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METALLOGRAPHIC INVESTIGATION OF IRON BLOOMS AND BARS FROM THE SMITHY SITE OF KÄKU, ESTONIA

Abstract

The smithy site of Käku, dated to the 14th–17th century CE, contains four different smithies built on top of each other. Finds from the site contain evidence from iron forging, casting and forging of copper alloys, and bone working. Metallographic analysis of iron blooms and bars from the smithy site has proved to be a valuable source of information for understanding the variety of activities performed at the site. The iron processing ranged from primary forging of iron blooms into bars, the manufacture of artefacts like knives, and the recycling of old cutting tools into bars which could be reused to produce new items. As smithies are quite rare sites to be excavated, the information obtained from Käku helps to shed light on the activities performed in the rural smithies and determine the rural smiths' role in the iron processing chain in the Late Medieval and Early Modern period.

Keywords: Early Modern, Medieval, metallographic analysis, metalworking, primary forging, smithy site

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INTRODUCTION

Skilfully crafted iron tools were a necessity for the medieval economy and many people were involved in the iron processing chain: beginning with the ore gathering and wood charring and ending with the finishing touch in a workshop of a smith. From all these activities specific traces (remains of constructions and implements) have been preserved in the cultural layer – red burned clay lumps with glassy melted surface, i.e. remains of clay lining of forges or furnace walls, and slags from different stages of iron production and processing, forging waste, etc. Although the slags from iron production and forging are in some cases discernible by diagnostic features, this fact is not particularly helpful, since the material reflecting separate stages of the process, i.e. separate slag lumps, cannot be found in temporal connection with each other or with other finds from settlement sites. Regrettably, the routine dating of single slag pieces and clay lumps using scientific methods is expensive, meaning that prehistoric and medieval slags cannot be distinguished from forging waste of a later period by their chemical composition.

Therefore, it is very important to use the full research potential of well-datable smithy re-

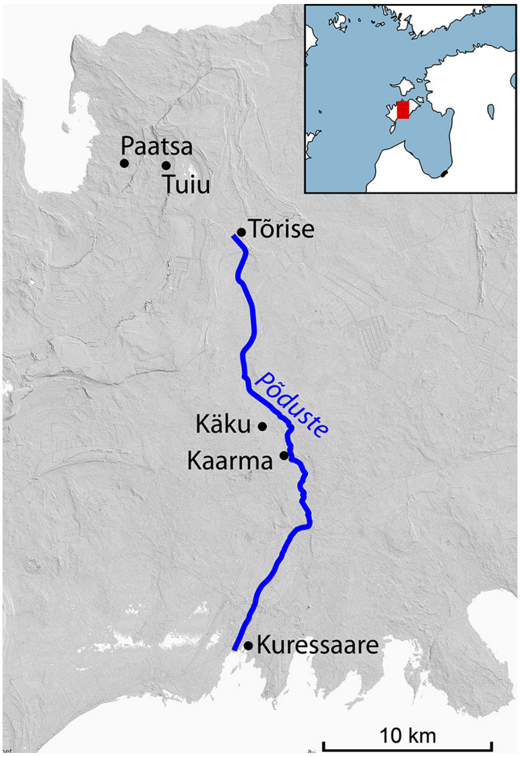

Fig. 1. The smithy site of Käku on the possible trade route on the Põduste River. Illustration: R. Saage (base map by Estonian Land Board).

mains that contain finds reflecting the performed manufacturing processes. Well preserved workshops with impressive finds discovered in Russia (Kirpichnikov 2004), Finland (Leppäaho 1949) and Sweden (Carlsson 1976; Gustafsson & Söderberg 2007), to name a few, have proven to be essential for studying the conditions in which ancient and historical metalwork was done. In addition to that, archaeologists' possibility to cooperate with material scientists has given the opportunity to research smithery waste using modern equipment, which gets us closer to the manufacturing processes that took place in the smithy. Metallographic analysis can reveal the smithy's position in the iron processing chain – whether it was a place of primary smithing, which is forging the spongy and slag rich blooms (about 50% of slag) into good quality iron bars (less than 5% of slag), or secondary smithing, which includes the production of a variety of artefacts from the iron bars. Smithy sites from Estonia (Peets 2003), Sweden (Lindman et al. 2007) and Finland (Heinonen 2012) have examples of different combinations, which is very useful as smithy sites are rare sites to be excavated.

The smithy site of Käku is the focus of the current study. The smithy site is located on the island of Saaremaa and situated at the edge of the Käku village, which has been continuously inhabited from the 12th century the latest. The smithy site is dated to the 14th–17th century CE, and it is one of the best-preserved smithy sites from Estonia yielding a large amount of iron, copper-alloy, and bone working finds and waste (Peets et al. 2013; Saage et al. 2015). One of the hypothesis that lead to excavation on the site was that the smithy of Käku practiced the primary smithing of blooms from the iron smelting site of Tõrise, which is about 12 km to the north from the smithy (Fig. 1) and the site itself is dated from the 11th–14th century CE based on two ^{14}C analyses (Peets 2003: 125–6).

The current article explores the subject using the metallographic analysis of bloom iron and iron bars from the smithy site. The analysis aims to answer the question: what raw material was available to the smiths and how was it processed in the smithy? This study is based on research carried out for an M.A. thesis (Saage 2013), but also incorporates finds from fieldwork done in 2013–4 (Saage et al. 2015) and recent analysis. All inventory numbers named in the text belong to collection AI 6845 in the Archaeological research collection at Tallinn University.

As the smithy site consists of at least four consequent smithies built on top of eachother, with only the earliest smithy having had a paved floor, it is difficult to allocate finds to a particular smithy. However, as the wall remains for each smithy could be used to determine the level on which the smithy was built on, height values were used associate finds and smithies. The dimensions of the smithy walls were different for all four smithies, while the same forge base was kept in use. The soil inside the walls does not have distinct destruction layers, as the charcoal stratified in the ground used for heating the forge is indistinguishable from the three layers of charcoal that were formed when Smithy 2, 3 and 4 burned down (smithies have been numbered

Fig. 2. Metallographically studied blooms, billets and iron bars. Rectangles mark the location of the cut cross-section. Illustration: R. Saage.

Inv. No.	Object	Weight (g)	Context	Date (CE)
155	Bipyramidal billet	158	Inside Smithy 1	mid-16th – early 17th century
345	Compacted bloom	196		
385	Iron bar	451	Outside Smithy 1	
175	Iron bar	94	Inside Smithy 2	15th – 16th century
218	Iron bar	244		
341	Bloom	221		
251	Scrap iron bar	118	Inside Smithy 3	14th – 15th century
307	Knife billet	77		
P56	Bloom	71	Outside Smithy 4	14th – 15th century

Table 1. Find context of metallographically investigated artefacts.

1–4 starting from the latest that was the topmost smithy). It is also possible that the soil has been disturbed numerous times with pits during the later smithies altering the stratification, but these pits would have remained unidentified because of the uniformly black soil in the smithy. The Smithies 2–4 are dated with radiocarbon analysis and Smithy 1 with artefacts (Table 1; for more details see Saage et al. 2015: 199–200). However, the smithies can be paired in two groups, 1–2 and 3–4, based on the orientation of the walls. The shift in the wall orientation compared to the forge happened after the destruction of Smithy 3. This could mean that Smithies 3–4 (and later Smithies 1–2) were temporally close and there was a discontinuation between Smithies 3 and 2.

METHODS

The initial preparation of the samples was done at the Laboratory of Archaeology at the University of Tartu using the following procedure: samples were cut off using IsoMet 4000 precision saw; mounted by SimpliMet XPS1 system with the Buehler PhenoCure resin; polished using Buehler AutoMet+EcoMet 250 grinder-polisher; and etched in 3% nital solution. The microstructures were studied at the Laboratory of Archaeology at Tartu University and at the Department of Mechanical and Industrial Engineering at Tallinn University of Technology with an inverted optical microscope. Vicker's microhardness was measured with a Wilson Tukon 1102 hardness meter, depending on the size of the structures at loads from 1–4.9 N during 10 seconds (from here on referred to as HV0.1–HV0.5). The locations of the microstructures and the hardness measurement points are marked on the cross-section with the corresponding letter. Scanning electron microscopy with energy dispersive spectrometry (SEM-EDS) analysis was performed at the Centre for Materials Research at Tallinn University of Technology using a Zeiss EVO MA 15 microscope with INCA Energy 350 analyser. The focus of the SEM-EDS elemental analysis was the quantification of phosphorus (the estimation of uncertainty for measuring P was 0.5%).

At least 42 iron bars and partly forged blooms were recovered from the site. They were distributed as follows: 18 in Smithy 1; 16 in Smithy 2; 5 in Smithy 3; and 3 in Smithy 4. Nine of these were selected for metallographic analysis from raw blooms to neatly processed iron bars so that samples with varying levels of processing would be represented (Table 1; Fig. 2). Samples No. 251 and No. 307 were initially thought to be iron bars, and only after the analysis they were identified as a scrap metal bar and a knife billet.

RESULTS

Blooms

The analysis revealed four blooms of spongy iron that were all in different stages of refining. The distinction between bloom iron and iron bar is in the case of these specimens rather vague because they represent the purification process from the former to the latter.

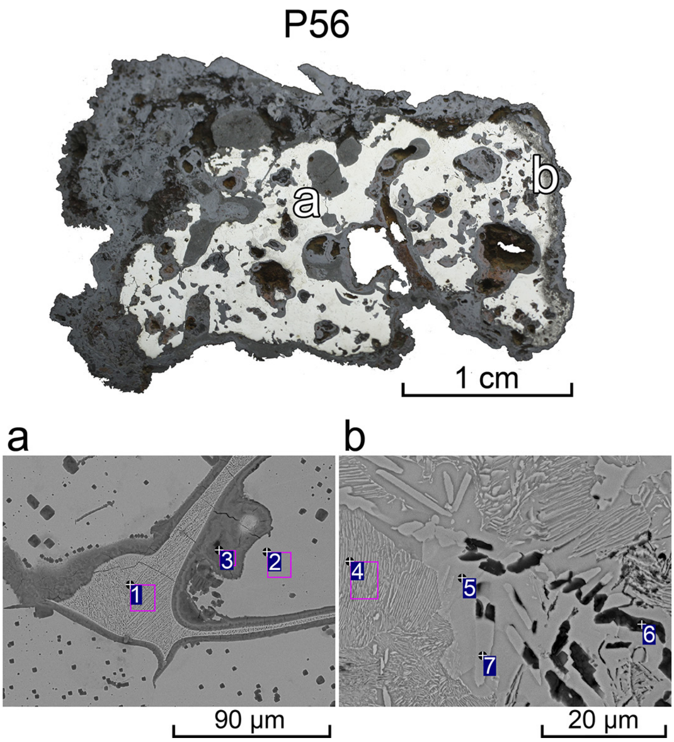

Fig. 3. SEM-EDS images of bloom No. P56: a) steadite and phosphorous iron; b) pearlite, ferrite, graphite, and cementite. The measured phosphorus content (marked by numbers): 1) 14.3%; 2) 2.4%; 3) 3%; 4) 0.2%; 5) 0.3%; 6) 0.5%; 7) 0.1%. Illustration: M. Viljus and R. Saage.

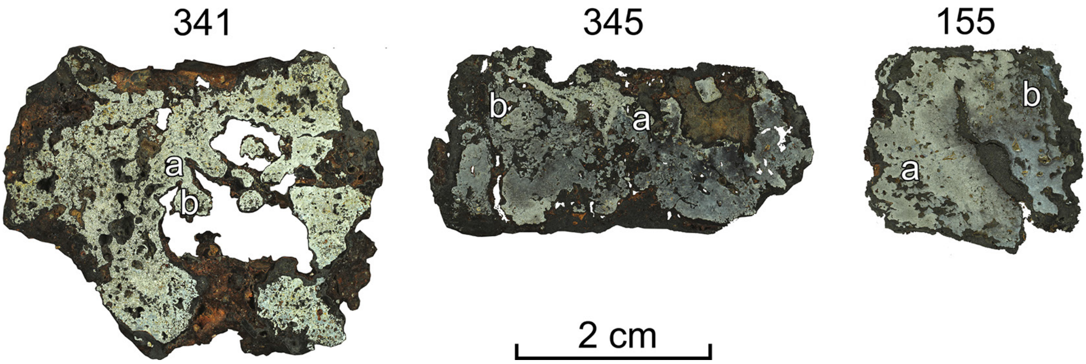

Fig. 4. Blooms Nos. 341, 345 and billet No. 155. Micrographs on Fig. 5. Illustration: R. Saage.

Bloom No. P56 is porous and has a high slag content (Fig. 3). It had been hammered very little, if at all, which is indicated by the round hollows in the core of the bloom. Most of the cross-section's metallic surface was relatively hard (Fig. 3: a; 271–317 HV0.5), resistant to etching and contained impurities of harder and brittle areas (696–916 HV0.3), which cracked when tested for hardness. The SEM-EDS analysis of the sample indicated a high phosphorus content in the alloy (Fig. 3: 1–3). The main alloy is phosphorous iron (Fig. 3: 2), where the measured phosphorus content was up to 2.4%. The hard and brittle component, containing up to 14% phosphorus, is steadite (Fig. 3: 1), which due its low melting temperature of 960 °C was the last constituent to solidify (Scott 1991: 38). The droplets are surrounded by a chloride rich iron oxide (Fig. 3: 3). Phosphorus is not a favoured element in the alloy as it can produce cracks during cold forging, but there are also cases where it has been employed when making knives as it is hard and will create a decorative pattern when etched (Vega et al. 2003).

The chemical composition of one edge of the bloom (Fig. 3: b) differed from the rest of the sample by containing more carbon and less phosphorus, which could be attributed to phosphorus burning out of the alloy at high temperatures. The higher carbon content reaches about 750–1000 µm in depth inside the alloy. Due to the fine microstructure, it was difficult to reliably measure hardness, but four different components could be determined. It contained fine-lamellar pearlite (Fig. 3: 4), ferrite (Fig. 3: 5), graphite (Fig. 3: 6), and cementite (Fig. 3: 7). This is an unusual mixture of white and grey cast iron as it is not in an equilibrium state. The formation of fine-lamellar pearlite means it was probably cooled by a forced air flow. This piece was presumably discarded in the early stage of the purification as its high phosphorus content made it too brittle to forge even at high temperatures.

Bloom No. 341 is very porous and the core of the bloom is still hollow (Fig. 4). The carbon content is relatively high along the surface of the cross-section (about 0.6%, estimation based on microstructure), having different heat-treated structures with few ferritic (Fig. 5: 341b) and mostly pearlitic areas. The piece has some phosphorous impurities containing steadite (Fig. 5: 341a), but if the purification process of material would have continued, the generally high carbon content would have been heat-treatable and therefore useful as raw material.

Bloom No. 345 has been refined more than bloom No. 341 and it has been compacted to have a rectangular cross-section (Fig. 4). The hollows in the core are longitudinal, which is also a sign of forging. In its microstructure, most of the bloom is ferrite (up to about 0.2% C; 80–94 HV0.5), with carbides in the grain boundaries, but there were areas with a 0.6–0.8% carbon content containing pearlite (Fig. 5: 345a). This piece could be an example of the bloom in its final stage before it was flattened and folded. However, the bloom has numerous small separate iron grains in the slag matrix (Fig. 5: 345b), which would probably result in a remarkable loss of iron during further refining. As raw material of mostly soft iron, with further refining this bloom would have been suitable for the back part of a knife.

Billet No. 155 marks the transition from blooms to bars. The slag pocket in the core of the billet indicates that it probably was not folded, as it would have fallen off if hammered (Fig. 4). The carbon content in the bloom is varying in the range of 0–0.8%, consisting of ferrite, Widmanstätten ferrite (Fig. 5: 155b), and pearlite (Fig. 5: 155a). Based on visual observation the latter is the most prevalent, which makes the material hardenable. While the slag content of the billet is still high, making it an undesirable raw material for manufacturing tools, the ends of the piece have been given a tapering shape that could be an intention to show the quality of the material (Fig. 2). If giving the billet a bipyramidal shape was a sign of quality and it was meant for trade, then the smith had either misjudged the purity of the billet or had done it intentionally.

IRON BARS

The three analysed iron bars differed in appearance and inner structure. Bar No. 218 is more irregular in shape than other bars and bears no signs of chiselling on its edges (Fig. 6). The bar has many slag pockets and its structure is mostly ferritic (Fig. 7: 218b), with only the upper-right part of the cross-section containing pearlite (Fig. 7: 218a). Corrosion has reached deep into the bar, even separating some smaller iron pieces, indicating that the welds were not very compact. One end of the bar was relatively flat and it is possible that the smith had planned to fold it. This bar would have needed further refining if it was intended to be used for the production of good quality artefacts.

Iron bar No. 175 has been previously considered to be a billet for a cutting tool (Saage 2013: 42), but a fresh look at its polish suggests otherwise (Fig. 6). The dimensions of the bar

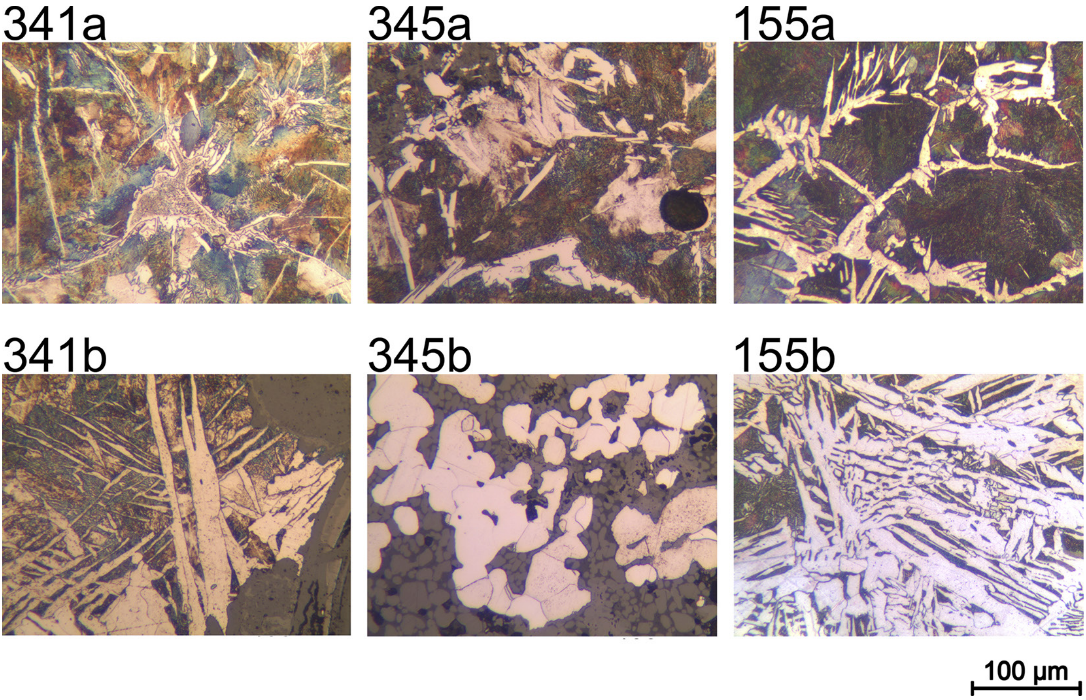

Fig. 5. Micrographs of blooms and the billet (shown on Fig. 4): 341a) steadite phosphorous impurity in the middle (590 HV0.1) with pearlite surrounding the cavity (279–293 HV0.5); 341b) ferrite (65–124 HV0.5) and pearlite (195 HV0.5); 345a) pearlite and ferrite (85–263 HV0.5); 345b) ferrite in slag (75–99 HV0.5); 155a) pearlite (178–196 HV0.5) and Widmanstätten ferrite (169–182 HV0.025); 155b) Widmanstätten ferrite (131–141 HV0.5) and pearlite. Illustration: R. Saage.

match well with the knife billet (No. 307) and on the left of the cross-section there seems to be a welded part with a higher carbon content (0.4–0.7%; Fig. 7: 175b) compared to the rest of the low carbon areas (Fig. 7: 175a). However, the weld is not tight and therefore deeply corroded. Therefore, it is likely that this forging pattern is a result of welding together strips of iron to make a larger bar and the occurrence of more carbon on one side of the bar was not intentional. This bar is of good quality compared to previously discussed blooms and bars. One end of the bar

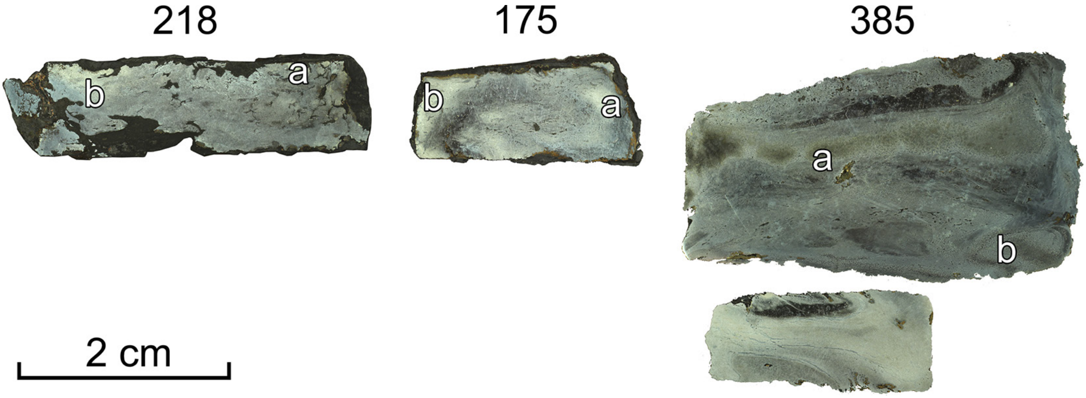

Fig. 6. Iron bars Nos. 218, 175 and 385. Micrographs on Fig. 7. Illustration: R. Saage.

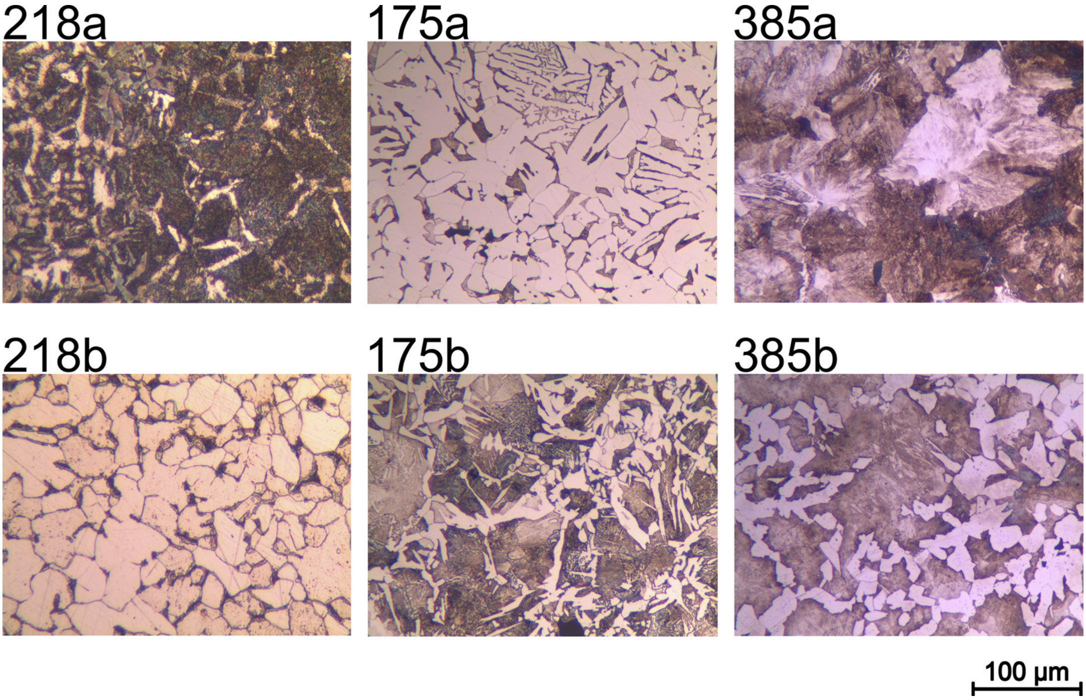

Fig. 7. Micrographs of iron bars (shown on Fig. 6): 218a) pearlite (180–194 HV0.5); 218b) ferrite (94–107 HV0.5); 175a) ferrite (115–123 HV0.5) and pearlite; 175b) pearlite (177–206 HV0.5); 385a) heat-treated structure (259–429 HV0.5); 385b) heat-treated structure with ferrite (158–335 HV0.5). Illustration: R. Saage.

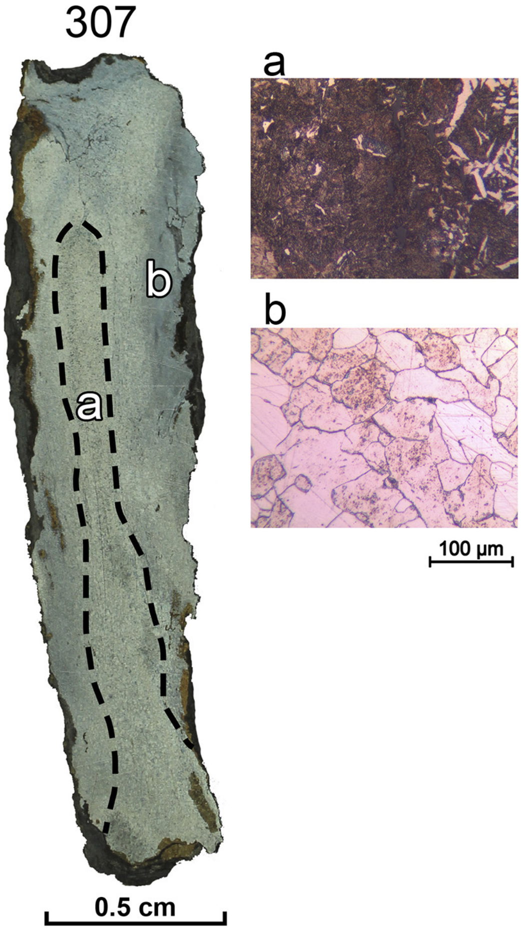

Fig. 8. Knife billet No. 307: a) pearlite (176–228 HV0.5); b) ferrite (102–109 HV0.5). The dashed line marks the presumed welding line. Illustration: R. Saage.

has been chiselled off, which means that either the studied part or the missing part would have been used for manufacturing artefacts.

Iron bar No. 385 was the largest of the bars (Table 1) and it seems that effort had been made to give the bar a smooth surface. Cross-sections cut from both ends were similar – the bar was made of at least eight layers (Fig. 6), which could have been achieved by folding the bar three times. The welds between the layers are well done and contain little slag and corrosion. The bar has been hardened by interrupted cooling into water and then air cooled (Fig. 7: 385a&b), which is normal practice when an object has received its final shape. Hardness measured from different areas of the bar (92–429 HV0.5) illustrates its varying carbon content. Whether iron bar No. 385 was refined in the smithy or whether it is bought as raw material, it represents a high-quality end-product of primary smithing.

Knife billet

A knife billet (No. 307) was found among the investigated iron bars. The dimensions of the billet are suitable for forging a knife, and the smith had started with hammering out the tang (Fig. 2). The forging pattern is visible through the carbon content difference, with the centre con-

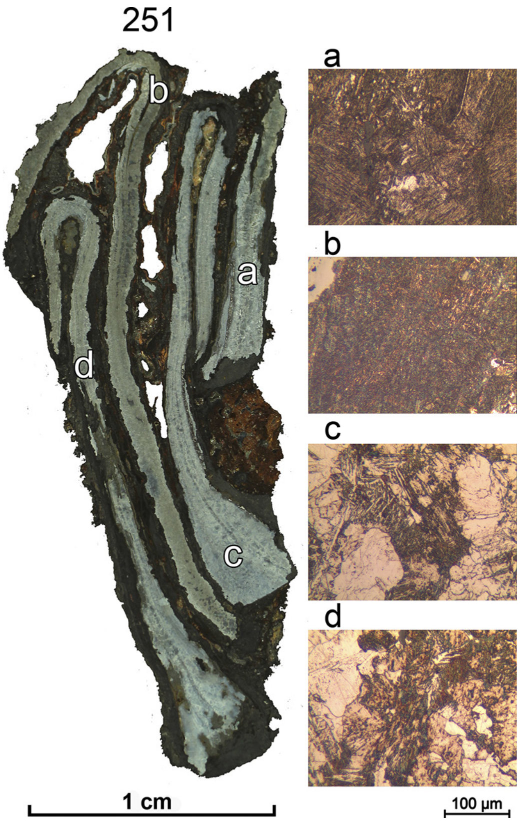

Fig. 9. Scrap iron bar No. 251: a) martensite (461–551 HV0.5); b) martensite (598–758 HV0.5); c) heat-treated structure (179–300 HV0.5); d) heat-treated structure (247–493 HV0.5). Illustration: R. Saage.

taining about 0.4–0.6% carbon, while the sides and back are mostly iron (Fig. 8: a&b). To make this billet, an iron plate was folded in a U–shape around the steel core and then welded together neatly. Based on the analysis of the finds from 13th–18th century rural cemeteries, this forging pattern was used in Estonia but it was not very common (Peets 2003: 259). Two out of 15 of the studied cutting tools from the smithy site were produced with this forging pattern (Saage 2013: 46). If properly finished and hardened, the billet would have produced a good quality knife.

Scrap iron bar

Iron bar No. 251 is forged together from scrap iron. While the cross-section reveals several hollows and much corrosion between the scrap pieces (Fig. 9), the objects used for making the bar were all steel tools. Different cutting tools can be found in the bar: two knives (Fig. 9: a&b) and two sickles or scythes (Fig. 9: c&d).

One cutting tool is a knife (Fig. 9: a) made in a three-ply technique. The second tool has a thin and wide blade but lacks the thick back part – which is why it is also considered to be a knife (Fig. 9: b). The third tool is a scythe or a sickle, having the widened back of a blade (Fig. 9: c). The fourth tool is also a sickle or a scythe (Fig. 9: d). Two parts of the scrap iron bar contain martensite (Fig. 9: a&b), therefore it must have been rapidly cooled in water after it was given its final shape. This scrap metal bar would have been good raw material for forging new cutting tools.

DISCUSSION

With the current knowledge of contemporary iron smelting sites near Käku, the most likely origin of the bloomery iron found in Käku is the Tõrise iron production site, which is about 12 km to the north up the Põduste River. The same river is a likely trade route as it leads past Käku to parish centre in Kaarma and to Kuressaare, which is presumed to have been a port already by the 13th century (Mägi 2002: 205) and which in the 16th century became the first town on the Saaremaa island. All the different actors of the potential iron processing chain are therefore represented on the Põduste River: iron smelters, smiths who refine iron and produce goods, and consumers in the parish centre and the port town (Fig. 1).

The metallographic analysis gave evidence of primary forging in different stages of refining. The occurrence of porous and slag rich sponge iron suggests that at least part of the raw material used in the smithy arrived from iron production sites with very little primary forging. That means the smiths refined the blooms to iron bars for their own consumption. However, it is also likely it was done for trade, as in the case of billet No. 155. By the end of field works in 2014, the slag heap collected from the excavation had reached 1500 kg (Saage et al. 2015: 196). As slag has been found all around the settlement, the total number of slag produced in the smithy could have reached several tonnes, meaning that primary and secondary forging was practiced intensively.

Some of the blooms brought to the smithy were discarded in a pile in the eastern corner of the smithy (Saage et al. 2015: 197). While there is evidence that phosphorous iron has been used in various artefacts from the Gallo-Roman period up to the 19th century (Vega et al. 2003), the phosphorus content in bloom No. P56 was too high to include it in the manufacture of artefacts. The most probable sources for high phosphorus content are either charcoal or ore. It has been argued that charcoal from deciduous trees contains four times the phosphorus conifer wood does, while the conifer tree bark can contain up to 15 times more phosphorus than the wood from conifers (Gurin 1982: 23). However, comparing the mass of the wood with the bark, it is unlikely that so much bark ended up in the charcoal. Elemental analysis of the Tuiu smelting site (Fig. 1) ores have shown very low levels of phosphorus (Peets 2003: 35), but this needs to be backed up by fresh analysis of ores near the Tõrise site as well in order to name the source of the high phosphorus content. However, the problem of phosphorous iron was widely spread in Europe in Medieval times as it reduces the penetration rate of carbon into the alloy, and for this reason, phosphorus free iron for cementation or finished steel was imported from areas with suitable ores (Tylecote 2002: 80).

The high carbon content in some of the blooms can have multiple explanations. First, it is possible that it originates from the used iron production furnace without having been intentional. Hence, the high carbon bloom pieces would have been regarded equal to the low carbon ones and forged into bars without selection. That kind of refining would produce a bar with occasional carbon-rich areas like observed in the case of bars Nos. 175, 218, 345 and 385.

The forming of steel during iron reduction is expected, but usually it is accompanied by areas with low carbon content (Gurin 1982: 5; Peets 2003: 149; Pleiner 2006: 18). In that light, the carbon-rich blooms (without low-carbon areas) might be seen as evidence of steel processing. As the carburization process would not reach to the core of the blooms (similar to No. 341), the carbon content must originate from the iron production furnace. Therefore, this may also be a deliberate manipulation of the reduction process by the iron smelters (Gurin 1987: 18; Peets 2003: 264). The raw bloom No. 341 and billet No. 155 might be examples of successful attempts for creating steel during the initial reduction in the furnace. Tylecote (2002: 81) has estimated that the price of (bloomery) steel might have been 4–5 times higher than wrought iron, which would have made the production much more profitable. The introduction of the blast furnace in the 13th century and its very effective production might have shifted that balance, as by the early 16th century osmund steel was only twice as expensive as wrought iron (Buchwald 2008: 262). In Estonia the first mention of osmund iron appears in written sources in 1364, whereas it dominated the market in the following centuries (Sepp 1991: 6). The appearance of osmund iron is contemporary to Smithies 4 and 3 in Käku. Hence, iron and steel produced through the bloomery process found from Käku might be examples of the last stage of local bloomery in Estonia. If the local smelters based their profits on the much higher price of steel, then the cheaper steel coming from Sweden could have put them out of business.

The scrap metal bar No. 251 is a rare find, which provides good insight into how the broken tools were reused. Tools with a high carbon content were welded into the scrap metal bar, so there was clearly an intent to reuse the bar forging object that benefit from hardening. While the analysed knife billet demonstrated that the smiths had access to homogeneous steel, scrap steel might have played a large role when the smithy of Käku was operating.

When comparing Käku with other well documented smithies, the most similar one would be the Salmered smithy in western Sweden. It was a farm smithy dated from mid-13th to 14th century where both primary and secondary smithing were undertaken (Lindman et al. 2007). While the possible iron smelting site providing sponge iron to the smithy is not known, the analysed primary forging waste indicates that the iron had been produced using ‘red earth’, lake or bog ore as raw material (Lindman et al. 2007: 26).

A smithy site in Paatsa, on the Estonian island of Saaremaa, which had at least 5 different phases of operation dating to the 11th–14th and 16th–17th centuries, has been connected to the nearby iron smelting complex of Tuiu (Fig. 1). The largest part of the 4–4.5 t of slag found in the course of the archaeological investigation of the Paatsa smithy remains consists of primary smithing slag. Evidence of forging commodities was scarce and these (e.g. horseshoe nails) could date from the latest period of the smithy complex (Peets 2003: 181–91, Table 9). It is most likely the main function in Paatsa was forging the furnace blooms from Tuiu into currency blooms or currency bars (Peets 2003: 196).

In the 12th–13th century smithy complex of Vantaa Gubbacka in southern Finland only commodities from imported currency bars were forged (Willim & Grandin 2010: 7). As there are no iron smelting sites in the area, it has been proposed that the iron originated from Estonian smelting sites or from the Häme region (Heinonen 2012: 301). Hence, the distance from iron production sites seem to be the main factor to determine the intensity of primary forging practiced in the smithy.

There are three ways of interpreting the iron refining evidence from the 15th–17th contexts from Käku. Firstly, as there are no known iron production sites in Saaremaa (or all of Estonia) dated later than the end of the 14th or early 15th century (Peets 2003: Fig. 118), there is reason to believe that the blooms recovered from the site – even the ones from higher depositions due to disturbed stratigraphy by later activities – originate from the earlier smithies.

Secondly, it should not be ruled out that the finds from the Käku smithy site indicate to a late phase of small scale local iron production in Estonia (during the 15th–17th centuries). There is numerous evidence from neighbouring countries, where peasants could pay their internal taxes with self-produced iron. The taxation list from the 16th century shows, that the peasants in 28 parishes in central Jutland in 1586 paid 410 *kloder* (clot – hand-shaped iron bloom weighing c 7 kg) to the representative of the crown in Silkeborg (Buchwald & Voss 1992: 33). Currency blooms have been mentioned in Finland among the taxes of the inhabitants of Olavinlinna *län* in 1543–1605, and from the Savonlinna *län* 66 *leisikas* (1 *leisikas* = 8.2 kg), i.e. more than half a ton of iron was paid as taxes in 1562 (Laine 1952: 20; Soininen 1981: 223–4, 391–4, 404–5; Pirinen 1982: 422–3). Similar sources are known from Sweden and Norway, where it was customary to pay taxes with iron in the Middle Ages (Kumlien 1981; Espelund 1995). As no such proof has been discovered for Estonia, only the discoveries of new iron production sites could serve as direct evidence for the local iron production in Estonia during Late Medieval and Early Modern period.

Thirdly, the unpurified currency blooms could have been traded from Finland or Sweden, where iron was still being produced by the direct reduction process. This took place in large furnaces often furnished with water-powered bellows and mechanical hammers. The earliest mention of the term *h*ütte, marking workshops, located in small log houses and mainly involved in producing and working iron, can be found in Bohemian written sources dating from 1269 (Kumlien 1981). In Swedish archival sources the term *jytte* appears already in 1328, and in Finland *hytti* is mentioned in 1563 (Kumlien 1981; Pirinen 1982). In the eastern counties of Finland local iron production persisted until the mid-19th century. Apparently, the increasing of iron production was essential for the Scandinavian countries, since even at the end of the 18th century a detailed instruction in Finnish and Swedish for producing iron from bog ore was published in Stockholm (Rinman 1997[1797]). In 1790 an analogous text in Danish was published in Copenhagen, which was translated into German in 1801 (Evenstad 1991[1801]; Espelund 1995). Also, an adequate description of the production of 'home iron', construction and organising the *hytti* was written down at the end of the 19th century (Damstén 1899: 16–7). Hence, the existence of the bloomery process from the late 15th to the 17th century (and later periods) is well documented in Sweden and Finland, while there is no direct evidence of it in Estonia.

CONCLUSIONS

The metallographic analysis of iron blooms and bars from the smithy site of Käku has provided evidence for different steps in iron processing. The appearance of iron blooms with little or no marks of forging indicate that primary forging was done in the smithy in order to produce good quality bars either for the smithy or for trade. Varying levels of quality could be detected among the iron bars as there were examples with large slag inclusions, but also bars of good quality which could be considered the desired end result of primary forging.

The analysis also revealed a knife billet, which is an example of secondary forging. The raw material with suitable carbon concentration has been put into use with neatly done weld lines between the different layers. It shows that the smiths in Käku had access to homogeneous iron and steel, whereas its carbon content must have been known to them. The scrap metal bar shows that steel was valued and re-used as a raw material even after the original artefact was broken.

The finds from the smithy site pose questions about the end of local iron production in Estonia. The evidence from the investigated iron smelting sites suggests that local iron production ends in the late 14th or early 15th century. While this overlaps with the earliest smithies, it is most probable that the blooms from younger depositions were imported from Finland or Sweden, where bloomery smelting was actively practiced.

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