Characterisation studies of industrial ceramics from Sigtuna, Sweden

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Excavations in Sigtuna, Sweden, revealed evidence for previous metalworking, the construction of composite iron objects, brazed together, and glass production (Sigtuna Museum Code SMUU 06 HUM 03). In order to investigate the raw materials used by these craftsmen in the working of their raw materials and the finishing of their artefacts, samples of the industrial ceramics used were taken for thin section and chemical analysis. Samples of daub and loom weights from the site were also taken to provide a standard which can be assumed to be of local origin and readily available (Table 1).

Table 1

TSNO	Context	REFNO	Form	Action	Fabric Group	subfabric
V4596	SL410	109306	CRUCIBLE	ICPMS;TS	Fabric A	V VESICULAR;S ANG ROCK FRAGS <2.0MM
V4597	SL316	108841	CRUCIBLE	ICPMS;TS	Fabric B	ANGULAR FELDSPARS;VITRIFIED FE-RICH AREAS;GREY FABRIC
V4598	SL295	106628	UNSPECIFIED METALLURGICAL PACKAGE	ICPMS;TS	Fabric C	?WHITE SST FRAGS IN A GREY MATRIX;THIN SLAGGY LAYER ON EXT
V4599	SL543	110023	SCORIFIER (MADE FROM RE-USED POTSHERD)	ICPMS;TS	Fabric B	LOW-FIRED RE-USED SHERD;M A ROCK FRAGS <3.0MM;LAYER OF OXBLOOD RED SLAG
V4600	SL287	110342B	MELTING BOWL	ICPMS;TS	Fabric D	A ORGANICS;A AQ <0.1MM;S AQ <1.0MM;FUSED SAND + VESICULAR LAYER ON EXT
V4601	SL448	110482	UNSPECIFIED METALLURGICAL PACKAGE	ICPMS;TS	Fabric E	FUSED QUARTZOSE SAND? V VESICULAR
V4602	SL287	109833	CRUCIBLE	ICPMS;TS	Fabric E	A ORGANICS;A AQ <0.1MM;S AQ <1.0MM;VESICULAR LAYER ON EXT
V4603	SL530	109581	BRAZING PACKAGE	ICPMS;TS	Fabric E	A ORGANICS;A AQ <0.1MM;S AQ <2.0MM;VESICULAR LAYER ON OUTER SURFACE
V4604	SL287	110342A	MELTING BOWL	ICPMS;TS	Fabric E	V VESICULAR;S ANG ROCK FRAGS <2.0MM
V4605	SL348	107922	SCORIFIER	ICPMS;TS	Fabric F	M A ROCK FRAGS; UPPER SURFACE VESICULAR?LEAD GLAZE ON UPPER AND LOWER SURFACES
V4647	SL316	108840	DAUB	ICPMS;TS	Fabric G	
V4648	SL543	110021	LOOM WEIGHT	ICPMS;TS	Fabric G	

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V4649	SL348	107917	DAUB	ICPS	Fabric G?
V4650	SL188	109464	LOOM WEIGHT	ICPS	Fabric G?
V4651	SL626	108025	LOOM WEIGHT	ICPS	Fabric G?
V4652	SL349	107845	DAUB	ICPS	Fabric G?
V4841	SL296	107528	GLASS CRUCIBLE	ICPS	Fabric E?
V4842	SL296	107528	GLASS CRUCIBLE	ICPS;TS	Fabric B
V4843	SL632	108037	GLASS CRUCIBLE	ICPS	Fabric E?
V4844	SL632	108037	GLASS CRUCIBLE	ICPS	Fabric E?
V4845	SL525	108081	GLASS CRUCIBLE	ICPS;SEM	Fabric E?
V4846	SL525	108081	GLASS CRUCIBLE	ICPS;SEM	Fabric E?
V4847	SL525	108081	GLASS CRUCIBLE	TS	Fabric E

The thin sections produced by Steve Caldwell, University of Manchester, and were stained using Dickson's method (Dickson 1965). Chemical analyses were undertaken under the supervision of Dr J N Walsh, Royal Holloway College, London using Inductively-Coupled Plasma Spectroscopy (ICP-AES). The samples of metalworking ceramics and the fired clay loom weights and daub were also examined using ICP-MS, which measures a wider range of elements. This was done in order to test whether metals or other elements associated with the processes being carried out in the ceramics were present. Clearly, this method runs the danger of including post-burial contamination alongside elements which actually entered the sample during use, and this was the reason for analysing the fired clays in the same manner. For the glass-melting vessels, a detailed study of the glass is being carried out by J Henderson and there is therefore no need to carry out this second analysis.

Thin Section Analysis

The 14 thin sections were examined and an attempt made to classify the fabrics on the basis of the identity of the inclusions larger than 0.1mm and the texture (size distribution). However, this proved to be extremely difficult because of the high temperatures to which some of the samples had been subjected. These were sufficient in many cases to vitrify the groundmass, producing an isotropic glass with variable quantities and sizes of spherical vesicles. In some cases, the contents of the ceramic object had also reacted with the body during use leading to the formation of vesicular slags containing fayalite. These use-related alterations have probably also affected the larger inclusions and the lower fired ceramics contain inclusion types whose absence from the higher-fired ones is very likely due to alteration during use. Consequently, the sections have been grouped into seven fabric groups but three of these consist solely of a single overfired sample whose original characteristics are now obscure.

Fabric A

A single thin section, V4695, consisting of vesicular isotropic glass with a groundmass of vesicles up to 0.2mm in diameter and some larger ones in excess of 2.0mm across. Some of these larger ones are not perfectly spherical and have long axes parallel to the vessel walls. Most of the smaller vesicles are void but some of the larger ones have a partial filling of unfired clay minerals and angular quartz and feldspar. These are presumably contaminated by the sediment in which the samples were buried. Some areas of opaque vesicular glass have formed and appear to represent the presence of iron-rich inclusions.

The following inclusions were noted;

> Quartz. Angular fragments, often polycrystalline, up to 2.0mm long.
>
> Unidentified rock. A single fragment 0.7mm long consisting of interlocking crystals of quartz and plagioclase feldspar ranging up to 0.3mm across.
>
> Unidentified cryptocrystalline material. Sparse grains with no clear grain boundary with the glassy groundmass, ranging up to 0.4mm across.

The glassy matrix contains moderate quantities of angular quartz up to 0.1mm across. There is no sign of plagioclase feldspar.

Fabric B

Three thin sections of this fabric were made (V4597, V4599 and V4842). V4599 appears to have been a re-used low-fired black pottery sherd and had a coating of ox-blood red glass. In thin section the red glass is seen to be poorly mixed with a glass which has adsorbed blue staining from Dickson's method, and therefore might contain ferroan calcite. Other areas of the glass are colourless. V4597, a crucible, was fired to a higher temperature and reduced throughout. Several vesicular opaque inclusions appear to be heat-altered iron-rich inclusions but there appears to be no other indication of alteration during use. V4842 is from an oxidized vessel associated with glass production although there is no glass or other traces of use in thin section.

The following inclusion types were noted:

> Feldspar. Sparse angular fragments of untwinned fresh feldspar up to 1.5mm long.
>
> Perthite. Sparse angular fragments up to 1.5mm long.
>
> Microcline. Sparse angular fragments up to 0.5mm long.
>
> Quartz. Sparse rounded grains up to 0.3mm across
>
> Vesicular opaques. Sparse rounded fragments up to 0.5mm across with no clear boundary with the matrix.

He groundmass consists of optically isotropic baked clay minerals and abundant angular quartz grains up to 0.1mm across. V4842 contains heat-altered biotite and fresh muscovite laths up to 0.1mm long but these are absent from the other two sections.

Fabric C

A single thin section, V4598, comes from a metallurgical vessel with a curved body. The vessel is highly vesicular, as with Fabric A. The interior has an opaque to blue-stained surface whilst a layer of light brown to colourless glass up to 0.4mm thick is present on the exterior.

The following inclusion types are present:

> Quartzite. Moderate angular fragments up to 2.0mm long composed of interlocking grains with euhedral grain boundaries. The individual grains range from c.0.2mm to 0.5mm across. This material might be the result of high grade metamorphism or authigenic overgrowth of silica in a sandstone.
>
> Microcline. Sparse angular fragments up to 0.5mm across.
>
> Unidentified cryptocrystalline material. Rare subangular fragments with indistinct boundaries between these inclusions and the groundmass.

The groundmass consists of isotropic dark brown to black vesicular glass containing sparse angular quartz up to 0.1mm across.

Fabric D

A single thin section, V4600, comes from a melting bowl and has a quartzose sand and vesicular layer adhering to the exterior. The sample is completely vitrified and composed of vesicular glass although patches in the centre of the section show what is probably less altered structure and texture, although still vesicular.

The following inclusion types were noted:

> Quartz. Abundant angular grains, some extremely angular, shard-like pieces, ranging from c.0.1mm to (rare) 1.5mm. Some fragments are elongate and have near-parallel faces but even these appear to be quartz rather than feldspar.
>
> Organics. Moderate elongated voids up to 1.5mm long containing carbonised organic matter.

The groundmass consists of the least altered parts of the sample consists of dark brown to opaque vesicular glass and in the rest consists of colourless vesicular glass.

Fabric E

The distinguishing features of this fabric are an abundant quartzose silt and the presence of moderate to abundant organic inclusions.

Four thin sections were made of Fabric E. One sample, V4601, has no suggested function but the thin section indicates the presence of fayalite slag and therefore one possibility would be that the piece comes from a iron smithing hearth or tuyere fragment. Sample V4602 comes from a crucible and has a vitrified vesicular layer on the exterior whilst the thin section indicates progressive vitrification throughout the sample. Another sample, V4603, appears to have been the clay coating used to contain a composite iron object whilst it was being brazed using a copper alloy, a “brazing package”. On examples from Birka the inner surface of the fragments include impressions of the iron object and organic material, straw, used to bind the pieces together whilst the outer surfaces are heavily vitrified. The Sigtuna sample is black throughout and shows no signs of its use. Brown phosphate, however, is present partially filling organic voids throughout the sample. Finally, sample V4604 is identified as a melting bowl. It shows the same firing gradient as V4603 but with the process being further advanced so that the outer layers contain large rounded vesicles and only the inner margin retains its isotropic clay groundmass.

The following inclusion types were noted in thin section:

Quartz. Abundant angular and very angular fragments up to 0.3mm long, several with shard-like shapes.

Organics. Abundant elongated voids up to 1.5mm long and 0.2mm wide, many still containing carbonised organic material.

Plagioclase. Sparse angular fragments, some lath-like in shape.

Unidentified cryptocrystalline. Rare subangular fragments up to 0.2mm across.

The groundmass varies from isotropic baked clay minerals through colourless vesicular glass with fine-grained vesicles to dark brown to opaque vesicular glass with a mixture of coarse and fine-grained vesicles.

Fabric F

A single section, V4605, comes from a scorifier and has a glassy deposit on both upper and lower surfaces. In thin section not only is the glass visible on the surfaces but has etched its way deep into the body. In most cases it is a light brown to colourless glass but in some places it has adsorbed blue staining, as with V4599 (Fabric B).

The following inclusion types were identified in thin section:

Relict clay. Moderate rounded pellets up to 0.5mm across. These have a similar colour and texture to the groundmass but show bedding. In some cases even within a small pellet there are clear variations in the clastic content of the laminae, suggesting that these are fragments of glacial lacustrine clay.

Igneous rock. Moderate rounded fragments up to 1.0mm across of rocks containing amphibole, plagioclase feldspar and quartz.

Plagioclase. Sparse angular fragments up to 0.5mm across.

Microperthite. Rare angular fragments up to 0.05mm across.

Biotite. Moderate laths up to 0.3mm long, mostly altered to an opaque mineral but retaining their distinctive sheave structure.

Muscovite. Sparse laths up to 0.2mm long.

The groundmass consists of optically isotropic baked clay minerals and abundant rock and mineral fragments, principally quartz with minor muscovite, biotite and unidentified amphiboles, all up to 0.1mm across.

Fabric G

Two thin sections of this fabric were produced. Both come from fired clay objects (V4647 is daub and V4648 is from a loom weight). The fabric is very different in texture to those of the industrial ceramics.

The following inclusion types were noted in thin section:

Quartz. Sparse angular grains up to 0.2mm across, mostly present in lenses and clusters.

Opaques. Rare rounded and subangular grains up to 0.2mm across.

The groundmass consists of optically anisotropic baked clay minerals and is cut by cracks which are surrounded by slightly darkened haloes c.0.2mm wide, indicating contamination from groundwater after burial.

Chemical Analysis

Contamination from use

By comparing the analyses of the daub and loom weights found on the same site and presumably subjected to similar burial conditions with those of the industrial ceramics it was thought that it would be possible to recognise elements which were present in elevated frequencies and therefore likely to indicate the use of the industrial ceramics. However, once the thin sections had been examined it was realised that none of the industrial ceramics were made from the same clays as those used for the daub and loom weights and that therefore differences between these two groups might be due to use, but also might be due to variations in the raw materials used. In addition, the higher quantity of quartz silt/fine sand in the industrial ceramics dilutes the frequencies of the measured elements and therefore all the data had to be normalised before comparison. All the data were therefore normalised to aluminium.

Comparison of the normalised data reveals some differences which are almost certainly due to the different source of the two groups. Chromium, for example is consistently higher in the fired clays as is calcium, strontium, manganese, lithium, nickel, scandium, vanadium, and zirconium.

Elevated levels of several elements, relative to those found in the fired clays, could be found in all but two of the industrial ceramics (both glass crucibles, V4842 – Fabric B – and V4841 – Fabric E).

High silver was noted in four samples (crucible, V4602; a crucible, V4597, and a scorifier, V4599; and the scorifier, V4605). Silver frequencies in the local fired clays ranged from 0.2 ppm to 2.2 ppm and in the glass crucibles ranged from 0 ppm to 1.6 ppm.

A single very high bismuth value was found, in the scorifier, V4605, whilst the bismuth content of the fired clays was either undetected or 1 ppm and in the glass crucibles ranged from 7 to 38 ppm (but was undetected in two of the samples).

High copper was present in one crucible sample (V4597 - Fabric B).

High copper and zinc were present in three samples (a crucible, V4602 – Fabric E; a melting bowl, V4600 – Fabric D; and a crucible, V4596 – Fabric A).

High iron and cobalt were present in one unspecified metallurgical package, V4601 – Fabric E).

Very high copper levels were found in one of the scorifier samples, (V4599 – Fabric B)

Very high copper and lead levels were found in the scorifier sample, V4605 – Fabric F)

Very high copper and zinc levels were found in two samples, the brazing package, V4603 – Fabric E and the melting bowl V4604, Fabric E).

Very high copper, zinc and lead were found in one metallurgical vessel, V4598 – Fabric C.

Finally, very high lead levels were found in four Fabric E glass crucibles (V4843, V4844, V4845 and V4846).

These results indicate that the glass crucibles were used to melt lead glass with no evidence for the use of copper as a colourant. The high lead levels occur also in the scorifier, but this can be distinguished because of the high silver and copper levels and in one of the samples, V4598, which has elevated copper and zinc. The elevated copper and zinc in the brazing package sample is presumably due to the use of brass as a brazing medium.

Source of Raw Materials

Normalized data for those elements which are not found in elevated levels in the industrial ceramics and which are not likely to have been seriously affected by post-burial alteration (such as phosphorus) were examined using the Factor Analysis package from the WinSTAT add-in for Microsoft Excel. The data were groups according to broad function: the brazing package; the fired clay samples; the glass crucibles and the remaining industrial ceramics. Factor analysis revealed four factors which together account for 84% of the variability in the data. A bi-plot of the first two factors (Fig 1) indicates that the fired clay samples can be distinguished from the remainder by their high F1 scores whilst there is a broad division between the glass crucibles and the remainder based on the F2 scores and that those industrial ceramics with low F2 scores can be distinguished from the glass crucibles by their lower F1 scores. The brazing package sample has similar F1 and F2 scores to the other industrial ceramics. High F1 scores are due to high weightings for a number of elements, such as magnesium; calcium; scandium; and manganese. The high magnesium is consistent with the southern Norwegian quaternary clay analyses for marine clays whilst the higher calcium values could be due to the lower firing temperature of the fired clays, or another indication of the use of a marine clay.

The high F2 scores found in the industrial ceramics but not in the glass crucibles are due to high weightings for barium, europium and potassium. Of these, the barium values overlap between the different groups but the europium and potassium values do distinguish the glass crucibles from the other industrial ceramics.

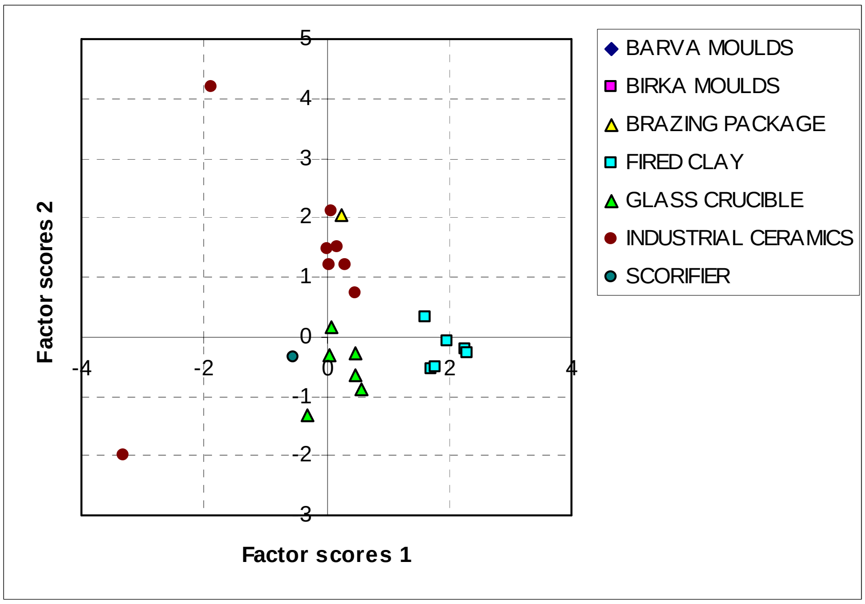

Figure 1

A bi-plot of the third and fourth factors (Fig 2) still shows that the glass crucibles can be distinguished from the remainder but the fired clay and industrial ceramics have similar scores. The brazing package sample again has similar scores to the other industrial ceramics.

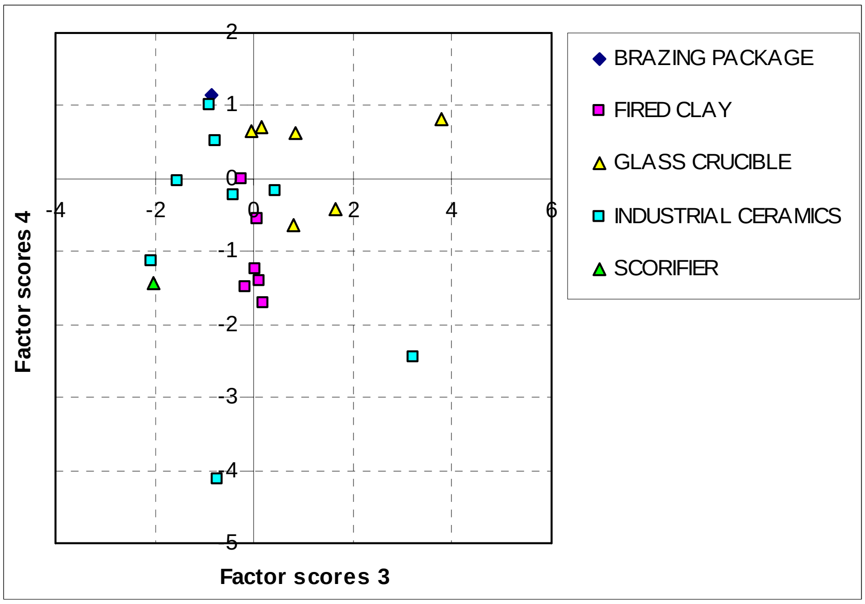

Figure 2

The high organic content and coarse silt/fine angular sand content of some of the glass crucibles and other industrial ceramics is reminiscent of that of copper alloy and silver casting moulds from Birka and Barva. The Sigtuna data was therefore compared with that for samples of those moulds. In this analysis, the glass crucibles emerge as being very similar in composition to the Birka and Barva moulds whilst the remaining industrial ceramics and fired clays are distinguishable (Fig 3).

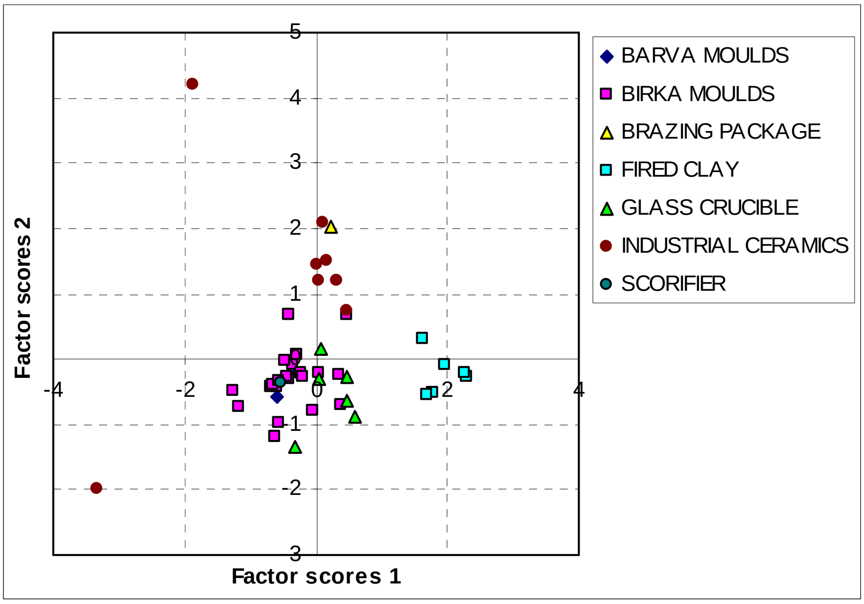

Figure 3

In all of these analyses, the data for the scorifier, whose thin section analysis suggests the use of a different, perhaps non-local, clay, reveals that the scorifier is not distinguishable from the remaining ceramics.

Discussion and conclusions

Thin sections

It is clear that there are at least three distinctive clays used for the Sigtuna industrial ceramics. The first, and most common, is Fabric E. The quartz-rich fine sand is probably of glacial origin and the complete lack of rounding and extreme angularity of some grains suggests that this is a lacustrine clay containing material derived from the frost shattering and ablation of pro-glacial gravels. Unfortunately, such clays are ubiquitous in glaciated regions. However, it is notable that in all of the industrial ceramics, apart from the Fabric F scorifier, the fine sand is composed almost entirely of quartz, which probably reflects the nature of the rocks from which this material was derived. The organic inclusions which are a feature of this clay might have been naturally present or might reflect the addition of material such as dung (a well-known tempering agent in Viking Age ceramics in Scotland and the Orkney Islands, for example, Gaimster 1986).

The second most common fabric, Fabric B, differs from Fabric E mainly in the presence of larger angular mineral fragments most of which are feldspars, the presence of sparse rounded quartz and a lesser quantity of quartz silt. The rock fragments might have been selected and added to a fine silty clay but similar textures occur in ceramics made from unmodified glacial till. The presence of sparse rounded quartz is noteworthy and has been noted in some pottery found at Birka, where it has been suggested that the vessels had a non-local origin (pers comm M Back).

The third fabric is represented by a single sample, the scorifier in Fabric F. This is completely different in its rock and mineral suite, the presence of relict clay pellets and the texture of the groundmass. It may be significant that very similar fabrics were found in the industrial ceramics of Kaupang, in southern Norway (Vince forthcoming) although it is probable that more local sources could be found.

The remaining fabrics are too altered by use for the thin section analysis to be able to reliably interpret their sources or their relationships with the three fabrics noted above. Biotite, muscovite and feldspar would probably have been dissolved into the glassy matrix, in that order, leaving higher and higher proportions of quartz. Nevertheless, the general similarity in texture argues that in fact these fabrics probably belong to either Fabric B or Fabric E, depending on the presence of coarser-grained rocks and the frequency of angular quartz silt in the groundmass.

Finally, it is clear that the fired clay used for daub is identical to that used for loom weights but that the clays are completely different from those used for industrial ceramics. The lack of quartz silt in Fabric G might indicate the use of a marine clay, deposited below the tidal zone. Quaternary marine clays are exposed throughout coastal Scandinavia, often at some distance from the present coastline, as a result of glacial uplift. In southern Norway one of the distinguishing features of the chemistry of these marine clays was raised magnesium levels but where this magnesium was present, such as in the clay fraction or as magnesium-rich rock or mineral fragments, is not clear (Roaldset 1972).

The chemical analysis produced evidence which may indicate the function of some of the samples and in particular indicates that the scorifier was indeed probably used in the purification or testing of silver and that the glass crucibles were used to melt plain lead glass whilst the brazing package was used with a copper/zinc brazing agent and a variety of different processes involving silver or copper were carried out using the other ceramics.

The ICPS analyses also confirm the suggestion made from the thin section analysis, that the fired clays were produced from marine clay whilst the silty/fine sandy clays used for the glass crucibles were probably lacustrine clays and cannot be readily distinguished in their chemical composition from those used at Birka and Barva for the production of silver and copper alloy casting moulds. By contrast, the other Sigtuna industrial ceramics can be distinguished from the Birka and Barva samples. These differences are not closely related to the fabric as defined by thin section analysis since the brazing package and three other industrial ceramics are also made from Fabric E clays and yet their chemical composition places them with the other industrial ceramics.

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