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SEM-EDS Analysis of Wealden Glass

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Summary

Samples of glass and glassworking waste from three different Wealden glasshouses were analysed to determine their chemical composition. The aim was to investigate what changes in glass composition may have been introduced by French immigrant glassmakers c.1567. Two of the sites (Idehurst North and South) were worked by English glassmakers in the 16th century (possibly spanning the arrival of French glassmakers) and the third site (Tanland Copse) was worked by French glassmakers in the early 17th century. The results confirm that the traditional 'forest glass' was replaced by high-lime low alkali glass.

Keywords

Glass
Medieval
Post Medieval

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Introduction

Evidence for medieval glass industry in England has been found in Staffordshire (Crossley 1967; Pape 1934; Welch 1997) and the Weald of Surrey and Sussex (Kenyon 1967). The Weald is especially important for the history of late medieval and early post-medieval glassmaking in England, as French immigrants brought by Jean Carré to the area *c*.1567 introduced new glassworking technologies (Crossley 1972; Kenyon 1967). The limited excavation of French immigrant glasshouses (e.g. Crossley & Aberg 1972; Kenyon 1967) suggests that French immigrant glassworkers introduced a new type of furnace (the winged furnace).

It has long been recognised that the quality of the glass from Wealden glasshouses varies dramatically from site to site (Kenyon 1967). At some sites the glass has suffered from corrosion and, in extreme cases, this may continue until little or no glass remains. At other sites the glass is of a very good quality and has suffered from virtually no corrosion. The limited evidence for dating individual glasshouses suggests that the poor quality, corroded glass probably pre-dates the arrival of French immigrants, while the good quality glass was produced after the arrival of French immigrants *c*.1567. These two types of glass (and the sites which produced them) are usually called Early and Late. A small number of sites with both Early and Late glass have been described as Transitional (Kenyon 1967: 172).

A limited number of analyses of Wealden glass from both Early and Late sites have been published (e.g. Kenyon 1967; Wood 1965; 1982) and some unpublished research has been carried out (Merchant 1998; Welham 2001). Kenyon commissioned a small number of analyses of both Early and Late glass in an attempt to provide an explanation as to why the former tended to be corroded so much faster than the latter (Kenyon 1967: 39–42). The results did not provide the clear explanation that Kenyon hoped for, but the reason for this is that one of the sites was probably misdated. Kenyon states that Wephurst, Kirdford (Kenyon site 21) is ‘unmistakably Early’ (Kenyon 1967: 181), apparently based on the appearance and condition of the glass. However, the small amount of pottery from the site was identified as early 17th century (Kenyon 1967: 181). The composition of the glass from Wephurst is similar to that from Late sites (Table 1) and so Wephurst should perhaps be regarded as a Late site.

Table 1. Composition of Early and Late Wealden Glass (Kenyon 1967: 39)

Site	Kenyon date	Revised date	Na_2O	MgO	SiO_2	K_2O	CaO	Fe_2O_3
29	Early	Early	2.3	6.7	56.0	11.1	15.0	0.5
21	Early	Late	2.2	3.6	56.7	6.3	23.0	0.4
14	Late	Late	0.4	2.6	64.7	4.7	20.8	0.7
38	Late	Late	1.2	2.7	59.5	4.4	24.9	1.0

The distinction between early ‘forest glass’ and late ‘high-lime low-alkali’ glass has become clearer in recent years (e.g. Mortimer 1991; Mortimer in Welch 1997; Merchant 1998; Welham 2001), however, much of the relevant analytical data has not been published. Early glass is a ‘forest glass’ with high levels of potassium oxide (*c*.10–15%), calcium oxide (*c*.10–15%) and magnesium oxide (*c*.4–8%). Late glass is a high-lime low-alkali glass (cf. Mortimer 1991) with low levels of sodium and potassium (combined total <10%) but very high levels of calcium (>20%).

Description of the Sites and Samples

Samples were selected from three sites: two have been known for some years and are listed by Kenyon (Kenyon 1967: sites 16 and 17) but the third is a recent discovery (by Colin Clark in 1998). The location of the sites studied and other Wealden glasshouses are shown in figure 1.

Idehurst North, Kirdford TQ 0315 2596
Idehurst South, Kirdford TQ 0316 2535

These sites (Kenyon 1967: sites 16 and 17) have produced surface finds including glass and crucibles as well as 16th century pottery. The glass from both sites includes both Early and Late types and Kenyon classifies both as Transitional (Kenyon 1967: 176–178).

These sites were probably worked by English glassworkers (the Strudwicks or Strudwyckes) in the 16th century. The Strudwicks were yeoman farmers who settled in the area in the 15th century. They are recorded as glassmakers (Kenyon 1967: 118–120) and iron smelters in the 16th century (Cleere & Crossley 1995: 312). Henry Strudwycke's 1557 will mentions a glasshouse and associated woodlands which were left jointly to his two sons until one was 22 when it was to be divided between them. It is possible that the two known sites at Idehurst represent Henry's original glasshouse and a second built by one or more of his sons. It is not known how long the Strudwick family continued to make glass after 1557 but various members of the family are recorded as glassmakers until 1586. The occupation of glassman is recorded in 1595 and 1597 but this could be a glass seller rather than manufacturer. Some undated (but probably early 17th century) Chichester court records contain references to Strudwick glass makers. A Strudwick 'glasscarryer' was buried in 1614 and his inventory survives (Kenyon 1967: 112), which makes it clear that he was a glass seller and not a manufacturer. Thus, at least one of the Idehurst sites probably started production before the arrival of the French immigrants (*c*.1567). Both sites may have continued to produce glass after the arrival of the French glassmakers, perhaps as late as the early 17th century.

Tanland Copse, Northchapel SU 949 288

This site is not recorded by Kenyon (1967) and was discovered by Colin Clark in 1998. A section through the site has been exposed by a stream which is eroding the site. It has produced crucible and glass fragments. The glass is of good quality and can be classed as Late. The site may have been worked by a Hensey/Hennezel. Edward Hensaye is recorded as a glassmaker in Northchapel in 1610–11. Hensaye appears to be a corruption of Hensey or Hennezel, a family of Lorrainer glassmakers who originally came to the Weald in 1568. Tanland Copse is a few hundred metres south-east of the village of Northchapel.

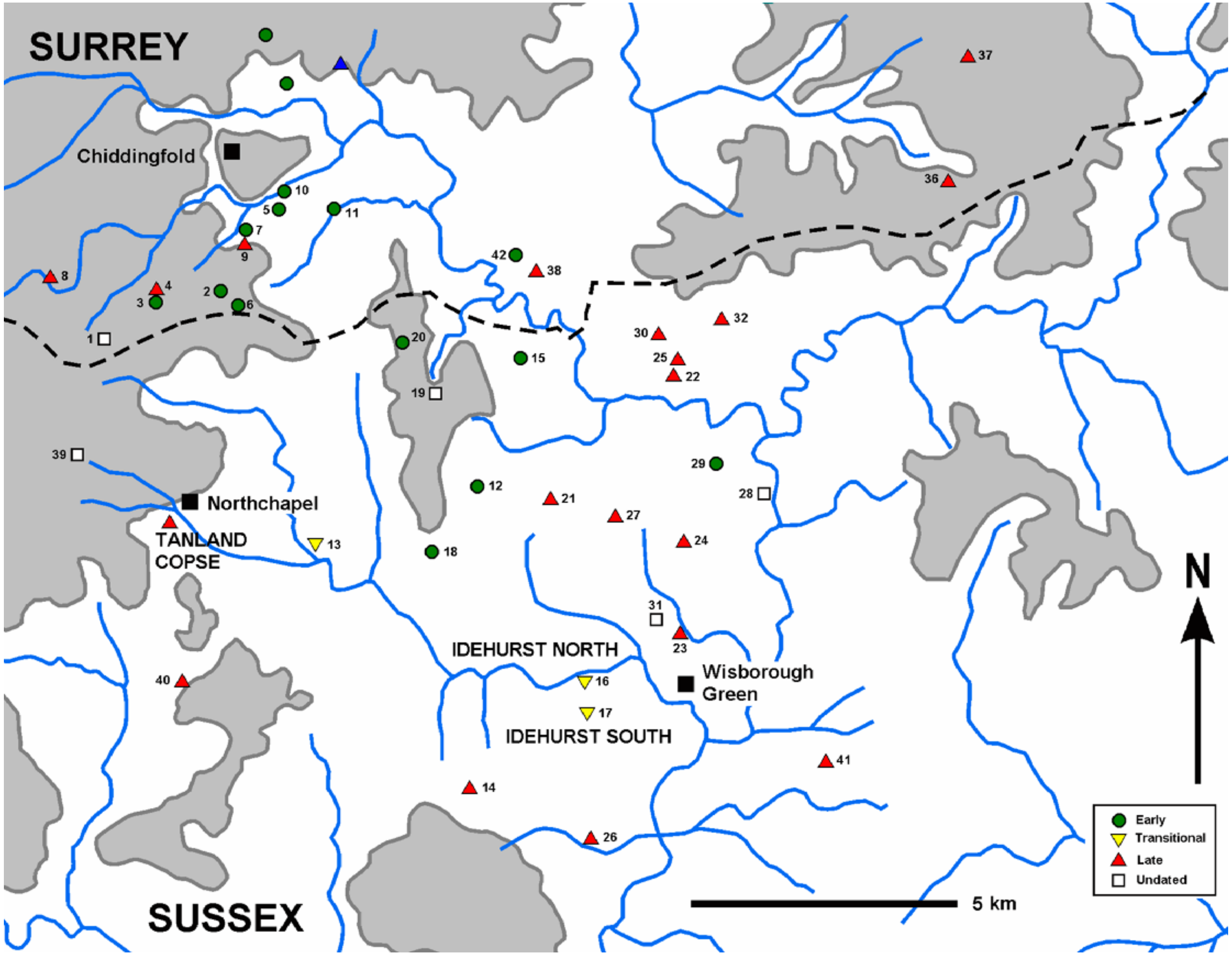

Figure 1. Map showing the location of Wealden Glasshouses (after Kenyon 1967 with additions). The grey areas show land over 200m AOD. The dashed line shows the boundary between Surrey and Sussex.

Sample Selection and Preparation

Fragments of glassworking waste (lumps and droplets) and glass artefacts were collected from each of the three sites. Some of the glass artefact fragments from the Idehurst sites were so corroded that no glass remained; these were not sampled. Samples of crucible and furnace were also recovered from the sites but these were not sampled. Previous experience (Dungworth 2003) has shown that analysis of these samples is time consuming and the glass adhering to them is often contaminated by reactions between the glass and the crucible ceramic or furnace stone. The selected samples (Table 1) were mounted in acrylic resin to expose a cross-section and then ground and polished to a 1-micron finish. The mounted samples were then coated in carbon for examination with the scanning electron microscope.

Table 1. Samples selected for analysis

	Working waste	**Artefact fragments**	**Total**
Idehurst, North	5	8	13
Idehurst, South	8	3	11
Tanland Copse	10	7	17
Total	**23**	**18**	**41**

Analytical Technique

The mounted and polished samples were examined using a Karl Zeiss S440 scanning electron microscope (SEM). Both secondary electron and back scattered electron detectors were used to asses the condition and homogeneity of the samples. The back scattered electron detector was most useful as it allowed the identification of weathered surface layers as well as heterogeneity.

The chemical compositions of the samples were determined using an Oxford Instruments energy dispersive X-ray spectrometer attached to the scanning electron microscope (SEM-EDS). The SEM was operated at a voltage of 25kV and a probe current of 1.5nA. The Oxford Instruments germanium detector allowed for the simultaneous detection of all elements from oxygen to uranium, providing the elements were present above the detection limits. Each spectrum was collected from an area approximately 200 by 300 microns for 100 seconds livetime. Each spectrum was calibrated using a cobalt standard and deconvoluted using the Oxford Instruments SEMQuant software (with phi-rho-z correction procedure). This made use of element profiles derived from single element or simple compound standards (pure iron, jadeite, etc). The profiles were standardised against appropriate glass reference materials (e.g. Corning standards). Energy dispersive X-ray sprectrometry provides no direct information about the valence state of any elements present (e.g. metallic iron, FeO, Fe_2O_3 or Fe_3O_4). In each case, an appropriate valence state for the analysed material was chosen and the oxide weight percent calculated stochiometrically.

Results

Introduction

The results of the analyses are listed in Appendix 1.

The chemical analysis of the Tanland Copse samples proved to be straightforward, but many of the samples from the two Idehurst sites presented problems. The areas chosen for analysis were initially in the centres of the mounted glass samples as far away as possible from the corroded surfaces. The results for Tanland Copse samples gave good analytical totals (100±1%), but many of the samples from both of the Idehurst sites consistently gave low analytical totals (95±1%). A detailed examination of one of the Idehurst, North samples (IDN01) was carried out to examine the reasons for this.

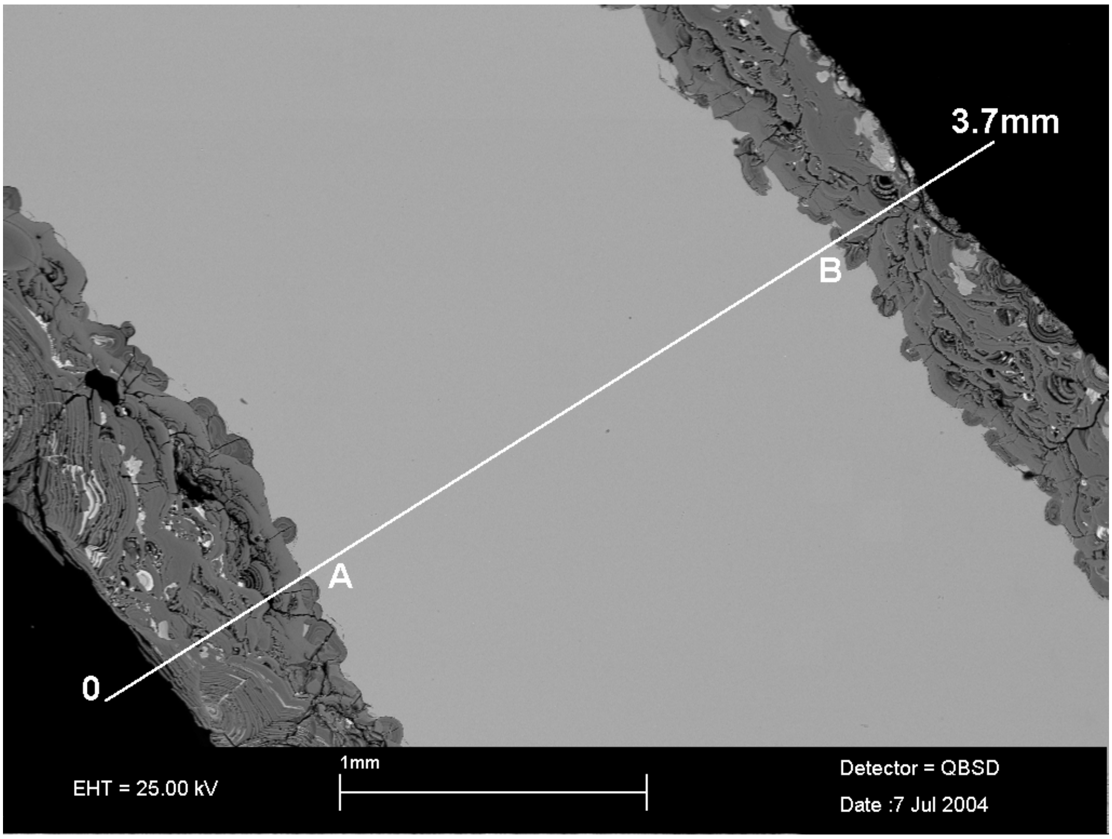

Figure 2. SEM image (back scattered electron detector) of sample IDN01 showing the position of the line scan. The black areas are the acrylic mount, the heterogeneous dark areas are the surface corrosion and the light grey area is the glass

Figure 2 shows an image of sample IDN01: the glass core (light grey, apparently homogeneous) is sandwiched between two layers of surface corrosion (dark grey, heterogeneous). The levels of all of the elements detected in the glass were examined across the width of the sample (i.e. line scans). Figure 3 shows the line scan for silicon: the levels of silicon are highest in the corroded crusts and lower in the central region. The potassium levels (Figure 4) are highest in the central part of the sample and very low in the corroded crusts. The differences visible between the corroded crusts at the surface of the glass and the core areas are well-known (Newton & Davison 1989). However, figures 3 and 4 also show that the core glass is not of a uniform composition. Further analyses have shown that analyses close to point **A** provide analytical totals of 100±1% while those close to point **B** provide totals of 90±5%.

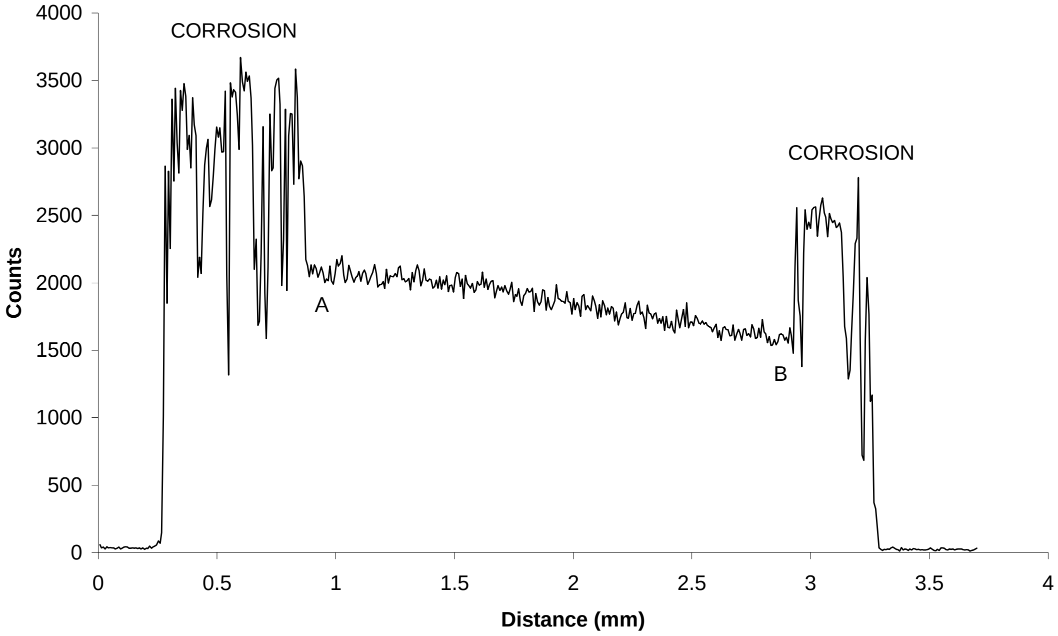

Figure 3. Line scan for silicon through the width of sample IDN01 (see figure 1 for the location of the line scan)

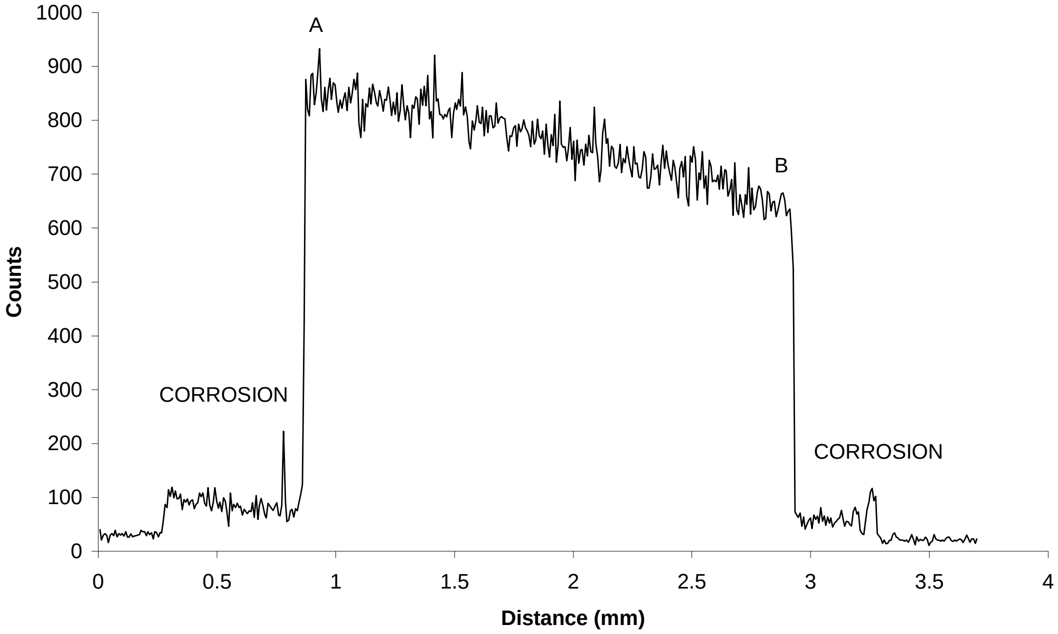

Figure 4. Line scan for potassium through the width of sample IDN01 (see figure 1 for the location of the line scan)

The variability described above was present in almost all of the samples from both Idehurst sites. It could be seen in glassworking waste as well as glass artefact fragments from the sites. The trends could be seen in the fragments which were of a completely different chemical composition to the working waste from these sites (both forest glass and high-lime low-alkali glass). Therefore, it is unlikely that the trends in glass composition through the thickness of the glass samples are related to some peculiarity of production at the Idehurst sites. It is more likely that the trends are the result of a post-depositional corrosion phenomenon. This phenomenon is not explored further in this report.

Types of glass manufactured

Both of the Idehurst sites produced forest glasses while Tanland Copse produced a high-lime low-alkali glass (Table 2, figure 5). The forest glass from the Idehurst sites have slightly different chemical compositions, for example the glass from the South site contains more magnesia than the North site (figure 6).

Table 2. Chemical composition of the glassworking waste (average and standard deviations)

Site		Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	MnO	Fe_2O_3
Idehurst	mean	2.1	7.2	1.1	55.3	3.2	11.6	17.0	1.1	0.6
North	sd	±0.2	±0.2	±0.1	±1.8	±0.5	±0.6	±0.3	±0.1	±0.1
Idehurst	mean	3.0	8.7	1.4	53.3	3.9	10.8	16.6	1.0	0.6
South	sd	±0.3	±0.2	±0.2	±0.8	±0.1	±0.8	±0.5	±0.1	±0.1
Tanland	mean	1.5	2.8	2.2	61.2	2.2	3.8	24.2	0.7	1.2
Copse	sd	±0.5	±0.2	±0.2	±1.1	±0.2	±0.8	±1.0	±0.1	±0.1

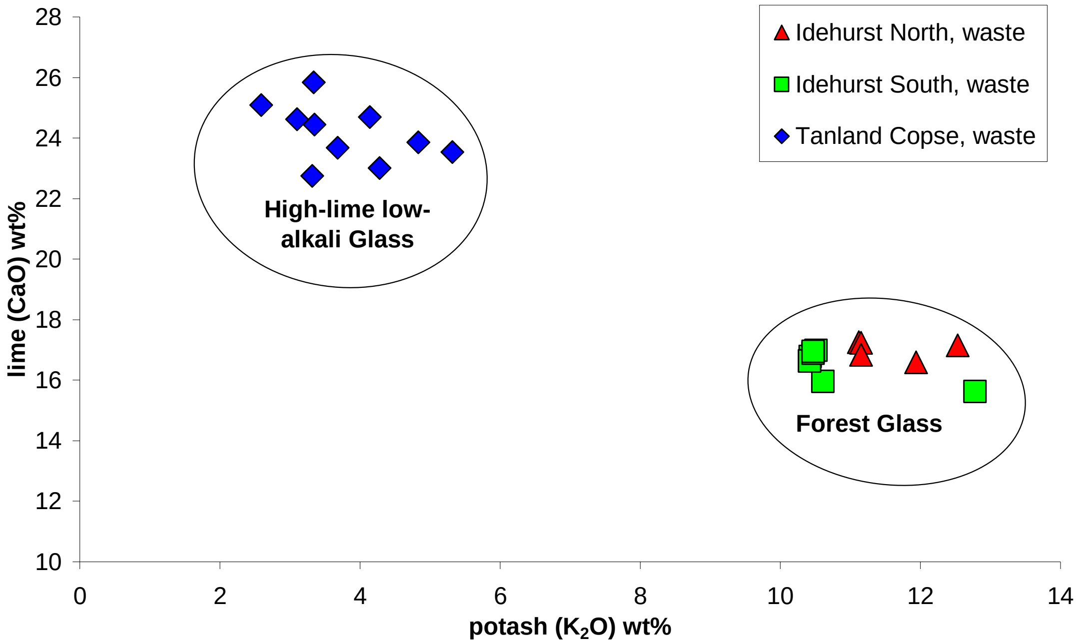

Figure 5. Plot of potash (K_2O) against lime (CaO) for glass working waste from all three sites

Comparing glass working waste with glass fragments

The fragments of glass artefacts from Tanland have chemical compositions that are indistinguishable from the glass working waste from the site (figure 6). It is possible that all of the glass fragments from Tanland were produced there.

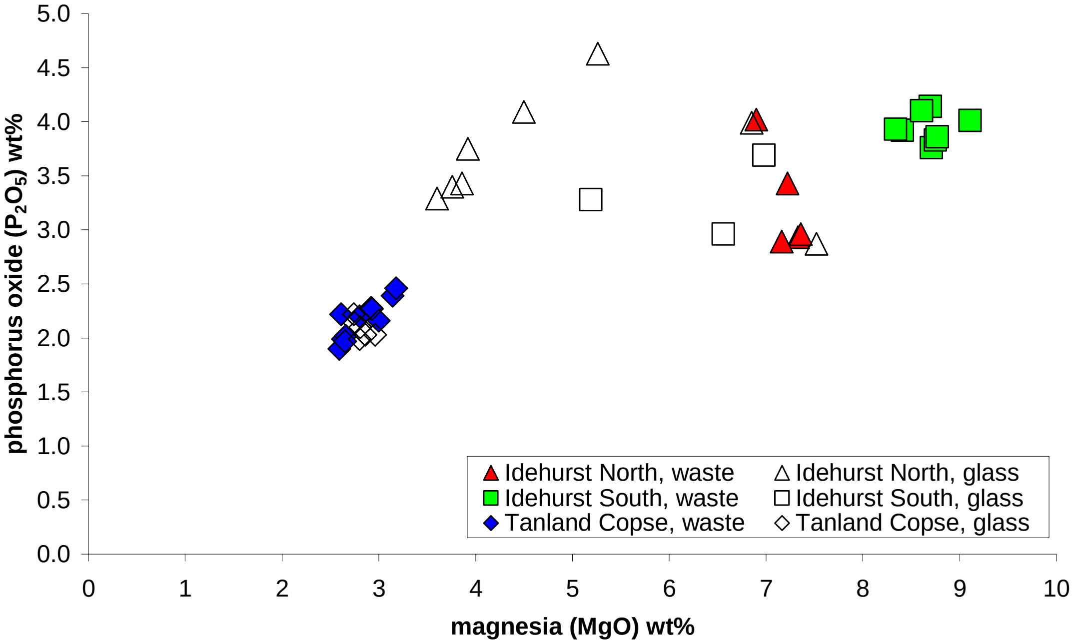

Figure 6. Plot of magnesia (MgO) and phosphorus oxide (P_2O_5) for all samples

The three fragments of glass from Idehurst South are forest glasses but they do not have exactly the same chemical composition as the glassworking waste from the site (see figure 6). These probably represent cullet brought to the site. They may originally have been produced at another Wealden glasshouse.

Two of the eight fragments of glass from Idehurst North (IDN09 and IDN10) have chemical compositions that are similar to the glassworking waste at the site and are likely to have been produced there. One fragment (IDN12) is a forest glass but with a very different chemical composition (e.g. low magnesia and high lime). The remaining five samples of glass artefacts from Idehurst North are high-lime low-alkali glasses. These do not have the same chemical composition (in particular the minor oxides) as the Tanland glass. These samples may represent glass brought to the site as cullet.

Discussion

The analysis of the glassworking waste from the three sites detailed in this report provide clear information about the sorts of glass that were manufactured at each site. The fragments of glass artefacts from the sites are of more varied composition and in some cases do not match the glassworking waste from the same site (cf. Dungworth 2003)

The Idehurst sites both produced forest glasses. At least one of these sites was likely to have been working before 1557 and both may have continued to produce glass until *c*.1600 (i.e. after the arrival of French immigrants *c*.1567). The Tanland Copse site, which was probably operating around 1610–11, produced high-lime low-alkali glass. Therefore, the analyses reported here support the hypothesis that the immigrant French glassmakers who came to England in the years after 1567 brought with them a new glass recipe. High-lime low-alkali glass was produced in France during the 16th century (Barrera & Velde 1989) and Germany during the 14th century (Wedepohl 1997).

The absence of high-lime low-alkali glass from Idehurst South might indicate that it completely pre-dates the arrival of French immigrants. It is tempting then to associate Idehurst South with the Henry Strudwick who died in 1557. The Idehurst North site produced forest glass broadly similar to that produced at the South site, but the presence of high-lime low alkali glass cullet suggests that the glasshouse overlapped with the immigrant glasshouses (i.e. it continued in operation after *c*.1567). It is therefore, tempting to associate Idehurst North with one of Henry Strudwick’s sons. Idehurst North might show that ‘native’ glassmaking continued after the arrival of the French immigrants and that the immigrants did not share their technology with the ‘native’ glassmakers. Carré’s 1567 patent to produce glass contained a provision for the training of English workmen but French immigrant glassmakers violently resisted (Godfrey 1975: 23). In the 1570s, after Carré’s death, glassmaking spread to other districts in England and the new type of glass became universal.

Conclusion

The chemical analysis of glass from three Wealden glasshouses supports the idea that forest glass was largely produced before the arrival of French immigrant glassmakers. It is clear that the immigrant glassmakers brought with them a new technology that included a new glass recipe. The two Idehurst sites were operated by native glassmakers who produced glass in a medieval tradition (forest glass). Idehurst South may have operated wholly before the arrival of immigrant French glassmakers, while Idehurst North may have continued to operate after the arrival of the Frenchmen. Tanland Copse was operated by a French immigrant who produced a high-lime low-alkali glass.

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Appendix

Chemical composition of the analysed samples

IDN = Idehurst North, IDS = Idehurst South, TAN = Tanland Copse

FOR = Forest glass, HLLA = High-lime low-alkali glass

Sample	Description	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Total	Type
IDN 1	Heat distorted glass	2.1	7.2	1.1	54.3	3.4	0.3	0.6	11.9	16.6	0.1	1.2	0.6	99.3	FOR
IDN 2	Glassworking waste	2.4	6.9	1.3	52.6	4.0	0.2	0.5	12.5	17.2	0.2	1.0	0.7	99.5	FOR
IDN 3	Glassworking waste	1.9	7.3	1.1	56.6	2.9	0.4	0.5	11.1	17.3	0.2	1.2	0.5	101.0	FOR
IDN 4	Glassworking waste	1.8	7.4	1.1	56.4	3.0	0.3	0.5	11.2	17.2	0.2	1.2	0.5	100.7	FOR
IDN 5	Glassworking waste	2.0	7.2	1.1	56.4	2.9	0.3	0.4	11.2	16.8	0.2	1.2	0.6	100.4	FOR
IDN 6	Glass artefact fragment	2.5	3.9	1.2	58.4	3.4	0.3	0.6	4.5	23.8	0.2	0.9	0.4	100.1	HLLA
IDN 7	Glass artefact fragment	3.1	3.8	1.7	57.3	3.4	<0.2	0.7	6.6	21.5	0.4	1.1	0.6	100.1	HLLA
IDN 8	Glass artefact fragment	2.6	3.6	2.2	57.3	3.3	0.2	0.6	6.7	21.5	0.3	1.0	0.6	100.1	HLLA
IDN 9	Glass artefact fragment	2.6	6.9	1.4	53.4	4.0	0.3	0.6	12.0	17.5	0.2	1.0	0.6	100.3	FOR
IDN 10	Glass artefact fragment	2.3	7.5	0.8	58.9	2.9	0.2	0.7	11.7	14.2	0.2	1.2	0.7	101.2	FOR
IDN 11	Glass artefact fragment	3.0	3.9	1.7	55.8	3.8	0.2	0.7	4.9	25.0	0.3	1.1	0.4	100.6	HLLA
IDN 12	Glass artefact fragment	2.0	5.3	2.8	53.2	4.6	0.2	0.5	18.2	11.5	0.2	0.7	0.9	100.1	FOR
IDN 13	Glass artefact fragment	3.4	4.5	2.8	52.6	4.1	<0.2	0.6	5.6	24.6	0.3	1.3	0.9	100.9	HLLA
IDS 1	Glassworking waste	3.6	8.7	1.3	51.6	3.8	0.3	0.3	12.8	15.6	0.2	1.0	0.6	99.7	FOR
IDS 2	Glassworking waste	2.9	8.7	1.4	53.5	4.1	0.4	0.6	10.4	16.8	0.2	1.0	0.5	100.5	FOR
IDS 3	Glassworking waste	2.8	8.4	1.5	53.5	3.9	0.4	0.5	10.5	17.0	0.2	0.9	0.7	100.4	FOR
IDS 4	Glassworking waste	2.9	9.1	0.9	54.1	4.0	0.4	0.5	10.6	16.0	0.1	1.1	0.5	100.3	FOR
IDS 5	Glassworking waste	3.0	8.8	1.4	53.7	3.8	0.3	0.6	10.4	16.6	0.2	0.9	0.5	100.2	FOR
IDS 6	Glassworking waste	2.8	8.8	1.5	53.7	3.9	0.4	0.6	10.4	16.6	0.2	1.0	0.6	100.4	FOR
IDS 7	Glassworking waste	2.9	8.6	1.4	53.1	4.1	0.3	0.5	10.5	16.9	0.2	0.9	0.5	99.9	FOR
IDS 8	Glassworking waste	2.9	8.3	1.5	53.3	3.9	0.4	0.5	10.5	17.0	0.2	1.0	0.6	100.0	FOR
IDS 9	Glass artefact fragment	2.4	6.6	2.3	56.8	3.0	0.4	0.5	9.4	16.9	0.3	1.0	0.8	100.1	FOR
IDS 10	Glass artefact fragment	2.3	7.0	2.8	55.2	3.7	0.2	0.4	9.2	16.3	0.3	1.1	1.1	99.7	HLLA
IDS 11	Glass artefact fragment	2.1	5.2	2.9	56.7	3.3	0.2	0.4	8.9	18.8	0.3	0.9	0.8	100.3	HLLA

Sample	Description	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Total	TYPE
TAN 1	Glassworking waste	1.7	2.6	2.1	61.6	2.2	<0.2	0.5	3.1	24.6	0.2	0.7	1.2	100.8	HLLA
TAN 2	Glassworking waste	0.7	2.6	2.3	62.0	2.0	0.3	<0.2	4.1	24.7	0.2	0.7	1.2	100.8	HLLA
TAN 3	Glassworking waste	1.5	2.6	2.1	60.8	1.9	0.3	0.4	3.3	25.8	0.2	0.6	1.2	100.7	HLLA
TAN 4	Glassworking waste	1.7	2.8	2.6	60.3	2.2	<0.2	0.5	3.4	24.4	0.2	0.7	1.4	100.2	HLLA
TAN 5	Glassworking waste	1.9	2.9	2.1	60.9	2.3	<0.2	0.5	3.7	23.7	0.3	0.7	1.1	100.2	HLLA
TAN 6	Glassworking waste	0.9	3.1	2.1	60.3	2.4	0.4	<0.2	5.3	23.5	0.3	0.8	1.3	100.4	HLLA
TAN 7	Glassworking waste	0.9	3.0	1.8	60.5	2.2	0.3	<0.2	4.8	23.9	0.2	0.7	1.2	99.4	HLLA
TAN 8	Glassworking waste	2.0	3.2	2.5	60.3	2.5	0.3	0.6	4.3	23.0	0.3	0.8	1.3	101.1	HLLA
TAN 9	Glassworking waste	2.3	2.7	2.1	61.6	2.0	<0.2	0.8	2.6	25.1	0.3	0.6	1.2	101.2	HLLA
TAN 10	Glassworking waste	1.6	2.7	1.9	63.7	2.0	0.3	0.4	3.3	22.8	0.3	0.7	1.4	100.9	HLLA
TAN 11	Glass artefact fragment	1.9	3.0	2.7	61.0	2.0	0.2	0.4	3.7	23.2	0.4	0.8	1.5	100.9	HLLA
TAN 12	Glass artefact fragment	1.8	2.7	2.1	61.6	2.2	<0.2	0.4	3.9	22.8	0.3	0.7	1.1	99.7	HLLA
TAN 13	Glass artefact fragment	0.8	2.9	2.0	59.5	2.3	0.2	<0.2	4.8	24.8	0.3	0.7	1.3	99.5	HLLA
TAN 14	Glass artefact fragment	2.0	2.8	2.1	60.9	2.1	<0.2	0.6	3.2	23.8	0.3	0.6	1.2	99.5	HLLA
TAN 15	Glass artefact fragment	2.0	2.8	2.1	61.8	2.0	<0.2	0.5	3.8	22.7	0.3	0.6	1.2	99.7	HLLA
TAN 16	Glass artefact fragment	0.9	2.9	2.0	61.4	2.0	0.3	<0.2	4.4	24.0	0.3	0.6	1.4	100.1	HLLA
TAN 17	Glass artefact fragment	1.8	2.8	2.2	62.4	2.1	0.3	0.5	3.8	23.0	0.3	0.7	1.2	101.0	HLLA