Stockholms universitet

Tools of the Trade

An analysis using conservation and SEM of the context and iron material from the excavation of House X in the city block Humlegården 3 in Sigtuna.

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Abstract

Sigtuna's trade and production has been the subject of an increasing amount of archaeological investigations during the last 30 years. However, most of the research has been conducted regarding the buildings, coin mints and precious metal objects. This thesis will instead research one of the basics of the production, namely the iron. By reviewing the iron objects and currency bars from house X in the city block Humlegården 3. Through high precision studies with conservation and scanning electron microscope I will be able to come one step closer to identifying what sort of items were produced on the site and discerning what status and function the smithy had. I will also investigate the possibility to track the origin of the iron.

Sigtunas handel och produktion har varit föremål för ett ökande antal arkeologiska undersökningar de senaste 30 åren. De flesta av dessa undersökningar har handlat om byggnader, mynthus och föremålsstudier. Den här uppsatsen kommer istället att undersöka ett av hantverken som krävs för att kunna utföra många andra hantverk, nämligen järnhantverk. Genom att undersöka järnfynden och ämnesjärnen från hus X i kvarteret Humlegården 3, via detaljerade studier som inkluderar konservering och Svepelektronmikroskop, kommer jag att komma ett steg närmare vilka föremål som producerats på platsen samt utröna vad för status och funktion smedjan hade. Jag kommer även undersöka om det är möjligt att säga någonting om järnets ursprung.

Keywords: Iron making, Iron object production, Smithy, Workshop, Tools, Conservation, Middle ages, Medieval Sigtuna, Element analysis, SEM

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1. Introduction

In 1978 the city Sigtuna was surveyed along with three other Swedish cities in conjunction with the project “The medieval city” (1976-1984). This was to be the first effort, since the 1940s, among many archaeological surveys and excavations, that was to follow until the present day. The last 30 years of excavation have revealed much in terms of how the society was in early medieval Sigtuna.

Even though scientists agree that trade never was the main reason for the establishment of Sigtuna, merchants and craftsmen of different sorts and specializations have been highly active within its borders. Manufactured items such as objects of precious metals, weights, combs and iron tools are among those that have been found. Scientific studies have recently been done on the manufacture of gold and silver items as well as combs; however, the iron tools and blacksmithing objects are left largely abandoned by researchers and it is on this aspect that this study will take its starting point. In order to further identify the different products that have been produced in Sigtuna I will have to review the number of tools and raw material that were used. When excavating a workshop you are likely to come across raw material, structural facilities involved in the production, tools and probably some products. The problem with the finished products found in workshops is that they might actually have been thrown away for a reason, and even though they hint towards the purpose of the workshop, it might not identify all of the items produced at the site. The first step in putting the tools and construction method first rather than the products in Sigtuna were made by Anders Söderberg and Ny Björn Gustafsson (2007) in their investigation of technical ceramics involved in preparation and construction of precious metal objects, however apart from this study not much has been done in terms of identifying trade through its tools. This essay aims to conduct the same type of investigation with the iron objects from house X in the city block Humlegården 3 as the above mentioned authors did with theirs.

1.1. Definitions

Atom%: When an element amount is presented in atom% it represents the number of atoms in the material regardless of weight or size of the atoms.

Bergslag: A Bergslag is both a geographical term for a number of specific areas in Sweden and an old economic term for an area with a royal permission to conduct iron making from a specific mountain range.

Counts: Numbers of unique counts of atoms that are presented in the spectrum result, which can be lowered and raised to look for certain information

Currency bar: An economic term used for the semi-manufactured iron that was exported from the iron production sites to the place where it was manufactured into actual products

EDTA: Ethylenediaminetetraacetate, a chemical solution designed to dissolve corrosion on metal objects.

keV: Strength of the electron current launched at an object from a SEM.

REM: Rare earth mineral, which is a bundle name for a collection of 17 elements that are found in very low amounts in the earth's crust.

SEM: Scanning Electron Microscope

Weight%: When an element amount is presented in weight% it represents the weight of that element in regards to the total weight of the found elements. This means that for example a 1-2% weight% of carbon(C) could very well amount to a number of 10-20% in atom% if for example steel was analyzed due to the fact that the weight of carbon in comparison to its actual amount is not equal.

1.2. Research background

It has been all the more apparent that the entire city of Sigtuna was planned and designed from the start instead of growing into a town like its early medieval counterparts like Lund, in southern Sweden, and Trondheim, in Norway, with its straight and ordered city plan (Fig. 1)(Tesch 2007:90ff). The hypothesis regarding why this city came to be and why it was designed as it was have been many. The most prominent of them is that it was built by the king to enhance his control of the lords of the countryside. This hypothesis is supported by the evidence for coin minting found during the excavation of the city block Trädgårdsmästaren. From those coins and moulds found in the excavations the first minters in Sigtuna were identified as Olof Skötkonung and Anund Jakob according to Kenneth Jonsson (2010) among others.

Figure 1 Reconstruction of the city block Humlegården 3 during phase 1b (980-1020 AD) (Ljung & Wikström 2008:89)

A lot of work has been carried out regarding the Sigtuna crafting quarters which has in turn revealed a great deal of different products being produced in early medieval Sigtuna. Among these there is a recent study reviewing the ceramics used in creating silver weights and preparing silver and bronzes for manufacture by Anders Söderberg and Ny Björn Gustafsson (2007). In this study a lot of the old classifications of ceramics found in a workshop environment were re-evaluated. In their material they have found some items that they interpret as indication of foreign craftsmen being active, at least temporarily in Sigtuna. The evidence in question was a ceramic device for melting precious metals that bear resemblance to similar items from the east and more specifically Kiev and Novgorod.

Another study that supports foreign influences or indeed direct manufacture regards a gold pendant with the motive of a “bird dragon” with clear influences from Denmark and northern Germany (Jansson 2010). The theories that have been presented regarding these above mentioned studies is that craftsmen accompanied foreign lords on visit from abroad to meet the king or conduct business or proto-diplomatic work. The picture of a town with a high level of contact with foreign powers is getting clearer. Apart from this evidence for production of weights and a number of glass kilns was found within the confines of a building foundation in the city block Humlegården 3 during the excavations in 2006 (Wikström 2010). Furthermore, evidence for extensive leatherworking and production of items of rock-crystals has been found during the excavations (Pettersson 1990). All this put together starts to produce a wide picture of the different crafts practiced in Sigtuna during the late Viking Age and medieval period. However, excavations done in villages in close proximity of Sigtuna proved that many of the products that were produced in Sigtuna did not reach the areas around the town however, and therefore the buyers were probably either from the town itself or foreign (Roslund 1990:53f).

All of these above mentioned trades used a number of tools within their own manufacturing processes, these were most likely also manufactured within the borders of Sigtuna. During excavations of different parts of Sigtuna, different kinds of iron products have been found ranging from construction accessories like nails, tools and weapons. A possible location for a smithy has also been found at the same location as the glass kilns mentioned above; but, no evidence for the process of preparing the iron ore has been found in or in close proximity to Sigtuna. This, along with the fact that the area itself was poor of bog ore have led previous researchers to the conclusion that the raw material was imported (Pettersson 1990).

1.3. Aims and Research Questions

In light of the previous research done and the extensive material of iron objects and evidence of blacksmith activity in Sigtuna it is interesting to see that there has been so little research done regarding them. The investigation itself aims to further our knowledge of early Sigtuna and especially the part concerning the organization and importance of the production and trade in this early medieval setting. What part did the iron object production play and will it be possible to identify any interesting traits within the finds which makes Sigtuna special? This is why the first thing that needs to be done is to review the iron material from House X in the city block Humlegården and compare this to other research that has been done concerning iron making and blacksmithing. The questions towards the material is as follows:

- What iron objects can be traced among the artifacts found in House X and what do these items tell us about the iron object production on the site?
- What conclusions can be drawn concerning House X function based on the context and the total amount of finds?
- Can a SEM analysis of the currency bars of the investigated area tell us something about differences in the material, technological advancements or indeed the origin of the raw material? And if a difference of this form is found, what can it imply?

2. Material

The material chosen for this investigation consists of finds from the city block Humlegården excavation of 2006 in Sigtuna and more specifically "House X" which has been interpreted as a smithy with some glassworks by the excavators and with a dating of 980-1010 (phase 1b)(Söderberg 2008:104ff).

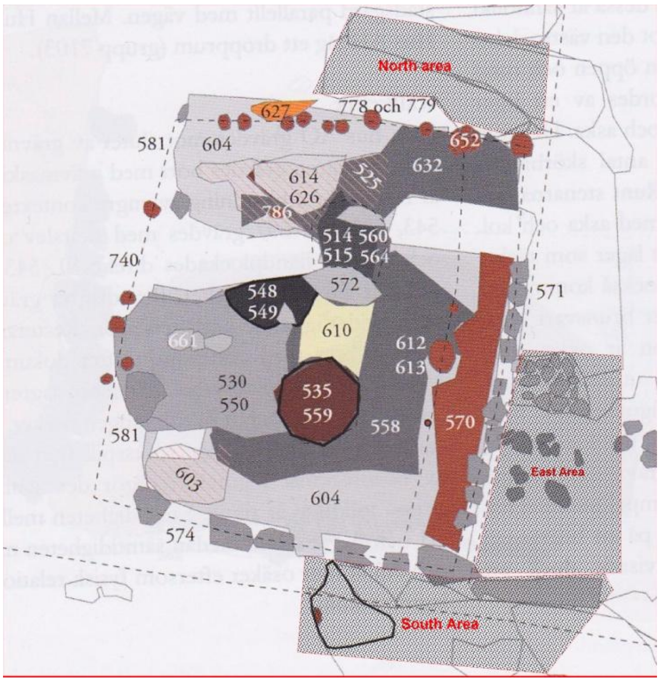

Figure 2 Excavation plan from house X. The additional areas that are under investigation in exception to the house itself are added to the picture (Wikström 2008:276)

2.1. The context

During the excavation remains of a hearth construction (661, 550, 530) as well as 2 - 3 separate glass ovens (515, 525, 603, 627) was found in an area of 4.7 x 5.2 m (Fig. 2). The hearth construction seems to have been situated in the west side of the building and with the glass kilns constructed more to the sides in the north and south, whereas the last oven seems to have been situated close to the hearth. The building has been constructed with a number of poles supporting a roof. No evidence of a wall construction has been found for this building, however the rest of the buildings seem to have them. Evidence for an anvil base construction has also been found (559) however no anvil has been recovered. (Wikström et al 2008:277ff). Apart from the building itself this investigation has chosen to include the space between House X and House F(to the east), the space directly north of House X and the space between House X and the street including the finds, to create a more complete picture of the products and waste produced by this building. These additional areas contain mostly waste layers and passage layers (in the case of the space between house X and house F) (Wikström et al 2008:280ff). These four areas have the internal numbers 7098(for house x), 7095 (north), 7082 (east) and 7100 (south) for the excavation and can be seen in figure 3.

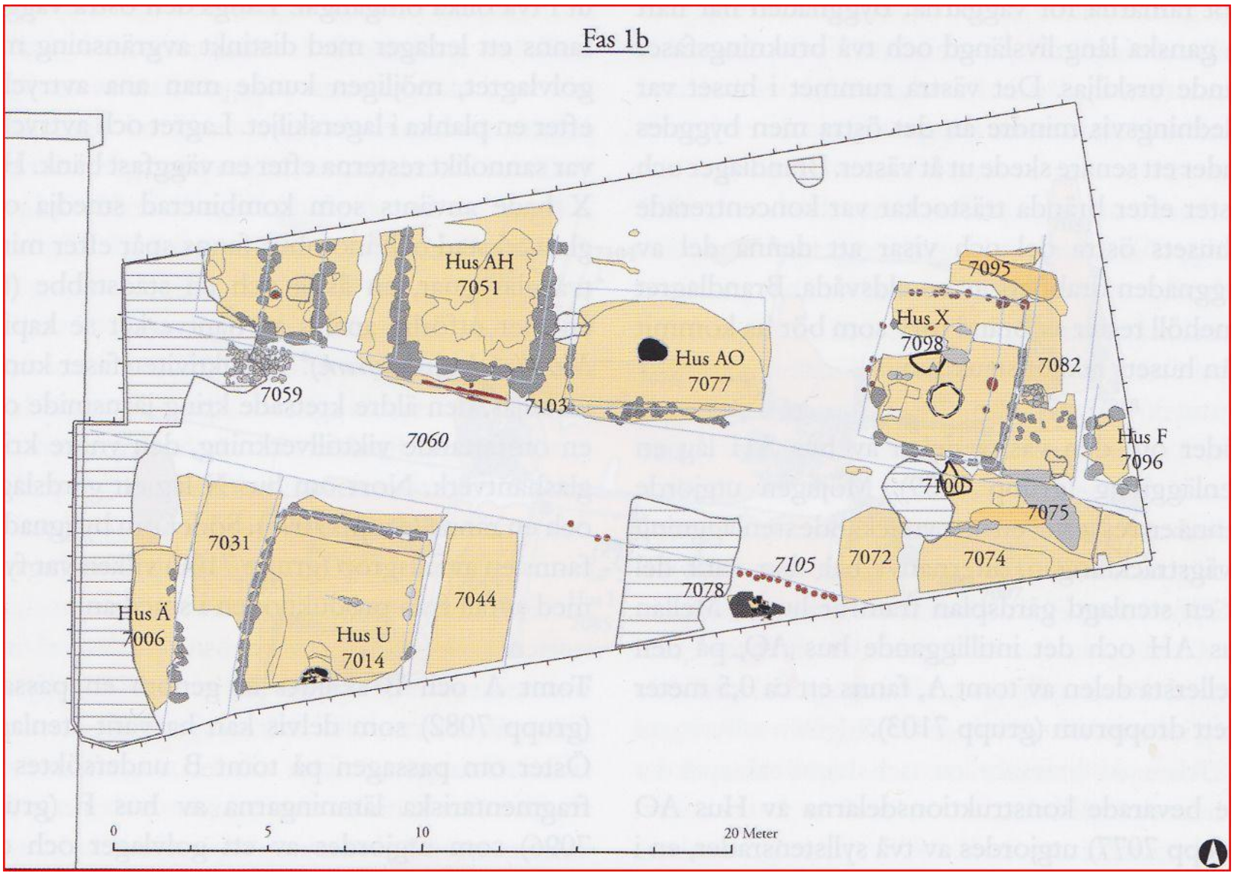

Figure 3 The excavation plan from the Humlegården 3 in Sigtuna from 2006. House X and the three additional areas (7082, 7095 and 7100) is also included (Ljung & Wikström 2008:66).

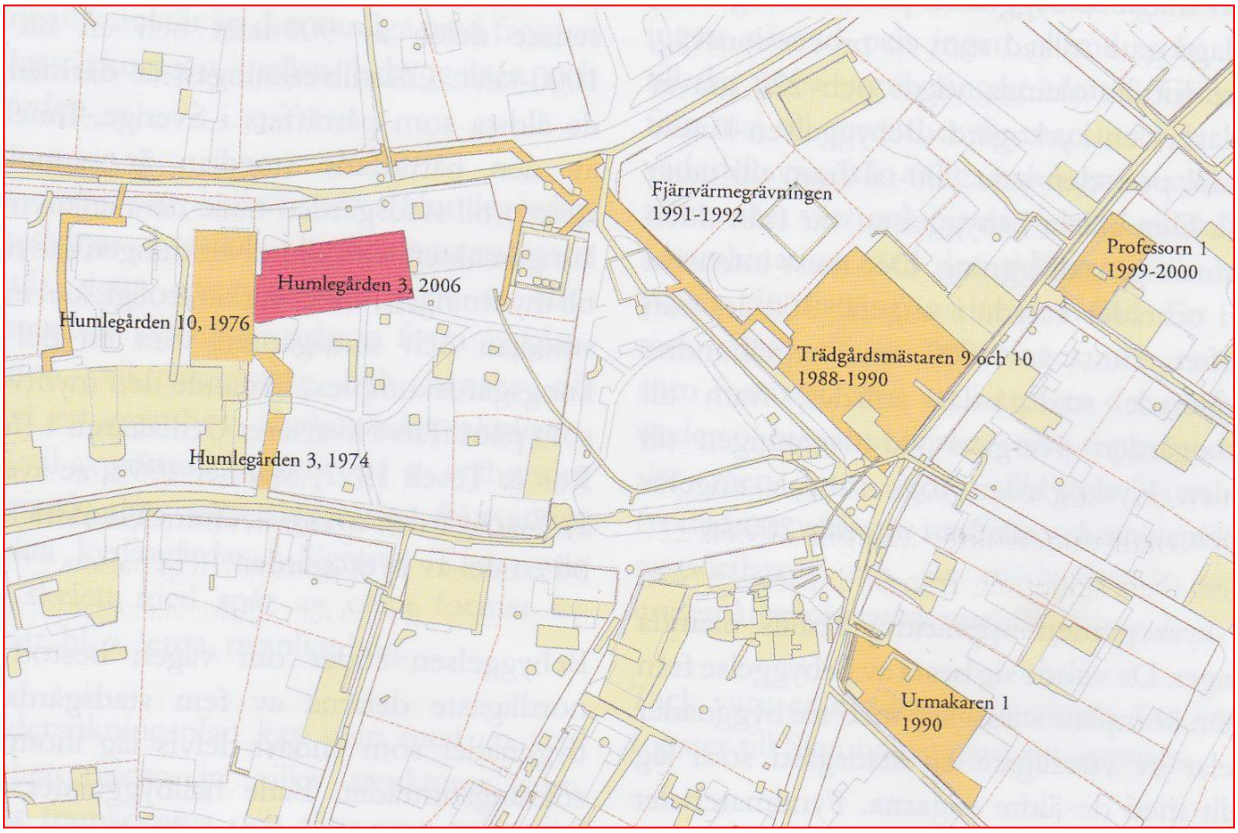

Figure 4 Map of the excavations in the central parts of Sigtuna during the last 30 years (Wikström 2008:10)

The excavation of the city block Humlegården 3 has not been the only excavation conducted in the centre of the present town. As previously mentioned a lot of scientific investigations have been conducted the last 30 years as can be seen above (fig. 4)

2.2. The finds

As can be seen above house X is but a small part of the excavation of Humlegården 3. The total amount of finds within house X and the three additional contexts adjacent to the building can be seen in table 1.

Table 1 Total amount and weight of all finds within House X (7098) and the three other areas (7082, 7095, 7100)

Type of finds	Number (incl. fragments)	weight (in g)
Iron	288	4109
Slag	1168	31558
Bone	7	160
Glass	16	22
CU alloy objects	6	16
Ceramics (general)	259	3083
Technical ceramics for glass production	859	6441
Technical Ceramics for metal production	4325	11973
Clay	100	1324
Leather	1	115
Organic material	7	9
Stone	22	1086

As mentioned this thesis will deal mainly with the iron objects and thus a summary of the database records and previous interpretations can be found in table 2. These constitute the grand total of 288 objects divided between 61 find posts from the four areas described in chapter 2.1 and have all been collected for further analysis in this essay. A complete list, including find posts, of the iron objects can be found in appendix 1.

Table 2 A summary of all iron finds within House X (7098) and the three other areas (7082, 7095, and 7100).

Iron finds	Amount	Weight (in g)
Unidentified	206	2814
Locks	3	25
Rivets and roves	13	181
Cylinder	1	22
Wedge	2	27
Chisel	2	169
Unspecified tool	1	2
Chain link	1	42
Currency bar	2	80
Plating	20	357
Iron bar	18	230
Nail	8	87
Punch	2	22
Ring	2	1
Awl	4	21
Weight fragment	1	6
Knife	2	23

A grand total of 71.5% of the iron items remain unidentified which is largely due to the problem of identifying items with corrosion surrounding the iron core of the artifacts. A rivet and a weight can sometimes look basically the same when surrounded by a more than 5mm thick corrosion crust (see fig. 5).

Figure 5 An example of the unidentified and highly corroded iron objects from the Humlegården 2006(Photo: Tomas Engerdahl 2011)

2.3. The currency bars from the 1995 and 1997 GAL analysis

Along with the above mentioned material I will be using an analysis made by GAL (Geoarchaeological laboratory) in Uppsala where they in two separate reports have made microprobe analysis of seven currency bars from the excavation of the block Trädgårdsmästaren in Sigtuna. They have not been collected from one spot but are from different locations of this quite large excavation. These currency bars have dating span of around 200 years and the results of their analysis will be used in comparison to the Humlegården ones(table 3).

Table 3 Summary of the dating and dimensions of the Trädgårdsmästaren currency bars(Hjärthner-Holdar et al 1995:8,10,12, Hjärthner-Holdar & Larsson 1997:17f, 20f)

Find Post	Interpretation	Dating	Dimensions	Weight
1199 A	Currency bar	1180-1205AD	110x26,8x6,9 mm	99,59g
1199 B	Currency bar	1180-1205AD	68,5x21,4x2,6 mm	11,04g
2078	Currency bar	1180-1205AD	104,5x16,3x13,8 mm	138g
2599	Currency bar	1105-1180AD	95,4x25,6x6,9 mm	56,94g
3689	Currency bar	1205-1230AD	50,3x25,6x7,2 mm	37g
22343	Ribbon shaped currency bar	1182-1105AD	137x16,5x10,5 mm	44,04g
27791	Ribbon shaped currency bar	1205-1230AD	108x55,4x17,4 mm	443g

3. Method

In this section I will discuss the three main methods that have been used during the investigation of the House X material. Firstly, a magnet and X-ray analysis were conducted to identify what items that have the potential of making it to the next step. Secondly, the actual mechanical and chemical removal of corrosion and conservation was conducted and the last step was the SEM analysis of the currency bars.

3.1. The identification

The first thing that has been done with the material is a thorough analysis using X-ray and a magnet. Every single iron object has been put through a simple test where a magnet is used to see the level of magnetism of the objects. This is done firstly to confirm the presence of iron in the material as well as being a first step in figuring out how much of the item that has been reduced to corrosion and how much represents the core. An item that has a low magnetism is probably corroded to the core and will probably not be a fruitful target of conservation. A three level scale was used to divide the results:

- High magnetism: The object attaches to the magnet
- Some magnetism: The object shows clear signs of movement towards the magnet
- No magnetism: The object shows very weak or no signs of movement towards the magnet.

The X-ray analysis of the material was done using a HP Faxitron 43805N X-ray system, a system rather old and lacking automatic systems or advanced configuration. This analysis was done to identify what objects showed a clear iron core and what items were fully reverted to its iron oxide state. If an item is corroded to the core the conservation process might not be fruitful and the risk of damaging or destroying the object might be too high. The process comes down to controlling the time of exposure (in minutes) as well as the strength of the x-rays (in keV). No point of reference exists for a given object type or any given material so it is basically a trial and error type of guessing game to get visible results. Along with the magnetism test this analysis also helped pick out the objects that were interesting for the next stage of the investigation. The objects were chosen after the following conclusions:

- The item might be a currency bar
- The item resembles a tool of some sort which makes it interesting to investigate.
- The item is listed under unidentified but have a solid core and high magnetism.

- The item looks as if it will not survive long in its current state and is in dire need of conservation.

The limits of this method lie in that even if the x-ray shows a clear core, this might be a shell where the core itself has been fully corroded.

3.2. The removal of corrosion

The second part of the investigation was to remove the corrosion from the chosen objects. For the items that were chosen to be potential currency bars, the process did not include a chemical component, instead it was managed by using only distilled water and heat along with purely mechanic removal of the corrosion. This was done to remove all chances of the chemicals usually used to affect the later SEM analysis of these objects. As for the rest of the objects an EDTA solution of 4% was initially used to soften up the corrosion. The rule here is to have between 4-8% EDTA for iron objects, and a time frame of exposure of between half an hour and 24 hours. The choice of only using 4% was done because of the possible vulnerability of the Sigtuna iron which in its heavily corroded state sometimes have a very weak or even non existing iron core. Instead a higher time frame for the exposure was chosen. For the smaller and thinner items 1-2 hours in a heated state was considered enough, after which the mechanical removal was carefully started. For more solid objects up to 24 hours after an initial 1-2 hours under heating was utilized. After the wet stage, including chemicals or not, the mechanic removal was started. This was done mainly with a scalpel, an ultrasound device and a rotating dental drill with a steel brush attached to it. After this the currency bars were temporarily removed from the process and dried in a hot air oven at 60 degrees C and later in vacuum drying. This drying process was needed for the SEM vacuum chambers requirement of a dry sample. As for the rest of the items a stabilization process was started using 1% phosphate buffer (Bisodium hydrogen phosphate) to remove any chlorides and effectively stop the corrosion process. Then the item was dried in the same way as the currency bars and lastly put into a bath of paraffin to create a protective coating for storage (Klockhoff 1993).

3.3. The SEM EDS analysis

A Scanning electron microscope can be used in a lot of different ways. With a SEM you can get up to 3000x magnification of a selected spot and therefore see details and even structural traits of the material (Fig. 6).

For this specific analysis I will use a LEO 1455 VP SEM with an Oxford Inca 300 EDS system, which in essence is an x-ray using electron bombardment of the object that is being analyzed. By firing electrons at the target object the atoms of the target will react with the added electrons by exchanging one of their own. This in turn produces an amount of excess energy that will return to the detectors in the form of x-rays. This process is called an emission and these x-rays bring with them a signal from the host element. In theory all these signals are unique, however when interpreted by the detector some elements have signals that are similar to other elements atom shell electrons. This type of analysis can be done on a small location; it can be done on a section of the object and in a straight line. (Hogmark et al 1998:26ff). It is therefore very important for any operator of this to be aware that some elements have these similar atom shell signals. These shared signals can make a quantified element analysis difficult to interpret when amounts are presented. An example of this is the elements Fe and Co where Irons Kβ shell shares signals with cobalt's K**α** shell. This is however not entirely impossible to work around. Even if these signals are very similar (Fe Kβ detected at 7.06 keV and Co K**α** at 6.93 keV) there is a difference. So when a high amount of Fe is present and smaller amounts of Co are detected, the Fe spectrum might overshadow the one of Co (Fig. 7). However, when lowering the number of counts in the spectrum you can make the element peaks clearer and can notice that the Fe peak is not fully smooth or that it might have a

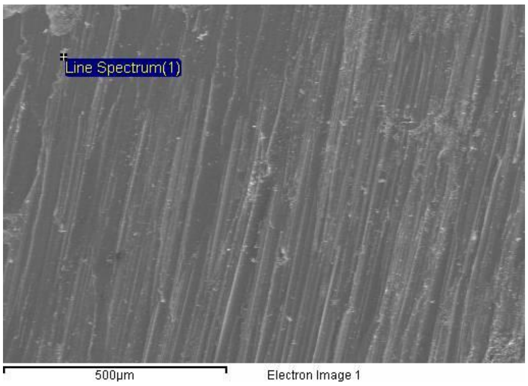

Figure 6 A highly magnified picture of one of the analyzed areas.

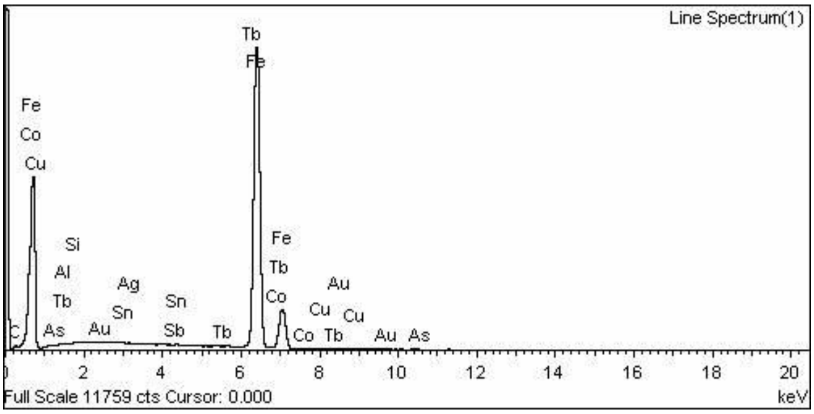

Figure 7 An example of a spectrum where Fe Kβ is shared with Co Kα in a high count and with a high keV viewed. By lowering keV and the counts you make the element peaks more visible and can see differences and even identify smaller peaks.

suspicious slope towards one side or the other. Most new instruments are equipped with an automated double check system and normalization which makes these mishaps less frequent (Hogmark et al 1998:71ff).

When doing an EDS analysis a highly magnified picture of the analyzed area is produced together with a spectrum as well as a quantification of the elements present in the area. The x-ray scans the surface as well as penetrating a small distance into the material depending on the elements analyzed. This quantification can give a researcher an idea of the element amount in atom% but this can vary because of the problem posted above as well as the instrument itself having an error margin of 1%. What this means is that when you find an element with lower than 1% atom% of the total amount of elements, you can never be entirely sure about the exact amount. If the instrument detects the element however, the researcher can be positive that the element exists in the material in most cases. And by double checking the spectrum together with the calculated amount one can make sure that an element exists by looking for unique peaks for that specific element.

4. Analysis

So with the methods presented as to what is to be done and why it has now come to the point where the strengths, weaknesses and results of this analysis are presented. This chapter will follow the same outline as the previous one to make it clear in what timeline the work has been done.

4.1. What iron objects has been identified?

As previously mentioned 71.5% of the iron material from house X is yet to be identified and the first and second step of this investigation has gone towards identifying different objects as well as conserving the ones in dire need of treatment to survive. The material from Sigtuna is heavily corroded which is due to a complicated chemical process as well as subpar storage facilities in which the finds have been stored since they were removed from the ground. As a first step all of the 288 iron objects have been photo documented according to general guidelines. In conjunction to this every single object was the subject of a simple magnetic test as described in the previous chapter.

54 % of the material was highly magnetic and firmly attached itself on the magnet, 12.5% was somewhat magnetic and the last 33.5% of the material showed almost no or none at all (Fig. 8).

Figure 8. An example of the photo documentation and magnetic analysis of find post 10347. M = highly magnetic, LM = some magnetism, MLM and IM = No magnetism. The items in the photo were not selected for conservation. (Photo: Tomas Engerdahl 2011)

All of the items in the 33.5% non magnetic category was also present in the 71.5% unidentified category. The entire material was also the subject of an X-ray analysis which revealed that 68% of the material had a solid metal core visible under the corrosion layer. In this analysis the selection towards the conservation side of the process was made. In addition of the two currency bars that was identified during the excavation itself another six possible currency bars were discovered for the third and final part of this investigation. In many cases of these X-ray plates a lot of objects could be identified. The majority of items containing a core were interpreted as semi-manufactured products like rods and plates. Figure 9 shows a number of objects to the right that can be interpreted as iron rods or other semi-manufactured goods. 51 items from 25 find posts in the database, which all contained a visible core, were selected for mechanical removal of corrosion and conservation from these tests and showed a varied condition(Fig. 10).

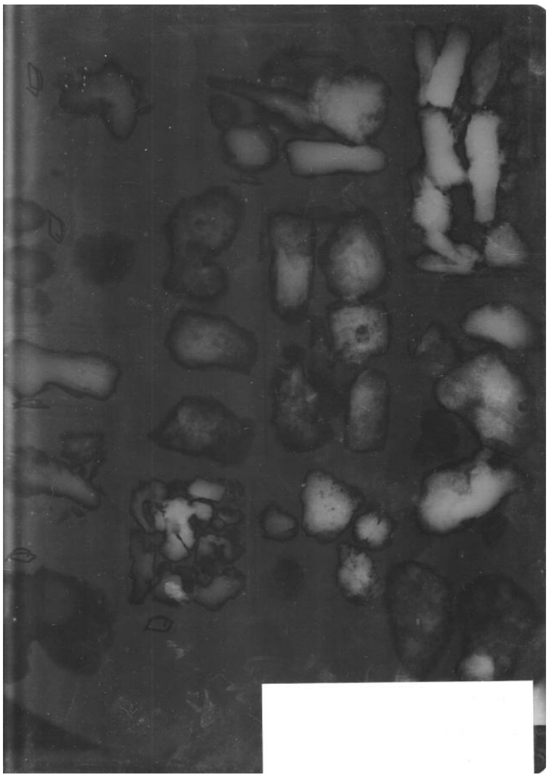

Figure 9 Scanned image of an X-ray plate containing a number of different findposts. The solid whiter sections represent solid metal and the cloudy greyer areas represent corrosion crusts. (Photo: Tomas Engerdahl 2011)

Figure 10 Iron rods before removal of corrosion and conservation(8013). (Photo: Tomas Engerdahl 2011)

Six of the unidentified objects were as mentioned earlier interpreted as possible currency bars and the rest showed a clear core and form which would be interesting to investigate. The lock was selected because a suspicion that it might not be a lock. The rods, the unspecified tool, the awls and the punch were selected both because of their current vulnerable state as well as looking somewhat similar in regards of form. The nails was selected for its poor state. And the plates were selected to reveal if there was a specific form or if they had broken off from a larger plate (table 4).

Table 4 A presentation of the finds selected for conservation.

Find post	Excavator Interpretation	Context	Amount selected	Reason
8010	Currency bar	7098	1	preparing for SEM
8012	Iron plating	7098	10	One big plate section or many smaller?
8013	Iron rod	7098	12	Looking for tools
8014	Unidentified	7098	2	Possible currency bars
8031	Nail	7098	1	Bad condition
8118	Currency bar	7095	1	Preparing for SEM
8119	Punch	7095	1	Investigating tool identification specifics
8120	Unidentified	7095	1	Possible tool?
8157	Unidentified	7098	1	Iron hook or rivet?
8166	Rivet	7098	1	Bad condition
9611	Unidentified	7098	2	Possible currency bars
9619	Unidentified	7098	1	Visible core, possible tool?
9623	Awl	7082	1	Investigating tool identification specifics
9746	Rivet	7082	1	Bad condition
9747	Lock	7082	1	Doubting excavator interpretation
9814	Unspecified tool	7095	1	Identification of tool
9815	Awl	7095	3	Investigating tool identification specifics
9816	Rivet	7095	2	Bad condition
9993	Iron rod	7098	1	Possible tool?
10136	Knife	7095	1	Bad condition
10137	Unidentified	7095	1	Possible tool or Iron rod?
10429	Rivet rove	7082	1	Bad condition
10431	Knife	7082	1	Item generally worth conservating.
10440	Rivet	7082	1	very bad condition
10534	Unidentified	7098	2	Possible currency bars

4.2. Dealing with the corrosion

The eight currency bars that were identified among the selected items were subjected to the non chemical wet treatment and mechanical removal of corrosion described in chapter 3.2. This was relatively easy and the crust came off with very little effort. A fatty substance was

also recovered from the water which had dissolved from the area between the crust and the objects. The recovered material went through a FTIR (Fourier Transform Infrared Spectrometer) analyzing instrument and turned out to be paraffin. How this paraffin got inside the crust is hard to say, but it has been a parking lot above the excavated area at one point as well as some telephone poles that might have been impregnated in some way. These eight currency bars are divided between six find posts and had the following dimensions. All measurements are taken at the longest/widest/highest point(table 5).

Table 5 Measurements of the currency bars from House X and adjacent areas

Find post	Dimensions(L/W/H)	Weight
X8010	44,55/15,75/11,25 mm	30,73g
8014 A	32,51/14,55/10,04 mm	16,59g
8014 B	24,77/20,31/11,19 mm	9,53g
X8118	38,09/18,41/8,52 mm	23,27g
X1 9611	31,49/16,09/7,20 mm	17,37g
X2 9611	41,43/23,03/5,59 mm	9,23g
X1 10534	33,31/13,12/8,94 mm	14,32g
X2 10534	42,78/17,68/6,02 mm	10,2g

The rest of the items were treated with an EDTA solution at 4% concentration, and subjected to the same treatment as described in chapter 3.1. The conservation process is very much a touch and go process where the process is decided from the object that is treated. Thinner and more vulnerable objects were subjected to a shorter period in the solution.

The four items that were still unidentified from the selected items were after the mechanical treatment interpreted as a nail, a rivet, another thin iron rod and the last item might be a broad iron rod or a heavily corroded iron key (Fig. 11). The potential key in this case has a circular cavity at one end and a broken tip at the other. If this indeed is a key, the end which goes into the lock has been broken off. The item that was initially interpreted as a lock was in fact a piece of folded plate, possibly welded at one side and with a clear cavity in the middle. The one thing that all the researchers queried about the item were sure about was that the item in question was not a lock (Fig. 12a and b).

Figure 11 Unidentified object(9619) with a possible key-shape. (Photo: Tomas Engerdahl 2011)

Figure 12a The item that is listed as a lock(9747) in untreated state. (Photo: Tomas Engerdahl 2011)

Figure 12b The item that is listed as a lock when conserved. (Photo: Tomas Engerdahl 2011)

There was a big difference in the level of deterioration of the items that was subjected to this treatment. In general the iron rods, the puns, the awl and the currency bars were very well preserved under the initial crust while the nails, rivets, roves and plates were in very bad shape. The later mentioned items were often corroded to the core with a thin iron layer between the corrosion crust and an inner, fully corroded core. These items were prone to break down and needed a softer treatment. The differences between iron rods, punches and awls were after the treatment very hard to see which raises the question to what preferences archaeologists generally use to differ between these item groups. Are there any clear rules (Fig. 13, 14 and 15)? It becomes clear that the iron material hidden in the soil beneath us is harder to interpret than one might think, especially when the material is as badly corroded as the material in Sigtuna. But this corrosion situation is far from unique and the case is exactly the same in a lot of places in Sweden.

Figure 13 Items interpreted as awls(9815). (Photo: Tomas Engerdahl

Figure 14 Item interpreted as an Iron rod(9993). (Photo: Tomas Engerdahl 2011)

Figure 15 Item interpreted as a punch(8119). (Photo: Tomas Engerdahl 2011)

4.3. Where were the objects found?

When looking at an excavation and a collection of finds it is important to take a look where the said items have been found. It will be presented in a terms of percentage of the total weight of the specific find type that were presented in chapter 2.2 (table 3). With the help of the finds database I was able to figure out to which area they belonged to.

It can clearly be seen that location house X (7098) has the majority of finds within its borders but some items (Fig. 16) technical ceramics for metal object production are concentrated towards the south area (7100) that is close to the street (Fig. 19). A majority of these technical ceramics are the moulds for production of weights. The technical ceramics for glass production is highly concentrated towards house X itself with very few items outside its borders (Fig. 18). The iron material that i have analyzed in this investigation is more evenly spread but house X and the east area (7082) dominate with over 87% of the iron items (Fig. 17). In general the north (7095) area is by far the least populated area when it comes to finds.

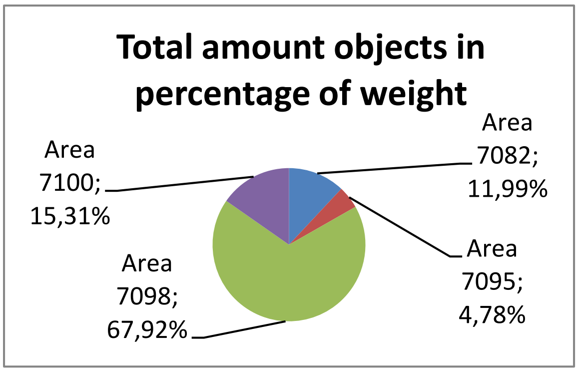

Figure 16 Presentation of each sub-area's percentage of the total weight of all the finds within the investigated area.

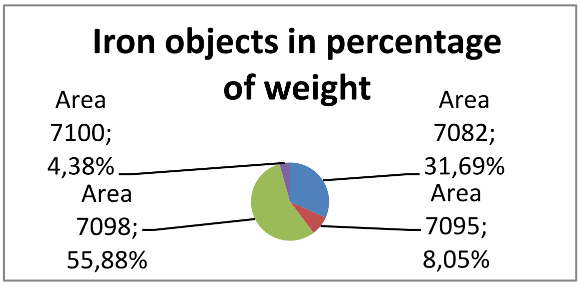

Figure 17 Presentation of each sub-area's percentage of the total weight of iron objects from the investigated area.

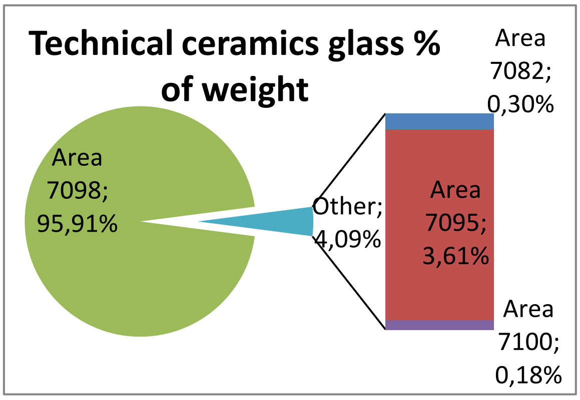

Figure 18 Presentation of each sub-area's percentage of the total weight of technical ceramics for glass production from the investigated area.

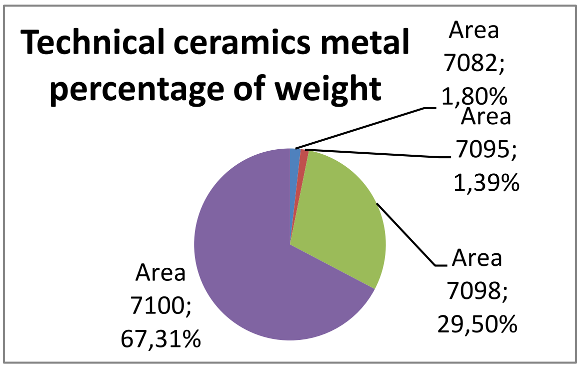

Figure 19 Presentation of each sub-area's percentage of the total weight of technical ceramics for metal production from the investigated area.

4.4. The Elemental analysis of the currency bars

With the conservation work on the currency bars done as far as the removal of corrosion, it was now time for the last part of the analysis. All of the identified currency bars was analyzed and as mentioned above a SEM was used and the analysis of the items were done on 3-4 areas of each item. To make the analysis as true to the original material as possible it was necessary to grind down beneath black protective oxide layer of the currency bars. Each of the locations were subjected to two types of analysis functions. Firstly a pure area sweep which counts the material in a given rectangular area selected and secondly a line spectrum which investigates five separate spots in a straight line. Both these analyze methods were done in close proximity of each other but without overlapping. The results of the two methods were then added up and divided by two to get a mean value of the analyzed spot. As our intention is to compare the quantified analysis with GAL's results from 1995 and 1997 I set the instrument to search for the same elements that they have presented as well as any other element the instrument could find. If the instrument gave a negative result on an element it was removed from the computer program and given a null value in the result. To be able to show the values of the trace elements in the objects, in which any difference in the different currency bars are seen the element Fe is excluded from the diagrams. The results of the analysis can be seen in diagrams below (Diagram 1-6).

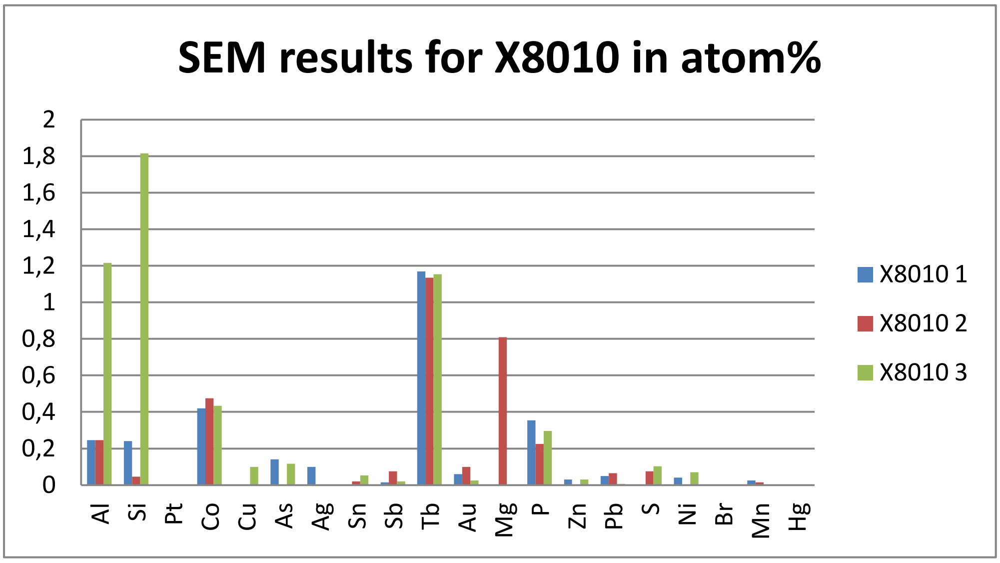

Diagram 1 Presentation of SEM results for item X8010. Y axel represents amount in atom% and X axel presents the elements

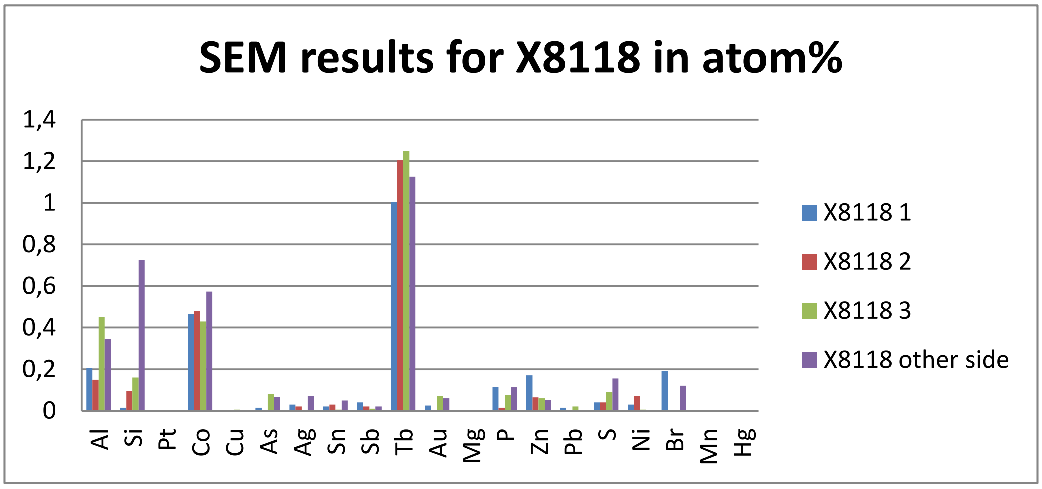

Diagram 2 Presentation of SEM results for item X8118. Y axel represents amount in atom% and X axel presents the elements

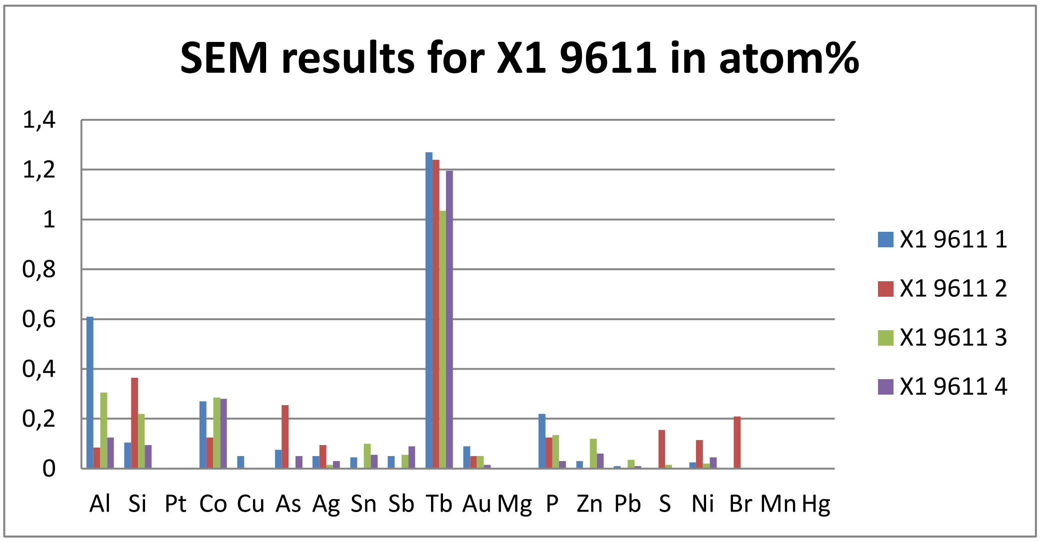

Diagram 3 Presentation of SEM results for item X1 9611. Y axel represents amount in atom% and X axel presents the elements

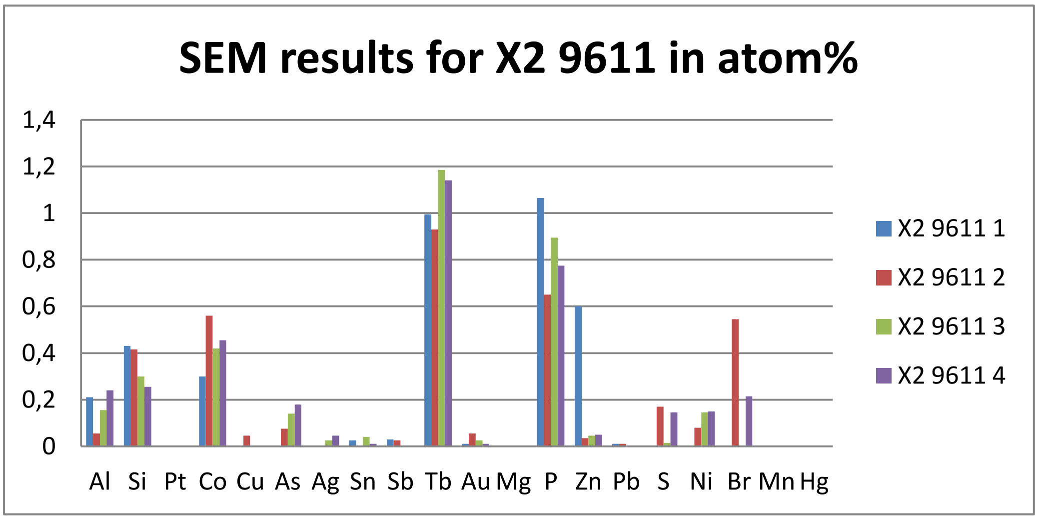

Diagram 4 Presentation of SEM results for item X2 9611. Y axel represents amount in atom% and X axel presents the elements

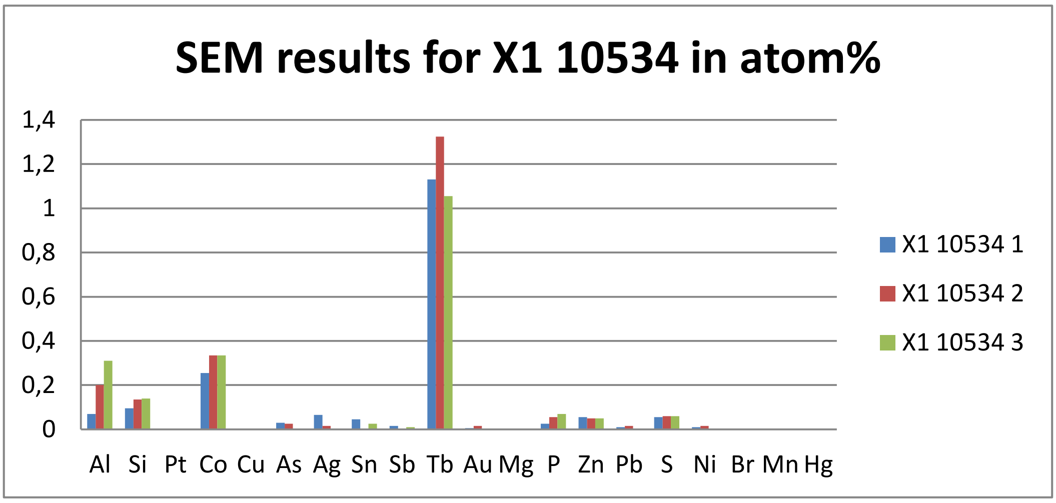

Diagram 5 Presentation of SEM results for item X1 10534. Y axel represents amount in atom% and X axel presents the elements

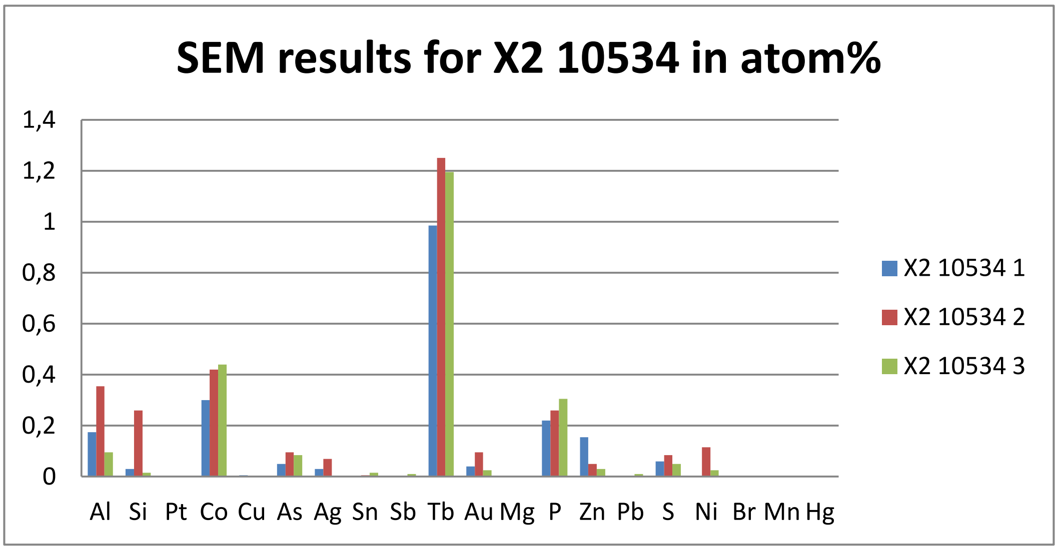

Diagram 6 Presentation of SEM results for item X2 10534. Y axel represents amount in atom% and X axel presents the elements

To begin with it is worth mentioning that the instrument had some sort of energy output malfunction during the tests of the two currency bars in find post 8014, which seems to raise the amounts of some trace elements and lower of some that in the other tests were a lot higher (Fe for example). They will therefore not be presented in diagrams but can be found in appendix 1. The problem in this case seem to be that the differences described in chapter 3.3 became even more vivid and atoms that should have been identified as a certain element ended up being identified as an element that was close in keV signal. The high amount of manganese (Mn) and terbium (Tb) should probably be translated in some extent to iron (Fe), which is not included in the diagrams above due to the fact that a peak of 96-98% would make it impossible to see the smaller ones due to similar atom shell Signals. It is also possible that iron or manganese stole some amount from cobalt (Co) in the case of 8014 A. Despite this however it can be seen that most of these currency bars had roughly the same setup of trace elements in the iron although the amounts of each of the elements varied. Some other elements that were identified are not likely to exist however. bromine (Br) and mercury (Hg) is for example highly unlikely because both are liquid in room temperature and both evaporate when heated in the iron reduction process (Diagram 3 and 4). They most likely have shared atomic shells with some other element and are therefore not likely to exist. Most of the items had around 0.4% - 0.5% cobalt, 0.2% - 0.4% phosphorus (P, except for X2 9611 which had a higher amount). Only 8010 had any signs of manganese when excluding 8014A and only three of the items lacked copper (Diagram 5, Appendix 1) although generally the amounts were low. All of the items contained some traces of sulfate (S), arsenic (As), gold (Au), silver (Ag) and aluminium (Al).

Another interesting result was that all of the items identified terbium (Tb) to up to 1.5% which is a REM. After a quick discussion with a geologist, other researchers and lectors at the lab as well as outside sources it was agreed that the amount was highly unlikely if not entirely impossible. And a closer look at the resulting spectrum of all these tests confirmed that terbium had similar atom shell Signals with iron and cobalt in all two out of five cases (Fig.

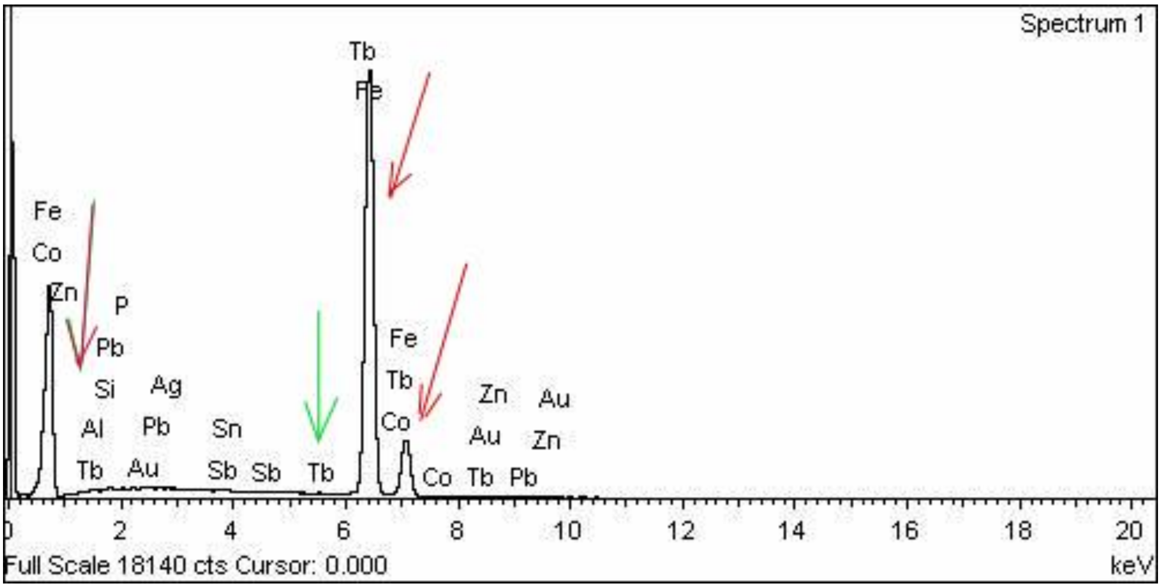

Figure 20 A Spectrum from X1 9611 where the red arrows point towards the shared atom signal peaks and the green arrow pointing towards the only unique location of Terbium.

20). Henceforth the amount of terbium is most likely over-quantified in this sense, but does it exist? To answer that question it will be necessary to have a closer look and see if the one unique spectrum peak actually exists which would be evidence of its existence in the slag inclusions of the currency bars. By lowering the counts of a spectrum there is a higher possibility to see if it is possible to get the smaller element peaks to appear (Fig. 21).

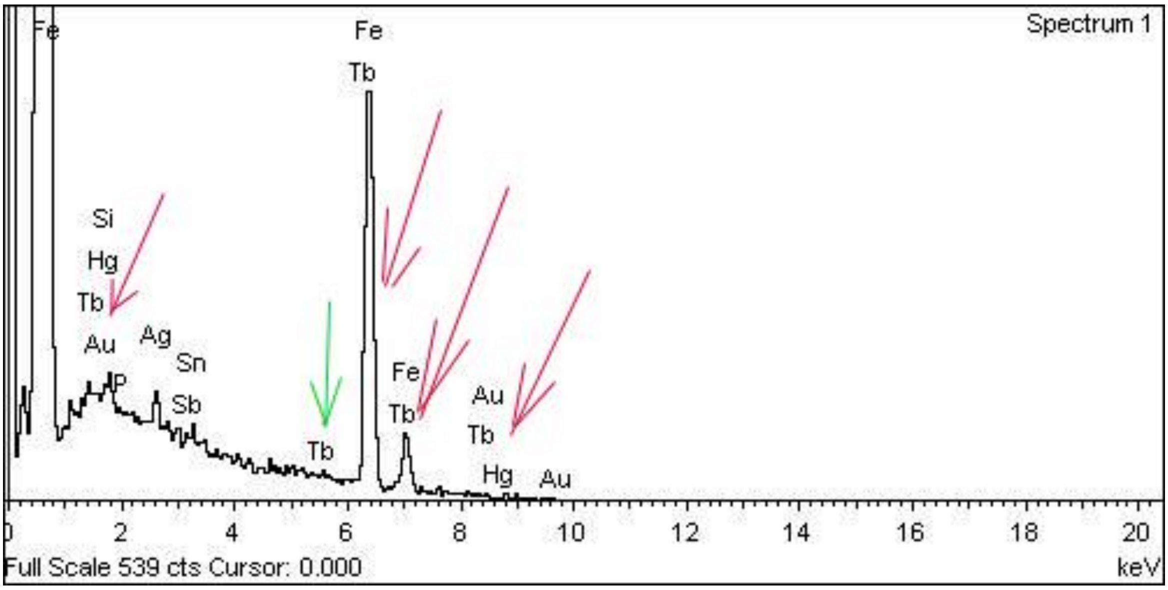

Figure 21 A SEM spectrum with lowered counts. The green arrow marks the only unique terbium peak.

In this picture I have lowered the visible counts to 539 instead of the initial 18140 counts. This means that the highest peaks will not be fully visible but the smaller ones will. In the middle of the spectrum above the only unique terbium peak can be seen. The problem with this peak is that it does not exist in the element charts where I manually look for the elements close Signal matches. It does however exist when looking on more recent and detailed charts for atom shell signals. Four additional terbium signals were identified, however these were all close to other elements. Two peaks that share signals with iron are to the right and even further to the right the final terbium peak, which is shared with gold, can be seen. The left peak shares signal location with a lot of different elements. When going back to the quantity numbers again i noticed that if terbium is removed from the equation entirely iron increases, cobalt increases slightly and aluminium decreases slightly. That iron and cobalt increases is logical because it shares peaks with terbium and thus the instrument compensates by giving the Tb signals to these two elements. That aluminium decreases however is very interesting in this case because it means that it initially borrowed a small amount from something that was removed from the calculation which in this case is terbium. When all facts are added together it can be said that I am as sure as the instrument permits me to be that terbium does exist in the currency bars from house X.

A full table of the results from the house X currency bar analysis can be found in Appendix 1.

4.5. Revisiting the GAL results

The results of the GAL will now be presented in largely the same way as my own SEM analysis in chapter 4.4. However, some things differ to begin with. Their results are presented in weight% which is a slightly different way of doing it. It is based on the weight of the different atoms which means that some of the results may vary quite a lot against those of the atom% from the SEM. The instrument they have used is an electronic microprobe which is also very different from the SEM. To begin with the method is destructive which means that you will physically need to destroy the part of the items you need to analyze. This is done either by means of a drill or saw. It analyses in roughly the same way that the line spectrum does by targeting a small spot in the material and penetrating deeper than the SEM (Grandin 2012-03-27 personal correspondence). Another problem with the GAL analysis, presented in chapter 2.3, is that they have not been looking for all the elements in the same way that I have and hence the resulting comparison will be slightly difficult. By taking a look at the separate weight of the different elements along with the presented results I will try to see how these figures might compare towards the atom%. The microprobe results can be seen in diagram 7 to 13.

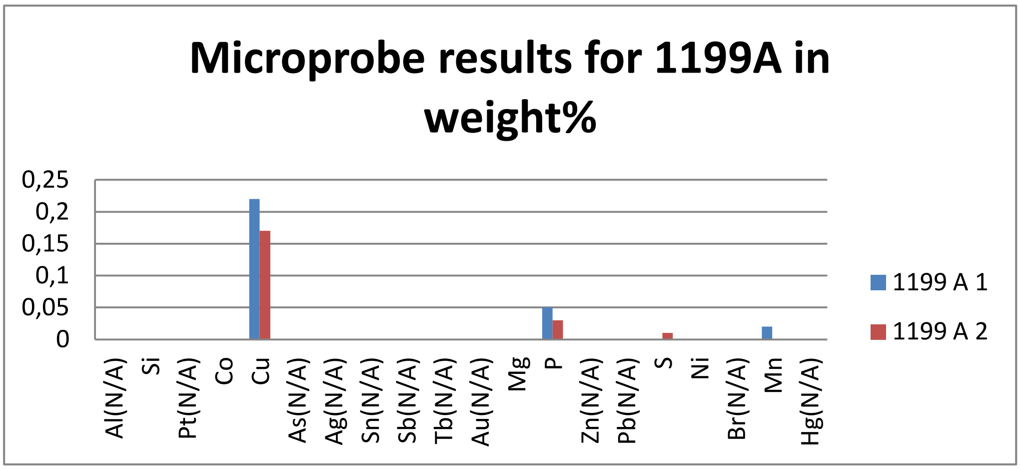

Diagram 7 Microprobe results presented for item 1199A. Y axel represents amount in weight% and X axel presents the elements

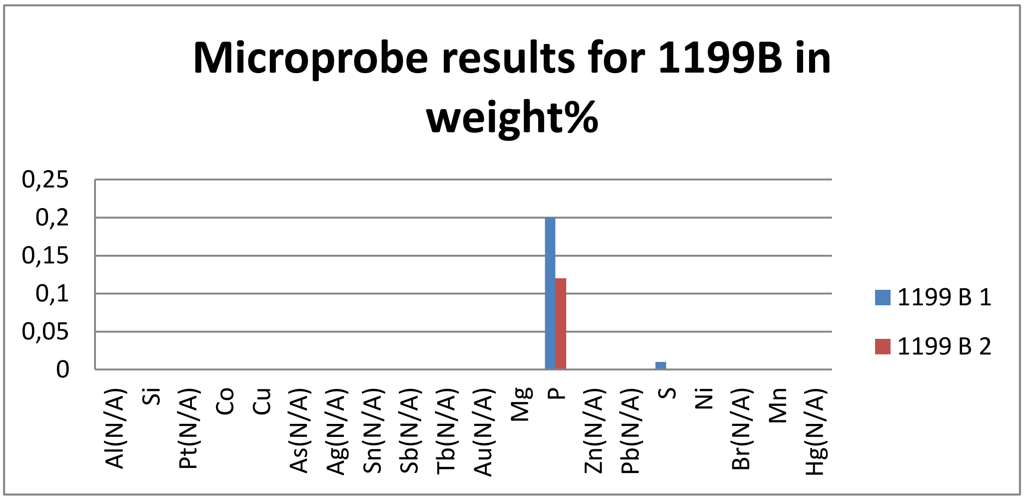

Diagram 8 Microprobe results presented for item 1199B. Y axel represents amount in weight% and X axel presents the elements

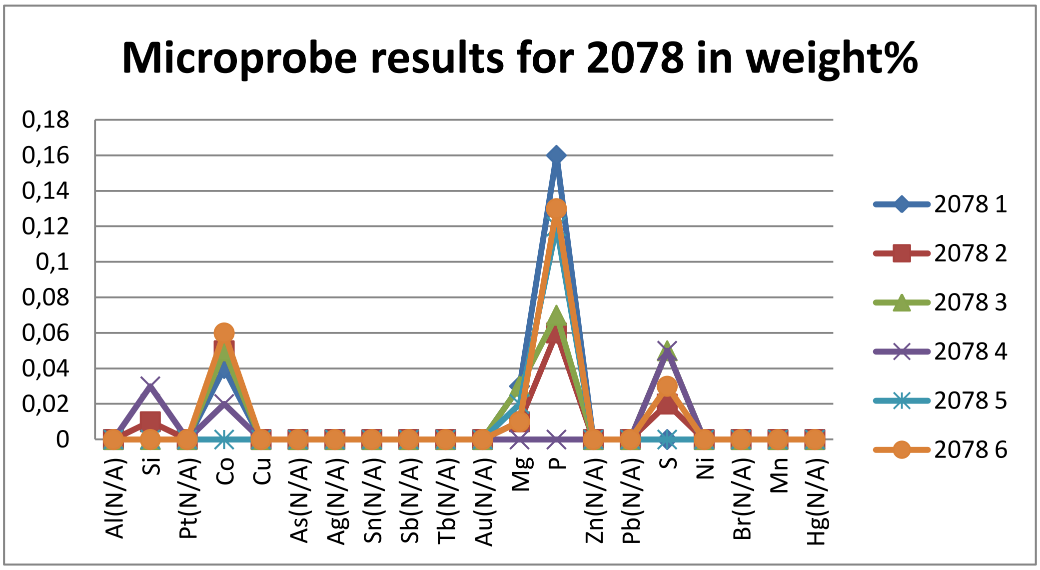

Diagram 9 Microprobe results presented for item 2078. Y axel represents amount in weight% and X axel presents the elements

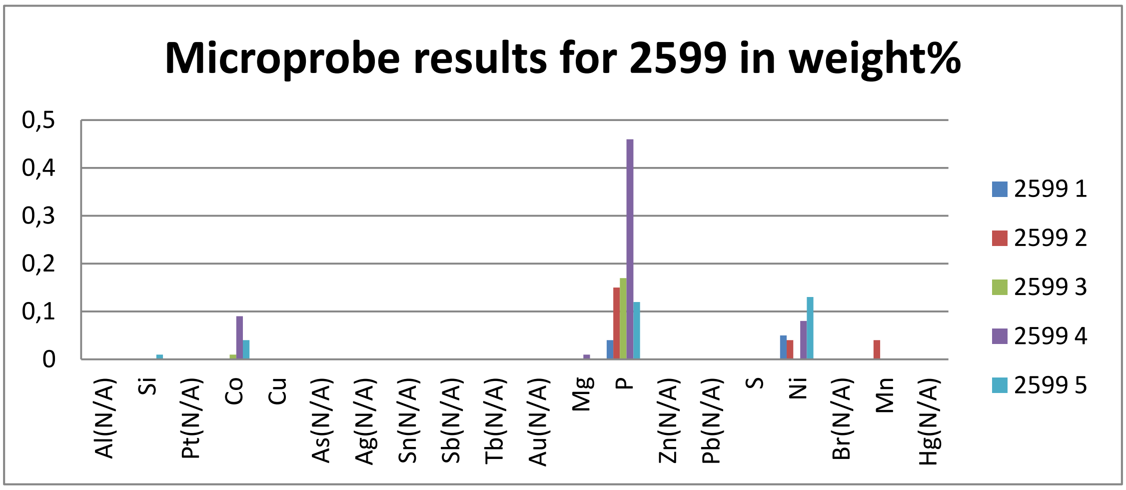

Diagram 10 Microprobe results presented for item 2599. Y axel represents amount in weight% and X axel presents the elements

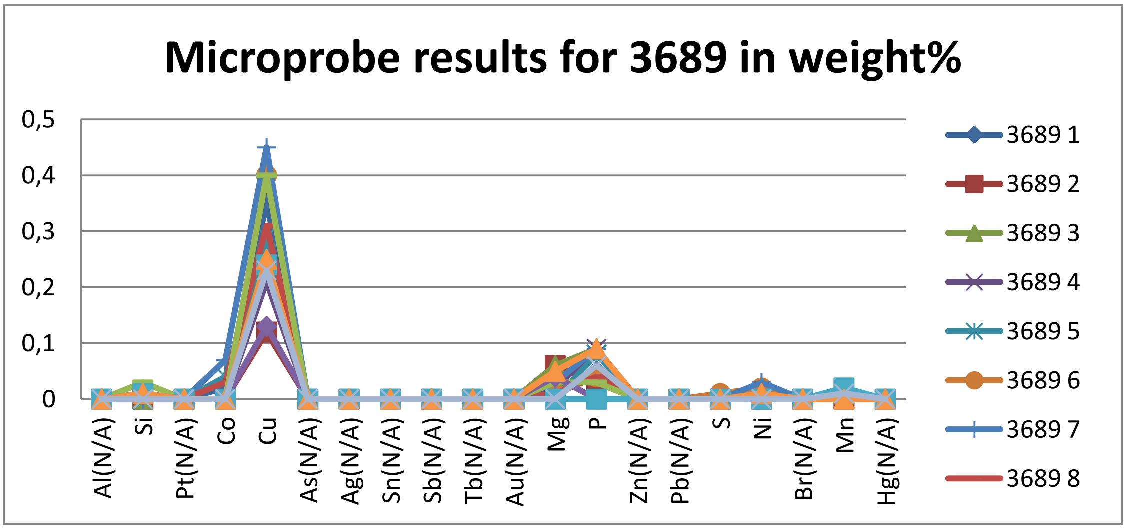

Diagram 11 Microprobe results presented for item 3689. Y axel represents amount in weight% and X axel presents the elements

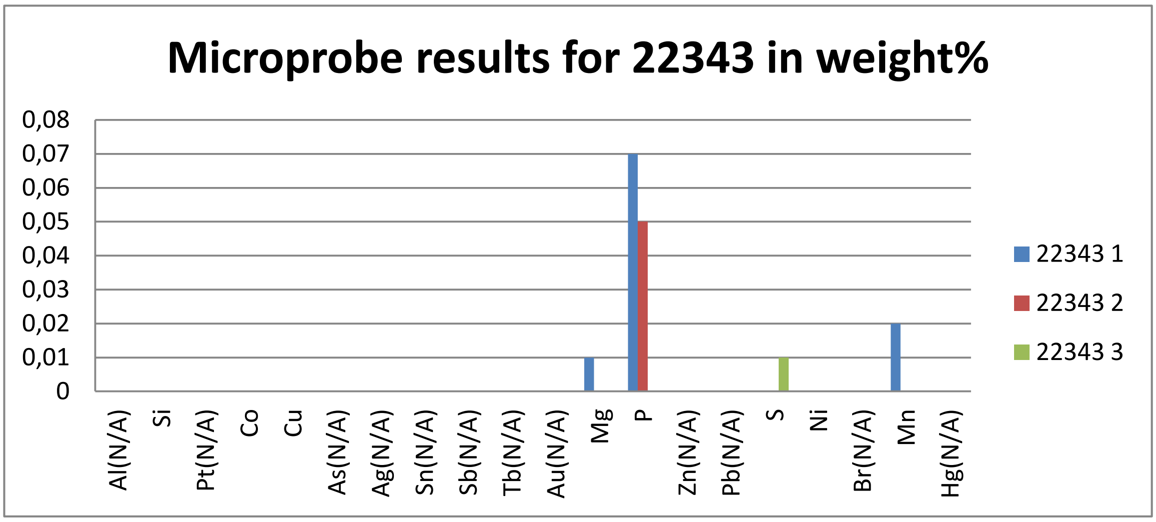

Diagram 12 Microprobe results presented for item 22343. Y axel represents amount in weight% and X axel presents the elements

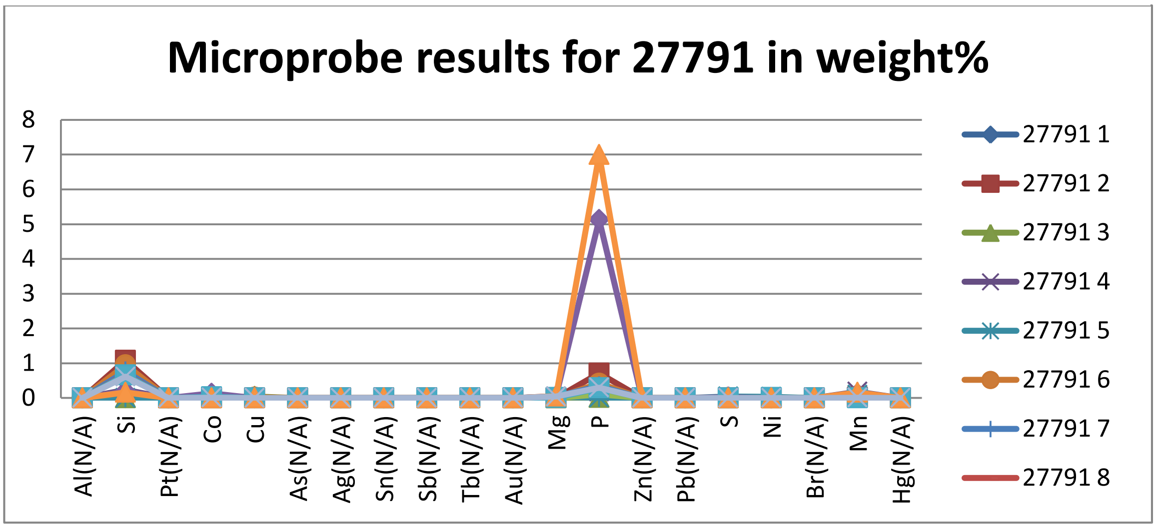

Diagram 13 Microprobe results presented for item 27791. Y axel represents amount in weight% and X axel presents the elements

The results from these show increased values of phosphorus, manganese, silicate, magnesium, copper and cobalt. The material which these are compared to is iron which is the major element in the items that both GAL and I have been analyzing. The next step is to look at the atom weight of all these elements (table 6).

Table 6 Atom weights of the different elements in Gal's analysis

Element	Weight/atom
Iron (Fe)	55.85
Phosphorus (P)	30.97
Silicate (Si)	28.09
Manganese (Mn)	54.94
Copper (Cu)	63.55
Cobalt (Co)	58.93
Sulphate (S)	32.07
Nickel (Ni)	58.69
Magnesium (Mg)	24.31

As can be seen the different materials have varying weights and I can therefore make a rough calculation towards how the amounts presented in the diagrams above counteract towards atom%. Iron is the major element as mentioned before and therefore that is the element to which the others are counted in weight. So if magnesium in 22343 1 with almost 0.05% weight% and an atom weight of 24.3050 is compared to the iron atom weight of 55.845 it would mean that a magnesium atom weighs roughly 43% of the iron atom. With a rough estimation this would indicate that the actual atom amount would be more than double that of the weight in comparison to iron. This would mean that the 0.05% weight% is more likely around 0.1% in atom%. This in turn would mean that sulfate, silicate and phosphorus would be around double the amount as well and the amount of copper would be slightly lowered. Nickel and manganese would stay roughly the same. It is important to mention that this calculation in no way represent the exact amounts due to the fact that GAL choses to exclude some elements and hence makes any direct translation to atom% void. But it gives a rough image of how the numbers translate. Although the amounts might have been raised for some of these elements it still does not eliminate the fact that these currency bars seem to be of purer quality than the ones from house X. Except perhaps 27791 which has a high amount of phosphorus and silicate, although I suspect that test 10 and 12 managed to hit a large concentration of phosphorus (diagram 13). A weight% of 0.5-1% phosphorus is enough to affect the materials properties. It is also possible to see that these items differ in their elemental setup quite a lot which is not very surprising considering that they are collected from more than one geographical point and more than one dating. For example 1199 A and 3689 show traces of copper while the rest lack it (diagram 7 and 11). The full amount of data of the GAL analysis can be seen in appendix 2.

4.6. Summing up the results

To begin with the X-ray and magnet analysis revealed that most of the iron items that showed magnetism and a solid iron core could in fact be counted to three categories: *small tools* like knifes and awls, *everyday products* like rivets and nails as well as *semi-manufactured products* like iron rods and plating. However some other items do exist, for example one weight and a reasonably large cylinder fragment. The mechanical removal of corrosion confirmed that this was the case with most of the items and also revealed how hard it might be to see the difference between find categories like puns, awls and iron rods. Furthermore, a possible key might also have been found.

The contextual survey of the location of the items revealed that the iron product manufacture was mostly situated in house X and to the east area while the process involving the weight moulds seem to be concentrated to the south side. The glass production seems to be fully concentrated to the house X building around the kilns.

The SEM analysis along with the GAL analysis showed that the currency bars from house X had less purity than the ones from the Trädgårdsmästaren excavation in all but one case. There is a possibility that the currency bar 27791 might actually be purposely composed as it is to reach different traits of the material. A direct comparison between the two cases could not be done because of the fact that GAL had not included all of the elements of the items in their analysis and thus the amounts could not be correctly converted towards atom%. This would mean that elements like zink, silver and gold could very well be present in their currency bars as well. But all in all the amount of impurities were far lower. Another interesting observation was the terbium content of the house X finds, although not present in the amounts that the SEM analysis showed it was still there and its implications will be discussed later.

5. The production in house X

So what form of production was really carried out in house X during its brief existence and what can be said about the smiths in Sigtuna? In this lies the question what form of function the smithy had as well. Can it even be called a smithy?

I will also discuss Sigtunas role in the iron production and supply chain and its role as a major city in proto-Swedish kingdom. This section will henceforth be split in two parts where the first section will discuss the finds and context in comparison to a few other places of iron production and a second part where the iron-making process and supply of iron is discussed.

5.1. Interpreting the evidence for house X and its craftsmen

When looking at the material there is evidence of a number of trades having been practiced at this location. First off, there is the evidence of a hearth and according to the excavators it was probably elevated in some way (Söderberg 2008:104). Along with the hearth there is also the existence of 31.5 kg of slag, almost 12 kg of technical ceramics interpreted as involved in the metal production and over 4 kg of iron objects which in most cases are semi-manufactured items. Among the tools found we have a number of small tools like awls, knifes, punches and wedges. Most of the activity seems to have been centered towards the central area but the east area seems to have been extensively used for iron working as well. Basically all of the waste products from weight production are concentrated to the south which is both logical and strange. The logical part comes from it making any kind of waste management far easier if it even existed. The strange part comes from actually putting the waste where the potential customer is passing by.

From the products it is difficult to place the smithy to a specific category of production as suggested by Lars-Erik Englund(2002:271). He suggests that it is in most cases possible to place a smithy's production into either fine, rough or manufacturing production. No evidence has been found of any large item production so the logical conclusion would be to say that the workshop produced a wide range of small iron items like nails and knives, rather than larger items like scythes, horse shoes and such items. It is therefore a hybrid of all three of Englund's categories, but only to the extent of the small items in the categories list of examples.

However, if we would for a second take a step back and look at other materials involving iron object production. In a gathered survey of materials from 52 medieval Swedish sites of metal object production there was a number of interesting points to be noticed. Most of these sites contained a hammer, chisels and wedges along with semi-manufactured products and currency bars. A total of 308 kg of slag was found at these sites and 652 pieces of random iron objects interpreted as semi-manufactured or waste products(Wallander 1977). Because no site specific data was revealed in this study I will do a rough estimate by dividing the total amount with 52 and end up with about 6kg of slag and 12.5 pieces per site. None of these sites had any evidence for reduction of iron ore, just like Sigtuna. In comparison we can see that the Sigtuna material is far larger than our divided numbers above. A production site with an output this big would probably leave a greater amount of worn out tools than the other sites. This is not the case because only a few small tools have been found. No hammers, no pliers and no files have been recovered which otherwise act as chief identifiers of metal object production.

A town that is reasonably comparable to Sigtuna during the early medieval period is Trondheim in Norway, but even here there is a considerably lower amount of slag. Only 6.4kg of slag was interpreted to come from the Folkebibliotek excavation in Trondheim in phase 1 (900-1050). The area has been interpreted as a crafting quarter and just as house X in Sigtuna, they also have evidence of casting of non-iron metal objects and numerous technical ceramic objects tied to metallic production have been found. The Trondheim material also includes pliers and small tools, but just as house X the area lacks hammers (Bergquist 1989). It becomes more and more clear that the situation of the missing tools is by no means unique. When looking at Sigtuna, Trondheim and the survey of Swedish sites it becomes apparent that most, if not all, of the sites lack one or more of the tools that our society so closely identify as standard metal production tools.

So why is there an almost complete lack of tools in workshop excavations? A Viking age find that might shed a bit of light on this matter is the Mästermyr find on Gotland where a chest of tools was found. It was roughly 88cm long, 26cm wide and 22cm in height with an iron and wood construction. It was locked with padlocks and with a 2.4m chain attached to it and filled to the edge with tools and raw materials. Except for iron currency bars a lot of tools could be counted towards the blacksmiths arsenal. A set of files, hammers, sledgehammers, tongs, a hacksaw, plate-shears, a chisel, punch, awls and a nail-making iron. In addition to these tools carpenter tools like rasps, saws, knives and an axe were found (Arwidsson & Berg 1983:8ff). This shows that the one who deposited the chest was not just a smith but a craftsman involved in more than one trade. But why was it deposited? Was this a reserve of tools and materials for when times became worse? Or was it an offering of items that were of importance to the one who deposited it? The same type of tools can be found on the nearby settlement Helgö but with a more specialized tendency towards precious metal object production with the addition of for example scrapes and different sorts of graving tools (Werner 1981:39ff). Helgö has been interpreted as a center of production for precious metal objects like brooches and pendants during the migration period to the Viking age. The tools found here share appearance with the items found in both Sigtuna and the Mästermyr find. Both Mästermyr and Helgö had anvils but Sigtuna lacked one. So why did Sigtuna, with such a large output in a short time span, and so many other workshops produce such a low amount of tools? Let us now move on to the rest of the material to see if that can show us a reason.

Besides the iron material house X also had a very large amount of ceramics for metal production. The material ranges from moulds, crucibles, and the lining of the hearth. What is most impressive with this material is the almost 4000 fragments of weight molds. And just as the excavators I will have to draw the conclusion that there has been a very high amount of weights produced at the site (Söderberg 2008:105).

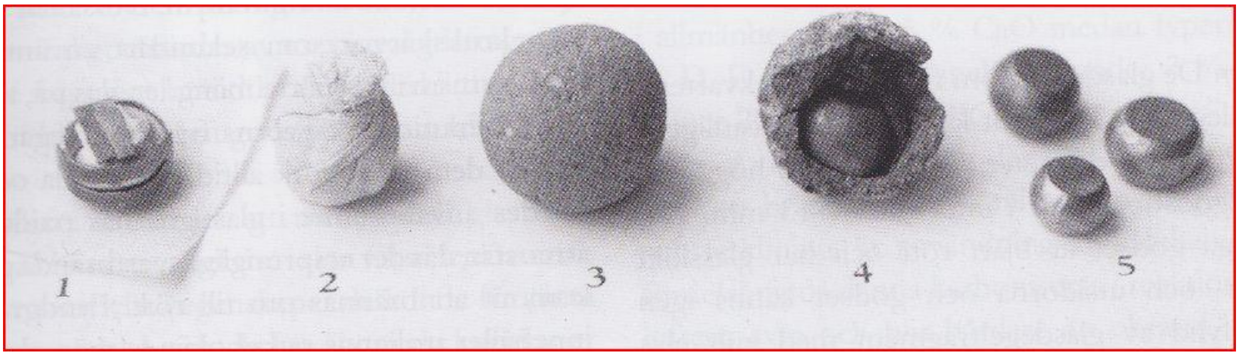

Figure 22 An experimental recreation of the weight manufacturing process. 1) The iron core is covered in thin straps of led or copper alloy. 2) The weight is covered in cloth. 3) The weight is enveloped in a ceramic shell and heated in the hearth. 4-5) The shell is cracked revealing the weight (From Söderberg 2008:99).

In Figure 22 we can follow the experimental recreation of the manufacture of a weight. Even if the process might seem simple, this was not the case. Weights had a very real and important value in that it was included in a specific weight system and it was therefore important that all the weights of a specific size actually weighed as much as they should (Schultzén 2009). This in turn would put a great deal of weight on the shoulders of anyone involved in the manufacture of these products. The one (or the workforce) dealing with this production probably had a very extensive knowledge of the weight of the materials used and the right ceramics needed to sustain the heat of the hearth.

The two to three glass kilns that were documented as well as plenty of crucibles and other technical ceramics are evidence for another form of trade present in house x. Apart from these two beads and a number of lumps of melted glass were recovered in conjunction to these ovens. It is apparent that this production was rather extensive as well, but it was not even near the extent of the iron manufacturing. Except for the beads no other glass products were recovered from the investigated part of the excavation. An interesting question here is why this production produces such a low yield of waste products in comparison to the iron production.

Apart from these two major find categories a few items of bone were recovered, which were mostly waste material from the manufacturing process. An item of leather was also recovered. These items might constitute the rests of accessory production for iron and/or glass items like for example handles. Some everyday household ceramics were also recovered, but no real evidence of any major pottery production of everyday goods has been found at this specific location. However it is not entirely impossible that the hearth or glass kilns have been used as a form of open pottery kiln when not used for iron object production (Rice 1987:152ff).

House X has been interpreted as a production site with two separate production phases. Firstly there is the iron production and then at a later stage there is the glass production (Wikström 2008:279). However, no real evidence has been presented to support that this separation actually existed in a chronological sense. It might therefore be possible that these two major productions took place at the same time and in the same place. And if this is the case it would be wrong to call this house a smithy. It was more likely a workshop for crafts dealing with extreme heat and therefore designed in that way. Now let us explore this theory for a bit. We have a house with 2-3 glass ovens in the north and south west side of the building, one hearth and an anvil base in the middle and south side. In this building there is evidence for large production of weights as well as other more household type products and tools. The production of weights was highly specialized and needed special knowledge to create the needed quality. The manufacture of nails, rivets and iron plating however did not require a highly specialized smith. These types of products were produced out on the farmsteads for household production as well. Add to the equation the glass production which was an entirely different craft as well and the potential craftsman would be a real rocket scientist of his days to be able to know all the trades. It would be more likely that we are dealing with a few different craftsmen in this case. These craftsmen used the same workshop and may have produced items on demand from the local population as well as the rulers and merchants in the case of the weights. A picture of a workshop run by two or more craftsmen and perhaps a few apprentices starts to form. The delicate products were dealt with by the master and the more everyday products might have been produced by apprentices as a step in their learning process (see fig 23).

The level of expertise needed to produce some items and control the iron material fully is high and would have taken years of training to get the grasp of it. The fact that the workshop did not have any evidence for walls is also an interesting fact in this case when discussing the symbolic value of the smith and his trade secrets. Jan Apel (2009) suggests that this was because of the smith's knowledge that his work could not be replicated only through watching.

Figure 23 Reconstruction of house X with the glass ovens and anvil visible, worked by three people, perhaps a master and two apprentices (from Söderberg 2008:121)?

This might also explain the lack of tools that were recovered from the site. If this was a sort of cooperative workshop each of the active craftsmen would have their own set/sets of tools which they brought along to the workshop when their crafts were required. Only the more ordinary tools were left on site and the individual ones, perhaps with personal affection value were taken along to where they lived for safe storage. And thus when the workshop was finally abandoned and moved they simply brought these items with them to the new workshop.

Another very interesting observation is the location of house X in early medieval Sigtuna. The crafting quarters are placed in the very middle of the town which is interesting from two points. Firstly it is the fire hazard of having a smithy in the middle of town. As a comparison it is relevant to mention that the smithy on the nearby Viking settlement Birka was located outside the settlement by the wall instead of being in the middle (Holmquist 2005:36). The latter is likely the most logical choice of location for a workshop dealing with high heat and flames. The second aspect of this is a social one in which important buildings and functions are located in the center of the town. House X does not seem to be unique in Sigtuna. Previous excavations of workshops in the city block Trädgårdsmästaren 9 and 10 showed workshops active with iron object production and bronze casting as well as being localized by the main street, in the middle of town (Petterson 1990:79). A more thorough investigation into the contextual differences and similarities of the two excavations is however not possible as the full report has not been published yet. The location of the workshops in the centre of town would perhaps implicate a high status of Sigtuna's crafting quarters and the workshops themselves. Past researchers have put a lot of weight on the creation of a proto-Swedish state and the solidification of political power, but this might actually tip the scale a bit more towards the trade and production side of a settlement. When Birka declined Sigtuna was born one might say, but how much of the past role of Birka was actually transferred to Sigtuna? Was Sigtuna only a playing field for the political powers and later the church or was early medieval Sigtuna actually a thriving trade center as well? This also raises the question of the professional craftsman's social standing. Was he just another serf serving a master or was he a valued member of the community whose abilities were sought by both ordinary townsfolk and the rich and powerful?

5.2. Iron supply and production in the case of early medieval Sigtuna

The Iron making process in Sweden goes back over 3000 years from the end of the Bronze Age. At this time it was mostly traces of iron at production sites where copper alloy items had been produced (Geijerstam & Nisser 2011:28ff). The early iron was probably produced in the same way the copper alloy had been produced, which meant that they were produced in a so called pit oven which according to experimental tests yielded quite low amounts of pure, workable iron (Tholander 1987:74). Around 500 BC, at the start of the actual Iron Age, the technology had seen some advancement and we begin to see the first signs of the bloomer type ovens and a considerably higher amount of yield. This type of oven was used well into 19^{th} century in modified size and form. These ovens were used to produce iron from bog and lake ore as well as the so called red sand. At the time of our investigated workshop the iron production for this type of oven was probably common knowledge and many parts of Sweden had extensive iron production. The evidence for the first use of a blast furnace ranges back to 12th century and with it the Osmund system was introduced (Geijerstam & Nisser 2011:17).

The debate around Osmund iron has been interesting and as the GAL report mentions that some of their currency bars might be Osmund iron bars it is worth mentioning something about the concept. The most recent theories around the definition is that it is an economic term introduced along with the bergslag, which in itself is a administration term for an area involved in rock iron production with a blast furnace. 24 Osmund bars were meant to weigh a pound according to laws from 1367. A pound in this case is probably the lispound (6,8kg) which would have put the individual Osmund bar at 283g (Buchwald 2008:213f).
Whether this standardization went as far as the form of the items is questionable but the two bars interpreted as Osmund bars do share some dimensions.

The introduction of the blast furnace and the start of pure rock iron ore have also been interpreted as going hand in hand. This is due to the fact that the rock iron ore have always been seen as much harder to reduce than the bog and lake ore counterparts. It also took a lot more effort to mine the rock ore from the bedrock, especially if compared to for example the bog ore or the softer European ores (Buchwald 2008:227ff).

We return to the analysis produced in this essay and the differences between our different currency bars. The GAL bars from the Trädgårdsmästaren excavation had very low amounts of trace elements in the material while the house X bars from the Humlegården excavation had considerably higher amounts of trace elements. This might be because of a failed batch to house X which lead to the discarded currency bars. However, it can also be a case of different providers, different ores used and different ways of manufacturing these currency bars. To investigate this I will take a closer look on the processes of the different ways of iron making and see if we can identify where these differences might occur.

I will use the terminology of Vagn Fabritius Buchwald (2008) where he described the process involving a bloomery oven as a direct iron making process and that of the blast furnace as an indirect one. Both methods starts with roasting the ore on a pyre of wooden logs to remove sulfur and water as well as making the ore more loose. After this each oven is put to the test and in the case of the indirect version the product of this process is fluid pig iron while the direct one produces a slag rich bloom. The next step for the indirect process is the fining in where the pig iron and charcoal by oxidization transforms into wrought iron which is divided up into Osmund bars. For the direct process the step is called purification where the bloom is heated in an open hearth and in combination of mechanical removal and inclusion of sand the slag is removed. The product is then divided into currency bars (Buchwald 2008:28, 229). The difference here is the second step of the process where the indirect process produces a much purer result than the direct one. The direct process makes up for this by having a more elaborate third step which purifies the iron more effectively. However the fact that the direct process never really creates a fluid iron which more effectively separates the slag from the iron might be one reason for the higher amounts of trace elements from the direct process. It is therefore highly likely that this is the reason for the difference in trace element amounts between the Trädgårdsmästaren bars and the house X ones is due to the production process.

Moving on to the ores and what the different trace elements can tell us there. The house X currency bars all show varying amounts of aluminium as well as what is probably very low amounts of terbium. So what do these two elements tell us? To begin with we can take a look at where they can be found. Aluminium is one of the most common elements in the earth's solid crust and is found in over 270 different minerals. The ore where aluminium is most prominent is in bauxite ore which also include iron oxides in hematite and magnetite form. The reduction process of iron would not be able to relinquish aluminium from oxides. However the low melting point of the element might eliminate it from any indirect iron production process, but it is more likely that it might follow the iron of a direct process. Terbium on the other hand is a REM which occurs in a number of minerals which includes iron. In contrary of its name this group of elements exists quite often in large rock formations. What makes it rare is that they exist in very low quantities. It always occurs in combination with a set of other REMs which makes it rather remarkable that the SEM managed to pick terbium up in the scans while ignoring the other more common REMs (http://www.hogrelius.nu 2012-04-16). In the light of these facts there might be evidence enough to actually start discussing if the ore from which the currency bars of house X were produced were actually rock ore. This in turn would imply that we are dealing with a very early production of iron from rock ore. It would also imply that the usage of rock ore might have been roughly 100-200 years prior to the first documented blast furnace. The fact would certainly explain the lack of purity in the currency bars due to the fact that the ore was harder to process. Even though GAL's analysis of their currency bars did not include these materials they did do some total chemical analysis of slag in conjunction to the analysis I have presented where they too have traces of REMs and terbium (Hjärthner-Holdar & Larsson 1997:62). So where they did not include terbium in the list of elements they looked for in the currency bars, they did include it in the total chemical of the slag found at the same location. This in turn would probably mean that it exists in the currency bars as well.

Let us yet again explore the scenario of late Viking age and early medieval Sigtuna. We have a king that has gathered and united a landmass that is proto-Sweden, to consolidate his power he establishes Sigtuna as a political center as well as filling the void of the declining Birka. He starts to issue coinage while still maintaining the weight system for trade. To further impress his competitors he issues a decree to import currency bars made from rock ore to prove his country's technological advancement.

The currency bars that were imported were still fully functional and is seemingly not harmed from the higher amount of other elements included. And we should not forget that the final step of the iron production also removes slag which makes the iron even purer (Buchwald 2008:28, 229).

6. Conclusion and reflections

The topic of iron-making and production of iron objects is a complex set of processes which has changed numerous times since iron started being used. The period when Sigtuna was established was very close to a major turning point in the iron production which might have affected even the earliest stages of the town.

6.1. Solving the riddle of house X.

In the case of house X there is yet again a workshop with more than one trade connected to it. This strengthens the hypothesis that there were no "real" blacksmith sites in the sense that it was never the lone production at the site. If looking at the material there has been a very large production of iron objects at the site, most notably the weights. Most of the technical ceramic waste material from this production has been placed within the building or south of the building, in conjunction to the street. This is rather logical when speaking about waste management. Other than this, most of the semi-manufactured items were plates and rods. Most of the items that could be interpreted as finished products that were not tools were nails and rivets. A chain link, a ring and something that might resemble a key was also found. It becomes apparent that the smith/smiths that were active in this workshop produced a wide array of items. From the most everyday items like nails to more elaborate items like weights that needed more specialist knowledge.

Most of the items found were semi-manufactured goods, waste products and slag and the few tools that were identified came from all of the areas except the south one. It seems like most of the activity has been in the central and east area. The northern and eastern area may have seen some production as well though, which might have been parts of the production that did not require the heat of the hearth or kilns. Another interesting fact is the lack of glass items. Two or three glass kilns, plenty of technical ceramics involved in glass production and only less than 50g of glass products? Either the ones involved in the glass production were incredibly tidy or they hardly ever failed in the production. The first one seems the most likely but it might not be the whole truth.

Another fact that this investigation reinforces is the apparent lack of tools in workshops involved in production of iron objects, or any workshop for that matter. That combined with the comparison to the very impressive deposition find of a complete tool chest in Mästermyr on Gotland brings light to the thought that a craftsman's tools could have been very personal and indeed loaded with a high symbolic value for the individual craftsman. Hence they would bring them home after each day for safe keeping. Another possible reason for this lack of tools is that the workshop was shared by more than one craftsman. They might have shared their craft or dealt with entirely different crafts but in the same workshop which indeed would make it even more relevant to safeguard ones tools.

The existence of aluminium and terbium in the house X currency bars is highly interesting. These two elements mostly exist in the bedrock and the second of the two is very rare. Although further analysis is needed on the subject to get the exact amounts of the different elements in the iron the fact that these two elements exists at all, might indicate that the iron that was used in house X was from rock ore. This in turn indicates an early mining operation, perhaps in the form of the "bergslag" that in medieval Sweden organized the iron making process. If the amounts of trace elements in the house X currency bars produced by the SEM are even close to correct it also means that they were a lot less pure than the later ones from Trädgårdsmästaren. And as mentioned earlier, this might indeed mean that this rock ore was reduced using traditional methods with a bloomery oven rather than a blast furnace which resulted in a product of lesser quality. This should not be considered as anything but a hypothesis at this point however due to the fact that there have not been that many experimental trials on reducing rock ore in bloomery ovens. It is however very interesting due to the fact that it places the start of organized usage of rock ore 100-200 years before the current estimates.

6.2. Reflections about methods and further future research.

When discussing iron material from mainland Sweden it is not uncommon for the corrosion to make interpreting some finds harder. It is therefore very important with conservation work to get the full picture of the iron finds. In the investigation above it has proven a more than able tool to identify or even reevaluate previous interpretations. In some cases it is favourable only to preserve the object and in some cases the corrosion crust reveals an entirely different object than what one expected. I would consider saying that the conservation work together with the X-ray and magnetic analysis was a stunning success in identifying what was hidden from the naked eye and it is sad that not every single metal object is subjected to this treatment.

As for the SEM analysis it proved far more complicated than what I first anticipated. The problems with the overlapping spectrum peaks which in turn produced inaccurate amount information for the quantified part of the result was a hard case to work around. It was chosen as a method because of the hope that it produced the result without the need for destroying or in a major way changing the sample. In this it was successful, however by looking at the results and the problems with them one might lean towards the more destructive kinds of analyzes to get more accurate readings of trace elements. It is very accurate for the major composition elements and you get a very good and solid picture of the content. To further our knowledge about the currency bars of house X it might be very interesting to look at them through a metallographic microscope and do the more destructive analyzes that are available. In addition to this it might be relevant to take a closer look at the other semi-manufactured products available as well as the slag. This way we can really confirm whether this is production slag or perhaps even purification slag. By analyzing for example the iron rods or plates and even finished products we can also see how much the items change in the process between a currency bar, an iron rod and an actual finished product

As is quite common in these kinds of investigations the researchers often end up with more questions than actual answers. This is certainly the case here and I feel like I have barely scratched the surface of a very interesting subject. However I am confident that my results have at least shed some light at the questions I aimed to answer.

7. Summary

House X in Sigtuna has been interpreted as a smithy with some glass production which can probably be leveled down to a bead production during the period 980-1010 AD. These two productions have in turn been seen as two phases of the building. By making a contextual analysis of the building, the surrounding area and where the different sorts of finds have been excavated together with an ocular and X-ray analysis of the iron objects I aimed to reach the answers of two out of three research questions.

The contextual analysis revealed that most of the production of metal objects had been spread between the central (house X), east and south of the investigated area whereas the glass production was concentrated in the central part. The northern part remained largely empty in comparison. Within the confines of house X the trades divide the spaces even further. Two out of three glass ovens were situated in the north side of the building, the hearth and anvil base were situated in the middle of the building and the final glass oven was situated in the south west corner. The south east corner remained open. It seems like the two crafts had divided the area rather than using the same area at two different points in time. It is most likely more correct to call this location a workshop rather than a smithy.

71.5% of the iron material was unidentified before this investigation and so the iron material was put to a simple magnetic test as well as an X-ray analysis in the hopes of identifying what was hidden in the thick corrosion crusts of the objects. The result of these analyzes were that most of the items in the iron material could be counted towards three major categories. *Everyday products* like nails, *small tools* like awls and knives and the greatest majority of the material was placed in the category *semi-manufactured products* like currency bars, iron rods and plating. A total of 51 items from 25 find posts were selected for conservation with the EDTA method to confirm this as well as prepare a total of eight currency bars for the last leg of the analysis. Although the conservation revealed some items of particular interest like for example a potential key it largely confirmed the previous categories. One interesting fact that remained was the lack of tools in general. The tools that were present were nowhere near enough to sustain the production that these trades hosted. By reviewing studies done on Helgö, in Trondheim as well as a survey of Swedish metal object production sites and comparing it to the Mästermyr find of a tool chest, Icame one step closer. Helgö was by far the workshop environment that presented the most finds but here as well as with Trondheim and the survey, clear evidence of a general lack of tools were presented. Add to this the fact that the Mästermyr find was deposited for some kind of reason it starts to produce the picture of a craftsman's tools as something of great symbolic value. therefore they would not likely be left lying around the workshop.

The last part of the study was regarding the currency bars and the origin of house X's iron supply. Through a SEM EDS analysis the major trace elements were identified and compared to the Microprobe results that GAL had presented in 1995 and 1997. The process was stalled somewhat because of the existence of similar X-ray signals from different elements in the SEM analysis which in a lot of cases made the quantified data hard to interpret. The general result of this analysis was that the currency bars that GAL had analyzed were considerably more pure in general although some elements had been deliberately removed from their analysis. The most interesting part of the SEM analysis was the identification of the trace elements aluminium and terbium. These are elements usually found in rock-ore. The usage of rock-ore has been closely tied to the introduction of the blast furnace in the early 12th century which places this particular rock-ore 100-200 years before its time. This result then indicates that the rock-ore was used and henceforth the existence of an early version of bergslag prior to the blast furnace. In this case a bloomery oven must have been used to reduce the iron ore. This in turn would explain the heightened level of trace elements within the currency bars due to the rock-ores suggested reduction difficulty.

The three research questions have received answers to some degree however I feel like the study itself has produced far more questions than actual answers and it is all the more clear that the iron making and production of objects is more complicated than many believe at first glance. The need for more in-depth analysis is to be considered large in a time when the scientific work concerning iron has in many cases stagnated.

The SEM as a method for tracking trace elements is probably not the best method due to the difficulty of identifying some elements. But the strength of the method remains in that it is largely non-destructive. Conservation with EDTA is however a great, although time consuming, aid to anyone aiming to interpret metal artifacts.

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9. Appendix

Appendix 1 Complete list of the iron finds that were collected from House X and the three contexts adjacent to it.

Find post	Excavator Interpretation	Context	Amount	Weight
7965	Unidentified	7098	1	3
7972	Unidentified	7098	2	15
8005	Lock	7098	2	4
8006	Rivet roves	7098	2	7
8007	Cylinder	7098	1	22
8008	Wedge	7098	2	27
8009	Chisel	7098	1	163
8010	Currency bar	7098	1	46
8011	Unspecified tool	7098	1	42
8012	Iron plating	7098	10	280
8013	Iron rod	7098	12	132
8014	Unidentified	7098	42	498
8031	Nail	7098	1	6
8032	Unidentified	7098	2	32
8082	Unidentified	7098	9	132
8117	Rivet rove	7095	1	17
8118	Currency bar	7095	1	34
8119	Punch	7095	1	14
8120	Unidentified	7095	1	13
8121	Punch	7095	1	8
8157	Unidentified	7098	3	26
8166	Rivets	7098	2	28
8167	Nail	7098	1	21
9579	Unidentified	7098	7	58
9580	Ring	7098	2	1
9609	Iron rod	7098	5	45
9610	Iron plating	7098	10	77
9611	Unidentified	7098	22	309
9618	Rivet rove	7098	1	7
9619	Unidentified	7098	7	115
9623	Awl	7082	1	12
9745	Nail	7082	3	29
9746	Rivet	7082	1	18
9747	Lock	7082	1	21
9749	Unidentified	7082	6	775
9812	Unidentified	7095	13	130
9813	Chisel	7095	1	6
9814	Unspecified tool	7095	1	2
9815	Awl	7095	3	9

9816	Rivet	7095	2	44
9817	Unidentified	7095	4	8
9818	Nail	7095	1	19
9819	Rivet rove	7095	1	12
9829	Unidentified	7100	3	11
9830	Weight	7100	1	6
9897	Rivet rove	7098	1	6
9993	Iron rod	7098	1	53
10132	Unidentified	7098	6	55
10136	Knife	7095	1	10
10137	Unidentified	7095	1	5
10337	Unidentified	7100	16	59
10338	Nail	7100	1	5
10347	Unidentified	7100	32	99
10428	Nail	7082	1	7
10429	Rivet rove	7082	1	28
10430	Unidentified	7082	14	132
10431	Knife	7082	1	13
10439	Unidentified	7082	8	102
10440	Rivet	7082	1	14
10441	Unidentified	7082	1	151
10534	Unidentified	7098	6	86

Appendix 2 Table of results from the analyzed “currency bars” presented in atom%.

Test nr:	Al	Si	Pt	Co	Cu	As	Ag	Sn	Sb	Tb	Au	Mg	P	Zn	Pb	S	Ni	Br	Mn	Hg	Fe
X1 9611 1	0,61	0,11	0	0,27	0,05	0,08	0,05	0,05	0,05	1,27	0,09	0	0,22	0,03	0,01		0,03	0	0	0	97,14
X1 9611 2	0,09	0,37	0	0,13	0	0,26	0,1	0	0	1,24	0,05	0	0,13	0	0	0,16	0,12	0,21	0	0	97,19
X1 9611 3	0,31	0,22	0	0,29	0	0	0,02	0,1	0,06	1,04	0,05	0	0,14	0,12	0,04	0,02	0,02	0	0	0	97,7
X1 9611 4	0,13	0,1	0	0,28	0	0,05	0,03	0,06	0,09	1,2	0,02	0	0,03	0,06	0,01	0	0,05	0	0	0	97,93
X1 10534 1	0,07	0,1	0	0,26	0	0,03	0,07	0,05	0,02	1,13	0,01	0	0,03	0,06	0,01	0,06	0,01	0	0	0	98,12
X1 10534 2	0,2	0,14	0	0,34	0	0,03	0,02	0	0	1,33	0,02	0	0,06	0,05	0,02	0,06	0,02	0	0	0	97,7
X1 10534 3	0,31	0,14	0	0,34	0	0	0	0,03	0,01	1,06	0	0	0,07	0,05	0	0,06	0	0	0	0	97,95
X8010 1	0,25	0,24	0	0,42	0	0,14	0,1	0	0,02	1,17	0,06	0	0,36	0,03	0,05	0	0,04	0	0,03	0	97,1
X8010 2	0,25	0,05	0	0,48	0	0	0	0,02	0,08	1,14	0,1	0,81	0,23	0	0,07	0,08	0	0	0,02	0	96,72
X8010 3	1,22	1,82	0	0,43	0,1	0,12	0	0,05	0,02	1,15	0,03	0	0,3	0,03	0,01	0,1	0,07	0	0	0	94,56
X8118 1	0,21	0,02	0	0,47	0	0,02	0,03	0,02	0,04	1,01	0,03	0	0,12	0,17	0,02	0,04	0,03	0,19	0	0	97,62
X8118 2	0,15	0,1	0	0,48	0	0	0,02	0,03	0,02	1,21	0	0	0,02	0,07	0	0,04	0,07	0	0	0	97,81
X8118 3	0,45	0,16	0	0,43	0,01	0,08	0	0,01	0,01	1,25	0,07	0	0,08	0,06	0,02	0,09	0,01	0	0	0	97,28
X8118 2nd s	0,35	0,73	0	0,57	0	0,07	0,07	0,05	0,02	1,13	0,06	0	0,11	0,05	0	0,16	0	0,12	0	0	96,51
X2 9611 1	0,21	0,43	0	0,3	0	0	0	0,03	0,03	1	0,01	0	1,07	0,6	0,01	0	0	0	0	0	96,87
X2 9611 2	0,06	0,42	0	0,56	0,05	0,08	0	0	0,03	0,93	0,06	0	0,65	0,04	0,01	0,17	0,08	0,55	0	0	96,71
X2 9611 3	0,16	0,3	0	0,42	0	0,14	0,03	0,04	0	1,19	0,03	0	0,9	0,05	0	0,02	0,15	0	0	0	96,61
X2 9611 4	0,24	0,26	0	0,46	0	0,18	0,05	0,01	0	1,14	0,01	0	0,78	0,05	0	0,15	0,15	0,22	0	0	96,33
X2 10534 1	0,18	0,03	0	0,3	0,01	0,05	0,03	0	0	0,99	0,04	0	0,22	0,16	0	0,06	0	0	0	0	97,96
X2 10534 2	0,36	0,26	0	0,42	0	0,1	0,07	0,01	0	1,25	0,1	0	0,26	0,05	0	0,09	0,12	0	0	0	96,94
X2 10534 3	0,1	0,02	0	0,44	0	0,09	0	0,02	0,01	1,2	0,03	0	0,31	0,03	0,01	0,05	0,03	0	0	0	97,69
X8014A 1	0	0,37	0,16	0	0	0	0,13	0,19	0,15	2,75	0,06	0	0,41	0,21	0,06	0	0,02	0	0	0	95,39
X8014A 2	0,34	0,06	0	0	0	0,06	0	0,1	0,24	2,23	0,05	0,22	0,15	0	0	0,19	0	0	4,77	0	91,55
X8014A 3	0,23	0	0	0,24	0	0,08	0	0,23	0,23	4,69	0,02	0	0,11	0,43	0,01	0	0	0	0	0	93,76
X8014B 1	0,18	0,47	0	4,94	0,35	0,32	0,16	0,17	0	5,24	0,11	0	0,43	0,14	0	0	0,95	0	0	0	86,57
X8014B 2	1,01	1,09	0	4,24	1,06	0,08	0,18	0,67	0,12	3,17	0,05	2,36	0,26	0,61	0,02	0,14	0	0	0	0	84,95
X8014B 3	0,33	0,04	0	2,36	0,57	0,06	0	0,21	0	6,23	0,37	1,52	0,43	0,65	0,11	0,97	0,95	0	0	0,07	85,99

Appendix 3 Table of the results of the analyzed "currency bars" from the GAL reports from 1995 and 1997 presented in weight%, the elements Al, Pt, As, Ag, Sn, Sb, Tb, Au, Zn, Br, Hg was not included in their study and therefore given the number 0.

Test nr:	Al	Si	Pt	Co	Cu	As	Ag	Sn	Sb	Tb	Au	Mg	P	Zn	Pb	S	Ni	Br	Mn	Hg	Fe
1199 A 1	0	0	0	0	0,22	0	0	0	0	0	0	0	0,05	0	0	0	0	0	0,02	0	97,34
1199 A 2	0	0	0	0	0,17	0	0	0	0	0	0	0	0,03	0	0	0,01	0	0	0	0	97,56
1199 B 1	0	0	0	0	0	0	0	0	0	0	0	0	0,2	0	0	0,01	0	0	0	0	98,94
1199 B 2	0	0	0	0	0	0	0	0	0	0	0	0	0,12	0	0	0	0	0	0	0	98,43
2078 1	0	0	0	0,04	0	0	0	0	0	0	0	0,03	0,16	0	0	0	0	0	0	0	100,4
2078 2	0	0,01	0	0,05	0	0	0	0	0	0	0	0,01	0,06	0	0	0,02	0	0	0	0	100,4
2078 3	0	0	0	0,05	0	0	0	0	0	0	0	0,03	0,07	0	0	0,05	0	0	0	0	97,35
2078 4	0	0,03	0	0,02	0	0	0	0	0	0	0	0	0	0	0	0,05	0	0	0	0	99,35
2078 5	0	0	0	0	0	0	0	0	0	0	0	0,02	0,12	0	0	0	0	0	0	0	99,09
2078 6	0	0	0	0,06	0	0	0	0	0	0	0	0,01	0,13	0	0	0,03	0	0	0	0	100,9
2599 1	0	0	0	0	0	0	0	0	0	0	0	0	0,04	0	0	0	0,05	0	0	0	97,72
2599 2	0	0	0	0	0	0	0	0	0	0	0	0	0,15	0	0	0	0,04	0	0,04	0	97,44
2599 3	0	0	0	0,01	0	0	0	0	0	0	0	0	0,17	0	0	0	0	0	0	0	97,77
2599 4	0	0	0	0,09	0	0	0	0	0	0	0	0,01	0,46	0	0	0	0,08	0	0	0	98,03
2599 5	0	0,01	0	0,04	0	0	0	0	0	0	0	0	0,12	0	0	0	0,13	0	0	0	97,06
3689 1	0	0,01	0	0,02	0,35	0	0	0	0	0	0	0,02	0,05	0	0	0	0	0	0	0	98,95
3689 2	0	0	0	0	0,12	0	0	0	0	0	0	0,06	0,03	0	0	0	0	0	0	0	97,08
3689 3	0	0	0	0	0,27	0	0	0	0	0	0	0,06	0,09	0	0	0	0,01	0	0,01	0	95,9
3689 4	0	0	0	0	0,21	0	0	0	0	0	0	0,02	0,09	0	0	0	0	0	0	0	99,36
3689 5	0	0	0	0,04	0,29	0	0	0	0	0	0	0	0,08	0	0	0	0	0	0	0	98,5
3689 6	0	0,01	0	0	0,4	0	0	0	0	0	0	0,01	0,04	0	0	0,01	0,02	0	0,01	0	97,13
3689 7	0	0	0	0,07	0,45	0	0	0	0	0	0	0,03	0,09	0	0	0	0,03	0	0	0	97,26
3689 8	0	0,01	0	0,03	0,31	0	0	0	0	0	0	0,01	0,04	0	0	0	0	0	0	0	96,22
3689 9	0	0,03	0	0	0,4	0	0	0	0	0	0	0,03	0,03	0	0	0	0	0	0	0	94,47
3689 10	0	0,01	0	0	0,13	0	0	0	0	0	0	0,04	0	0	0	0	0	0	0	0	92,87
3689 11	0	0,01	0	0	0,24	0	0	0	0	0	0	0	0	0	0	0	0	0	0,02	0	97,19
3689 12	0	0,01	0	0	0,25	0	0	0	0	0	0	0,05	0,09	0	0	0	0,01	0	0	0	97,6
3689 13	0	0	0	0	0,23	0	0	0	0	0	0	0	0,06	0	0	0	0	0	0,01	0	99,11
22343 1	0	0	0	0	0	0	0	0	0	0	0	0,01	0,07	0	0	0	0	0	0,02	0	97,35
22343 2	0	0	0	0	0	0	0	0	0	0	0	0	0,05	0	0	0	0	0	0	0	98,78
22343 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,01	0	0	0	0	97,35
27791 1	0	0	0	0,03	0	0	0	0	0	0	0	0	0,03	0	0	0	0	0	0,07	0	92,47
27791 1	0	1,08	0	0	0	0	0	0	0	0	0	0	0,71	0	0	0	0	0	0,02	0	98,02
27791 1	0	0	0	0	0,04	0	0	0	0	0	0	0	0,01	0	0	0	0	0	0,13	0	92,75
27791 1	0	0,23	0	0	0	0	0	0	0	0	0	0,04	0,18	0	0	0	0	0	0,18	0	94,47
27791 1	0	0	0	0	0	0	0	0	0	0	0	0,03	0,01	0	0	0,04	0,03	0	0,09	0	93,94
27791 1	0	0,95	0	0,01	0,02	0	0	0	0	0	0	0,01	0,42	0	0	0,01	0	0	0,05	0	99,32
27791 1	0	0,77	0	0,04	0	0	0	0	0	0	0	0,04	0,34	0	0	0	0	0	0,08	0	99,21
27791 1	0	0,68	0	0	0	0	0	0	0	0	0	0,01	0,29	0	0	0	0	0	0,04	0	100,4
27791 1	0	0,64	0	0	0	0	0	0	0	0	0	0	0,11	0	0	0,01	0	0	0,03	0	98,98
27791 1	0	0,19	0	0,13	0	0	0	0	0	0	0	0,05	5,13	0	0	0,02	0	0	0,12	0	92,15

27791 1	0	0,66	0	0,03	0	0	0	0	0	0	0	0,01	0,29	0	0	0	0,01	0	0	0	99,21
27791 1	0	0,16	0	0	0	0	0	0	0	0	0	0,05	7	0	0	0	0	0	0,16	0	87,53
27791 1	0	0,61	0	0,01	0	0	0	0	0	0	0	0,04	0,3	0	0	0	0	0	0,01	0	97,89