20.53	60.96	0.11	0.00	12.70	0.29	2.19	0.04	0.44
				2.49	0.40	19.82	60.13	0.12	0.07	11.49	2.86	1.98	0.05	0.58
				2.51	0.39	20.09	60.70	0.03	0.08	12.40	1.33	2.11	0.00	0.36
Crucible 99E191: 42	2	C13	Fabric (bulk)	bd	0.37	24.14	70.05	0.25	0.04	2.29	0.36	1.80	0.00	0.68
				bd	0.43	25.50	68.30	0.29	0.06	2.23	0.44	1.74	0.00	0.67
				bd	0.41	23.13	71.00	0.23	0.05	2.15	0.37	1.82	0.03	0.61
			Glaze bottom	2.08	0.40	21.43	61.61	0.17	0.00	11.21	0.61	1.96	0.02	0.43
				2.17	0.45	22.03	57.87	0.17	0.03	13.61	1.66	1.28	0.05	0.52
				2.07	0.51	23.40	54.80	0.17	0.02	13.63	2.87	1.66	0.04	0.64
			Glaze top	2.37	0.46	19.80	61.08	0.13	0.00	11.15	3.06	1.36	0.02	0.46
				2.36	0.86	19.34	59.07	0.23	0.03	10.06	5.80	1.46	0.07	0.65
				2.44	0.32	21.03	60.24	0.15	0.00	11.08	2.66	1.79	0.04	0.27
Crucible 99E191: 91C	2	C29	Fabric (bulk)	0.34	0.39	21.61	72.56	0.15	0.06	1.62	0.36	2.33	0.02	0.55
				0.37	0.35	20.37	73.86	0.20	0.04	1.57	0.35	2.40	0.00	0.49
				0.43	0.35	20.75	73.59	0.16	0.04	1.37	0.37	2.43	0.00	0.51
			Fabric (grog)	0.28	0.34	20.89	74.13	0.10	0.00	1.39	0.35	2.03	0.01	0.47
				0.31	0.35	22.78	71.70	0.25	0.06	1.51	0.34	2.15	0.01	0.56
			Glaze top	1.80	1.17	16.81	58.09	0.40	0.00	9.58	9.63	1.81	0.19	0.51
				1.90	1.39	16.38	57.10	0.24	0.00	9.15	11.24	1.84	0.23	0.53
				2.00	0.94	17.28	59.40	0.41	0.07	10.49	7.16	1.79	0.12	0.33
			Glaze bottom	1.54	0.46	15.14	64.76	0.33	0.02	9.84	6.18	1.42	0.01	0.30
				1.52	0.36	15.96	64.97	0.25	0.04	10.19	4.92	1.50	0.01	0.28
				1.71	0.29	17.15	65.34	0.28	0.08	11.15	1.51	1.87	0.00	0.61
Vesicular brown waste	2	C4		2.85	0.34	18.55	66.56	0.09	2.71	5.30	1.43	1.62	0.02	0.53
				2.83	0.33	17.79	69.49	0.23	0.88	5.51	0.60	1.72	0.00	0.59
				3.10	0.41	18.39	67.98	0.16	0.82	6.09	0.85	1.69	0.03	0.48
				2.51	0.32	18.59	68.22	0.02	0.68	6.11	0.40	2.45	0.03	0.61

Table 11: SEM-EDS analyses (normalised) for furnace materials and related waste from Shinrone, results for at least 3 separate areas on each sample, bd = below detection limit

Sample	Cutting	Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Furnace fragment	2	C10 (bulk fabric)	bd	0.16	3.40	91.31	0.31	0.01	1.64	0.03	0.08	0.31	2.74
			bd	0.41	6.51	87.24	0.23	0.03	1.68	0.01	0.13	0.28	3.40
			bd	0.21	5.94	87.60	0.36	0.19	2.33	0.04	0.04	0.40	2.76
	2 (glaze)	C10	1.56	0.62	5.19	77.61	0.29	0.02	7.92	4.13	0.25	0.20	2.17
			1.58	0.72	4.88	77.34	0.39	0.02	7.80	4.42	0.43	0.18	2.19
			1.28	1.07	5.19	77.64	0.45	0.12	7.83	3.81	0.35	0.17	2.02
			1.17	0.37	4.70	81.92	0.22	0.03	8.55	0.79	0.19	0.18	1.89
			1.44	0.39	4.25	80.27	0.32	0.06	9.42	1.61	0.32	0.17	1.75
Pale blue glassy droplets	2	C5	3.15	0.44	5.58	79.11	0.29	0.01	8.08	2.53	0.13	0.07	0.53
			2.02	0.26	6.10	82.27	0.25	0.01	7.17	1.06	0.19	0.05	0.58
			2.40	0.35	5.36	80.28	0.22	0.08	7.68	2.77	0.18	0.05	0.64
	2	C12	2.17	0.58	3.98	80.09	0.24	0.00	6.85	3.94	0.17	0.22	1.65
			1.73	0.44	4.30	81.48	0.15	0.00	6.66	3.18	0.24	0.23	1.53
			1.84	0.44	4.02	81.03	0.27	0.02	6.80	3.53	0.13	0.21	1.60
	2	C29	1.45	0.37	4.11	81.81	0.30	0.00	7.17	2.72	0.23	0.19	1.65
			1.23	0.37	4.52	81.38	0.22	0.00	7.46	2.61	0.27	0.18	1.70
			1.45	0.38	4.54	81.01	0.37	0.00	7.45	2.66	0.27	0.19	1.65
	2	C29	1.80	0.46	4.55	81.36	0.22	0.03	6.13	3.18	0.28	0.23	1.76
			1.81	0.44	4.49	81.60	0.23	0.01	6.27	2.98	0.29	0.21	1.67
			1.85	0.50	4.54	81.49	0.22	0.03	6.09	3.04	0.24	0.24	1.71
	2	C29	2.24	0.56	4.25	80.75	0.33	0.04	5.97	3.50	0.21	0.34	1.66
			2.02	0.52	4.59	81.61	0.30	0.00	5.89	2.59	0.11	0.32	1.93
			2.37	0.55	4.28	80.63	0.22	0.02	5.94	3.75	0.18	0.27	1.65
	2	C29	1.39	0.31	4.14	80.63	0.21	0.03	9.59	1.52	0.12	0.19	1.85
			1.60	0.31	3.72	80.30	0.11	0.00	9.83	1.94	0.13	0.19	1.74
			1.37	0.34	4.00	80.60	0.12	0.00	10.04	1.62	0.10	0.19	1.62

Table 11: Continued

Sample	Cutting	Context	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
	US		bd	0.81	5.63	74.99	0.46	0.00	10.41	5.07	0.33	0.11	1.93
			0.44	0.83	4.69	76.72	0.22	0.14	9.67	4.96	0.28	0.13	1.94
			bd	0.58	3.98	79.14	0.19	0.03	9.74	4.21	0.12	0.13	1.73
Pale blue glassy droplets	2	C19	1.94	0.85	3.95	74.02	0.43	0.01	9.28	7.66	0.23	0.20	1.39
			1.84	0.84	3.79	75.12	0.35	0.11	9.26	6.93	0.23	0.19	1.35
			1.92	0.96	3.85	74.50	0.45	0.04	9.06	7.30	0.19	0.17	1.49
	2	C30	1.02	0.61	5.84	76.47	0.12	0.00	8.50	6.13	0.25	0.07	0.96
			0.89	0.56	6.45	76.37	0.23	0.04	8.70	5.59	0.16	0.03	0.95
			1.13	0.63	5.98	76.60	0.13	0.01	8.23	6.06	0.20	0.03	0.90

Table 12: SEM-EDS analyses (normalised) for glass waste from Glaster, results for 3 separate areas on each sample, all unstratified

Type	Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
	A	1.18	1.82	1.25	65.72	1.03	0.43	4.14	23.86	0.12	0.01	0.42
		1.21	1.88	1.25	65.59	1.03	0.49	4.07	23.88	0.12	0.11	0.36
		1.27	1.84	1.21	65.56	0.92	0.50	4.11	23.96	0.08	0.05	0.45
	B	1.26	2.10	1.19	63.17	1.05	0.63	4.59	25.32	0.15	0.08	0.40
		1.32	2.20	1.21	63.14	0.96	0.52	4.61	25.32	0.20	0.07	0.43
		1.35	2.07	1.18	63.04	1.14	0.67	4.53	25.36	0.11	0.13	0.37
	C	1.18	2.06	1.40	63.18	1.15	0.59	4.23	25.31	0.18	0.08	0.65
		1.21	2.11	1.34	63.21	1.04	0.63	4.24	25.41	0.12	0.10	0.57
		1.14	2.12	1.39	63.07	1.14	0.63	4.27	25.35	0.07	0.12	0.64
	D	1.17	2.11	1.26	62.82	1.05	0.47	4.71	25.64	0.08	0.13	0.51
		1.15	2.08	1.25	62.84	1.08	0.51	4.76	25.67	0.12	0.10	0.45
		1.31	2.02	1.26	62.99	1.13	0.51	4.73	25.43	0.13	0.11	0.38
Lumps and dribbles	E	1.27	2.00	1.19	63.28	1.16	0.62	4.71	25.01	0.13	0.12	0.44
		1.36	2.14	1.23	63.28	1.06	0.50	4.71	25.11	0.12	0.09	0.39
		1.39	2.06	1.25	63.48	1.08	0.58	4.69	24.88	0.09	0.03	0.44
	F	1.64	2.09	1.18	64.05	1.00	0.61	4.16	24.61	0.16	0.11	0.36
		1.65	2.12	1.18	64.17	0.98	0.54	4.13	24.56	0.18	0.10	0.38
		1.64	2.18	1.13	64.02	0.94	0.52	4.19	24.71	0.10	0.10	0.36
	G	1.23	2.24	1.43	60.95	1.08	0.72	4.87	26.64	0.12	0.10	0.61
		1.23	2.14	1.58	60.96	1.08	0.75	4.80	26.52	0.08	0.19	0.61
		1.11	2.10	1.47	61.15	1.07	0.69	4.84	26.78	0.10	0.14	0.55
	H	1.15	1.91	1.26	62.29	1.04	0.51	4.55	26.57	0.13	0.08	0.41
		0.93	1.84	1.32	62.49	1.03	0.54	4.41	26.69	0.10	0.12	0.47
		0.97	1.82	1.30	62.46	1.10	0.57	4.51	26.68	0.12	0.02	0.41
	I	1.24	1.99	1.29	63.02	1.08	0.58	4.40	25.68	0.11	0.10	0.47
		1.37	2.01	1.30	63.05	1.06	0.62	4.41	25.42	0.16	0.12	0.48
		1.29	2.06	1.29	63.30	1.09	0.53	4.34	25.42	0.11	0.06	0.51

Table 12: Continued

Type	Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
	J	0.94	1.74	1.18	65.30	0.96	0.43	4.15	24.65	0.14	0.09	0.43
		0.97	1.82	1.16	65.07	1.04	0.48	4.18	24.77	0.08	0.06	0.39
		1.04	1.79	1.20	65.11	0.89	0.43	4.12	24.79	0.11	0.08	0.40
	A2	1.29	2.35	2.04	62.65	1.11	0.54	4.70	24.18	0.13	0.17	0.82
		1.33	2.38	1.99	62.77	1.13	0.49	4.72	24.01	0.21	0.16	0.81
		1.37	2.41	2.01	62.71	1.18	0.52	4.75	23.95	0.12	0.15	0.80
	B2	1.32	2.15	1.62	63.27	1.01	0.49	4.99	24.35	0.12	0.08	0.56
		1.39	2.14	1.71	63.16	1.12	0.52	4.92	24.14	0.14	0.11	0.64
		1.41	2.18	1.61	63.09	1.06	0.59	4.92	24.32	0.14	0.09	0.56
	C2	1.23	2.01	1.37	63.35	1.11	0.61	4.71	24.72	0.17	0.12	0.59
		1.30	2.08	1.41	63.38	1.09	0.66	4.73	24.56	0.10	0.12	0.54
		1.22	2.10	1.48	63.46	1.02	0.61	4.68	24.54	0.11	0.13	0.60
Lumps and dribbles	D2	1.14	1.86	1.18	63.75	1.07	0.51	4.63	25.16	0.17	0.09	0.44
		1.14	1.96	1.07	63.90	1.10	0.55	4.59	25.05	0.15	0.09	0.39
		1.05	1.93	1.12	63.97	1.01	0.44	4.70	25.14	0.12	0.12	0.40
	E2	1.29	2.13	1.71	63.16	0.96	0.63	4.98	24.33	0.14	0.10	0.57
		1.24	2.12	1.65	63.23	1.02	0.55	5.01	24.31	0.16	0.04	0.64
		1.46	2.25	1.57	63.12	1.05	0.59	4.92	24.10	0.16	0.09	0.64
	F2	1.43	2.17	1.19	63.65	0.92	0.58	4.22	25.18	0.10	0.09	0.40
		1.51	2.03	1.15	63.74	0.92	0.46	4.31	25.20	0.15	0.04	0.48
		1.48	2.00	1.16	63.75	0.87	0.54	4.21	25.39	0.13	0.00	0.47
	H2	1.12	1.92	1.36	63.25	1.00	0.55	4.71	25.29	0.14	0.10	0.52
		1.11	1.92	1.37	63.40	1.15	0.51	4.71	25.06	0.14	0.05	0.48
		1.13	1.99	1.38	63.36	1.11	0.51	4.74	25.05	0.13	0.03	0.51
	O2	1.19	2.09	1.16	62.38	1.11	0.53	4.80	26.03	0.11	0.10	0.43
		1.23	2.09	1.20	62.37	1.09	0.56	4.76	25.98	0.13	0.13	0.45
		1.19	2.11	1.20	62.34	1.14	0.51	4.71	26.10	0.08	0.15	0.46

Table 13: SEM-EDS analyses (normalised) for crucibles and related waste from Glaster, results for at least 3 separate areas on each sample, all unstratified, bd = below detection limit

Sample	Area	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3	BaO
Crucible	Fabric	bd	0.22	10.46	86.31	0.24	0.02	0.78	0.23	1.03	0.00	0.38	bd
		bd	0.22	10.35	86.07	0.16	0.01	0.93	0.26	1.14	0.00	0.46	bd
		bd	0.26	11.46	84.76	0.24	0.13	0.92	0.36	1.06	0.00	0.53	bd
	Glaze	1.39	0.43	7.26	77.33	0.23	0.04	10.03	1.85	0.82	0.09	0.44	bd
		1.61	0.50	6.82	76.39	0.17	0.00	10.36	2.67	0.86	0.06	0.57	bd
		1.24	0.28	8.13	77.41	0.16	0.00	10.07	1.35	0.85	0.02	0.39	bd
	Grog	bd	0.31	19.62	74.87	0.19	0.00	1.66	0.32	2.12	0.01	0.60	bd
		bd	0.29	17.64	76.62	0.20	0.02	1.58	0.41	2.22	0.01	0.73	bd
		bd	0.22	20.29	74.25	0.23	0.05	1.37	0.37	2.29	0.04	0.54	bd
Refractory clay with glaze on one side	Fabric	bd	0.31	16.36	78.64	0.19	0.00	1.14	0.29	2.28	0.04	0.56	bd
		bd	0.29	19.61	74.96	0.33	0.00	1.27	0.28	2.29	0.04	0.67	bd
		bd	0.26	18.43	76.40	0.21	0.05	1.20	0.25	2.39	0.00	0.54	bd
	Grog	bd	0.26	16.36	78.82	0.27	0.08	1.10	0.19	2.33	0.01	0.51	bd
		bd	0.38	22.35	72.53	0.25	0.00	1.23	0.23	2.26	0.07	0.51	bd
		bd	0.23	18.33	77.16	0.25	0.00	1.10	0.25	2.01	0.02	0.50	bd
	Glaze	1.28	1.14	9.24	65.48	0.20	0.02	8.29	12.65	1.07	0.04	0.59	bd
		1.34	1.10	9.64	65.80	0.13	0.00	8.48	11.99	1.08	0.07	0.37	bd
		1.38	1.02	9.58	66.19	0.14	0.02	8.54	11.54	1.09	0.03	0.48	bd