RAGNAR SAAGE

Metalworking Sites in Estonia during the 7th–17th Centuries
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Metallitööpaigad Eestis 7.–17. sajandil

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Humanitaarteaduste ja kunstide valdkond, Tartu Ülikool

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V  Saage, R., Russow, E. (ilmumas/forthcoming). Urban casting tools as evidence for transfer of technology across the Baltic Sea in 13th–17th century Estonia. [Avaldamiseks vastu võetud ajakirjas Medieval Archaeology / Accepted for publication in Medieval Archaeology].4

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1 Autori panus: artikli põhiosade kirjutamine (v.a osteoloogiline analüüs ja šlaki tõlgendamine), metallograafilise analüüsi, röntgenuringute ja jooniste 1–7 tegemine ning retsensentide ettepanekute sisseviimine. / Author contribution: writing the passages chapters of the article (except osteological analysis and slag interpretation), metallographical and X-ray analysis, making figures 1–7, and revising the manuscript.

2 Autori panus: uurimisküsimuste püstitamine, pXRF analüüside, 3D-mudelite ja jooniste tegemine, artikli käsikirja kirjutamine ja retsensentide ettepanekute sisseviimine. / Author contribution: setting the aims, pXRF analysis, 3D-modelling, making the figures, writing the first full manuscript with subsequent review and editing.

3 Autori panus: uurimisküsimuste püstitamine, proovide ettevalmistamine ja esmame analüüs, jooniste tegemine, artikli käsitserk põhiosade kirjutamine ja retsensentide ettepanekute sisseviimine. / Author contribution: setting the aims, preparation and initial analysis of the samples, making the figures, writing most the first full manuscript with subsequent review and editing.

4 Autori panus: uurimisküsimuste püstitamine, pXRF analüüside ja jooniste tegemine. E. Russow dateeris Tallinna leiud ja iseloomustas keraamika koostist. Artikli käsikirja kirjutamine ja retsensentide ettepanekute sisseviimine toimus ühiselt. / Author contribution: setting the aims, pXRF analysis, making the figures. E. Russow dated the finds from Tallinn and characterised the ceramic fabrics. The manuscript was written and revised together by the two authors.
METALLITÖÖPAIGAD EESTIS 7.–17. SAJANDIL

1. SISSEJUHATUS

1.1. Uurimisküsimused


Minu peamised allikad on arheoloogilised leiud. Nende uurimisel ühendas traditsioonilised arheoloogia meetodid tänapäevases materjaliteaduses kasutusel olevate uurimisvõtetega. Arheoloogia abil saame mineviku metallitöö kohta infot peamiselt kahe tüüpi allikatest: esiteks metallivalamise jälge dega töökodade jäänused koos tööriistade, tooraine ja tootmisjääkidega ning teiseks valmised, mille arv erinevates leiukogudes ulatub sadadesse tuhandesse. Minu uurimus keskendub just esimeeslule rühmale, mistõttu jääb tihti vastamata küsimuse „Mis esemeid nendes töökodades valmistati?“. Küll aga vastab käesolev uurimistöö küsimusele „Milllega ja kus esemeid valmistati?“ ning „Mis materjaile selleks kasutati?“.

Töö eesmärk on anda uut teavet Eesti metallitöö kohta 7. sajandist kuni 17. sajandi lõpuni. Minu panus on arheoloogilise, loodusteaduslike ja digitaalsete meetoditega metallitööpaikade ja tootmisjääkide uurimine. Täiendades tulemusi peamiselt esememäärluusil tugevate teadustöödega, annab doktoritöö laiema pildi metallitöö tasemest ja spetsialiseerumisest. Kuna sepatööst ja värviliste metallide valamistest jäävad järele spetsiifilise iseloomuga jäägid, siis on mõlema metallitööharu uurimiseks kasutatud erinevat lähemamist. Sepikodades on tavaliselt väikesed rauatükid, kuna nende kokkukeevitamine on ressurssi- ja ajamahakas tegevus, mis ei pruugi end ära tasuda. Seevastu valukodadest on vanametalli leidmine palju haruldasem, kuna väär- ja värvilisi metalle, kuitakes on töökodade töökodade, on lihtne taaskasutada. Kuna valamis töörüstut ja abivahendeid, nagu katkiseid tiigleid ja kivist valuvorme, enamasti ei taaskasutatud (kui siis ainult šamotina), siis teoge neid ohtralt. Sepatööristest on samas pigem haruldased, kuna rauast vahendid, näiteks vasarad ja pihid, olid vastupidavamad ja suure metallisalduse tõttu kergesti ümbertöödeldavad.
on ka viimase kahe tuhande aasta jooksul kasutatud sepistamistööriistade vähe-
muutunud vormide ja sellest tulenevate dateerimisraskustega, sest isegi sadade
aastate vanuseid leide on lihtne pidada etnograafilisteks või isegi tänapäevasteks (Peets 2008, 133–134).

Uurimistöö lähtekoht on hüpotees, et 13. sajandil käivitusid Eesti alal Saksa-
Taani vallutuse järgselt ühiskonnas mitmed arengud, mis põhjustasid metallitöös
olulisi muudatusi ja mis jõustusid arheoloogilises aineses. Selle kinnituseks või
ümberlükkamineks oli tarvis kaardistada metallitöö tase rauaaajal⁵. Tiigide ja
valuvorme on suuremal hulgul leitud alates 7. sajandist, mis sai ka uurimistöö
algusajaks. Paremini säälinud sepikodade jäänused pärinevad siiski alles 11.
sajandist ja sellest hilisemast ajast. Järgmiseks vaadeldakse metallitööd kesk- ja
varaussajal. Kuna mitmete sepikodade, aga ka värviliste metallide valuga seotud
muististe datering ulatub Põhjasõjani, siis sobib 17. sajandi lõpp uurimuse
ajaliseks ülempiirk. 18. sajandi alguse sõjategevus, näljahäda ja epideemiaid
viisid katastroofilise rahvastiku vähenemiseni, millest ilmselt ei pääsenud ka siin
töötlatud metallitööolis. Kahtlemata väärib uurimistööd Põhjasõja-
järgne periood, mille puhul võiks märksa enam kaasa astuda kirjalikke ja etnograafilisi
allikaid, kuid käesoleva töö raamidesse see enam ei mahu.

Sepatöö uurimisel võtsin vaatuse alla Eestis teadaolevad 11.–17. sajandi sepi-
kojad ning sealt leitud ehitiste ja seadmete jäänused (IV artikkel). Hästi säilitinud
sepikodajad on suhteliselt haruldased, mistõttu tuli analooge otsida ka Rootsist,
Soomest ja Venemaalt. Täpsemalt analüüsides sepikodadest leitud ääsed, mis eel-
nimetatud ajaperioodil muutuvad lihtsastest lohkääsidest massiivseteks tõstetud
tasapinnaga ääsideks. Sellega seoses püstitasin uurimisküsimused:
• Kas massiivse tõstetud nelinurkse ääsi kasutuselevõtt on seotud lääne päritolu
  käsitoöliste siserändamisega Liivimaa vastrajatud linnadesse?
• Miks võeti see äästitüüp kasutusele?

Eraldi juhtumina käsitlen Käku 14.–17. sajandi sepikoda, kus kaevasin koos Jüri
Peetsiga (I artikkel). Lisaks sepikoja ehitusjäänuste uurimisele andis väärtus-
ikku teavet metallograafiline analüüs sealt leitud rauakangidest (III artikkel).
Käku uurimise käigus otsiti vastust küsimustele:
• Milline oli Käku sepikoja põhiplaan ja kuidas see aja jooksul muutunud on?
• Mida toodeti Käku sepikojas?
• Millise toorainega tõötasid sepad Käku sepikojas ja kuidas seda töödeldi?

⁵ Eesti rauaaja kronoloogia (Tvauri 2012, 17):
500 eKr – 50 pKr eelrooma rauaaeg;
50–450 rooma rauaaeg;
450–550 rahvasterännuaeg;
550–800 eelviikingiaeg;
800–1050 viikingiaeg;
1050–1227 hilisrauaae.
Värviliste metallide valamise töökujad on Eesti arheoloogilises aineses halvemini esindatud ja enamasti tulevad selle tegevusega seotud jäänused välja muu oma-aegse prügi hulgast. See tõttu valisin peamiseks uurimisobjektsiks sulatamiseks kasutatud tiigid, valamiskulbid ja valuvormid. Raauaegsete leidude põhiosa päinelt 7. sajandist kuni 13. sajandi esimese veerandini (II artikkel). Valamisvahendeid leitakse kõige enam linnamägedelt ja nende kõrval asuvatest asulatest, maailnades, asulakohtades ja matmispaikades. Seeega on uurimisobjektidega kaetud nimetatud perioodi peamised muistiseliigid. Artiklis otsit vastuseid järgmistele küsimustele:

- Milliseid valamisvahendeid rauaaja teisel poolel Eesti alal kasutati?
- Milliseid sulameid nendega valati?
- Kas leidub seoseid muistise liigi, valamisvahendite ja nendes valatud sulamite vahel?
- Millised on saadud tulemused võrreldes Eesti naabermaadega?


- Millised valamisvahendeid linnades kasutati?
- Milliseid sulameid nendega valati?
- Millised muudatused metallivalus toimusid 13. sajandil?
- Kuidas need tulemused suhenevad teiste Läänemeremaade leidudega?

1.2. Varasem uurimistöö

raamatut *De diversis artibus* (Hawthorne, Smith 1979) kui ka 16. sajandi metallitööd puudutavaid teoseid, nagu Georg Andreas Agricola *De re metallica* (Hoover, Hoover 1950) ja Vannoccio Biringuccio *Pirotechnia* (Smith, Gnudi 1990), pidada omas ajas kirjutatud teadustöödeks. Tänapäeva uurijatele on need ühtlasi väärtuslikeks kirjalikeks allikateks.

Oberstockstallist Austrias avastatud rikkaliku leiulainesega 16. sajandi teise poole labor või metallitöökoda sisaldas vahendeid, millega oli süstemaatiliselt läbi viidud keemilisi katseid (Martinon-Torres, Rehren 2005, 17). Kuna testimisnõus on leitud ka keskajast (Bayley 1992, 6), siis polegi ehk mõistlik jagada metallurgiat rangelt praktiseks ja uurivaks, kuna ainult arheoloogiliste leidude abil ei ole enamast võimalik öelda, kas tegemist oli katsega millegi uue teada- saamiseks või igapäevase toiminguga, millega kontrolliti metallide puhtust.


Koltšin töö olid kasutatud Venemaa uurimistöödeks ja olid suurte kasutustel Venemaa laenuristajatele seintest.


Eesti sepikodade arengu uurimiseks on arvukas ja võimaldab erinevaid distsipliine kasutades mõista paremini mineviku sepatööd ja seppasid.


Naabermaadest on metallivalula seotud leidud analüüsid Lätis ja Venemaa, kus elementanalüüsi abil on tuvastatud tiiglites leiduvaid metallijääki (Daiga, Grosvalds 1964; Eniosova, Rehren 2012). Sel moel uuritud tiiglile põhjal võib teha järeldusi omaeasest töökodade spetsialiseerumise kohta, näiteks mis sujamid olid kätesaadavad, kui levinud olid väärismetallid. Rootsis toimunud ulatuldikud väljakaevamised on andnud võimaluse uurida sõltuvalt mõningaid tootmispaiku, nagu Helgö saar (Lamm 2012), Sigtuna müntimiskoda (Söderberg 2011) ja Fröjeli töökoda Ojamaa saarel (Söderberg, Gustafsson 2006).


1.3. Uurimistöö kulg

Käesolev uurimus kasvas välja Jüri Peetsi ja Ain Mäesalu juhendamisel valminud bakalaureusetööst, mis käsitles Kääku sepikojas ja asulakoha (Saage 2011). Aastatel 2012–2013 hangiti Tartu Ülikooli arheoloogia laborisse aparatuur
metallograafiliste analüüside ja spektraalanalüüside (pXRF-ga) läbiviimiseks, mis võimaldab viia uurimise uuele tasemele. Tekkinud võimalusi kasutades valmis samade juhendajate käe all autori magistritöö, mis keskendus taas Käku sepikoaasemele, ent hõlmas ka 2012. aasta välitööd ning seal kõrvald võimalusi kasutades analüüsid waaraanuliseid esemete metale ja vasesulamist esemete spektraalanalüüside tulemusi (Saage 2013).


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ja 7880, institutsionaalsed uurimistoetused IUT20-7, IUT18-8 ja IUT19-29 ning TLÜ Ajaloo Instituudi sihtfinantseeritav projekt SF0130012s08.


2. METALLITÖÖGA SEOTUD MÕISTED

Järgnev nimekiri aitab orienteeruda käesolevas töös sageli esinevate mõistete ja sulamite koostiste osas. Analüütiliste meetodite lühendid ja toimimispõhimõtted on lahti seletatud 3. peatüks. Alltooodud mõistete nimekiri vastab ingliskeelsetele nimekirjatulemusel.

Amalgaam – sulam, mille üks koostisosa on elavhõbe.


Malm – raua ja süsiniku sulam, kus süsinikusisaldus ületab 2%.

Messing (ehk valgevask) – põhilisandina tsinki sisaldav vasesulam.

Pronks – põhilisandina tina sisaldav vasesulam.

Punapronks – põhilisandina tina ja tsinki sisaldav elast.

Putter – tina ja liii sulam, mis võib sisaldada väiksema kogust antimi, vismutit ja vaske.

Raua otsetaandamine – termoökeemiline protsess, milles redutseeriva gaasiga maagist tuaadad raud saadakse tahkedel kujul ja on praktiliselt süsinikusisaldusvaba (nn käsnraud). Otsetaandamisprotsess toimus erineva konstruktsiooniga savist sulatusahjudes, energiallikaks ja redutseeriva vinguga tekitajaks olisi puussi. Selline tootmisviis oli Eestis kasutusel vahemikus 1–1400 aastat pKr. Raud (või separaud) – madala süsinikusisaldusega teras (kuni 0,3%), ei ole termiselt järeltöödeldav, nt seda ei saa karastada.

Tiigel – kõrget temperatuuri taluva keraamiline anum metallide sulamamiseks.

Apteekrid ja alkeemikud kasutasid tiigleid reaktiisiooninõuna.


Teras – raua ja süsiniku sulam, kus süsinikusisaldus on 0,3%–2%, mis loob võimaluse materjali omadusi parandavaks termootõttuseks. Teras oli enamasti rauatootmise lõpprooktu, mille saamiseks lisatakse otsetaandatud rauale süsinikku (nt tsementitiitmine), kõrgahjuprotsessiga (kaudne taandamine) saadud malmist see eemaldatav.
Tsementiitimine – rauast või terasest eseme süsinikusisalduse tahtlik töstmine selle kõvaduse suurendamise eesmärgil.
Ääs – metallitööks ehitatud kolle, kus lõõtsa abil kuumutatakse metalli sepištamiseks või valamiseks.
3. MEETODID

3.1. Metallograafiline analüüs


Ristlõigete tegemine on eriti informatiivne terariistade uurimisel, kuna nende puhul on käsitletava ajaperioodi kihilisi tehnikaid ja termotöötlust. Käik toorerra lai teadlikab puhul andsid ristlõikede informatsioonisalt (šlakist puhastamise) ja süsinikusisalduse ühtsuse kohta. Samas on ristlõigete analüüs aeganõudev ja destruktiivne, mis saab infot materjali maagist, toorerra jaoks, eseme valmistustehnoloogist, materjali maast pastust, meistrite oskustest ja materjali mättumise järgse seisundi kohta.

Kõik doktoritöö raames analüüsitud ristlõikede on võetud ja ette valmistatud Tartu Ülikooli arheoloogia laboris.

3.2. Elementanalüüs


Portatiivne spektromeeter on kasulik suure valimi analüüsimiseks, kuid sellel on ka omad piirangud. Võrreldes SEM-EDSiga suunata konkreetse metallioskese peale, vaid see mõõdab umbes 5×3 mm suurust ala. Metallijääkide tuvastamiseks SEM-EDSis on tarvis proov panna vaakumkambrisse, mis seab piirid proovi suurusele, näiteks terved tiiglid sinna tavaliselt ei mahu. Kuid teisalt võimaldab vaakumisse tuvastada ka kergemaid elemente, mida pXRF ei näita. Lisaks võimaldavad SEM-EDSi analüüsiprogrammid kaardista da elemendid jaotumist proovi pinnal ning võimaldavad vaakumis mõõtmine tuvastada ka kergemaid elemente, mida pXRF ei näita. Lisaks võimaldavad SEM-EDSi analüüsiprogrammid kaardistada elemendid jaotumist proovi pinnal. Näiteks saab selle abil välja selgitada, kas metallijäägid on seotud oksiididena tiigli või vormi materjalis ühtlasiselt või moodustavad need suuremaid äratuntavaid metallilisi osakesi (II artikkel, 41–42).


3.3. Fotogramm-meetria

liita ühtseks tervikuks kokku kahe aasta aevandi eri osad (I artikkel). Fotogramm-meetria abil dokumenteeritud ehitusjaanuseid oli hiljem hõlbus üle joonistada mustvalgeteks plaanideks (IV artikkel, jn. 5).

4. ALLIKAD

4.1. Rauatöö

Raua töötlemise eri etappidest jääb maapööre eriilmelisi jääke ja konstruktsioone, mis aitavad iseloomustada teatud paigas toimunud metallitööd. Üldjoontes saab rauatöötlusahela jagada järgmisteks etappideks:

1. Rauslatus
   a. Maagi kogumine
   b. Maagi rõstimine
   c. Õhi miilamine
   d. Ahju ehitamine
   e. Raua sulatamine

2. Rauarikastus
   a. Toorraua sepistamine
   b. Raua voltimine sepakeevisega kangi

3. Sepistamine
   a. Tooriku sepistamine
   b. Sepakeevisega raua ja terase kihtide liitmine
   c. Kaju andmine

4. Termotöötlus
   a. Karastamine
   b. Noolutamine

5. Viimistlus
   a. Lihvimine
   b. Teritamine


edasine töö rauarikastusest termotöötluseni. Ääside arengule on käesolevas töös pühendatud IV artikkel, mis käsitleb lisaks Eesti leidudele ka naabermaade ääse.


Kuigi sepaspšlaki koostis võib olla rauasulatusšlaki omaga väga sarnane, on tema tekkepõhjus täiesti erinev: šlakk moodustub oksüdeerunud rauast, sepaeevituseks vajaminevast liivast ning ääsi voorendusse pärit liivast ja savist (Pleiner 2006, 119). Selline šlakk on enamasti ebaühtlast koostisega ja sisaldab mitmeid kihte, põlenud savi ja muud ääripõhja hangunud materjali. Kui seda pole ääsit eemaldamise käigus ära lõhutud, siis on šlakk samuti poolsfäärilise kujuga ja savist ääsi voorenduse negatiivis kujulis.


4.2. Tiiglid ja valuvormid

Vasesulamite ja väärismetallide valamiseks on tarvis lõõtsaga ohutatavat kollet või ääsi, suurt kuumust taluvat tiiglit, tiigli tõstmise tange ja ettevalmistatud valu-vormi. Kui metallitöötusjääkidega ääse on leitud harva, siis tiiglite katked on tootmispaikadel levinud. Käesolevas töös uuriti 175 rauaegset tiiglit ja valuvormi, mis pärinevad 29 eri muistisel (II artikkel). Analüüsid esemed jaotati dateeringu järgi kolme gruppi: perioodist 500 eKr kuni 599 pKr on tiiglifragmente vaid 4; vahemikust 600–1050 pKr 41; 1051–1227 pKr 61. Ülejäänud katkete dateering ulatus üle mitme perioodi. Valamisvahendeid on leitud kõige
enam linnamägedelt, vähem maalinnadest ja asulakohtadelt ning vaid üksikute leidudega on esindatud erinevat tüüpi matmispaigad (II artikkel, Tabelid 1, A.1 ja A.2). Linnamägede ja maalinnade domineerimine valamisvahendite leiukohtade hulgas on tõenäoliselt uurimisloolise kallutatus – neid lihtsalt on põhjalikult kaevatud kui avasulajad. Ilmselt oli ka avaasulatuse metallivalamine tavaline. Käsitöö koondumist võimukeskustesse on samas täheldatud nii meil kui ka naabermaades (nt Pihkva ja Novgorod).


Rauaaegsetelt muististelt leitud purunenud tiiglite fragmentid ei ole ilmselt kandunud kuigi kaugele oma algsest kasutamise kohast, mistõttu kirjeldavad nad hästi muistisel toimunud metallitööd. Kivist valuvormide puhul, mis on tihti tehtud imporditud kivimitest (Moora 1963, 358), jääb alati võimalus, et neid on vahetatud või ostetud valmis kujul. Haupanustena kaasa pandud valuvormid (nt Arniko käabaskalmistul) on head näited valamisvahenditest, mis pole leiutud eeslinnade tootmispaigast. Samuti on tõenäoline, et matmispaikadesse sattunud tiiglifragmentid on sinna kandunud koos mujalt toodud metallist või Põlga tarandkalme. Matmispaikadest leiutud tiiglid ja valuvormid on küljelt ja lagukski laadi, kuid annavad see-est väärtslikku infot vähesele leidudega perioodile kohta (500 eKr–700 pKr).

13.–17. sajandi tiiglite ja valuvormide käsitlemisel piirdusin Tallinna ja Tartu leinainesega, ent valim on sellegipoolest võrreldav II artiklis käsitletud leidudega. Kokku analüüsisis 96 tiiglit, 27 kivist valuvormi, seitset savi- ja potikilduid, ühte puust ja ühte metallist kahe poolega vormi (V artikkel). Paraku on linnade leinaines, näiteks eeslinnade aladele ladestunud prügi, tihti raskesti dateeritav ja seetõttu on paljude tiiglite kasutusaeg määratud pikemaks, kui see tegelikult oli (V artikkel). Samuti on prügiladestest leitud tiiglifragmentid esimeteid või seda tüüpi seda ühirkatitud leidudega, kuid suure tõenäosusega võib eeslinnade alalt leiutud jäätmest sattuda linnas toimunud käsitööga.

5. METALLITÖÖ RAUAAJAL

7. SAJANDIST 13. SAJANDI ALGUSENI

5.1. Rauatöö

5.1.1. Rauasulatus


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6 https://www.eki.ee/dict/ety/index.cgi?Q=maage (05.05.2019)
7 https://www.eki.ee/dict/ety/index.cgi?Q=teras (05.05.2019)


8 Suuline info, 15.10.2018.
Lohkääside lihtne ehitus teeb nende eristamise majapidamiskolle test keeruliseks. Ülalmainitud Savastvere tiiglid tulid välja samast koldest koos toiduvalmistamisele viitavate leidudega ja tiiglite puudumisel oleks avastus majapidamiskoldeks liigutatud. Lihtne tuleuse võiski samal ajal täita mitut ülesannet, mistõttu on köige olulisem indikaator kolde ümbrusest leitud või puuduvad metallitööjäägid (šlakk, sulanud savi, hangunud metallitilgad, tiiglite ja valu-vormide katked jms).


5.1.3. Sepatöö


1. Madala süsinikusisaldusega tera
2. Tsemelltüüditud tera
3. Sepakeevisega ühendatud raud ja teras
4. Karastatud teras
5. Karastatud ja noolutatud teras
6. Damastseeeritud teramik


Sama saadeti Eestis, Edela-Soomes ja Lätis, kus seppade toodet oli lihtne ja kiire. Samal ajal hakkas seppade toodet levinema hilisrauajal, kus peelistel seppadele kuulusid samal ajal kohalikud õpetusage kaasa adad, kes saadeti teistet eraldistus ja tootmisprotsessi. Sellist on näha Eestis, Edela-Soomes ja Lätis, kus seppade toodet oli lihtne ja kiire.


Kuigi Eestist pole teada surulukkude vasetamisele iseloomulikke savist pätse, õnnestus mul Soontaganama maalinna leidude hulgast tuvastada kaaluvihtide vasetamise jääke. Nende leidude pinnalt tehtud pXRF analüüs9 tuvastas piiliga punapronksi (PäMu 2767: 1241, 1246). Nelja kaaluviht oli vasetamine oli ebaõnnestunud ja neid pole savist katte seest välja võetud (Lisa 6). Tänaseks on kaaluvihtides suured õhuds, kuid vasetamise läbikukkumist võis omal ajal märgata juba seda teinud käsitööline. Need viimased neli on määratlemaks üsna leidud, sest kuigi need on tootmispraak, võib eeldada, et vasetamise tehnoloogi tunti. Seejärel jälki õhtegi vastuväärt, miks ei võinuks hilisraaaaja olla Eestis surulukke tootvaid peeneseppasid, kuid kindlalt saaks seda võida alates lukkude vasetamise jääkide leidmisest.


9 Leide analüüsid TÜ arheoloogia labori pXRF-iga Bruker Tracer III-SD. Mõõdeti kaaluvihi pinda seda eelnevalt töötlemata. Mõõtised toimused seadetega: 40 kV, 10,7 µA, 60 sek, koile ühine filter (305 µm Al + 25µm Ti).


Kokkuvõttel võib rauatöös täheledata muutusi 11.–12. sajandile jooksul, kui intensiivistus kohalik rauatoomine nii Eesti alal kui ka naabermaades. See tegi
raua kahlemata senisest kättesaatavamaks ja soodustas kohaliku sepatöö arengut, mille üks väljendus oli näiteks sõjanugade asendumine mõõkadega ja viskedoade massiline levik. Rauatöö kõrgsaavutusteks muutusid damastseeritud tera ja hõbedaga kaunistatud odaotsad.

5.2. Värviliste ja väärimetallide töölemine

5.2.1. Valukojad, tooraine ja töörliistad


**Tabel 1. XRF analüüs Eesti vasesulamikangidest**

<table>
<thead>
<tr>
<th>Objekt</th>
<th>Cu</th>
<th>Zn</th>
<th>Pb</th>
<th>Sb</th>
<th>Fe</th>
<th>Ag</th>
<th>Bi</th>
<th>As</th>
<th>Sn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedassaare 1</td>
<td>81,4%</td>
<td>4,0%</td>
<td>4,9%</td>
<td>0,5%</td>
<td>8,0%</td>
<td>0,5%</td>
<td>0,8%</td>
<td>0,0%</td>
<td>0,0%</td>
</tr>
<tr>
<td>Pedassaare 2</td>
<td>94,5%</td>
<td>2,8%</td>
<td>1,3%</td>
<td>0,3%</td>
<td>0,2%</td>
<td>0,3%</td>
<td>0,5%</td>
<td>0,0%</td>
<td>0,0%</td>
</tr>
<tr>
<td>Pedassaare 3</td>
<td>96,9%</td>
<td>1,7%</td>
<td>0,8%</td>
<td>0,2%</td>
<td>0,1%</td>
<td>0,3%</td>
<td>0,0%</td>
<td>0,0%</td>
<td>0,0%</td>
</tr>
<tr>
<td>Pedassaare 4</td>
<td>92,6%</td>
<td>3,5%</td>
<td>2,3%</td>
<td>0,3%</td>
<td>0,3%</td>
<td>0,4%</td>
<td>0,7%</td>
<td>0,0%</td>
<td>0,0%</td>
</tr>
<tr>
<td>Pedassaare 5</td>
<td>92,3%</td>
<td>3,5%</td>
<td>2,2%</td>
<td>0,3%</td>
<td>1,0%</td>
<td>0,3%</td>
<td>0,5%</td>
<td>0,0%</td>
<td>0,0%</td>
</tr>
<tr>
<td>Rõuge kang</td>
<td>81,1%</td>
<td>11,2%</td>
<td>4,1%</td>
<td>0,2%</td>
<td>0,7%</td>
<td>0,2%</td>
<td>0,0%</td>
<td>1,1%</td>
<td>1,4%</td>
</tr>
</tbody>
</table>


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10 Kange analüüsiti TÜ arheoloogia labori pXRF-iga Bruker Tracer III-SD. Kangide korrodeerunud pindu ei lihvitud, mis vähendab mõõtmiste täpsust. Tulemused kalibreeriti tehasekalibritest CU1 abil, mõõtmised toimisid seadetega: 40 kV, 10,7 µA, 30 sek, kollane filter (305 µm Al + 25µm Ti).
Vasesulamite ja väärismetallide valamisega seotud leidude hulgad domineerivad tiiglikatked, samas kui savist valuvormid on täiesti puudu. Kuna nooremast pronskaiaastast on säilinud sadu valuvormide katkeid, siis peab raauaegete valuvormide puudumist seletama muutusega savimassiga koostises, nende põletuses või valamisjärgses tegevuses. See võib olla ka kõige kolme teguri koosmõju. Näiteks savimassi koostis võis olla varasemast palju suurema liivisaldisega, vormid ise nõrgema põletusega ja tekkis vajadus neid lõhkuva palju väiksemateks tükideks – suures osas pronskaiaegsetest valuvormidest valati lihsataid röngaid, mille sai vormist kergesti käte. Taolise kehva säilivusastmaga vorme on ilmselt väga raske arheoloogidel ära tunda, eriti kui vormid pudisevad näppude vahel või sõelal tükideks (II artikkel, 45).

Tuuli Kurisoo, kes uuris noorema rauaaja ripatseid Eestis ja liivlaste aladel, leiab, et vasesulamist ripatsite tootmiseks kasutati üsna lihtsaid tehnikaid (2018). Enamik ripatsitest on suhteliselt lihtsad ja nende puhul piisas vaid märja savi sisse pressitud kujutist; vaid keerulisena kujundusega ehted tehti kadunud vaha tehnikas (Kurisoo 2018, 179). Savist vormide massilisese tarvitamisele viitab ka teatud seeria ripatsite üldise kuju sarnasus koos väikeste erin evustega, mis saab tekkida siis, kui ühtne emamudelit on kasutatud korduvalt (ibid.).


Unipiha linnamäe kõrval asuva asulakoha kaevandist pärineb Eesti suurim tiiglikatke kogu, mis sisaldab ligikaudu 600 fragmenti (Aun 1992, 55). Unipihal tiiglid on dateeritud 8.–10. sajandisse (Tõnisson 2008, 300) ning on samuti ümara põhja ja ümmarge või kolmnurkke suudmega. Lisaks on nende hulgas esindatud ka haruldaseheneva suudmega pirnikujuline tiiglivorm, mida on leitud veel Soontagana maalinnast (II artikkel, jn. 3).


5.2.2. Tina, plii ja putteri valamine


Kivist valuvormidega valati peamiselt ripatseid ning tekstiilide ja nahale kinnitatavaid tinulisi, millega enamik vajab kahets poolest koosnevad vormid. Eelvikingi- ja viikingajal olid kasutusel ümmargused kodaratega tinulised ja geometrilise mustriga nelinurksed tinulised (Keeman 2017). 11.–13. sajandi lisanudvad eelnimetatud silmusnelinurjaga tinulised (ibid.). Kuna tina säilib tava – tingimustel väga halvasti, siis on meiene jõudnud ainult väike osa kunagi kasutuses olud ehetest ja tinulistest: näiteks võib Lõhavere linnamäe ühel kivivormil näha vähemalt kolme siiani tundmatu eseme kujutist (II artikkel, jn. 4: 1). Tinuliste tagumisel poolel oli tavaliselt riidele õmblemiseks kaks aasta, mis saadi

Ma nõustun Moora põhiliste järeldustega: kivist valuvorme ja valamiskulpe kasutati tina või tinasulamite valuks; suur osa valuvormide jaoks kasutatavaid kivimeid toodi väljastpoolt Eestit ning et tinst esemeid valati ja kanti riitel ilmselt märkimisväärselt rohkem, kui arheoloogilises aines säilinud on (Moora 1963). Täpsustusena tuleks märkida, et osas valuvormides valati ka hõbedat ja vasesulameid (II artikkel), kuid see näib olevat olevat võrreldes tina valamisega märksa vähem levinud praktika.


5.2.3. Metallitöölised


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Moora väitis, et Baltimaades töötasid nooremal rauaajal sepaad onemasti ka pronksivalajatena ja ühtlasi valmistatud mõned sepaad ka hõbeeheteid (1966, 125). Moora väite põhjal on tühjatest valjatud juures, et siiamiAnime pole ühtegi hästi säilinud töökoda. Unipiha linna kõrval asetsev töökoda võis olla, kuid see ei olnud ainult metallivaluga tegelemiseks. Väikesed sepaad oskasid sellest vähe, et nende töövõimalused selle suhtes olid kindlalt vähem.


Samas on Eestis täiesti puudu tõendid teatud esemeliikide tootmisest nagu suured tinast lauanõud ja tehnoloogilistest võtetest nagu metalli ilma tiigli otse sulatusahjust vormi valamine, mida kasutati suurte esemete valmistamisel (nt kirikukellad). Neid tehnikaid on detailset kirjeldatud 12. sajandi esimese poolde dateeritud allikas De diversis artibus, mis sisaldab praktilisi öpetusi metallitoöst, maalimisest ja vitraažide tegemisest (Hawthorne, Smith 1979).
Joonis 1. Metallijäägid rauaegsetest tiiglitest, valamiskulpidest ja valu vormidest jaga-tuna kahe perioodi vahel: 600–1050 a pKr (n=42) ja 1051–1227 pKr (n=61) (II artikli järgi).


Kuna tinavalamine on tehniliselt üsna lihtne, siis said vasesulamite ja väärismetallide töötlemise lihtsuse vastu tõsta toodud metalli, samuti oli mitmel juhul ka kivivormide materjal imporditud. Mitmete leitud valuurmehed pinnad on maksimaalselt ära

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kasutatud, mis viitab sellele, et heade omadustega vormikivi oli kõrgelt hinnatud. Tinavalamise kulpide ja valuformide leiukontekstid on sarnased hõbeda-
valamisele ning esinevad eelkõige käsitöökeskustes, nagu linnamäed ja maalinnad. Ilmselt oli tegemist käsitööharuga, mida praktiseerisid ehtesepad, aga ka näiteks tekstiilide ja nende juurde mõeldud kaunistuste tootmisega seotud käsitöölised.

Kokkuvõttes võib öelda, et ehkki arheoloogilises aines kes esinevad sepikojad, siis rangelt metallivaluks ehitatud kolded puuduvad. Vasesulamite valu on esindatud nii asulate kui ka linnamägede ja maalinnade aines seas, samas kui hõbeda- ja tinavalamine koondus voidi viimastesse. Mõningad leid, nagu Soon-tagana maalinna kaaluvihide vasetamispraak ja suur hõbedajääkidega tiiglite osakaal Otepää linnamäel, torkavad Eesti kontekstis erandlike nähtustena silma ja ilmselt oli võõmukeskuste jaures võimalik spetsialiseeruda ka teatud eseme-
rühma tootmisele. Samas on puudu kullassepatoole, peensepisele ja müntimisele iseloomulikud leid, mis näitavad madalama metallitöö spetsialiseerumise astet võrreldes selliste naabermaade käsitöökeskustega nagu Sigtuna ja Novgorod.
6. METALLITÖÖ 13.–17. SAJANDIL

6.1. Rauatöö

6.1.1. Kõrgahjud ja osmund


12. sajandil võeti kasutusele esimesed varased kõrgahjud, ent laiemalt levis see tehnoloogia Rootsis, Saksamaal ja Itaalias alles 13. sajandil (ibid., 226). Buchwald järgi tõi kaudne rauataandamine ja kõrgahjud kaasa järgmised muudatused (ibid., 228):
1. paljud rauasulatusöökojad kolisid voolava vee äärde, kus oli võimalik kasutada veejõul töötavaid suuri lõõtsi ja raskeid vasaraid;
2. ehitati püsivad kivist rauaasulatusahjud (otsetaandamisel olid ahjud tihti ajutised);
3. toimus mangaanirohkete ja fosforivaeste mäemaakide kasutuselevõtt;
4. küütusena kasutati vaid puusütt (otsetaandamisel kasutati ka turvast).

Kaudse taandamise puhul oli esimene samm samuti maagi rõstininge, kuid teises etapis toimunud rauasulatus andis tulemusena vedela toormalmi ja madala rauasulatusega šlaki (ibid.). Kolmandas etapis vähendati koldes oksüdeerimise teel toormalmi süsiniksisaldust nii, et järele jäi vähese süsiniksisaldusega raud (ibid., 229). Kaudsel meetodil oli rauda odavam olguvada ning see oli ühtlasi ja pultama koostisega kui otsetaandamise teel toodetud raud, mistõttu sisenes ta mitmes pikrammas turule tõsisel konkurendina kohalikele rauaottajatele.


1) Kaudse tõendina on Saksamaalt 1010. aastast teada kohanimi Schmidtmühlen, kuid seda sepikoda või rauasulatusöödus pole arheoloogiliselt uuritud (Buchwald 2008, 211).


6.1.2. Kohaliku rauasulatuse lõpp

linnades üha enam võimu tsunfšid (vt IV artikkel), mis võisid olla huvitatud standardsema raua hankimisest, kui kohalikud rauatootjad pakkuda suutsid.

Käku sepikojast leitud toorraua kangi tekitasid siiski mõned kõrvalmised kohaliku rauasulatuse jätkimises 15.–17. sajandil. Kuna Eestist pole leitud rauasulatustohti, mis oleks hilisemad 15. sajandi alguses, siis võib Käku 15.–17. sajandi kihistustest pärit toorraua kange tõlgendada kolmel erineval moel (III artikkel, 55–56):
1. toorraua kangi pärinevad tegelikult 14. sajandist või 15. sajandi alguses ja on hilisematesse kihistustesse sattunud sepikojas tehtud muutuseid, mida ühtlaselt sõese pinnase tõttu oli võimatu tuvastada;
2. toorrauda tootsid Eesti kohalikud rauasulatjad 15.–17. sajandil, kuid seni pole önnestunud nii hiliseid rauasulatuskohti üles leida;
3. toorraud on imporditud Skandinaaviast või Soomest.

Esimest varianti annab tulevikus kinnitada või ümber lükata rauakangidest tehtava radiosüsiniku dateeringuga. Kui kohalik rauasulatus aga jätkus Eestis 15.–17. sajandil, siis oleks eelkõige vaja avastada sellese perioodi dateeritud rauasulatustohti. Kolmas variant on meie praeguste teadmiste juures siiski tõenäolisem, kuna otsetaandamise teel toodeti rauda üsna laial alal 17. sajandini.

Hea pidepunkti otsetaandamise lõppemiseks Läänemere regioonis annab rauarikastuslakkide kadumine Taanis, Norras, Rootsis ja Soomes 1600. aasta paikul. Kuna kohalik rauasulatus aga jätkus Eestis 15.–17. sajandil, siis võib kõrvalmised jätta üsna laial alal 17. sajandini.

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1. korduvkasutatav ahi, millel ei lastud vahepeal maha jahtuda;
2. küttepuude kasutamine puusöe asemel protsessi alguses;
3. toorravaa kompaksemaks pressimine ahjusüü kaudu enne selle ahjust välja-
võtmist.

Protsessi kasumlikkus võis olla põhjuseks, miks otsetaandamise traditsioon Root-
sis nii vord pikalt püsis. Lisaks ei sobi mitte kõik maagid kõrgahjudes taanda-
miseks – näiteks Soome järveaegad, mis sisaldavad palju fosforit, andsid otsetaandamisel hea kvaliteediga raua (fosfor jääb šlaki sisse), kuid kõrgahjus läheb fosfor malmi koostisesse, kust te ada saadud ra fluorimisel kätte (Buch-
wald 2008, 68). Seega oli otsetaandamine mõnel pool looduslikest oludest tule-
nev paratamatus.

6.1.3. Sepikojad

13.–14. sajandi jooksul jõudsid koos sisserännanud käsitööliste ja munkadega
Eestisse mitmed tehnoloogilised uuendused, mis väljendusid ka sepikodade üles-
ehituse. Riia lähened olis vesiveski olemas juba 1220. aastatel, Saare-Lääne
piiskopkonnas 1238. aastal ja Jägala jõel Koilas hiljemalt 1241. aastal (EA II
2012, 189). Euroopa kõige varasem arheoloogiliselt uuritud veejõul töötav sepiki-
doda pärineb 12. sajandi lõpu ja see töötas tänapeeva Edela-Rootsis paikneva
Hallandis (Buchwald 2008, 9). 13. sajandist on üksikud teated veejõul töötavat
sepikodades, mis muutuvad sagedasemaks 14. sajandil (Pleiner 2006, 238). Sepi-
kojas aitas veejõul töötav haamer suurendada töötõlkust märkimisväärsest: 13. sajandi Dalarna sepad tootsid vee jõuta umbes 2–3 korda vähem vikateid nädalas
kui Austrias vee abil töötavad sepad, seejuures peeti mõlemaid oskustikeks
väikesepadeks (Buchwald 2008, 193). Minule teadaolevalt on Eesti alal vara-
seim näide veejõul kasutamisest metallitoöö turviseopp Wilm Platenslegeri raja-
tud vaseveski, mis töötas Härjapea jõel12 1531.–1662. aastal (Kaplinski 1995, 25;
Lavi 1998, 224). Vasepada esineb Härjapea jõel ka 1688. aasta kaardil ning seal
sulatati, valati ja taoti katuseplekki ning erinevaid sööginõus erinevaid (Kaplinski 1995,
25). Kuigi 13.–15. sajandist ühtegi veejõul töötavat sepitöökoda Eestist leitud ei
ole, on tõenäoline, et neid tunti ja kasutati ka sellel perioodil.

Lossi 3 krundi kaevandist Tartus leiti mitu keskaegset sepikoda, millest pole
kull plaane, aga neid on kaevamiste dokumentatsioonis kirjeldatud. Eismeli oli
meetri jagu maaasse sünditud postkonstruktsioonis hoone, mille puuplankudest
põrand oli saviga määritud (Metsallik 1992, 154). Metsallik mainib ka pörand-
tasapinnast 150 cm kõrgusel asuvat ääsi, kuid paraku ei täpsusta sa selle
ehitust (ibid.). Kuna sepikoda on korduvalt põlenud, siis ilmselt oli säilinud ääsi-
ase tegelikkuses olnud seotud hoopis kõrgemat asuva põrandanivooga, kuna 1,5
m kõrgune aäsisasapid ei ole ergonoomiline kõrgus tööks. Sepikojast leiti ka üks
suur kivi, mida Metsallik tõlgendab alasikivina (ibid.).

12 Tänapeaval asub see Tallinnas, Masina tn 6 krundil.


Kaevamiste käigus tuvastati Käkus neli sepikoda, millest kolm varasemat olid vundamendita rõhtpalkhooned ning kõige hilisem kividest vundamendiga ja ilmselt samuti rõhtpalkkondel hoone (Peets et al. 2013; I artikkel). Sepikodade põhiplaan on kõikidel sarnane, kuna loodeseina keskel paiknevad ääsalust kasutatud kõikide hoone puhul (IV artikkel, jn. 5). Kuigi ühtub uste pole säilinud, siis 2. ja 3. sepikoda lävepakukivide ning suuremate šlakihunnikute järgi on tõenäoline, et uks paiknes hoone edelaküljes. Kõige varasema sepikojaga nr 4 puhul oli see samade tunnuste alusel ilmselt kõrgeim. Seega tehti teks eelkõige sepikojad pärast põhja poole põrandast, mis kõrge hoonest sepikojas valmistatud laevastikust vundamenditä juhtis. 4. ja 3. sepikoda (ja võib-olla ka 2. sepikoda) põrandad olid kividest vooderdatud veesilm, mis kõige viimase sepikojaga (nr 1) ajaks oli ära täidetud. Taolist vooderdatud veesilm kohtab juba Rooma perioodil Britannias, aga ka viikingiajal Islandil ja 16. sajandist Austrias hõbedase tudelise mõõtalkaudse sepikoda (Pleiner 2006, jn. 57, jn. 61, jn. 63). Lisaks rautati sepikoda ees hobuseid, mille puhul võite veel sulatada rajalakaelded.

Käku kõige varasem (14.–15. saj) sepikoda (nr 4) ehitati sillutatud põrandaja suure tõstetud ääsiga (I artikkel, 195). Kui vaadata kronoloogiliselt Käku erinevaid sepikosaid, siis võib iseigi kõnelda teatavast taandarengust – kui kõige varasem 14.–15. sajandi järk oli 43 m² suurune ja sillutatud põrandaga, siis kõige hilisema 16.–17. sajandi sepikoda (nr 1) suurus oli vaid 26 m² ning sellel oli muldpõrand (Peets et al. 2013, 97; I artikkel, 195). See võib viidata tootmisteguvuse vähenemisele, mille põhjustas kohaliku rauasulatuse lõpp ja rauarikastamise kui ühe sissetulekuallika kadumise.

6.1.4. Sepatöö


Mingil põhjusel on Käku sepikotta maha jäänud ka parema kvaliteediga toorraua ja kangide tükkne. Nende puhul ei ole võimalik välja tuua selget põhjust, miksi see raud peaks olema kõrvale praagitud. Tegemist võib olla sepikoda mitme põlengu ajal töökojas varuks olnud toormaterjaliga, mida hiljem sepikoda rusede

50


6.2. Värviliste ja väärismetallide töötlemine

6.2.1. Metallitöölised

13. sajandi vallutustele eelnestav periodist puuduvad metallitööd puudutavad kirjalikud allikad ja vastust kõikidele küsimustele tuleb otsida arheoloogiast. Alates keskajast olukord muutub ja hästi säilinud Tallinna linnaarhiivi töö võime kõneleda üsna hästi dokumenteeritud arengust seoses linnas töötavate metallitööliste hierarhia, spetsialiseerumise ja kutselise organiseerumiga. Siiski ei saa kirjalike allikate alusel kuigi hästi hinnata käsitööliste taset ja samuti ei


säilinud üsna arvukalt 16. sajandi II poolde ja 17. sajandi algusse dateeritavaid aardeid.

6.2.2. Tooraine, tiiglid ja valukojad


Joonis 2. Metallijäägid 13.–17. sajandi tiiglitest (n=96) (V artikkel, tabel 1 järgi).

Kaks näidet olid ka puhta kullal valamisest, mis pole üllatav arvestades kullaseppade sagedast esinemist kirjalikes allikates. Esimene tulemus saadi Tartu Riia eeslinna ala tehit kolmnurkse suudmega Hesseni tiigli katkest. Teine näide
põrines Tallinna Harju värava eeslinna alalt ja oli samuti ilmselt Hesseni tiigel. Samas esines kõikide analüüsitud esemete seas ka tiigleid, kus kuulda oli koos hõbeda ja vasesulamitega, mis näitab ilmselt eelkõige erinevate meistrite eelistusi tiiglite valikut värismetallidega töötamisel (V artikkel).


13.–14. sajandist on kasutusel eri koostise ja välisilmele importtiiglites. Levinud tüüp on suhteliselt madal, laia lamedat põhja ja ümara suudmega tiigel (V artikkel). Suudmel oli ilmselt ka tiga, aga paraku pole säilinud mitte ühtegi terviklikku eksempleri, kus see näha oleks. Tiiglite murdepinnana järgi on neid valmistatud väheimalt kolmel erineval viisil: 1) valgest või helehallist savist tiiglid; 2) põletamisel osaliselt või täielikult kokkusulatud hallist savist tiiglid; 3) läikiva murdepinnaga suure graafidesisaldusega tumedast savist tiiglid.


Ulaltoodud arvenimistus mainitud linna marstalli juures toimunud kaevamistelt leiutati suurte tiiglite abil tuginevaid kellale valamistest. Selleks kasutatavad tiiglid piidid oema lisaks kuumakindlusele ka mehaaniliselt vastupidavaks, sest metall on raske. Tallinna leiutatud hulgas on mõned grafiittitiiglid, mis võiks selliste esemete valamiseks sobida, kuid paraku on need kõik ilma selge kontekstita juhuleid (V artikkel). Elementanalüüsi käigus on tavaliselt tiiglide kasutamisest edukaid tulemusi, kuid ahjule omistatavaid esemid siiani ära põletada. Tiiglute kasutamine jääb üheks põhjusena, et sulapronksi abil seostust vahele jääb.


6.2.3. Tina, plii ja putteri valamine

Nooremal rauaajal oli madala sulamistemperatuuridega metallide valu levinud ning sellega seotud kivivormide ja valamiskulpidate leide on teada pea kõikidel ulatuslikumalt kaevatud linnamägedelt ja maalinnadest (II artikkel). Seega sai 13. sajandil Kesk-Euroopas suure hoo sisse saanud tinavalu siissetel aladel kokku juba sajandeid eksisteerinud traditsiooniga (V artikkel). Tallinna ja Tartu leiutainese põhjal võib öelda, et Saksamaal kasutusele võetud innovatsioonid kivist valuvormide tegemisel (näiteks kanalid gaaside ärajuhtimiseks) jõudsid ilmselt tänä välismaistele meistriletele hiljemalt 13. sajandi II poolel ka Eesti ala linna-

desse (V artikkel). Lisaks muutusid kivivormid varasemast keerukamaks ning seniste kahepoolsete kõrvaliste ilmusid ka vähemalt kolmeosalised vormid nõöpide ja sõrmuste valamiseks. Savist valamiskulbid, mis olid praetuliselt muutumatu
del kujul kasutuses hiljemalt 8. sajandist kuni 13. sajandini esinevad veerandide, kivid
sajandil Kesk-Euroopas suure hoo sisse saanud tinavalu siissetel aladel kokku juba sajandeid eksisteerinud traditsiooniga (V artikkel). Tallinna ja Tartu leiutainese põhjal võib öelda, et Saksamaal kasutusele võetud innovatsioonid kivist valuvormide tegemisel (näiteks kanalid gaaside ärajuhtimiseks) jõudsid ilmselt tänä välismaistele meistriletele hiljemalt 13. sajandi II poolel ka Eesti ala linna-
desse (V artikkel). Lisaks muutusid kivivormid varasemast keerukamaks ning seniste kahepoolsete kõrvaliste ilmusid ka vähemalt kolmeosalised vormid nõöpide ja sõrmuste valamiseks. Savist valamiskulbid, mis olid praktiliselt muutumatu kulutusel 8. sajandist kuni 13. sajandini esinevad veerandide, kivid

Tähelepanuväärse leiurühma moodustavad sööginõusid meenutavad kausi, mis sisaldavad pliisulatusjääke (V artikkel). Tallinnast on neid leitud nii linna-
müüri piiravalt, mis ka eeslinnade alal, seega oli tegemist mitte ainult juhuslikku laadi kasutusega. Kausisulav plii on suure oksüdeeruva pinnaga, misliítöö ei ole
tegemist kõige otstarbekama vahendiga plii valamiseks. Kausi positiivne külg on
tselle suur mahutavus – näiteks kui oli käsil aknaraamideks kasutatava plii või
muu suure mahuga esemeliigi ümbersulatus.

Kivivormidesse valamise traditsioon on olund märkimisväärselt püsiv. Tinu-
listate tagumiste poolte aasadega valuvormide tükid Rõuge (Keeman 2017, 69) ja
Lõhavere rauaasetsed linnamägededelt (II artikkel, jn. 4: 8) on väga sarnased. Tallinnast Kalamajast (Jahu tn 6) leitud ja ilmselt 15. sajandist pärit pliisulatusulise
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muu suure mahuga esemeliigi ümbersulatus.
Proovivalamisi on tehtud ka teiste ajalooliste kivivormidega (näiteks vormiga AI 4061: 2333).


Käesolevas uurimistöös tegelesin Eesti aladel avastatud 7.–17. sajandi metallitöö paikade harule – esiteks rauasulatamine ja -tüütmine ning teiseks värviliste metallide valamine. Minu panus seisnes eelkõige arheoloogiliste leidude põhjal tehnoloogiliste ja toorainetega seotud küsimustele vastamises, mille puhul olid abiks nii loodudeaduslikud analüüsid (spektromeetria ja metallograafilised analüüsid) kui ka digitaalsed dokumenteerimusmeetodid. Töö ajalised raamid võimaldasid vaadelda metallitöötlemisega seotud käsitöö üldist arengut pika aegusse aastapereandina ja analüüsida toimunud muutusi ja mõjutusi seoses ühis-kondlike protsessidega.


Kivist valuvormid ja valamiskulbid on seotud madala sulamistemperatuuriga metallide valamisega. Analüüsitud esemed sisaldasid ülistöö näiteks tina ja putteri jääke. Valuvormid ja -kulbid esinevad samuti kõige sagedamini linnustel, mis tähendab, et tina valati üldiselt samades kohtades kus hõbedat. Tinavalamise vähendeid pandi kaasa ka hauapanustena, mida ei saa tõlgendada tootmispaigana.


nii selgelt koodunud linnamägedele, siis 13. sajandi vallutussõda ja uute käsitöökeskuste teke linnades avaldas sepatööle vähem või vähemalt aeglasemat mõju kui metallivaluade.


Töös keskendusin rohkem Käku sepikoja Saaremaal, mis häsitisäinud kompleksina on tunduvalt rikastanud meie arusaamu maal tegutsenud sepatöölistest keskaegas. Käku sepikoda kasutati 14.–17. sajandil ja seal toimetamas mitu päevikonda seppasid, kes töötasid ääsimaks poliitilistest ja majanduslikes oludes. See väljendus ka neile kättesaadavate tööliste sepetamiseks ja kvaliteedis. Sepikoja leiutised seispina seas on seetõttu tõstetud meie arusaamu maal tegutsenud sepatööliste ja Majanduslike oludes. See väljendus ka neile kättesaadavate tööliste sepetamiseks ja kvaliteedis. Sepikoja leiutised seispina seas on seetõttu tõstetud meie arusaamu maal tegutsenud sepatööliste ja Majanduslike oludes. See väljendus ka neile kättesaadavate tööliste sepetamiseks ja kvaliteedis.
METALWORKING SITES IN ESTONIA DURING THE 7TH–17TH CENTURIES

1. INTRODUCTION

1.1. Research questions

The question “why study past metalworking” can be answered in several ways. During the Bronze Age the demand for tin in bronze alloy production, changed tin into a strategic resource, much like petroleum is today. Furthermore, the spread of iron smelting made better quality tools and weapons more readily available, which in turn facilitated better agriculture, ship building, woodworking, and other crafts. The overall state of archaeometallurgical research is uneven for Estonia and Europe as a whole. There are many gaps in our knowledge about past metalworking in Estonia and this thesis fills some of them. The principle data sources for this thesis are archaeological in nature, to which I applied traditional archaeological approaches coupled with methods usually reserved to the material sciences. Archaeology provides two main sources for archaeometallurgical research: firstly, there are metalworking sites with tools, raw material and production waste; and secondly there are the finished artefacts themselves, which number many hundreds of thousands in the archaeological collections. The current research concentrates on the first source of finds and is able to answer questions like “where are the production sites”, “what tools were used”, and “what raw material was available.”

The main goal of this thesis is to provide new information on Estonian metalworking between the 7th–17th centuries. My original contribution focuses on the study of metalworking sites and production waste. The approach involves archaeological, instrumental and digital analysis techniques and when these results are coupled with earlier research on finished artefacts, a more refined picture emerges of the level of specialisation that characterises Estonian metalworkers. A different approach is used to study ferrous and non-ferrous metal working as they leave behind different production waste. It is common to find small pieces of scrap iron from smithies, as welding them together wastes time and resources. Conversely finding scrap metal from casting sites is rare, as pieces of non-ferrous metals, however small, are easy to remelt in the crucible. At the same time, fragments of casting tools such as crucibles, and to a lesser extent stone casting moulds, are quite common as they were not generally reused. Blacksmith’s tools such as tongs and hammers are quite rare finds, as they did not break as often as crucibles and the iron they were made of was easy to reuse or repair. Also, forging tools are difficult to date, because even the tools used by the ancient celts can be confused with ethnographic or even modern equivalents (Peets 2008, 133–134).

One hypothesis in this thesis is that after the 13th century crusade society started to change significantly, which in turn impacted local metalworking and
these developments can be traced in the archaeological record. In order to test this idea, metalworking from the pre-crusade period\textsuperscript{15} needed to be studied in detail. Crucibles and casting moulds have been found in greater number on archaeological sites dating to the 7\textsuperscript{th} century CE onward, hence this also became the starting point for my research. However, there are no well-preserved smithies from Estonia older than the 11\textsuperscript{th} century. As several of these well researched smithies and casting related finds were dated towards the beginning of the Great Northern War in the early 18\textsuperscript{th} century, it also became a natural end date for my research. The Great Northern War witnessed a catastrophic decline in population, which clearly took its toll on local metalworkers. The metalworking from the 18\textsuperscript{th} and 19\textsuperscript{th} centuries also deserves the attention of future researchers, especially those who can interpret the written and ethnographic sources. But this is beyond the scope of my thesis.

To study the working conditions of past blacksmiths, I looked at the smithies of the 11\textsuperscript{th}–17\textsuperscript{th} century (\textbf{Article IV}). Since well-preserved smithies are rare, analogues from Sweden, Finland and Russia were also included. Emphasis was placed on the forge construction, as there is a technological shift from ground level forges to raised forges during this period. The main research questions of this study were:

- Was the adoption of large rectangular stone forges (instead of pit forges) in Livonia in the 13\textsuperscript{th} century connected with the immigration of western smiths into the newly founded towns?
- Why was this new forge type adopted?

The 14\textsuperscript{th}–17\textsuperscript{th} century smithy site of Käku is one of the best preserved rural smithies in Estonia and it was utilised as a case study. I excavated it with Jüri Peets (\textbf{Article I}; Peets \textit{et al.} 2013) between 2012–2014. In addition to the smithy’s construction remains, there was a lot of production waste present and a selection of the iron blooms and bars were analysed metallographically (\textbf{Article III}). In these articles, answers to the following questions were sought:

- What was the layout of the smithy at Käku and how did it change over time?
- What was produced at the smithy?
- What kind of raw material was available to the smiths and how it was processed?

\textsuperscript{15} The chronology of Iron Age in Estonia (Tvauri 2012, 17):
500 BCE – 50 CE Pre-Roman Iron Age;
50–450 Roman Iron Age;
450–550 Migration Period;
550–800 Pre-Viking Age;
800–1050 Viking Age;
1050–1227 Final Iron Age.
Casting sites in Estonia are less well defined in the archaeological record compared to smithy sites, and in most cases casting related finds are unearthed alongside contemporary trash. Hence, crucibles, casting ladles and moulds were chosen for the main source material for the study. Most of the casting related finds date from the 7th to early 13th century, which I subsequently analysed to determine their residues (Article II). The finds originate from hillforts, settlements, strongholds, and burial sites. Because of which the main monument types for this period were included in the study. The article answered the following questions:

- What kinds of casting tools were used, where and when?
- Which alloys were cast with these tools?
- Are there connections between the type of site, the tools used, and the alloys cast?
- How do the results compare to those in neighbouring countries?

The 13th century crusade brought changes to local casting sites, which mainly manifested in their relocation from hillforts to the newly founded towns. Hence, in order to study 13th–17th century casting, the crucibles and casting moulds from two of the largest medieval and Early Modern towns, Tallinn and Tartu, were chosen for the investigation (Article V). The study asked the following questions:

- What changes took place in casting technology in Estonia after the 13th century crusades?
- Which casting tools and alloys were used between the 13th and 17th centuries?
- And how do the results compare to other countries in the Baltic Sea region?

1.2. Previous archaeometallurgical research

Modern day metallurgy is defined as a branch of technology and industry. A fundamental part of this includes the study of the extracting and metal processing methods and subsequently their alloys. Ronald F. Tylecote proposed that up until the 18th century, metallurgy was confined to the practice of smelting, casting and processing of metals (2002, xi), without the study of their properties. However, Marcos Martinón-Torres and Thilo Rehren suggest that this way of thinking might be a legacy from the Age of Enlightenment, when early encyclopedists like Denis Diderot connected the previous periods to alchemy (Martinón-Torres, Rehren 2005, 17). Prior to the 18th century, the terms alchemy and chemistry were used as synonyms, and the preference for either seems to have been up to the individual author (ibid.). The best example for this “confusion” is the work from 1597 by Andreas Libavus called *Alchemia*, which is considered to be the first handbook on chemistry, particularly because it does not mention the mystical art of metal transmutation (ibid.). The early 12th century handbook *De diversis artibus* by Theophilus (Hawthorne, Smith 1979) and other works from the 16th century like Georg Andreas Agricola’s *De re metallica* (Hoover, Hoover 1950) and *Pirotechnia* by Vannoccio Biringuccio (Smith,
Gnudi 1990) can be considered in a similar light. They were the scientific literature for the scholars of the time.

The laboratory (or workshop) found in Oberstockstall Austria, contains waste from the second half of the 16th century. This evidence from this waste points to systematic chemical operations taking place (Martinón-Torres, Rehren 2005, 17), hence it can be suggested that the properties of metals were already being studied in a scientific manner by the 16th century. As testing vessels also exist from the medieval period (Bayley 1992, 6), the separation of metallurgy into purely practical or scientific activities, seems unreasonable. This is because the archaeological finds frequently cannot tell us if they were used in scientific experiments or just for routine assaying.

We do however know more about the time when archaeometallurgy (the study of past metalworking) began. The Czech archaeometallurgist Radomír Pleiner provides an overview of the study of iron working: from the late 19th century up until the mid-20th century there were numerous metalworking publications but these were mainly regional studies, making it difficult to draw conclusions on a wider European scale (Pleiner 2000, 1). After World War II, scientists working in the metallurgy field started to show an interest in archaeometallurgy. Subsequently they brought their modern methods of materials analysis with them (ibid.). Although trained as an archaeologist, Pleiner also belonged to this scientific group, from which he left a legacy of 12 books and more than 250 articles (Crew, Hošek 2015, 1). Pleiner managed to concentrate his life’s work into two monographs concerning early European iron smelting and blacksmithing (2000; 2006). The information gathered about smithy sites dating between the 8th century BCE and 16th century CE is especially useful for my thesis (Pleiner 2006, 135–183), particularly because this topic is rarely written about.

Of the countries bordering Estonia, the metalworking in Russia has had the most attention. The monograph by Boris Kolchin on Old Russian iron working (1953), then also Aleksis Anteins for Latvia (1976), and Mihhail Gurin for Belarus (1982; 1987), are examples of USSR scientific research of the time. Kolchin started to analyse very many samples, which was easier to do in the Soviet sphere, than in Western Europe. To this day, the metallographic analyses from thousands of tools and weapons provide a valuable data source for research. In the 1970’s this method was applied to Estonian finds when pattern welded spearheads and seaxes were analysed metallographically (Selirand 1975; Anteins 1976; Mandel 1977). Metallographical analysis as a research method is still being used in Russia: Vladimir Zavyalov (Kolchin’s student) and his colleagues published a book about the blacksmith’s craft of the Finno-ugric nations living around the river Volga and its tributaries (2009). The article by Zavyalov (2011) regarding the development of metallographical analysis in Russia provides a good overview of the subject. Metalworking has also been studied extensively in Western Europe and Scandinavia, and the work of Vagn Fabricius Buchwald must be mentioned in this context as as he gathered information about the most important iron producers of Europe in the second millennia CE (2008).
Iron smelting sites have been the most extensively excavated metalworking sites in Estonia. Jüri Peets published his research results on ferrous metallurgy, focusing on iron smelting techniques and the manufacture of cutting tools (2003). Peets proposes that the excavation and research of Estonian smelting sites began in the 1960’s, when Aita Kustin started her work on the island of Saaremaa and Vello Lõugas investigated sites around Tallinn (Peets 2003, 18). Peets also provided a short overview on smithy sites in Estonia and Eastern Europe, and a very detailed description of the smithy site of Paatsa, which he excavated (ibid., 175–197). One of the few studies on smithy sites in a neighbouring region, was authored by the Finnish scholar Mikko Moilanen (2011), which was published just prior the discovery of the well preserved Gubbacka smithy (Heinonen 2012). Ny Björn Gustafsson also published research about Scandinavian smithies and he included mostly Swedish and Danish sites (2011).

There are some Estonian smithies that have been published as separate studies or reports including: the smithies of Kuresaare I and II (Püüa 2013; Selirand 1973), and Haapsalu I and II (Pärn, Russow 2006; Pärn 2004). There are also three well preserved smithy sites in Finland: Gubbacka (Heinonen 2012), Turu (Ainasoja 2012), and Räisäla Hovinsaari (Leppäaho 1949). This short list shows how rare it is to find well-preserved smithies, because of this I have also included other written sources and ethnographical research in this thesis. Subsequently the Tallinn city archives have provided written sources by several scholars including an in-depth study of metal workers by Kullike Kaplinski (1980; 1995). Gold and silversmiths have been studied using both written sources and objects in the historical collections (Friedenthal 1931; Vende 1967; Kirm 2000). Valli Konsap combined written sources with an analysis of forgings still preserved in the old town of Tallinn, to investigate the decorative forgeworking (Konsap 1971). More recently, a surprisingly detailed list of expenses from the casting of a 15th century bell was published by Anu Mänd, which provides a good overview of medieval bellfounding (2016).

Credit must be given to Jüri Linnus for gathering the ethnographical sources on Estonian smithies and blacksmithing. With the help of correspondents from all over Estonia, 158 smithies were recorded between 1959–1961. This is in addition to the additional 270 smithies Jüri Linnus documented himself (Linnus 1962, 141). Using these sources, Linnus published articles about the smithies across the whole of Estonia, with a particular focus on Saaremaa (1960; 1962). This huge source material still holds a lot of potential for further research. Linnus and his correspondents used a questionnaire "Sepis 1" (Eng Forging 1), which makes it possible to quantify some of the trends among the ethnographic smithies (see articles I and IV).

The find categories most associated with metalworking sites are casting mould and crucible fragments. There are several Late Bronze Age (1100–500 BCE) sites in Estonia, where casting evidence has been found. The study of crucibles and casting moulds from several sites, including Asva in particular, have helped to better understand Bronze Age society in Estonia and other areas around the Baltic Sea (Sperling 2014). However, the casting evidence from later periods has
received much less attention. Andres Tvauri provided a brief overview of casting tools dating between the 5th–11th centuries (2012). Stone moulds have also been investigated using both elemental analysis and experimental archaeology (Moora 1963; Keeman 2017), which makes it a slightly better researched artefact type. The crucibles and casting moulds from these later periods are therefore a focal point for this thesis.

Estonian crucibles have also been mentioned in foreign publications, but unfortunately they have relied on outdated Estonian publications. For example, when Natasha Eniosova and Robert Mitoyan write about Medieval Russian crucibles, they suggest that thimble-shaped crucibles are the dominant form in Estonia (2005, 328). However, the current research does not agree with this (see Article II). Elemental analysis has been employed in Latvia and Russia to study metal residues in the crucibles (Daiga, Grosvalds 1964; Eniosova, Rehren 2012). Elemental analysis can provide information about the specialisation of the workshop, such as alloying choices, and the use of precious metals. Extensive excavations in Sweden have provided an opportunity to study some metalworking sites in detail, for example the workshop on Helgö (Lamm 2012), the mint in Sigtuna (Söderberg 2011), and the site of Fröjel on Gotland (Gustafsson, Söderberg 2005).

Ülle Tamla’s thesis and subsequent publications provide a useful overview of the research history of the production methods, composition and developments in silver smithing in 9th–13th century Estonia (Tamla 1998; Tamla, Kallavus 1998; Tamla et al. 2002). Tuuli Kurisoo, in her recent doctoral thesis on 9th–13th century pendants found in Estonian and Liv sites, provides insights into how the pendants were made (2018). Some medieval casting sites have also been excavated, namely the workshops found on Lossi street in Tartu (Metsallik 1992, 1995; Trummal 1992). Medieval metalworking in Tartu was briefly described by Arvi Haak based on the finds recovered there (2007). The abovementioned list does not include all the research conducted on Estonian archaeometallurgy. The study of certain artefact types has yet to be mentioned, and these can be found in the in chapters 5 and 6 of this dissertation.

1.3. Research overview

This research evolved from my bachelor’s thesis regarding the settlement and smithy site of Käku, which was supervised by Jüri Peetsi and Ain Mäesalu (Saage 2011). In 2012–2013 the archaeology department of the University of Tartu procured equipment for metallographical analysis including a portable x-ray fluorescence spectrometer (pXRF), in order to facilitate a higher level of archaeometallurgical research. I subsequently focused my master’s thesis once again on the smithy site of Käku, specifically focusing on the fieldwork conducted between 2007–2012. This involved fresh metallographical analyses of iron artefacts, and elemental analyses of the copper alloy finds (Saage 2013). Metalworking in general in Estonia had been studied previously by several scholars,
but there were large gaps in the research, particularly in the investigation of metalworking sites, which is the main topic of this thesis. During the years 2013–2014, fieldwork continued at Käku and in collaboration with Jüri Peets, Liina Maldre and Elis Tiidu, an article entitled New Research Results from the Smithy Site of Käku in 2013–2014 was published in the journal Archaeological Fieldwork in Estonia (Article I). I undertook many trips to the archaeological collections in Tallinn, Tartu and Võru between 2014–2016, I subsequently made over 400 pXRF analyses from Iron Age crucibles, casting ladles and moulds. In addition, I made three trips to Stockholm University and one visit to the geology department of the University of Tartu with 13 finds for SEM-EDS analysis (see ch. 3.2). The article Metal residues in 5th c. BCE–13th c. CE Estonian tools for non-ferrous metal casting was published with my co-author Sebastian Wärmäländer (Article II) in Journal of Archaeological Science: Reports.

In 2016, Jüri Peets made a proposal to study the iron objects from Käku in collaboration with material scientists (Priti Kulu, Mart Viljus, and Priidu Peetsalu) from the Tallinn University of Technology. The blooms and bars from Käku were investigated metallographically and with SEM-EDS, and the results were published in the article Metallographic investigation of iron blooms and bars from the smithy site of Käku in the journal Fennoscandia archaeologica (Article III). By the end of 2017 I managed to complete the manuscript concerning smithies, which I had been working on since 2013. In hindsight, this elongated period for writing the article was essential, in order to find all the literature that was subsequently included in the article. The results of this study were presented at three conferences, where I was awarded with the best student presentation and the best student poster awards by the Historical Metallurgy Society. The article Smithies and forges around the North-eastern Baltic Sea from the 11th to the 17th century AD was published in the Historical Metallurgy journal (Article IV).

I also visited the City Museums of Tartu and Tallinn, the Estonian History Museum and the Archaeological Research Collection of Tallinn University in 2017–2018. This was to measure metal residues from medieval and Early Modern crucibles and casting moulds with the pXRF. The article Urban casting tools as evidence for transfer of technology across the Baltic Sea in 13th–17th century Estonia was written in collaboration with Erki Russow and it has been accepted for publication in Medieval Archaeology (Article V). The dissertation was written in 2019.

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2. DEFINITIONS RELATED TO METALWORKING

The following definitions explain some of the more frequently used metalworking terms and alloy compositions. The analytical methods are explained in the next chapter. The order of the list corresponds to definitions given in Estonian.

Amalgam – an alloy containing mercury.
Pattern welding – a method of structural strengthening and decoration used mostly on weapons (knives, swords, spearheads, and guns in the Early Modern period), which was achieved by forge welding, twisting, and etching layers of iron and steel with a different carbon content.
Blast furnace – a type of iron smelting furnace that emerged in Europe during the 12th century at the latest. The furnace produced carbon-rich pig iron which needed to be remelted in a finery forge in oxidizing conditions to produce iron. This process is considered to be indirect iron smelting. There is no evidence of iron smelting in a blast furnace in Estonia between the 12th–17th centuries.
Cast iron – an alloy of iron and carbon, where the carbon content is above 2%.
Brass – an alloy of copper and zinc.
Bronze – an alloy of copper and tin.
Gunmetal – an alloy of copper, tin and zinc.
Pewter – an alloy of tin and lead, which can also contain antimony, bismuth or copper.
Direct iron smelting – an iron smelting process, during which oxygen is reduced from the ore to produce metallic iron (also known as the bloomery process). This kind of smelting was used in Estonia during 1–1400 CE.
Iron (or wrought iron) – steel with a carbon content below 0.3%, which means it is not heat treatable.
Crucible – a refractory ceramic vessel for melting metals. Crucible were also used as reaction vessels by apothecaries and alchemists.
Casting ladle – a ceramic vessel with a socket or a tang for melting metals with a low melting temperature.
Casting mould – mould made out of clay, stone, wood, or metal for casting molten metal into it.
Steel – an alloy of iron and carbon, where the carbon content is between 0.3–2%, which enables the material to be heat treated.
Carburising – the intentional increase of carbon content in an iron or steel object.
Forge – metalworking installation, where metal is being heated for forging, or casting in a bed of charcoal that is induced with an airblast from the bellows.
3. METHODS

3.1. Metallographic analysis

The difference between finds from smithy and casting sites is also reflected in the methods employed to study them. The making of cross sections from iron artefacts and studying them under optical microscopes began in the first half of the 20th century and it is still a widely used method for investigating iron artefacts today. This is because it provides information about the method of iron smelting, the quality of the raw material, forging pattern, skill of the craftsmen\(^{16}\), and also post-depositional processes (Berger 2011; Scott 2014).

It is especially useful for studying bladed weapons and tools, as a variety of forging methods and heat treatments were used during 7th–17th century. The blooms and bars from the smithy site of Käku for example provided information about the level of refining and carbon content present in the items produced there. While informative, metallographic analysis is both destructive and time consuming, and sets a limit on the number of the investigated samples. All the samples taken for this thesis were prepared and recorded in the laboratory of archaeology at the University of Tartu.

The samples were cut as cross sections with a precision saw. The location of the cross section is important as it is the only region of the artefact you can study in detail. For this reason the studied artefacts were examined with an X-ray to reveal possible cavities and corrosion levels. All the samples were mounted with PhenoCure phenolic thermoset resin using a Buehler automatic compression mounting system. The mounted sample was then ground, polished, and etched with acid. Before etching, the polished surface of the sample will reveal non-metallic compounds such as slag inclusions and corrosion, and cavities. I used a 3% nitric acid solution in ethanol for the etchant. The etchant will effect the phases of the metal differently, which brings out the borders of grains and phases making it possible to identify iron, steel, cast iron, and the heat treatments they have been subjected to. The etched surface is like a miniature landscape, which makes it possible to study it with an optical and an electron microscope.

To study the samples at the laboratory of archaeology at the University of Tartu I used an optical metallographical microscope and a micro hardness tester, both having a magnification of up to 500 times. I also investigated samples together with Priidu Peetsalu under an optical microscope (magnification of up to 1000 times), and with Mart Viljus using a SEM-EDS, both analyses were conducted at the Tallinn University of Technology (see Article III, 49).

\(^{16}\) Throughout the thesis, the term „craftsmen“ refers to people involved in crafts without the aim to determine their gender.
3.2. Elemental analysis

The analytical work on non-ferrous metalworking was mainly undertaken with a portable x-ray fluorescence spectrometer (pXRF). This was done to find out which metals and alloys had been cast from a number of crucibles and moulds (Articles II and V). This approach was inspired by a similar study performed on medieval crucibles from Novgorod (Eniosova, Rehren 2012). All the pXRF measurements taken for this thesis were gathered with a Bruker Tracer III-SD at the University of Tartu archaeology laboratory. To test the results of the pXRF study a scanning electron microscope equipped with an energy dispersive spectrometer (SEM-EDS) was used (Article II, 41–42). The SEM-EDS measurements were performed in the biophysics department at Stockholm University with Sebastian Wärmländer and at the department of geology at Tartu University with Kalle Kirmimäe.

The pXRF is good for measuring many samples, but it also has its limitations. Compared to the SEM-EDS, the pXRF cannot be aimed at a specific particle as it measures an area of 5 × 3 mm. SEM-EDS operates using a vacuum chamber, which sets a limit to the sample size (the larger intact crucibles would not fit into the chamber), however it can detect lighter elements than the pXRF. The SEM-EDS is also very useful for determining if the metal residues are evenly spread out in the crucible or mould matrix, or if they are discernable particles (Article II, 41–42).

The elemental analysis carried out with the pXRF is qualitative, although comparing the level of residues in relation to each other might provide useful information how an artefact was used. The qualitative analysis is complicated by the tendency of elements like zinc and lead to being inflated from minor concentrations to the proportion of alloying elements (Renzi, Rovira-Llorens 2016, 162). The SEM-EDS analysis proved to be useful for solving this problem, as it allowed to locate the particles of the original alloy to measure its composition (Article II, 44).

3.3. Photogrammetry

3D models that are made with photogrammetry can be used in a variety of ways: documentation, measurement, illustration, reconstruction etc. All the 3D models for this thesis were made at the department of archaeology at Tartu University. Agisoft Photoscan Professional Edition was used for making the models and between 2013–2018 the programme was updated many times, every time increasing its capability. I used it during the excavation of the smithy site of Käiku, primarily for documenting the construction remains of four smithies between the years of 2012–2014. The consistent use of photogrammetry allowed me to merge the parts of the smithies excavated during different seasons into single 3D models (Article I). The construction remains were later more readily convertible into plans that could be published along with other smithy remains (Article IV, Fig. 5).
Photogrammetry was also used to produce an illustration of the grindstones from Käku. An exported ortophoto from the model was used to reconstruct the original shape of the grindstone (Article I, Fig. 4). Three crucibles, one casting ladle, and one stone mould were captured by photogrammetry to measure the volume of metal that they could have held (Article II). Nine other Iron Age casting moulds were also captured as 3D models, so their quite shallow relief could be emphasised using QGIS software, coupling their ortophoto with slope shading (Article II, Fig. 4). In order to do this, the objects were photographed with a 3D scale, so that the models could be georeferenced (on a local scale) in Photoscan. A coordinate system on paper acted as the 3D scale and markers for the georeference were marked on it (App. 1). The methodology for combining photogrammetry and the capabilities of QGIS was adapted from De Reu and his colleagues (De Reu et al. 2013), while the method of using local coordinate systems to capture and measure 3D models of the artefacts was my own further development.
4. SOURCES

4.1. Iron processing

Different activities in the iron working chain leave different waste and other remains, which enable archaeometallurgists to characterise a site. The processing chain for smiths working with iron from direct smelting (bloomery iron) can be broadly divided into the following stages:

1. Iron smelting
   a. Collecting the ore
   b. Roasting the ore
   c. Charcoal burning
   d. Building the furnace
   e. Iron smelting
2. Primary forging
   a. Compacting the bloom
   b. Flattening and forge welding the iron into a bar
3. Secondary forging
   a. Shaping the bar
   b. Forge welding iron and steel
   c. Shaping the object
4. Heat treatment
   a. Quenching
   b. Tempering
5. Finishing
   a. Grinding
   b. Sharpening

There could be some changes to the order of these different activities depending on the overall technology – for example carburising to produce steel out of iron could instead occur in the iron smelting furnace (Gurin 1987, 18–20; Peets 2003, 264), after smelting in a smaller furnace (Lorenčič 2017, 19), or carburising an iron bar in a clay package (Gustafsson, Söderberg 2005, 17; Söderberg 2008, 164–165) or carburising the finished object (Buchwald 2008, 465).

The most in-depth research into Estonian iron smelting was undertaken by Peets (2003). Other scholars such as Lavi (1999), Metsallik (1992), and Kiudsoo (2016) have also contributed, based on the sites they excavated. All the iron smelting furnaces were made out of stones and clay, although some may have featured wooden frames that were compacted with soil (see ch. 5.1.1). Only the bottoms of furnaces have been found up until now and even these are rare finds. Iron smelting experiments in the last decade have provided valuable new experiences, which have raised some questions about previous reconstructions. For example, the reconstruction of a smelting furnace from Raatvere made by Lavi (1999, 44), cannot successfully function as it is not possible to blast air into a furnace through a channel made out of rocks. The channel was found to be too
long (1.1 m) and not airtight, which means there would not be enough pressure to direct air into the furnace. It is even rarer to find forges, especially where you could find traces of primary forging through to the hardening and finishing stages. Forges from Estonia and neighbouring countries are discussed further in Article IV of the thesis.

The most common find from iron working sites is slag, because it preserves excellently in the soil. Slag does not have many uses besides being dumped as landfill, which means it is prehistoric garbage. This attitude towards slag can also be seen in ethnographic sources: the alternative name for slag is sometimes the “shit of the iron”, and the hole in the wall of a forge for pushing slag out of the smithy is sometimes called the “shithole of the smith” (ERM KV 99, 431). Sonja Hukantaival provided examples from ethnographic sources, where slag has been attributed with magical properties, which could be connected with slag finds from buildings and beneath them (2016, 141). However, one might argue if these practices can be transferred to the Iron Age and these practices could only have used a fraction of the thousands of tons of slag that were processed over the centuries.

Ironworking slag has been understudied in Estonia and the main reason for this is probably the difficulty in identifying slag from the different processes and the large amount of time needed to do it. Peets, however has analysed the chemical composition of iron smelting slags (2003, 45). There is also an unpublished manuscript by Kalju Utsal, who investigated the chemical composition of medieval slags from Estonia (1992), but to my knowledge this analysis has not been used in any other studies. Furthermore there are no publications of metallographic analyses on Estonian archaeological slags.

Slag can only be attributed to specific ironworking processes in certain cases. Tapping slag for example, which was either released from the furnace or solidified on the bottom of it. This slag looks grey and homogeneous, and when it solidifies in the furnace it has a plano-convex shape, but when the slag level has reached the tuyere holes, its shape is cylindrical (Peets 2003, 90). A good indicator of a smelting site is the occurrence of magnetic roasted iron ore pieces (ibid., 53, 97, 133), which are not found at smithy sites.

Slag from secondary smithing can have a similar chemical composition to smelting slags, although the formation process for smithing slags is completely different. The slag forms from oxidised iron, together with sand used as a welding flux, and the melted lining of the forge, which is usually sand and clay (Pleiner 2006, 119). Secondary smithing slag is heterogeneous and it can be formed in several layers, which means it could have been formed over a longer period of time. If it was removed from the forge in one piece it is usually plano-convex in shape like tapping slag, but it could have also been broken into pieces while being removed.

Primary forging can also be detected from slag, but if secondary forging was practiced at the same site, then the distinction is very difficult to see. Slag from primary forging includes smelting slag, melted hammerscale, and also all variations of secondary smelting slag (ibid.). If the slag contains pieces of steel
or cast iron, then is is very likely to originate from primary smithing (*ibid.*).
Pleiner writes that the slags from hillforts and towns are usually not from primary forging (*ibid.*, 120), but this does not seem to be the case for Scandinavia up to the 17th century, where in many cases the slag has turned out to be primary forging slag (Buchwald 2008). Hence, slags from primary forging events should be looked for at Estonian hillforts and towns.

According to Pleiner, the smith when creating a new artefact had to choose between a bloom that needed primary smithing or a bar that was already cleaned from slag (2006, 23). I will add a third option, which might be underrepresented in our view of past ironworking. That is the use of scrap iron. In the smithy of Käku there is evidence for all of these choices, and in the case of scrap metal, the bar was forged together from old cutting tools, so it could even be called a scrap steel bar (Article III, 54).

The results of articles I, III and partly article IV are based on the analysis of construction remains and artefacts from the smithy site of Käku. The production waste from the smithy was created from ironworking events, the forging and casting of copper alloy, and the working of bone and antler (Peets *et al.* 2013; Article I; Article III). The construction remains of the smithy include the burnt wood remains of the walls and in one case a stone foundation for one of the walls. The excavations also revealed the forge base, a water tank, the location of the anvil stump, also the doorsills, and a stone pavement from the earliest smithy (Article IV). Taking this all into account, Käku may be considered to be of the best preserved smithies in Estonia.

The other excavated smithies discussed in this thesis are Paatsa (Peets 2003), two smithies from the town of Haapsalu (Pärn 2004), and a further two from Kuressaare castle (Selirand 1973; Püüa 2013). Smithies were also found at Tartu during the excavations on Lossi street, but these results were problematical as I was unable to connect the remains on the plans with the descriptions in the text, and in many cases the documentation involved only the forges (Metsallik 1992). The widespread adoption of cast iron technology began in the second half of the 15th century and in this process, cast iron was melted in a blast furnace and cast straight into the mould (Bayley 1992, 3). A separate study is needed therefore to answer the question “when did ferrous casting begin in Estonia”. One of the likely places for this was the town workyard of Tallinn, but so far it has only been mentioned in connection with bronze casting (see ch. 6.2.1). Unfortunately, when this site was excavated, the production waste was not collected, so we are unable to better identify the production activities at the site. Finally the melting of iron in large crucibles is a later technology (Bayley 1992, 3), which was used in a time period not covered in this thesis.

### 4.2. Non-ferrous casting

In order to achieve the temperatures needed to cast copper alloys and precious metals, the metalworker needs a hearth or a forge with a sufficient airblast from
a bellows, also a crucible with sufficient refractory properties,\textsuperscript{17} crucible tongs, and a preprepared casting mould. While melting hearths or forges found with metal casting waste are rare, crucible fragments are quite common finds. Therefore I was able to study 175 crucibles and casting moulds, which originate from 29 Iron Age sites in Estonia (Article II). I separated them into three groups based on their age: there were only four crucible fragments from 500 BCE to 600 CE; 41 artefacts from 601–1050 CE; and 61 objects dating to 1051–1227 CE. The dating of many objects spanned across these periods. Iron Age casting tools have mostly been found from hillforts or the settlement sites adjacent to them. Less have been found from strongholds and other settlement sites, and only a few artefacts can be connected with various burial sites (Article II, Tables 1, A.1, A.2). However, there is probably a bias towards hillforts and strongholds being overrepresented with casting tools, as they have been excavated more extensively, hence I would suggest that unfortified settlement sites were also sites of non-ferrous casting. However, the concentration of crafts into large power and population centres has been noticed abroad as well (Pskov, Novgorod etc).

The crucible fragments from unfortified settlement sites are usually collected as stray finds with the exception of the settlement site of Savastvere, which has one of the best collections of crucibles recovered from one site. The Savastvere crucibles, both intact and fragmented, were found from a hearth area together with stones, burned clay, domestic ceramics, a knife, and burnt and unburnt animal bones (Saadre 1937). A hoard was also found seven meters away from the hearth, which can be dated to the 12th century (Jaanits \textit{et al.} 1982, 365).

The broken crucible fragments have probably not moved far from their original metalworking site, which is why they are good indicators of nearby metalworking activity. The moulds, which were often made out of imported stone (Moora 1963, 358), could equally have been imported with the ornament shape already carved into the stone. The moulds deposited in burials as grave goods are examples of casting tools where their context with the original metalworking site has been lost. The crucible fragments from the Alu and Põlgaste burial sites were very likely brought there with the soil from a nearby metalworking site (Article II, 37–38). That being said, the casting tool finds from burial contexts still give valuable information about a time period (500 BCE – 700 CE) when settlements and other monuments are quite rare.

To help organise the large amount of crucible and mould finds from the 13th–17th centuries, I narrowed my research onto the two largest Estonian towns during this period – Tallinn and Tartu. The sample range included 96 crucible fragments, 27 stone moulds, 7 clay mould fragments, also one wooden and one metal mould (Article V). Unfortunately, many of the finds came as loose or stray finds from refuse layers. This means that it is difficult to date the typological of features of different crucibles (Article V). The crucibles found from trash deposits in the

\textsuperscript{17} Although crucibles used in Iron Age Estonia are not refractory in the modern sense, they are still specialised vessels that are made to withstand high temperatures and the sharp temperature changes.
suburbs have been moved quite far from their original location compared to their Iron Age counterparts, but it is likely these still originate from local workshops operating inside the town.

The excavations on Lossi st. in Tartu revealed several workshops and although the preliminary results have been published (Trummal 1992; Metsallik 1995), there are still thousands of finds unresearched that could provide a lot of new information. This work has been hindered by a lack of useable documentation. Inventory numbers have been changed, for example, meaning I was unable to find the lidded triangular crucibles from the Tartu City Museum collection, although they are described in the excavation report (Trummal 1987, 12). To progress with this site, the first task would be to salvage as much information as possible about the find contexts.
5. METALWORKING FROM THE 7TH TO EARLY 13TH CENTURY IN ESTONIA

5.1. Ironworking

5.1.1. Ironsmelting

Local iron production in Estonia either started during the last centuries BCE or in the first century AD (Peets 2003, table 4). The Estonian word for iron is *raud*, which has a close parallel in the Old Norse word *raudi*, which means bog ore and which has an etymological link to the adjective for the colour red (Viitso 2012, 189). The first iron objects preceeded the local iron smelting by 300–600 years, therefore the word must have already been in use during the pre-roman Iron Age. The Estonian word for ore (*maak*) is derived from the word *maage* (which means rusty),18 and the word for steel (*teras*) is a finno-ugric word meaning the cutting edge.19 Language therefore does not provide a useful indication of where the iron smelting technology came from. The possible routes are either through South Scandinavia, Central Europe and Poland, or South Russia, where local iron smelting was present even before the 5th century BCE (Peets 2003, 47–48).

The oldest radiocarbon dates come from the smelting sites of Tindimurru, Puiato and Mäetaguse Metsküla, and range from the 2nd century BCE to the 3rd century CE (Peets 2003, table 4). The construction method for these early furnaces is unclear, but the furnaces from Mäetaguse Metsküla and Tindimurru were probably surrounded by a wooden frame containing soil (ibid., 68). A similar furnace with a wooden frame dating to the 4th–5th century CE was found in Poland, although Pleiner points it out as unusual compared to the dominant slag-pit furnace type (2000, 187).

Peets suggests that a recession in local iron smelting took place during the 8th–11th century, which is also visible in Latvia, Lithuania, Finland, and Carelia (2003, 82). It may have been caused by the intensive iron smelting in Scandinavia and Great Moravia, which brought down the price of iron and iron artefacts (ibid.). While the most intensive iron smelting period in the Tuu-Pelisoo area on Saaremaa is dated to the 12th–14th century, there are also radiocarbon dates that fall between the 8th–11th centuries (ibid., 102). Slag is also mentioned in the excavation report from the 7th–10th century hillfort and settlement site at Rõuge (Schmiedehelm 1955), but unfortunately it was not measured nor collected. Hence, we can be confident that iron smelting and smithing took place there, but there is no way to find out the intensity of it.

Mauri Kiudsoo does not see a recession during the Viking Age and his opinion is based on his excavations at the 9th–11th century iron smelting site of Tödva (Kiudsoo et al. 2009b, 100). Kiudsoo suggests that there is evidence for slag pit furnaces, which means that slag was not tapped there but rather gathered in the

18 https://www.eki.ee/dict/ety/index.cgi?Q=maage (05.05.2019)
19 https://www.eki.ee/dict/ety/index.cgi?Q=tera (05.05.2019)
bottom of the stone lined furnace (2016, 86–87). Slag pit furnaces are mostly accompanied by medium sized slag blocks (20–25 kg) or sometimes by huge monolithic blocks weighing up to 450 kg (Pleiner 2000, 149), which are often just left on the ground by the past iron smelters. The furnace bases in Tõdva had been cleaned of slag and Kiudsoo thinks it is because they broke open the slag to get at even the smallest pieces of iron (Kiudsoo 2016, 86). A plano-convex slag cake found near Võhma had a large bloom trapped inside it (App. 2), and is an example of past iron smelters not breaking open every slag cake to find iron, as it was probably more profitable to concentrate on the larger and more compact blooms. Furthermore, during the excavations at Tõdva the slag heaps were not found (Kiudsoo et al. 2009a, 12). As the volume of iron smelting from archaeological contexts can only be estimated by the amount of slag found at a site, then I have to agree with Peets20, that the idea of Tõdva being a large smelting site has yet to be proven. Also, the lack of any large slag blocks from Estonia makes me doubt that slag pit furnaces were used here at all.

Metallographic analysis from a 3rd–5th century socketed axe from the Kohtla weapon and tool deposit, revealed that unworked iron together with slag had been put into the core of the axe, that shows that the smith forging it either melted the iron himself or at least was taking part in the primary forging (Saage et al. 2018, 60). Hence, iron smelting could have been undertaken by smiths, who had to make their own iron and steel. Specialised iron smelting might have separated from general blacksmithing only in the 11th or 12th centuries, when large-scale iron smelting began in Estonia. Research by Peets indicates that during the 12th–14th centuries, iron smelting was concentrated to the island of Saaremaa, and East and North-East Estonia (2003, 84). The sites in these regions are characterised by the occurrence of slag, burnt furnace remains and tuyeres. The largest iron smelting complex is located in the Tuiu-Pelisoo-Tõrise area in North Saaremaa, where an estimated 1500–2000 tonnes of iron was produced based on the volume of the slag heaps (ibid., 135). The sites on Mainland Estonia could well have equaled this, as 10 out of the 14 smelting sites from North-East and East Estonia are dated to the 12th–14th century (ibid., 84).

When looking at large smelting centres in neighbouring countries, Jämtland in Sweden could be one of the most important ones as it was active in exporting large amounts of iron to the Baltic Sea region during the 9th–13th centuries. The 11th century law code issued by Magnus, king of Norway and Denmark, provides useful data about the different names and prices of iron products. Buchwald thinks that the blastr jarn mentioned there was the plano-convex bloom that was sometimes almost split (2008, 36). One plano-convex currency bloom has been found from Kuusalu in Estonia (Peets 2003, 154), but the origin of this bloom could also be local. The more expensive product called fello jarn was supposedly steel with a heterogeneous carbon content that was made from the most carbon rich area of the bloom (ibid., 37). However, there are no archaeological finds that could be a candidate for fello jarn (ibid.). Steel formed in the bloomery furnace

20 Personal communication, 15.10.2018.
has only been found as small fragments from Estonian iron smelting sites (Peets 2003, table 7), but carbon rich currency blooms have not yet been discovered (if they were traded at all).

Metallographic analysis of small pieces of iron from Estonian smelting sites showed that the bloomery iron had a heterogeneous carbon content ranging from 0–0.9%, but mostly it was low at around 0.1% (Peets 2003, 146). The phosphorus content was low at the Tuiu iron smelting complex (less than 0.1%), while in East and South Estonia it was almost 1% (ibid., tabel 8). Some of the iron was probably recovered from the furnace as small pieces (ibid., 150), but the main goal was to get one or several larger compact blooms. Pleiner drew attention to the past phenomenon of exchanging currency blooms in the shape of tools (2006, 50). It started in Ancient Greece (8th–4th century BCE) and it was still practiced in Scandinavia and Western Slavic tribes between 6th–9th centuries CE (ibid.). These were traded as currency and at the same time a tool-shaped currency bloom was a good starting point for the smith to begin his forging (ibid.). They can sometimes be found in hoards, where similar currency bars have been deposited in large quantities, but none of these hoards have been found in Estonia. Good candidates for currency blooms from local iron smelters are rectangular prism-shaped blooms, which have been unearthed in the last decade all around Estonia: Maalasti village in Viljandi county (App. 3, d–e), Neemi village from Saaremaa (App. 3, a–c), Kahala smelting site in Harju county (Kiudsoo 2016, 89), and Varja village in Ida-Viru county (Kiudsoo 2018). Unfortunately, none of currency blooms have been precisely dated, but doing so along with metallographic and provenance analysis from these finds would provide more information about the local iron economy.

5.1.2. Smithies

Peets provided an overview of Iron Age and Medieval rural smelting tools (2008). The most important find since this article was published is the anvil found at the Viking Age hillfort of Alt-Laari (Valk et al. 2014, 78). The anvil weighs 686 g and the face has a dimension of 8.4 × 5.1 cm (App. 4). Larger artefacts (like blooms) were probably forged on anvil stones, which have been found at iron working sites (e.g. Metsallik 1992, 149).

Unfortunately there are no “intact” smithies in Iron Age Estonia, by which I mean that the full layout of the smithy is reconstructable using the archaeological remains. The best preserved smithy so far is probably the 11th–12th century smithy of Paatsa II, that consisted of a pit forge and the burnt log remains of one corner of the building. The finds were slag, charcoal and roasted ore (Peets 2003, 188). Forges from the rest of the pre-crusade iron working sites are also pit forges (ibid., 175). To find more information about Iron Age smithies in the region, Finland is a good place to look for parallels, as pit forges also dominate the archaeological record there (Moilanen 2011, 119). Moilanen, who has used both pit forges and raised forges in his metalworking experiments, suggested a forge typology, which
includes both these forge types (App. 5; Moilanen 2011). This is a useful typology and several forges will be characterised by it in this thesis.

Pit forges are difficult to distinguish from cooking hearths. The Savastvere crucibles mentioned above were found from a hearth with cooking waste, and without the crucible finds, the hearth would have been considered a cooking hearth. A simple pit in the ground probably did serve several functions, so the best indicators for metalworking are slag, melted clay, drops of metal, and crucible, tuyere and casting mould fragments.

There is probably a preservation bias when we compare pit forges and raised forges, as the latter might only be preserved in very rare cases (Moilanen 2011, 123). Raised forges might have quickly eroded into unrecognisable heaps when exposed to the natural elements (ibid., 124), or their construction material might have been reused for something else. If raised forges were made with timber-framed bases, then they needed an anaerobic environment or partial charring in order for them to be preserved. Timber framed forges were a good option for the building of raised working platforms in environments where stone was rare. Workshops containing such forges are known from the 11th century, specifically from Viborg in Denmark and the Minino I settlement in Russia (Jouttijärvi 2014, 102; Zaitseva 2012, 79–81), which are forges of type e, although they have the frame built on the ground without the supporting legs (App. 5; Moilanen 2011).

The Gubbacka smithy from Finland provides some insight into smithy design in the 11th–13th centuries (Heinonen 2012). The Gubacka smithy had been rebuilt in the same place: the older smithy has a stone lined pit forge (type b); but later a large raised forge (type d; Moilanen 2011) was constructed. Unfortunately, the later smithy with its raised stone forge can either be dated to the pre-crusade era or the 13th century. It remains unclear therefore if this forge type should be connected to the immigration of craftsmen from the West (for more discussion see Article IV). In conclusion it is unclear when the Estonian smiths transitioned from sitting or crouching positions to standing when forging. As there already were raised forges in the West and East of Estonia during the 11th and 12th centuries, it is probable that they were aware that metalwork was being undertaken this way, but the local smiths were used to working on the ground level (Article IV).

5.1.3. Smithery

According to Peets, the ironworking began with local iron smelting, as the Bronze Age techniques, tools and knowledge were not sufficient for working iron (2003, 222). Techniques with a varying level of production complexity can be distinguished among bladed iron tools (Pleiner 1967, 98):

1. Iron blade
2. Iron blade with a carburised surface
3. Forge welded steel and iron
4. Hardened steel
The metallographic analysis of iron blades suggests that the first five of these techniques were already in use by the 1st–2nd centuries CE (Peets 2003, 209–226). One possible direction for the Roman metalworking technology to reach the Baltic region might have been through Poland and the active iron smelting complex at the Holy Cross Mountains, where it was already being practiced from the La Tène period (Pleiner 2006, 234).

Tanged knives with a wood, bone or antler handle were the most common tools among iron artefacts during the second half of the 1st millennium CE (Tvauri 2012, 90). The most common way to make knives in the 8th to early 13th century was by using a three-ply technique, where a steel core is welded between iron strips. Fully steel knives were less numerous (Peets 2003, 254). This shows that the smiths were familiar with steel and knew how to use it well.

Based on the forging patterns of knives, sickles, and axes, the level of smithing in Estonia was similar to its surrounding regions by the 9th century at the latest (Peets 2003, 268). However, this does not include the large crafting centres such as Ribe, Staraya Ladoga, and Visby (ibid., 270), where smiths could specialise in a more narrow, higher specialised craft. Gurin studied Belarusian knives and noticed that there was a rise in the number of steel-edged knives during the 12th–13th centuries compared to the 9th–11th centuries, when iron knives were still common (1987, 97–98). The variation of iron artefact types also doubles in the 12th–13th centuries, which Gurin connects with a shift of production to the market instead of individual customers (ibid., 111–112).

A knife-shaped javelin head was widely used from the 2nd half of the 11th century up until the early 13th century in Estonia, South-West Finland, and Latvia (Peets, Valt 2011, 20). As the production of this javelin head was relatively easy, the only prerequisite for its large scale use was good access to iron (ibid., 4). A connection can then be drawn between the intensification of local iron production with local weaponry and its use in battle.

Locksmithing seems to be quite rare between the 7th–11th centuries, judging by the lack of locks and keys in the archaeological record (Tvauri 2012, 93). The specialisation needed particular skills like brazing (soldering with copper) and the use of fine files. According to my knowledge, there is only one fine file found in Estonia. It was found at the Käku burial site, along with a key, belt fittings, jewellery, and ceramics, from a grave of a woman dating between the mid-10th to mid-11th century (Mägi 2002, 42; Saage 2011, 11). Brazing waste from the production of padlocks has been found at Ribe, Birka and Sigtuna, and brazing was technically the most challenging part of their production (Söderberg 2014, 23). The iron parts of the padlock were covered with solid copper-alloy pieces, which were in turn coated with clay to keep oxygen out of the process. Clay balls were then heated up to a temperature where they glowed so that the copper alloy would melt and fuse together the iron components of the padlock (ibid., 25).
There is no evidence of brazing packages in Estonia for the production of padlocks, but there is evidence of weight brazing from the stronghold of Soontagana. A pXRF analysis identified leaded gunmetal from the surface of iron weights\(^{21}\) (PäMu 2767: 1241, 1246). The brazing packages were not opened, so maybe something went wrong during the process and they were discarded (App. 6). These are remarkable finds, as they are the only Estonian examples of brazing technology being used in the 12th or early 13th century. Hence, the technology and the tools to make padlocks were present, but only the brazing waste from the production of padlocks would confirm local locksmiths in pre-crusade Estonia.

Weapon smithing was considered the most advanced branch of smithery by the 1960s, when Harri Moora suggested that local smiths adopted pattern welding in the 11th century (1966, 123). He primarily based his conclusions on the research of Aleksis Anteins, who mostly concentrated on Latvian finds. This is why no Estonian areas were mentioned where weapon smithing could have been more advanced. Moora thought that most of the weapons were imported from Scandinavia, Courland and Russia, and that only a small part of the weaponry was local production (ibid., 125). Later studies by other scholars present other views, as more in-depth research has since shown more local weapon and ornament types (see below).

Research into Iron Age seaxes revealed that they were made in a 3-, 5-, or 7-ply technique, with alternating layers of iron and steel (Mandel 1977, 243). The oldest seax made in a 3-ply technique was found at the Jäbara burial site and is dated to the 5th–6th centuries (ibid.). Mandel thinks that the weaponry during the 5th–8th centuries was not standardised and a dominant seax type did not emerge during this time (ibid., 240). The height of their use was during the 10th–11th centuries, when the size of seaxes was less varied and they were common weapons (ibid., 244). Seaxes lost their importance towards the end of the 11th century, when they seem to be replaced by double-edged swords (ibid.). This development might have been connected with the intensification of iron smelting, which made iron and steel more accessible, and with the advances in forging as the production of swords is challenging to say the least.

Amongst Iron Age weaponry, Estonian spearheads have received the most attention. By 1975 over 600 Estonian spearheads from the 6th–13th centuries had been investigated and 226 of them had been found to be forged using pattern welding (Selirand 1975, 186). The fact that over a third of them were made using pattern welding (including 13 javelin heads), shows that it was a common technique by then. The oldest pattern welded spearheads originate from the 9th–10th centuries, while the majority are from the 11th–12th centuries, and only a few are known from the early 13th century (ibid.). Selirand concluded that while there were imported spearheads, some pattern welded spearheads were made locally and Estonia was one of their production centres for the Baltic Sea region.

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\(^{21}\) The weights were analysed with the pXRF Bruker Tracer III-SD. The surface was measured without grinding it. The following settings were used for the measurements: 40 kV, 10.7 µA, 60 s, yellow filter (305 µm Al + 25µm Ti).
Kristina Creutz concentrated her research on the M-type spearheads of Petersen’s typology and found the subtype M5 (App. 7). It is characterised by a high ridge on the blade and a triangular ornament between the socket towards the blade (Creutz 2003, 166). Nine of these have been found on the islands of Saaremaa and Muhu, one from Kostivere on the Mainland, one from Jaunzemji in Latvia and one from Valsgärde in Sweden (ibid.). Seven of the spearheads from Saaremaa and Muhu were made using the same pattern welding technique (type 1 after Selirand 1975), and the same pattern was used to produce the spearhead from Valsgärde (Creutz 2003, 166). The latter was found in an elite boat burial and Creutz attributes the spearhead as a gift from Saaremaa (ibid.). If the other spearhead subtypes she created have less qualitative characteristics, then the triangular ornament on M5 spearheads is either present or not. Creutz suggests that the production of the M5 spearheads took place somewhere on the island of Saaremaa (ibid., 166). Radomir Pleiner, who was familiar with different pattern welded artefacts, thinks that the spearheads around the Baltic Sea rank among the top artefacts of this kind (2006, 219).

One of the earliest M5 spearheads could be the one found at the burial site of Käku (App. 7, a), which was dated to the first half of the 11th century by Marika Mägi (2002, 42). The spearhead has an impressive lenght of 52 cm, which demonstrates that local weapon smiths were accustomed to forging long bladed weapons. Mikko Moilanen drew similar conclusions while conducting his research on pattern welded swords from Finland, between 700–1200CE (2016). His metallographic analyses together with his own experiments showed that swords could be produced in a simple forge using the same blacksmith tools that have been found in Scandinavia (ibid., 313). Furthermore he suggests that the swords with written inscriptions should be attributed to Frankish smiths, but the ones that have been misspelled or feature other symbols, could have been made in Scandinavia or Finland (ibid., 324). In this light, swords found in Estonia should be considered to have been produced locally, unless there is good evidence for them being imported. One of these indicators is the use of letters as ornamentation as we can see on the ULFBERHT swords.

In conclusion, there is evidence for change in local iron working during the 11th–12th centuries, when iron production intensified in Estonia and its neighbouring countries, making it more accessible. This facilitated innovation in the blacksmith’s craft, resulting in seaxes being replaced by double edged swords and the production of pattern welded spearheads.

5.2. Casting of non-ferrous metals

5.2.1. Workshops, metal, and tools

Non-ferrous casting in Iron Age Estonia was conducted in simple pit forges or hearths, examples of which have been found from Rõuge and Savastvere. The elemental analysis showed that the crucibles and casting ladles from the hillfort
at Rõuge had traces of tin, pewter, and brass on them, while the adjacent settlement had residues of pewter, silver and leaded brass (Article II, Table A.1). A pit forge was discovered between the wall of the hillfort and building A, which could be attributed to metalworking. It was lined with stones, and the sand within it was heavily burned. It also contained finds of crucibles and stone casting moulds (Moora 1955, 57–59). As there were burnt log remains around the forge, it could also have been a lighter building structure or a shelter built against building A (Järvpõld 2014, 23).

The other hearths from Rõuge are more difficult to classify, either as cooking or metalworking pits. It seems that they were used for both (Tõnisson, Valk 2008, 326). A smaller fire pit is needed for heating a crucible with a bellows than you would need for heating cooking pots, but the size could have been modified by adding or removing stones. If classified as pit forges, these hearths can be assigned to type b pit forges (App. 5, b; Moilanen 2011).

While the hillfort at Rõuge can be mainly dated to the 7th–10th centuries (Lillak, Valk 2009), then the Savastvere workshop can be dated to the late 12th or early 13th century. The pit forge or cooking hearth seems to be multifunctional, containing burned stones, crucibles (intact and fragmented), but also domestic pottery, animal bones and a knife (Saadre 1937). However, a hoard found only seven meters away consisted of copper alloy jewellery out of which the pendants seem to have been made by the same craftsman (Jaanits et al. 1982, 363–365; Leimus 2009, 8). While the workshop and the hoard cannot be linked with certainty, the group of pendants and numerous crucibles point to a workshop operating at the Savastvere settlement.

About 600 crucible fragments were found from the settlement site next to Unipiha hillfort (Aun 1992, 55). Aun connects these finds to a ground level stone forge, which was unfortunately already destroyed by the time archaeologists reached the site (ibid.). The high number of fragments and the silver residues found in the crucibles suggest the presence of a casting workshop.

In 2018, metal detectorist Peep Nõggo handed in five copper alloy bars to the National Heritage Board, found at Pedassaare in Lääne-Virumaa (Kiudsoo 2019). Based on their surface texture, these bars were cast in open, one-sided wooden moulds. All five bars consisted of brass with varying lead content (Table 1), which is a common alloy between the 7th to early 13th century. The weight of the bars was between 63–165 g (Kiudsoo 2019), which does not exceed the volume of Iron Age crucibles (Article II, 43). However, this alloy is also often used in medieval and Early Modern times (Article V, Table 1), which is why the bars cannot be dated based on their composition. These were probably recast from scrap metal. For comparison, a bar found at the Rõuge hillfort, has a trapezoidal cross-section, indicating that it was cast in an open, one-sided stone mould. The composition of the Rõuge bar is leaded gunmetal with arsenic, which also suggests the use of scrap metal of a mixed composition.
The regular influx of silver coins from the Middle East and Central Asia began in the 9th century and lasted until the second decade of the 11th century (Leimus et al. 2018, 28). After that, the Eastern coins were replaced by imported silver artefacts, and coins from Western Europe (ibid.). Locally made silver artefacts make up the majority of finds in the 12th–13th century hoards (Tamla, Kallavus 1998). Also elemental analyses from the silver artefacts demonstrate that the silver content of the artefacts was quite varying (Tamla 1998; Tamla et al. 2002). Copper, zinc and tin were regular additional components in the silver alloy of jewellery and locally made jewellery has a lower silver content than imported artefacts (Tamla 1998, 21–22). The reason for this might be that only high quality jewellery was imported. The two silver bars that were found from the hillfort of Lõhevere were both with a high silver content, containing 94–95% silver and 5–6% copper (Tamla et al. 2002, 17). Hence, high content silver was also available to local jewellers.

There are hundreds of crucible fragments connected with the casting of non-ferrous metals, but there is a surprising lack of clay casting moulds. As casting mould fragments are found at Late Bronze Age casting sites, the dissapearence of clay moulds in the Iron Age must be connected with changes in the composition of the clay mix, the burning temperature, or with how the mould was cleared away from the cast artefact. It could also be a combination of all three options – the clay mix could have had more sand in it, the burning temperature could have been lower, and moulds were broken into smaller pieces, than the Bronze Age equivalents which were mostly for casting simple rings, that were easy to clean from clay. The fragile mould pieces are also difficult to identify, especially when they crumble to pieces when roughly handled or pushed through a sieve (Article II, 45).

Tuuli Kurisoo investigated pendants between 800–1200/1250 CE, from the Estonian and Liv areas, and discovered that locally made pendants were produced

<table>
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<tr>
<th>Object</th>
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<td>3,5%</td>
<td>2,3%</td>
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Tuuli Kurisoo investigated pendants between 800–1200/1250 CE, from the Estonian and Liv areas, and discovered that locally made pendants were produced

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22 The bars were analysed with the pXRF Bruker Tracer III-SD. The surface was measured without grinding it. The compositions were calibrated using the native Bruker calibration CU1. The following settings were used for the measurements: 40 kV, 10,7 μA, 30 s, yellow filter (305 μm Al + 25μm Ti).
using rather simple techniques. A smaller part of the more complicated pendants was produced using the lost-wax technique, but the majority of the pendants were made in piece moulds, which were done by pressing an original model of a pendant into wet clay (Kurisoo 2018, 179). This is confirmed by the similarity in the pendant shape and in minor details, which can only be achieved by using the same model for making a whole series of moulds (ibid.).

The earliest Iron Age crucible fragments are too small to reconstruct the whole crucible. However, Bronze Age crucibles are completely different as they had thick walls and were heated from above (Sperling 2014), whereas Iron Age crucibles were heated through the side and the bottom. It is unclear when this change happened, but when looking at the crucible finds from Latvia (Daiga, Grosvalds 1964), then this transition happened during the Roman Iron Age (first half of the 1st millennia CE). This also means that some of the crucibles investigated in Article II, which I previously dated to a quite long time period (Toodsi-Liidva settlement and Alu burial site), cannot be older than the beginning of the Roman Iron Age.

The crucibles from the hillfort and settlement of Rõuge are mainly dated to the 7th–10th centuries (Lillak, Valk 2009), and they form the oldest collection where the whole shape of the crucibles can be reconstructed. The crucibles of Rõuge had a round bottom and a round or triangular mouth. Some of the crucibles have been made in two layers, so that the inner layer is made out of a finer fabric, while the outer layer is more porous to stand the thermoshock that comes out of very sharp temperature changes. This two-layered crucible technology was widely used – one earlier example was found in the Roman provinces (modern day Germany; Bayley, Rehren 2007). This way of making crucibles was in use at least up until the 13th century crusades.

As mentioned above, the largest collection of crucible fragments (600 fragments) comes from the 8th–10th century settlement next to Unipiha hillfort (Aun 1992, 55; Tõnisson 2008, 300). The crucibles are very fragmented, but judging by the more intact pieces, the crucibles were round bottomed with a round or triangular mouth. There is also a rare pear-shaped crucible with a tapering mouth, which was found at the stronghold of Soontagana (Article II, Fig. 3).

Conical crucibles appear in the Final Iron Age (1050–1227 CE), and were found at the Naanu hillfort, and at the strongholds of Varbola and Soontagana (Article II, Fig. 3). Crucibles from the Savastvere workshop are also conical, although their outer surface has been deformed by heat. There are also examples from cylindrical crucibles with a round bottom from the Final Iron Age (for example from Tartu and Otepää hillforts). I must correct a misleading statement that was published in Article II. The misconception was that a regional divide existed with South Estonia using the round bottomed cylindrical crucible, and West and North Estonia using the conical crucible. Actually, conical crucibles appeared in post-crusades contexts in Tartu, in South Estonia (TM A 43: A 2412), while round bottomed cylindrical crucibles have been found at Tallinn in North Estonia (TLM 19361: 123). One round bottomed crucible was also found at the stronghold of Soontagana (PäMu 2766: 610). Hence it seems that there are no
regional types of crucibles, but rather there are very similar crucibles from one site (Savastvere, Otepää, and Varbola), which were probably made locally.

There are two crucible types that appear in neighbouring regions, but have not been found in Estonia (Article II, 44). Firstly, the tanged boat-shaped crucible, that was used in a wide area from Sweden to Ukraine in the 8th–9th centuries and also in slavic areas up until the 11th century (Lamm 2012). A similar closed crucible type has also been found at Novgorod from the 12th–13th century contexts (Eniosova, Rehren 2012). Secondly, there are no shallow cupels for refining or testing, which have been associated with precious metalwork or minting in other places (Eniosova, Rehren 2012; Söderberg, Gustafsson 2006; Söderberg 2011). It is possible that similar workshops have not been found, but it is more likely that the assaying of precious metals was not undertaken, and there is no pre-crusade minting evidence in Estonia.

There is one find connected to crucibles that should also be mentioned, they are the tongs from the Raatvere smith burial, dated to the mid-11th century (Lavi 1999, 51). These are thought to be tongs used to take the bloom out of the iron smelting furnace (ibid.). After examination however, these tongs cannot grip very large objects. The jaws are quite different from the Mästermyr and Starya Ladoga tongs, as they have a very large contact surface, but are not very thick. Jaws like these would easily be deformed holding a hot piece of bloom, which would then be hammered vigorously. However, the large contact surface would be excellent for gripping crucibles, which at high temperatures are quite soft and require gentle handling. Of course, tongs can be used in a variety of ways and the jaws can be reforged, but the Raatvere tongs as found, could easily be called crucible tongs.

5.2.2. Casting of tin, lead, and pewter

Socketed casting ladles and stone moulds from the Iron Age should be seen as one tool kit for the casting of alloys with a low melting temperature. Harri Moora proposed this in 1963, although at that time he was not able to conduct residue analyses on all of the moulds and ladles (Moora 1963). My analysis showed that all of the ceramic casting ladles with residues contained tin or pewter (Article II, Table A.1). Unlike crucibles, that often have a vitrified outer surface, casting ladles appear to not have been heated at high temperatures. The appearance between casting ladles is quite similar, although some finishing touches have been added: a ladle from Rõuge has an ornament around the socket and the ladles from Lõhavere have been burnished, while the Varbola and Soontagana ladles were not decorated in any way (Article II, Fig. 5).

The contemporary casting ladles from Latvia either had a socket or a tang (Daiga, Grosvalds, 1964), while only socketed ladles are known from Estonia. During casting experiments with similar ladles, I found that it was relatively easy to grip the empty socket with tongs. So the socket could have been meant for both—a wooden handle or gripping with tongs (the latter notion is reinforced by the
Latvian tanged ladles). The ladles were used to cast small items, as the largest intact casting ladle from the burial site of Arniko had the volume of 10 cm³ when filled to the brim, while the other ladles were a similar size or smaller (Article II).

The only analysis to determine the provenance of the mould stone so far was undertaken in the 1960s (Johannes, Jürgenson 1960). Of the 23 Iron Age moulds that were analysed, 15 originated outside of Estonia. Three stone moulds from the Arniko burial site, 11 mould fragments from Rõuge, and one from the hillfort of Otepää were made from fine-grained Mesozoic limestone, which does not occur in Estonia. The closest regions where it could be obtained is South Lithuania, and Erika Jürgenson herself suggests it might have originated from Germany (ibid.). Jürgenson also identified two siltstone, four fine-grained sandstone, and two marly limestone moulds among the moulds at the Lõhavere, Rõuge, and Otepää hillforts, all of which could have been local (ibid.). Homogeneous and carvable stone is essential for making moulds, especially when the ornaments have fine details. As tin casting seems concentrated to hillforts, as was silver casting, it is not surprising that stone was imported for making them.

Stone moulds were mainly used to cast pendants or plaques (small studs or mounts that were sewn on textile), which needed two-sided moulds to be cast. It must also be said, that tin or pewter preserves very poorly in the soil, and today we only know of a small number of ornament shapes. For example, the Lõhavere stone mould has three unique ornaments carved into it (Article II, Fig. 4, 1). The backside of the plaques usually has two loops, which were cast using the two mould halves and a stick, wire, or cord that would act as a core (Keeman 2017, 79). In that sense, these were actually three-piece moulds, and the core would also help to align the moulds to the right position (App. 8). The same applied for casting pendants, where a core was used with the two-sided moulds, so that the bail would already have a hole in it. One-sided moulds were also used if the shape of the ornament was very simple.

I agree with Moora’s main conclusions: that the stone moulds and casting ladles were mainly used for alloys with a low melting temperature, good quality stone for making the moulds was mainly imported, and tin plaques were cast and subsequently worn on clothes on a much larger scale than is preserved in the archaeological record (Moora 1963). From my own research I can add that the stone moulds were occasionally also used for silver and copper alloys (Article II), but this seems to be a less common practice.

One technological innovation that was adopted in Germany in the High Middle Ages (around 11th–13th centuries), was the use of lead pegs for fixing the two or more mould halves into position (Berger 2012, 53). Lead pegs had already been used in the Viking Age, as can be seen from the mould of Birka and Hedeby (Oldeberg 1966, fig. 130; Lønborg 1998, 29). Lead pegs are also present on moulds from 10th century Kiev and 12th century Novgorod (Eniosova, Murashova 1999, fig. 8). As lead pegs are only present on the moulds from the Lõhavere hillfort, then this innovation reached Estonia in the first quarter of the 13th century. Among the numerous stone moulds from Latvia, the first ones with lead pegs appear in the town of Riga in the early 13th century (Svarâne 2013, 221).
Hence, it seems that the adoption of this technique is contemporary with the crusades and probably originates from Germany or Scandinavia, although a Russian influence cannot be excluded either.

5.2.3. Metalworkers

In 1966, Harri Moora assessed the level of specialisation of metalworkers in pre-crusades Estonia. He suggested that blacksmiths also cast copper alloys, but there were some smiths making silver jewellery as well (1966, 125). The lack of well preserved workshop remains only containing casting activities supports his claim. The workshop next to the Unipiha hill fort might have been one, but we will never know as it was destroyed. Usually crucible fragments have instead been found with other domestic waste and slag from ironworking. It is reasonable to presume that skilled blacksmiths could perform non-ferrous casting and vice versa, but casting as a separate specialisation is not apparent in the archaeological record, in the way we see it at the workshops of Helgö in Scandinavia (Lamm 2012). The lack of specialised crucible types found in Scandinavia and Novgorod, that can be associated with goldsmithing and minting is also telling (Article II, 44).

It has been suggested that pre-crusade handicrafts were not completely separated from agriculture at this time (Jaanits et al. 1982, 394). Although, there were highly specialised metalworkers by the end of the 14th century, but they also had land plots outside the town walls to grow their own vegetables (Kaplinski 1980, 68). It is also quite difficult to determine what other activities they pursued when they were not in their workshop. In that sense, concepts of differing handicraft categories, where crafts have been divided into independent or attached to elite sponsorship, and part-time or full-time crafts (Costin 1991, 9) are difficult to use with the fragmented data from Estonian metalworking sites (especially regarding the products that came out of the workshop).

Some qualitative criteria for specialisation could be of use. For example, the number of alloys in crucibles, ladles, and moulds as identified in the residues. When we divide the 7th–early 13th century results into two groups, 600–1050 and 1051–1227 years CE, then we can see two trends (Fig. 1). Firstly, brass, leaded brass, pewter, and precious metals are the most numerous alloy groups in both periods. However, there is a difference in the occurrence of other metals and alloys such as leaded bronze, copper, leaded copper, and gunmetal, which are completely missing in the first period. Based on these results it can be suggested that an increase in the availability of pure metals took place during the second period. This means that copper and bronze were probably traded as ingots, which could be explained by the increase of trade in the Baltic Sea region. A similar situation is visible with crucibles from Novgorod, where the increase in alloys has been dated to the 12th century (Eniosova, Rehren 2012, 222). However as discussed above (ch. 5.2.1), the Novgorodian craftsmen had vessel types that point to specialised jewellers, which are absent in Estonia. Hence in the case
presented here, the number of alloys used is better for discussing the nature of trade contacts with the metal extracting regions.

![Residues in casting tools](image)

**Figure 1.** Residues from crucibles, casting ladles, and moulds from 600–1050 (n = 42), and 1051–1227 (n = 61) (after Article II).

Some casting methods are completely absent in Iron Age Estonia that are described in the 12th century manuscript *De diversis artibus* (Hawthorne, Smith 1979). Large objects such as church bells could only be cast straight into the mould from the furnace. Also, there is no evidence of casting tin or pewter tableware, although small ornaments from the same alloys were very common.

Previous research on Estonian metalwork has been limited by the sample sizes when performing elemental analyses. Crucible pieces were selected for analyses in the cases where metal drops were visible to the naked eye, for example the fragment from Unipiha, where silver was detected (Aun 1975, 356). However, it is more common to have no visible metal drops on the crucible surfaces. With the adoption of a portable XRF for studying archaeological artefacts, much larger sample sizes could be investigated. The elemental analysis found silver residues in 27% of the crucibles, which showed that is was common to cast silver (Article II, 41).

The most significant results for silver casting are those using SEM-EDS where only silver residues were discovered in the crucible. Such crucible fragments were taken from the stronghold of Soontagana, the hillfort of Unipiha, and the settlement of Pada I (Article II, Table 2). In other cases (Rõuge settlement, and
the hillforts of Peatskivi and Otepää), silver was cast in the same crucible as copper alloys. The finds from Otepää are especially interesting, as six of the seven crucibles had silver residues in them, which might indicate a silver casting workshop. If we look at silver casting from a technological point of view, the crucibles made from local clay were better suited for casting silver than copper alloys. This is illustrated by the numerous crucibles since found that were deformed by high temperatures (Article II, Figs. 2–3). The melting temperature for a silver-copper alloy in a 9/1 ratio has a melting temperature below 900°C, while 9/1 copper-zinc and copper-tin alloys both melt above 1000°C (Article V).

Hence, if the metalworkers were able to successfully cast copper alloys, they were not limited by their casting tools to cast silver. In the end, the quality of the final product was determined more by experience, both in the skill of making the models and finishing the cast objects.

There was a fast development in Estonian silversmithing around the 12th–13th centuries according to Kaalu Kirm, which manifested itself in local forms of penannular brooches, sheet pendants, bracelets, neck- and finger-rings (2000, 16). The abundance of silver hoards indicates that silver was widely available, which was a prerequisite for the development of local silversmithing (Tamla 1998, 17).

One silversmithing innovation in the Final Iron Age was the use of a thin silver sheet as the main material of an ornament, which had punched or engraved decorations (Kirme 2000, 16; Tamla 1998, 26). Broad but very thin, convex silver bracelets illustrate the presence of skilled hammering techniques and material knowledge (Tamla 1998, 26). The earliest evidence for silver soldering also dates to this period (Tamla 1998, 29).

Kirme claims that silversmithing in the 10th to early 13th century could just be classified as jewellery making, because the local craftsmen lacked the skill and demand to make larger objects such as tableware (2000, 16). I would add, that one of the reasons why Iron Age craftsmen did not cast larger objects was the restriction of the crucible charge volume, set by the low refractory properties of the local clays.

Techniques like filigree, granulation, inlay, and niello however were not used by local metalworkers, and only appear on imported artefacts (Tamla 1998, 41–43; Kurisoo 2018, 180). There are also scholars who claim that North Estonian silversmithing was more advanced than in South Estonia (Jaanits et al. 1982, 394). When looking at the metalworking sites, it is not possible to estimate the level of craftsmanship, but based on the amount of crucible fragments and the residues in them, silver casting was very common at South Estonian hillforts.

Gilding has so far only been discovered on imported goods (Tamla 1998, 39), which has lead to the belief that local smiths did not use it. The elemental analyses of gilded artefacts have determined that amalgam was used for the gilding (Tamla, Kallayus 1998, 258). I found traces of mercury on two crucible fragments from the hillforts of Tartu and Otepää. The fragment from Tartu contained mercury with zinc and silver (Article II, Table A.1). The crucible fragment from Otepää (AI 4036: I 1973) had traces of mercury, copper, zinc, gold, lead, silver and tin. In both cases, there is a chance that mercury got into the crucible when a
previously gilded object was remelted, but both hillforts were prominent regional craft centres, where craftsmen capable of gilding could have worked.

The casting of tin and pewter artefacts into stone moulds was not so technically challenging for craftsmen who were proficient in making jewellery from copper alloys and precious metals. This craft was more dependent on the raw materials as the metal and easily carvable stone had to be imported. There are many examples where all the surfaces of a good quality stone have been used to carve moulds into, strongly suggesting that it was a valuable resource for the metalworker. The find contexts for ladles and stone moulds are similar to silver casting, concentrating to large centres like hillforts and strongholds. It was probably a profession practiced by jewellers, but possibly also craftsmen involved in textile production, where tin plaques were used in large quantities.

In summary, the archaeological record contains many smithies, but no workshops dedicated only to casting. The casting of copper alloys was conducted in settlements, hillforts, and strongholds, while silver and tin casting was concentrated to hillforts (and the settlements next to them) and strongholds, but not unprotected settlements. Some finds, like the brazing evidence at Soontagana and the many silver casting crucibles at Otepää, stand out in Iron Age Estonia. In the larger centres it was probably possible to specialise on producing single objects of a higher quality. However, the absence of gold and locksmithing and minting evidence, indicate a lower level of specialisation than the neighbouring craft centres at Sigtuna and Novgorod.

6. METALWORKING FROM THE 13TH–17TH CENTURIES IN ESTONIA

6.1. Ironworking

6.1.1. Blast furnaces and the osmund

Estonia and Latvia were conquered by German and Danish crusaders in the 13th century. The crusade of the Estonian lands took place from 1206 until the surrender of the Valjala stronghold in 1227, which marks the end of Iron Age and the beginning of the Middle Ages (see Articles IV and V). Intensive iron smelting in bloomery furnaces continued in the 13th–14th centuries, and the island of Saaremaa, and Virumaa in North-East Estonia continued to be the largest iron producing regions in Estonia (Peets 2003, 136). Meanwhile, water-powered ironworks brought forth big changes in ironworking in the rest of Europe. A water-powered iron smelting workshop operated in Ugglehult (in Danish Halland), between 1150–1230 CE, which is the earliest archaeologically excavated
example (Buchwald 2008, 74–76). Buchwald studied the slags of Ugglehult and a nearby bloomery site at Jernvirke, and found that while the same ore was used at both, the water-powered bellows in Ugglehult gave a better yield (with a higher carbon content), than at Jernvirke (ibid., 83–85).

Early blast furnaces were adopted in the 12th century, but this technology became widespread during the 13th century, when blast furnaces were adopted in Sweden, Germany and Italy (ibid.). According to Buchwald several changes accompanied this shift towards using blast furnaces (ibid., 228):

1. Many iron smelting workshops relocated near running water to power large bellows and hammers.
2. Instead of the temporary furnaces often used by bloomery smelters, permanent blast furnaces were built out of stone and refractory materials.
3. Mountain ores rich in manganese and poor in phosphorus were adopted instead of the traditional bog ore.
4. While peat could be used in the bloomery process, only charcoal could fuel the blast furnaces.

Indirect iron smelting starts in a similar way to the bloomery process, with roasting of the ore, but then the iron smelting becomes quite different. During the smelt, liquid cast iron is produced, that is cast out of the furnace (ibid.). The most difficult process is the fining phase, during which the cast iron is remelted in an oxidising blast, losing most of its carbon content and leaving behind iron with a low slag and carbon content (ibid., 229). It was cheaper to produce iron in this indirect method and the iron had a more homogeneous content, which is why it entered many markets as a serious competitor to local bloomery iron.

The Swedish iron produced in blast furnaces was called osmund. Written sources in England show a drop in the price of osmund iron in the 2nd half of the 14th century (Crew 2015, 160), which coincides with the appearance of osmund in the written records of Tallinn. The first hard evidence of importing osmund to Tallinn comes from the year 1364, although there is a source from 1336 that describes a citizen of Narva exchanging rye for iron and copper in Stockholm, which could also have been osmund (Konsap 1971, 36; Sepp 1987, 31). Osmund became the most common iron bar in Tallinn by the 16th century (Sepp 1991, 5). There are several characteristicstics that enable osmund iron to be identified: the bar weighs about 260 g (usually between 225–300 g), and the cross section has round pores containing slag which has not been hammered flat (Wallander 2015, 129–130). There are also carbon poor areas that alternate with high carbon areas, and chisel marks on the edges of the bar (ibid.). Three iron bars found at the village of Põrga in Viljandimaa county fit this description well (App. 9). The bars weighed 253, 246 and 330g before conservation, and metallographic analysis from one of the bars showed that it matched the microstructure of osmunds (Kogger, Saage 2019). It should be noted that this bar had been hardened, so the

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23 There is written evidence of a workshop called Schmidmühlen in Germany from 1010 CE, but this site has not been archaeologically investigated (Buchwald 2008, 211).
carbon-rich areas had turned to martensite. This could have been a test carried out by the smith, to find out if the bar was heat treatable. The rural population had access to osmund iron through dealers either in the towns or among the rural nobility (Sepp 1987, 41–42).

Cast iron, which is an intermediate result of indirect iron smelting, became an end product for iron smelters in the 15th century. Research in Estonia has not yet investigated the early stages of cast iron casting. The first indirect evidence comes from a dispute in 1417 when the town council of Tartu blames a merchant in Tallinn for selling them two barrels of “fake iron.” While it is not clear what is meant by the phrase “gesmedet were von kusysern” it is very likely that this was cast iron (Sepp 1987, 40–41; 1991, 8). In this light the large ingots recently found on Saaremaa are especially interesting (App. 10). The metallographical analysis showed that these were ingots of pig iron, but unfortunately I cannot date them more precisely than the 15th–19th centuries (Saage 2019), although their origin from the 20th century cannot be ruled out as well. The unfinished and rough appearance of the ingots indicates that these are either casting waste or a semi-product. Regardless of their dating, these pig iron bars have been imported, as there is no evidence of iron production in blast furnaces in Estonia.

6.1.2. End of local iron production

The radiocarbon dates for some iron production sites link them to the early 15th century, but the 2nd half of the 14th century seems to be a period of decline for local iron production (Peets 2003, fig. 118). Several reasons have been proposed for this: Peets connects it with the violent suppression during the revolt of St. George’s Night in 1343–1345 (ibid., 290), and it could also have been the competition from the imported osmund iron that put the locals out of business (Article III, 55–56). There is also a decline in bloomery iron production in Norway in the 2nd half of the 14th century, which has been attributed to the plague epidemic in the 1350s (Buchwald 2008, 27; Espelund 2013, 274). However, in the peripheral areas of Norway, iron was produced in bloomery furnaces up until the mid-19th century (Buchwald 2008, 39). Maybe the end of local iron production could have been the result of a combination of all these factors. This could have started with the suppression of the revolt in the 1340s, which was followed by a plague epidemic in the 1350s (EA II 2012, 171), and in these conditions the availability of cheaper and good quality osmund iron was too much competition for local bloomery smelters. The craft guilds in the towns were gaining more influence over metalworking during the 14th century (see Article IV), and might also have preferred the more standardised osmund iron, than the local produce.

The bloomery iron found at the smithy site of Käku raised some questions regarding the possibility of local iron smelting in the 15th–17th centuries. As there are no smelting sites dating later than the early 15th century, there are three ways
of explaining the bloomery iron finds from the 15th–17th century layers (Article III, 55–56):

1. The bloomery iron bars originate from the iron smelting sites dated to 14th or early 15th century, but the stratigraphy of the smithy has been disturbed by later activities, which is difficult to determine as the soil was homogeneously black in colour.
2. The bloomery iron is locally made, but the 15th–17th century sites have not yet been found.
3. The bloomery iron was imported from Scandinavia or Finland.

The first hypothesis could be checked by radiocarbon analysis of the steel from the blooms. However, if there was local iron production in the 15th–17th centuries, then this would need to be confirmed by finding the smelting sites dating to this period. The third hypothesis seems to be the most likely as iron was produced in bloomery furnaces in several neighbouring regions up until the early 17th century. A good indicator for the end of bloomery smelting is the disappearance of primary smithing slags from Denmark, Norway, Sweden and Finland around the year 1600 (Buchwald 2008, 67). The four-pronged currency bloom known as klode was produced in Sweden and Denmark from the 13th to early 17th century (ibid., 62). In the early 17th century, klode no longer features in the tax registers in Jutland, which supports the argument for the end of bloomery smelting in the region (ibid., 119).

An “iron factory” (Eisenhütte in Germ.) was built in the parish of Räpina in 1689, which unfortunately was destroyed in the Great Northern War (Tiik 1964, 333). It was named the first of its kind in Livonia, which shows that there was no living memory of the previous bloomery iron smelting phase by the end of the 17th century. Leo Tiik suggests that the location for this factory was at Hüttimäggi farm, which also features in the contemporary sources (ibid.). However, the general absence of toponyms containing the word hütti and the total lack of iron in the tax registers of peasants (Article III, 56), are good indicators that local iron smelting did indeed end by the 15th century. A question then arises from this conclusion: why didn’t indirect blast furnace production replace bloomery production in the rural areas of Scandinavia? In medieval and Early Modern Sweden and Denmark, simple funnel-shaped furnaces without a slag pit were used for smelting, which were surprisingly efficient (Buchwald 2008, 40). Professional iron smelters for the inspectors of Swedish Jernkontoret used this furnace in the mid-19th century and managed to produce iron with a yield of 21%. They undertook four consecutive smelts and the yields for the later smelts were better because the furnace was already warm (ibid., 43). The process had several characteristics (ibid.):

1. The furnace was built out of stone, it was reusable, and it was kept hot between the smelts.
2. Firewood was used instead of charcoal in the beginning of the process, which lowered the fuel cost.
3. The bloom was compacted during the process through the mouth of the furnace.

This high efficiency might have been the reason why this process survived for so long. Besides, not all ores are good for indirect iron smelting. For example the Finnish lake ores have a high phosphorus content, which is not a problem in the bloomery process, where most of the phosphorus stays in the slag. With the high temperatures of the blast furnace, the phosphorus alloys with the cast iron and is very difficult to remove through fining (ibid., 68). In some areas therefore, bloomery smelting was the best option when using the local iron ores.

6.1.3. Smithies

Foreign craftsmen and monks settling in Livonia, brought several technological innovations with them during the 13th–14th centuries, which is reflected in the way smithies were constructed. A watermill was built close to Riga during the 1220s, then one also existed somewhere in the Ösel-Wiek bishopric in 1238, and one in Koila on the river Jägala in 1241 at the latest (EA II 2012, 189). The oldest excavated water powered ironsmelting workshop in Europe is from the late 12th century (Buchwald 2008, 9). Water powered smithies occasionally appear in European written sources in the 13th century, and they become common in the 14th century (Pleiner 2006, 238). A water powered hammer raised the productivity of the smithy by a large margin. The 18th century scythe makers in Austria made about 2–3 times more scythes in a water-powered smithy than their counterparts in Dalarna in a regular smithy, while both smiths were considered skilled craftsmen (Buchwald 2008, 193). To my knowledge, the oldest water-powered workshop was built in 1531 by the Tallinn armourer Wilm Platenslegeri, who established a copper smithy on the river Härjapea, that operated until 1662 (Kaplinski 1995, 25; Lavi 1998, 224). Another copper smithy is marked on a map on the river Härjapea in 1688, where copper roof panels and cooking utensils were cast and hammered (Kaplinski 1995, 25). While there are no water-powered smithies found in the archaeological or written sources from the 13th–15th centuries, is is likely that they were known about and probably built in Estonia during this time.

There were at least three smithies found during the excavations of Lossi street 3 in Tartu, which were detailed in the report, although they are difficult to match with the excavation plans. The first smithy was built in a post frame construction, that was sunken into the ground about 1 m deep, and it had a plank floor that was smeared with clay (Metsallik 1992, 154). Metsallik also mentions a forge base that was found 150 cm above the floor level, but doesn’t mention its construction (ibid.). As the smithy has been burned several times, it is likely that the forge base was connected to a later smithy as 150 cm is not an ergonomical height for a forge to be built on. A large stone was in the smithy, which Metsallik interprets as an anvil stone (ibid.).
The second smithy found at Lossi street was situated just next to the previously mentioned workshop, and it was separated from it with a ditch. The dimensions of the smithy are unclear, but this workshop also contained an anvil stone and a forge built from clay and stone, which was supported on a wooden frame (Metsallik 1992, 154). Although the description of the forge was brief, it could be classified as an e-type forge (App. 5; Moilanen 2011). The forge could have originally featured legs or some other support, which raised it to a comfortable standing working position. As a unique find, the heavily burned wooden door of the northeastern wall of the smithy was preserved on foundation stones with a corroded lock (Metsallik 1992, 154). This find indicates a larger fire in the town (and maybe the death of the smith), as the lock would have been recovered from the door if only one building had caught fire.

The remains of two 14th century smithies from Jaani street in Haapsalu are different in their building style (Article IV, 15–16). The older of the two smithies was in use in the 1st half of the 14th century with a massive raised stone forge in one corner. The smithy was built next to the living quarters containing a kiris-stove, which probably belonged to the smith’s family (Pärn 2004, 274). Another smithy, with a similar overall plan, including the living quarters, was built on top of the older smithy (Pärn, Russow 2006, 491). The difference between the Tartu smithies lies in the use of stone as the main construction material for the forge, and combining the workshop together with the living quarters. This difference might indicate a variation in the craft organisation between the smaller town of Haapsalu and the larger town of Tartu. The Tartu smithies were excavated near the former Smith street, where different activities like iron, bone, and non-ferrous craftwork were practiced (Haak 2007, 22), and it is likely that the craftsmen lived someway away from the dust, smell and noise of the workshops.

Innovation was slower to reach the peripheral rural areas, where Iron Age traditions were more persistent. The earliest smithies at the Paatsa site are mentioned above (see ch. 5.1.2), but the three smithies dating to 13th–14th centuries were very well preserved (Peets 2003). Paatsa is similar to other smithies like Gubbacka and Käku that subsequently burned down but were rebuilt on the same place. The smithies of Paatsa III and IV are dated to the 13th century, and from the late 13th to late 14th centuries respectively. They were both built with ground level pit forges (ibid., 181–187). The latest smithy of Paatsa V, dated to about 1325–1400, and was built with a larger forge, which could have been fitted into a timber frame (Article IV, 15). This puts the smithy of Paatsa in the same group as four other smithies, which originally contained a pit forge, but was replaced with a large raised forge in the later stages of the smithy (Article IV, 20). According to Peets, the Paatsa smithy was mainly focused on primary forging with the bloomery iron coming from the nearby Tuui smelting complex (2003, 352). As the most intense iron smelting in the Tuui region is dated to 12th–14th centuries, the smiths working in the Paatsa III-V smithies would have inherited the pre-crusade traditions. As the Gubbacka smithy in Finland has a raised rectangular forge in the 13th century the latest, and the smithies of Paatsa V and Käku have them in the 14th century, it is most likely that the practice of building
large raised rectangular forges spread to the rural areas during the 13th–14th centuries.

Käku is an example of a rural smithy where diverse crafts were being practiced, including primary smithing, the forging of bladed tools and other artefacts, the casting and forging of copper alloys, and boneworking (Peets et al. 2013; Article I). In addition to production waste, the smithy contained a large quantity of objects which could either have been scrap metal brought to the smithy, or finished products made there. The smithy operated during the 14th–17th centuries and the tonnes of slag present indicate that intensive activities happened there (Article I, 196). The excavations revealed four smithies, of which the three earlier ones were log houses, and the latest smithy was a log house with a simple stone foundation (Peets et al. 2013; Article I). The layout of the smithies was similar, as all of them had reused the massive stone forge (Article IV, Fig. 5). While there are no door remains, the doorsills of smithies 2 and 3, and the location of the large slag heaps enable the door to be located in the southwestern wall. For smithy 4, the same features placed the door in the southeastern wall. Therefore, the door in all cases was located on the southern side of the smithy, perhaps to maximise the amount of sunlight let in if the door was open. There was a water tank in the floor of the smithy during its earlier phases, which was filled in when the latest smithy was in use. A similar water tank can be seen in use in many periods, starting with smithies in Roman Britain and Viking Age Iceland, and ending with a 16th century gold and silver mine workshop in Austria (Pleiner 2006, fig. 57, fig. 61, fig. 63).

Only the base of the forge had remained and it seems that the two earlier and two later smithies had a slightly differently shaped forge. The earlier had a dimension of 2.3 × 1.8 m, while the later was slightly larger, reaching 2.6 × 2 m (Article I, 195; Article IV, 17). Both forges did not have any compartments under the forge, which is a feature of older forges based on ethnographic sources. In the 19th century, rural forges usually had the space to store charcoal or iron beneath the forge (KV 98, 173). A fire pit lined with stones and clay was made on top of the large forge base, which based on the slag bottoms was between 10–20 cm in diameter. Unfortunately, not much can be said about the upper parts of the forge. The ethnographical smithies were either open, had one wall for the protection of the bellows, had a stone or metal arch, or had a full chimney (Linnus 1962, 163–167), out of which the open forges are the oldest types (Article IV, 17). The forge construction of the smithy at Käku is more similar to the urban smithy at Haapsalu than the rural smithy at Paatsa. The smithy at Käku expresses a new way of building smithies, that was copied from urban ones, which continued to be in use up until the early 20th century.

The earliest Käku smithy (14th–15th centuries) already had a stone-paved floor and a massive raised forge, therefore we cannot see a development in how the earliest Käku smithies were designed compared to the later ones. A degeneration of the smithy could also be seen, as the earliest one was paved and had an area of 43 m², while the latest (16th–17th centuries) was unpaved and the area was only 26 m² (Peets et al. 2013, 97; Article I, 195). It could indicate a decrease in
production caused by the end of local iron smelting, as primary smithing might have been one of its income sources.

### 6.1.4. Smithery

The craftsmen who settled into the newly founded towns in 13th century Estonia arrived with new techniques. Also the constant movement of craftsmen during the 13th–17th centuries kept metalworkers up to date with the rest of Europe (Article V). The investigation of arms and armour provides a good reference point for the level of metallurgy during this period. For example, the Kodasoo kettle hat studied by Jaak Mäll is one of the few pieces of armour that can with certainty be dated to the 13th century (Mäll 2011). Mäll rules out this helmet being locally made (ibid., 86), but I think this argument needs consideration. I agree with Mäll’s opinion that the kettle hat probably did not belong to local Estonians fighting against the crusaders. But the armour in the second half of the 13th century was probably very varied. German or Danish soldiers could have instructed local smiths to make this type of helmet, or alternatively it could have been produced by a newly settled foreign armourer. The main argument for it being foreign is that the iron has a high manganese content (ibid., 88), but this is not a good indicator as the North-Estonian iron ore can also have a high manganese content. For example, a high manganese iron ore found near the Tallinn TV tower has been used three times in successful iron smelting experiments.

The slag from the iron smelting site of Tõdva also has high levels of manganese, which could originate from maritime iron concretions (Kiudsoo et al. 2009b, 101).

Mäll’s analysis determined that the helmet was made from bloomery iron (although the indirect process cannot be ruled out), and the iron it was made from had a heterogeneous carbon content, a layered structure, and it was not heat treated (2011, 89–91). The helmet was made from plates with an approximate thickness of 2–2.5 mm, which were cut with the help of a pattern, then hammered to the right shape, and riveted together (ibid., 90). Steel was not used for making the helmet, but even though iron is rather soft for armour, it is found even among 15th century Italian specimens (Williams 2003, 62, table 1). Thus, the hardness of the metal should not be overemphasised. Metallographical investigations by Peets of 14th–16th century crossbow bolts also found examples of soft iron (Mäesalu 2004, 240), which suggests that good quality steel was highly valued.

Peets researched 13th–18th century smithery using the archaeological assemblages from six village cemeteries. He concluded that the general quality of the objects was lower compared to those from the 9th to the early 13th century (Peets 2004, 240).
2003, 260). But, he left out the 13th–14th century knives from the castle of Otepää on the assumption that these were imported (ibid., 240). However, this might not be correct, as the smiths who settled in Estonia after the crusade mainly came from German speaking regions, and the castle of Otepää certainly needed at least one smith. The knives from Otepää could also have been made in Tartu, which was the closest large handicraft centre. The rural smithy at Käku was quite far from any castles or towns, but it also had knives with riveted bone and antler handles among its assemblage that are similar to the Otepää knives (Saage 2013, 38).

The investigation revealed that out of the 21 Otepää knives, only 1 was made out of plain iron and one was incorrectly made as the steel and iron had been mixed up (Peets 2003, table 14). The rest of the 19 knives were either made of steel (3), had a layered forging pattern of steel and iron (12), or had a carburised blade (4) (Peets 2003, 240). By adopting the grading system by Pleiner to determine the quality of the metalwork (Pleiner 1967, 98), then the Otepää knives score as highly as the 9th to early 13th century Estonian knives (Peets 2003, 260). While the hillforts and strongholds of the Viking and Final Iron Age relate to people of a higher status, the medieval and Early Modern village cemeteries do not. Hence, the greater quality of the Otepää castle knives compared to the village cemetery finds probably reflects the wealth inequality of the medieval people.

While osmund iron gained a strong position in the marketplace, bloomery iron continued to be made in Scandinavia and Finland in the 15th–16th centuries. During the primary forging of bloomery iron the smiths could evaluate its quality and working properties. The finds from the smithy site of Käku contain blooms at different stages of refining, but also an example of a discarded bloom piece (Article III). One of the reasons why iron could have been discarded was its malleability, which is connected to its carbon and phosphorus content. A bloom piece (AI 6845: P56) that was rejected had an average phosphorus content of 2%, which in some measurement locations reached as high as 14% (Article III, 49-50). Phosphorus content this high makes the iron very brittle and this was probably noticed by the smiths, who had thrown this piece along with other similar lumps into the corner of the smithy (Article I, 197).

The other bloom pieces and bars left in this smithy are more difficult to explain, because they were of a good quality and there seems no reason why they would have been rejected. These items probably represent extra material stored in the smithy at the time it burned down. The bloom pieces reveal that at least part of the assemblage arrived at the smithy without prior primary forging (Article III, 54). The 12th–13th century finds from the smithy of Gubbacka show that not all smithies were involved in primary forging (Willim, Grandin 2010, 7). Hence, some smithies such as Käku and Paatsa, were also involved in preparing material for other smithies.

The scrap metal bar from Käku is a unique find, as it demonstrates how old tools were reused. The bar consists of one knife, two scythes or sickles, and one wide-bladed knife or scythe (Article III, 54). Regardless, all four blades have been made from steel and iron, so it could also be called a scrap steel bar. The
microstructure has martensite, which suggests that the bar might have been hardened to test its carbon content. The finds from the smithy also include 26 padlocks or their fragments, most of which were deliberately broken (Tammoja 2016, 36). When looking at the hundreds of iron objects found here, it is likely that there was a significant amount of scrap metal used in the forging of new items using, and that scrap metal was systematically collected for that purpose.

The local smiths probably faced a lot of competition from imported iron goods, sold in both the towns and rural areas. The imports included knives, razors, kettles, needles, plough shares, scythes, and other tools as well as jewellery (Sepp 1987, 35–36 and the cited literature). Weapons and armour were also imported – the latter is illustrated by a 16th century armour set in the Estonian History Museum, that contains pieces made in the Innsbruck, Augsburg, Ladshut or Nürnberg region (Mattila 1998).

New trends in building construction appeared in 16th century Europe, and at this time nails started to be used in greater numbers, mainly for floorboards (Buchwald 2008, 282). Englebert des Presseux invented the splitting mill in Wallonia in 1513, which enabled the production of iron rods from iron bars and greatly increased nail production in the region (ibid.). This invention also reached Sweden and Germany in the 17th century (ibid.), and it is reasonable to believe that the price of nails (or at least the price of the rods they were made from) went down as well. In addition to rods, the splitting mills could also produce other iron objects, for example barrel hoops, horseshoes etc (ibid., 283).

6.2. Non-ferrous metalwork

6.2.1. Metalworkers

The pre-crusade period is characterised by a lack of written sources about metal-workers and their craft. This leaves archaeology as the only source of evidence to elucidate different aspects of this trade. The situation changes from medieval times onwards, as the Tallinn city archives have provided substantial information about the hierarchy, specialisation, and organisation of the craft. While informative in many ways, the written sources do not tell us much about the skill levels of the craftsmen nor do they go into technical details. There are two separate data sources, where the written records talk about the craftsmen, their professions and guilds, and where the archaeological sources, while including tens of thousands of finds, usually are difficult to associate with the different branches of metalworking. Researchers, who have combined written sources with artefact studies (e.g. Vende 1967; Konsap 1971; Kirme 2000), have usually used items from the historical collections of churches, brotherhoods, and other organisations, which are mostly intact and uncorroded. I was also unable to totally close this gap and the sources provide a historical framework to interpret the finds.

The organisation of metalworkers in the second and third quarter of the 13th century is difficult to characterise, as there are no written sources and it is unlikely
that any paperwork was generated at all among them. Most likely it was a period, when local craftsmen worked together alongside foreign metalworkers and many new techniques were introduced in a short period of time. That being said, Kirme thinks that local silversmiths, and goldsmiths with a western origin did not form a single school of metalworking, although they were working in one region (2000, 17). The technical innovations and tools moved around with the help of travelling masters and their apprentices between the German speaking towns (Article V).

The medieval and Early Modern craft guilds are the epitome of the metalworkers professional organisation, and after their demise, this level of organisation has not been seen again. This professional organisation was a gradual process, which according to Kaplinski can be separated into an early crafts guild period between 1275–1350, and a developed crafts guild period 1350–1775 (1980, 149). In the early period, there were no ethnic restrictions for joining the guild, and there are no surviving guild charters (ibid., 139). The developed craft guild period was characterised by it being compulsory to be a member of the guild, which had a monopoly over the production and marketing of all metalworking products (ibid.). Economic sanctions were employed against guildless smiths, who were seen as competition (ibid.). The town council established charters for the craft guilds – the first charter for the goldsmiths' guild was in 1393, and the earliest blacksmith's guild charter dates to 1423 (ibid., table 7).

The implementation of the craft guild system with its regulations must have unified the artistic and technical competency of metalworkers to some degree, although an individual’s skills should also not be underestimated. While knowledge about 13th–14th century church silver is lacking, 15th century pieces were crafted to a quality that sets the local goldsmiths at the same level as their European counterparts (Kirme 2000, 207). The evolution of local Renaissance art was hindered by the Reformation and by losing the Roman Catholic Church as its main sponsor (ibid., 42). Whilst rich citizens took over the role of buying art across the rest of Europe, the long period of war and disease in Livonia during the 2nd half of the 16th century slowed the advance of local goldsmithing (ibid.). On the other hand, many silver hoards were buried during this time that provide some insight into rural silversmithing.

The written sources involving metalworkers often appear in the context of competition between the guild members and those that were not. During the Livonian Diet of 1495, there was a complaint that local silversmiths were competing with the craftsmen of German origin (Vende 1967, 30). Another account from 1540 mentions the monasteries of Padise and Kärkna, and some noblemen, housing guildless craftsmen, who put the town metalworkers out of their jobs (Friedenthal 1931, 33). These conflicts also reflect cooperation and exchange of skills and techniques between urban and rural metalworkers – there is a complaint from 1611 by the blacksmiths to the town council of Tallinn, that the rural smiths have so many apprentices of Estonian decent, that there is no room for German apprentices (Article IV, 19). This shows that the urban smiths considered the rural smiths skilled enough to train their apprentices. In addition, the metalworkers seem to be quite mobile, as between the years 1461–1906, a
total of 937 apprentices studied goldsmithing in Tallinn, 63 of them never finished and 147 of them became master goldsmiths (Vende 1967, 15). That leaves 727 trained goldsmiths of whom, most probably moved to other towns. Some of them could have set up their workshops in manors, monasteries, suburbs, small towns, or rural settlements.

### 6.2.2. Metal, crucibles, and casting sites

The research into provenancing the sources of imported copper alloys, tin, pewter and precious metals is fragmentary at best, but holds great potential in the future. There are occasional references to copper being imported from Sweden in the 15th century (Sepp 1987, 31), and also some 17th century tin tableware, where England can be identified as the source of tin (Liivak 2018, table 2). Craftsmen were required to punch the mark of the town on their produce if they got their raw material from the town council. The earliest evidence for this practice is written in the charter of the goldsmiths’ guild in Tallinn in 1537 (Vende 1967, 13). Scrap metal was probably used as much as possible, and a good example of reuse comes from the smithy of Käku, where a copper alloy cauldron leg has been split with a chisel, probably for it to fit in a crucible (Article I, Fig. 7).

The first direct evidence of Swedish silver mines originate from the mid-14th century (Oldeberg 1966, 30), and Swedish silver was probably also used for making jewellery. However, as a result of a silver shortage in the 17th century, Sweden was the first country in the Early Modern Period to adopt copper for minting their coins (Tvauri 2016, 43). There are also examples of coins minted in Bolivia and Mexico in 16th century hoards found in rural Estonia (Tvauri 2017, 87). There were coins from Sweden, Poland, Russia, Netherlands, Germany, and England circulating in Livonia from the mid-16th century up until the end of the 17th century as nominals from (Küng 2013, 183–184 and the cited literature), some of which were probably also used by the local silversmiths in their work. Hence, there were a number of silver sources and both the written and archaeological records could be employed to clarify the source regions for different time periods.

The use of mixed scrap metal means that provenance studies from crucible residues might be misleading. However, the residues still give information about the use of alloys. I employed the same pXRF methodology for measuring 13th–17th crucibles and casting moulds, as for studying the Iron Age finds. The crucibles from 13th–17th centuries Tallinn and Tartu frequently originate from uncertain contexts, which is why I examined the residues based on crucible types (Article V). The residues detected with the aid of pXRF do not directly correspond to the metal melted in the crucible. This is because residues from different casting events can give a mixed signal in the crucible, but larger trends can still be identified in the metalworking. The use of imported refractory crucibles in the medieval and Early Modern Period should mean that the better quality crucibles lasted for a longer time period and therefore would have more
mixed residues in them. It seems however that the opposite is true, that in many cases the crucibles might well have been reserved for selected metals or alloys (e.g. just gold or just copper). The most common residue is gunmetal (or leaded gunmetal), which can be created in the crucible if brass and bronze are consecutively cast (Fig. 2). The residues also show that copper and tin bronzes become more available to the metal casters at this time compared the pre-crusades period.

![Figure 2. Metal residues from 13th–17th century crucibles (n=96) (after Article V, Table 1).](image)

There were two crucibles that contained casting residues of pure gold. This is not surprising if we take into account the numerous mentions of goldsmiths in the written sources. The more intact of the two was a triangular Hessian crucible found in the Riaia suburb of Tartu. The other was probably also a Hessian crucible and it was found from the Harju suburb of Tallinn. There are also crucibles where gold residues were found along with silver and copper alloy, which shows that the craftsmen had different preferences, when working with precious metals (Article V).

The excavations at Lossi st 3 in Tartu revealed several furnace remains that were attributed to casting non-ferrous metals. Two of them were found close to a 13th–15th century workshop (Metsallik 1992, 158). One of them was built from clay on a wooden frame and it had an opening about 30 cm wide (ibid.). The copper alloy waste on the ground, a clay buckle mould, and tuyere fragments around the furnace, all indicate that copper alloy casting took place (ibid.). The other furnace was also built on a wooden frame and it had a clay dome about 20
cm thick, and there were also tuyere fragments and casting waste in the proximity of this furnace (ibid.). As with the smithies that were burned down and rebuilt, these could have been furnaces from different time periods, but originating from the same workshop. Furnaces like these could be used to heat the casting moulds and melt the metal. These furnaces demonstrate that a wooden frame (App. 5, e) was used to make a raised platform for ironworking and non-ferrous casting.

A heavier furnace was also found at Lossi st. It was built from stones, bricks, and clay, and the bottom of the furnace was inclined towards the mouth (Metsallik 1992, 155–156). As two lead ingots were found near the furnace, its function is thought to be either for lead casting or roasting iron ore (ibid.). Instead, I see a similarity with German melting furnaces for non-ferrous casting. The Tartu furnace can be compared to the furnace from Bonn-Schwarzreindorf (Drescher 1987), in that the preserved part of the furnace could be the bottom level meant for ventilation and ashes (App. 11). A surface of clay reinforced with iron would have been built on top of it, where the crucibles and the metal stood. Another massive furnace was found at the site, which has been connected with non-ferrous casting (Trummal 1992, 9–10). These remains could also have belonged to a similarly constructed furnace, meaning that the preserved part was used for ventilation and ashes. But there are no analogues for this furnace that I know of. As most of the imported crucibles had a flat bottom, then the 13th century furnaces could have featured a solid surface for placing the crucibles on (Article V). Also, as crucibles were part of the essential working kit for a non-ferrous metalworker, it can be assumed that the first foreign craftsmen settling into Tartu brought some crucibles with them.

A variety of crucibles were in use during the 13th–14th centuries, but the most dominant type seems to be a quite wide, flat-bottomed crucible with a round mouth (Article V). It probably also had one sprue, but unfortunately no intact examples have been found. At least three compositions can be observed based on the fracture surfaces: 1) white or light grey crucibles; 2) grey crucibles with a partly or completely vitrified fabric; 3) dark and glossy crucibles made from a graphite rich clay.

It is likely that pit forges continued to be used after the crusade. Conical crucibles (most likely made from local clay) that resemble their Iron Age counterparts have been found in both Tallinn and Tartu (Article V). Although, attempts to connect ethnic groups with archaeological finds can be misleading, these crucibles might have been used by local Estonian craftsmen that moved into the growing towns during the 13th century (Article V). In the towns the use of conical or round-bottomed, cylindrical crucibles from local clay extends to the 13th–14th centuries, but by the 15th century they had fallen out of use (Article V). The rural smiths seem to have been reluctant to stop making their own crucibles. This is illustrated by the deformed 14th–17th century crucible fragments from the rural smithy at Käiku (Article I, 198–199).

A number of casting related finds at Tallinn concentrate in the vicinity of the river Härjapea (Article V, Fig. 1), some of which relate to the casting of pewter or lead into stone moulds. There are also two crucible fragments (AI 7032:
that date roughly between 1250–1500 (Article V). The remains of a copper foundry were also found in this area, dating to 1297–1430 (Lavi 1998, 223). Although the foundry was situated about 130 m away from the river Härjapea, it is possible that a watercourse was directed towards the workshops to run the bellows via a waterwheel. While the earliest written evidence for a copper smithy on the river Härjapea comes from 1531, further archaeological investigation might reveal evidence of water powered foundries and smithies dating back to the 13th–15th centuries.

The evidence for casting large objects such as church bells and cannons is very fragmentary. A useful source for the study of bellfounding is the list of expenses incurred for the casting of St Olaf’s new church bell in Tallinn (Mänd 2016). This list contains information about the number of the workers and their salaries, and the raw materials needed (Mänd 2016, 59–60). Caldron caster Merten was hired as the bellfounder, while the iron parts were commissioned from blacksmith Gosschalk, and the hemp rope was bought from Andreus Resenborch. Amongst the 42 auxiliary workers hired were a cook and a man to heat the sauna. A quarter of a cow, three rams, and 17 barrels of beer were bought to feed the men. Six men from the town workyard were also on the payroll (ibid.). Included in the expenses were 100 bricks that were probably for the furnace and the mould. In a 16th century treatise, Biringuccio mentions that masonry skills are required to build a furnace and mould (Smith, Gnudi 1990, 216). The materials needed for the mould (and the model) included eggs, tallow, metal wires, and 10 oaken rings, while wool, charcoal and vinegar were also bought for the casting (Mänd 2016, 59–60). Biringuccio also mentions wool as one component of the mould. He suggests mixing clay with woollen cloth clippings in the ratio of 1/2 (Smith, Gnudi 1990, 219). The sacristian was another specialist who was hired to place letters on the church bell (Mänd 2016, 49). The bronze for the bell originated from two sources: firstly, the old bell was broken apart and brought down from the tower, and secondly extra bronze was bought from Andreus the coppersmith (ibid.). Based on the list of expenses, the casting most likely took place at night (ibid.), which was necessary to evaluate the temperature of the furnace and the burning of the mould.

Biringuccio wrote that bellfounding needs determination, to learn from your failed attempts and not to give up (Smith, Gnudi 1990, 214). There is one account in 1441 of a bellfounder coming from Gotland to Tallinn, to cast a church bell, and failing in his first attempt (Mänd 2016, 49), hence there is good written evidence for how demanding this process was. If we consider the list of expenses and the number of people involved, then a failed cast must truly have been a disaster for the bellfounder. The aforementioned casting of a bell for the church of St Olaf seems to have gone well.

The archaeological excavations in the town workyard (mentioned in the list of expenses as the casting site) revealed a wall made from bricks and limestone with traces of high temperatures on it (Tamm 1974, 9). Tamm thinks that the remains belong to the foundry that operated in the workyard from the late 14th to 16th century (1976, 74–75). As the wall is situated very low compared to the buildings
next to it, it might be the location of the casting mould for a large object like a church bell or a cannon. The casting mould was burned on the site prior to the casting event, which would explain why the walls were exposed to high temperatures. The furnace for melting the bronze had to be positioned higher than the mould, as the molten metal was poured directly into the mould. Unfortunately there are no furnace remains at this site.

Smaller bells and cauldrons could also be cast with large crucibles. These crucibles had to be resistant to high temperatures and mechanically strong enough to withstand the weight of the metal during lifting and pouring. There are some large graphite crucibles from Tallinn that could have served this purpose, but unfortunately they were all excavated as loose finds (Article V). The elemental analysis from these crucibles detected the following residues. Leaded copper, leaded gunmetal, and leaded gunmetal with antimony (Article V, Table 2). There are examples of cauldron fragments in Estonia that contain all of these alloys (Saage 2013, 27–28; Article V).

Jaak Mäll is convinced that Hessian mullite and Bavarian graphite crucibles were already available to Estonian craftsmen through the Hanseatic trade network in the 15th century (2017, 82). Previous research has not investigated the composition of medieval and Early Modern crucibles, so it is possible that Hessian mullite crucibles are among the low and wide crucible types with a round mouth (Article V, Fig. 3, Group C). The current evidence suggests however that the tall and narrow crucibles with a triangular mouth (the form that is generally referred to as the Hessian mullite crucible), were adopted in the 16th century. Dating the arrival of Hessian crucibles to Estonia is problematic due to the quite imprecise contexts in which the Hessian crucibles usually are found. However, the the well dated contexts containing a high number of crucible finds from the 15th century do not feature the triangular Hessian type (Article V). Mäll is right about the graphite crucibles. While graphite crucibles are quite rare among Estonian finds, there are some examples that date earlier than the 16th century (Article V, Fig. 3).

### 6.2.3. Casting of tin, lead, and pewter

The casting of alloys with a low melting point into stone moulds was common in the pre-crusade period, and the casting waste can be found at hillforts and strongholds (Article II). This means that the boom in tin casting in central Europe during the 13th century met a tin casting tradition in Estonia that was centuries old (Article V). The tin casting innovations (such as air vents to let out excess gases) that were adopted in Germany in the 13th century, reached the medieval towns of Tallinn and Tartu during the second half of this century at the latest (Article V). Stone moulds also became more complicated, as three-piece moulds for buttons and finger rings appeared among the 13th–14th century finds in Estonia (Article V). The socketed casting ladles that had been used continuously from the 8th to early 13th century, were rejected by town craftsmen, as they have not yet been found in urban contexts. Crucibles were one alternative option to these
ladles, as I found lead and pewter residues from four different crucible fragments (Article V, Table 1). The other option is that they used metal casting ladles, but unfortunately no such ladles have yet been discovered that contain residues of tin, lead, or pewter.

Another option would have been to use domestic pottery, and there seems to be evidence for that. Three different sites in Tallinn, both from inside the town and in the suburbs, have revealed ceramic bowls containing mainly lead melting residues (Article V). The bowls are not optimal vessels to melt lead though, because of the very large oxidizing surface. However, they might have been chosen because of their volume, if it was necessary to melt lead window camees or other large objects.

It is remarkable just how persistent the tin casting tradition has been. The rear of two-part casting moulds from Viking Age Rõuge (Keeman 2017, 69), Final Iron Age Lõhavere hillfort (Article II, Fig. 4: 8), and the 15th century suburb of Kalamaja, Tallinn, differ only by the number of fastening loops on the rear. Also the round tin plaques found on clothes from the 7th or 8th century up until the late 16th century remained relatively unchanged, as do the rectangular plaques that appeared at the same time, but lasted up until the 19th century (Keeman 2017, 84).

Most of the surviving moulds were made out of stone, but there were also wooden and metal moulds. The rear of a two-part wooden mould was found in the suburb of Tallinn (Jahu st 6) in which two rectangular objects could be cast at the same time. This 15th century mould also countained zinc and lead residues (Article V). A metal mould was made to produce tin tokens for the house of the poor of the Holy Spirit in Tallinn, about the mid 16th century (Leimus 2012, 268). It is a two-sided mould, which was in turn made in leaded gunmetal using the lost wax technique. Ten tokens could be cast at a time, and the pXRF measurements of the residues identified tin. Although it must be remembered that this residue might originate from much later casts, as the mould is not an archaeological find, but a historical curiosity collected in the 19th century (Article V). Also similar experimental casts during the 19th–20th centuries have been made with other moulds (e.g. AI 4061: 2333).

The low number of stone moulds from the 13th–17th centuries makes it difficult to find temporal changes in mould residues. The residues from the 13th–17th centuries are quite similar to those from the Iron Age. Tin, lead, and pewter dominate the finds, and residues were undetected in about half of the moulds (Article V, Fig. 7). There was one unique find among the stone moulds. The mould for casting mill tokens in Tallinn (dated to 1537) had residues of lead and mercury. A mill token that had been cast in the same mould consisted of tin, mercury and lead (Article V, Table 2). This unusual alloy could have originated from recycling tin-mercury mirrors, which were also made in the 16th century (Article V). The stone mould from 1537 also had venting channels, and it was very finely carved, which points to a highly skilled craftsman.

In summary, the biggest changes in the casting of tin, lead, and pewter in Estonia occured during the 13th century. From that period onward the technology persisted unchanged up until the 19th century.
7. SUMMARY

This thesis analyses Estonian metalworking sites and their waste from the 7th–17th centuries. I focus on two branches of metalworking: ironworking and non-ferrous casting. My contribution has been to answer certain questions regarding workshops, production technologies and available metals by using analytical methods (metallographical and pXRF analyses) and digital documentation techniques. Time frame of the research enables me to look at developments over a long time span and see the connections between metalworking and changes in the society.

The research into the casting tools employed in the production of copper alloys and precious metals suggested that the Iron Age metalworkers in Estonia only used crucibles made from local clay. These crucibles were heated from the side and the bottom during the 7th century at the latest. Their shapes were mainly round-bottomed and cylindrical, conical, or pear-shaped. A degree of standardisation took place during the 11th to early 13th century, but mainly manifests within the confines of a single metalworking site. As these crucibles are very similar within this site, it can be assumed that they were made locally from one template. Some ceramic types used for crucibles in Scandinavia and Russia are associated with goldsmithing and assaying, have not been found in Estonia. This suggests a lower level of goldsmithing specialisation (or the absence of specialised goldsmiths altogether), which is supported by the low number of gold artefacts and the rarity of gold in the residue of crucibles.

The residues from crucibles and stone mould casting were analysed using pXRF. The results revealed the alloys cast in them. Copper alloys were most common in the Iron Age crucibles, and creating temporal groups helped to spot some trends. Between 600–1050 CE, brass and leaded brass residues were the most common, but the casting of silver and tin was also took place. These alloys were also the most frequent for the next time period, 1051–1227 CE, but several new alloys appear during this time including leaded bronze, gunmetal, unalloyed copper and leaded copper. The variety and circulation of fresh metals therefore improved during this period, which suggests that copper, tin or bronze ingots became more readily available to metalworkers. This result agrees with the elemental analysis of Novgorodian finds and is probably indicative of an intensification in metal trade around the Baltic Sea. Silver casting finds were found to concentrate near hillforts, strongholds, or the settlements next to them. Silver residues where found in 27% of the crucibles, which was unexpected, making it a common casting metal.

Stone casting moulds and ceramic ladles were part of a tool kit for casting alloys with a low melting point. They mainly left behind tin and pewter residues. These finds mostly occured in the same context as silver casting. Tin casting tools were also deposited as grave goods, although the burial sites were not places of production. The analysis of the tools from these burials showed that they contained residues. This means that they had been used prior to burial and were
not specifically made for it. Casting ladles retained their socketed shape and oval mouth throughout the 7th to early 13th century. In many cases stone casting moulds were made out of well carvable stone, imported into Estonia. The moulds were used for casting simple pendants, mounts, and plaques that were sewn on clothes and belts.

A tin casting boom happened in Europe during the 13th century aided by the opening of new tin mines. This resulted in a greater variety of tin artefacts being produced, together with more complicated moulds to cast them. These changes also reached Estonia, as evidenced by the stone moulds from the towns of Tartu and Tallinn, possessing new technological innovations (gas vents), and also new artefacts types (rings and buttons) not seen in the pre-crusade period. The production of tin plaques, in stone moulds in rural areas, seems to be the most conservative branch of this metalworking tradition. It can be traced from the 7th to the 19th century. However, socketed casting ladles disappear after the 13th century crusade, following which tin was cast either with metal ladles or crucibles.

A number of metalworkers continued using Iron Age crucible types in the towns of Tartu and Tallinn during the 13th–14th centuries. The immigration of western craftsmen in the 13th century led to the appearance of new types of imported crucibles, which were more resistant to heat and therefore lasted for longer than locally made crucibles. Another change was the building of large furnaces, probably featuring a solid floor, as most of the imported crucibles were flat bottomed. Future research will be need to identify where these 13th–15th century crucibles were imported from. By the 16th century at the latest, triangular Hessian mullite crucibles reached Tallinn and Tartu. This is part of the wider spread of this crucible type across Europe and America.

The residues left behind in 13th–17th century crucibles were dominated by copper alloys, with leaded gunmetal being the most common. While local crucible types seem to go out of use in the 15th century, the phenomenon of melting lead in large open bowls, reminiscent of domestic pottery, took place. There were two instances where pure gold residues were identified, indicating specialised goldsmithing took place. It is not surprising to find evidence of goldsmithing as it is mentioned numerous times in the written sources, but it contrasts sharply to the evidence from the Iron Age, which lacks such finds.

Metal casting in the newly founded towns replaced production in the hillforts and strongholds after the early 13th century crusade. Towns were thriving centres of commerce, including the trade in metals and imported crucibles, as well as a popular destination for foreign craftsmen. Hence, the towns had a high impact on the local crafts. European trends were more visible in urban casting techniques than local peculiarities by the 15th–17th centuries.

The analysis of the different tools and weapons from Iron Age Estonia, has provided evidence of specialised weaponsmithing taking place. This competence in ironworking was unlikely to disappear after the crusade, hence there is reason to believe that many local ironworking specialists existed in the 13th century, who had to cope with a changing situation. Local iron smelting in the 13th–14th
centuries provided a degree of independence for the smiths. As iron smelting and forging was not concentrated to hillforts prior to the crusade, local ironworking was less, or at least more slowly influenced by production at the newly founded towns. Several smithies dating to the 12th–14th centuries around the Baltic Sea region show evidence for the technical evolution from a simple pit forge to a large raised rectangular forge base. There are too few smithies dated to the 13th century to draw firm conclusions, but at least this development from pit to raised forges is contemporary to the influx of German and Scandinavian craftsmen into the growing towns. While the local blacksmiths were familiar with this kind of smithy design by the Iron Age, it was widely adopted during the 13th–14th centuries. Forges that are similar to the 14th century design can also be found among many 20th century ethnographic forges, which demonstrates how conservative metalworking traditions can be. The spread of this forge design might have been aided by the exchange of smiths between rural areas and the towns. A raised forge means that the working stance of the smith changed from crouching or sitting to a standing position.

The smithy site at Käku on the Island of Saaremaa, has provided useful information about rural smiths working in the Late Medieval and Early Modern Period. The smithy operated from the 14th–17th centuries, which is quite a long time period, and survived numerous political and economic changes that would have had an effect on the availability of raw material for continuing production. The finds from the site include discarded bloomery iron, blooms and bars at different levels of primary forging, and a reused scrap metal bar. This suggests that the first stage in forging an object could have been primary smithing, in order to obtain an iron bar suitable for secondary forging. The finds also included a knife billet showing that good quality steel was available there. However, the scrap metal bar was forged from old tools with a high carbon content, which suggests that steel was expensive and reused whenever possible. When local iron production ended in the early 15th century, the local smiths had to use imported iron. It is likely that there were multiple sources of iron, but one source seems to be bloomery iron produced in Scandinavia or Finland.

There were thousands of finds from the smithy site at Käku, and their ongoing analysis will continue to answer different questions in the future. Knives were certainly made in the smithy, which is evidenced by the knife billet and tens of knives, together with bone and antler waste from the manufacture of knife handles. Intensive primary forging was also undertaken in the smithy, as attested by the 1.5 tonnes of slag found in the excavation plot alone. Primary smithing was a source of income for the smithy as the purified bars could have been sold to other smiths. Copper alloys were also forged and cast in the smithy using scrap metal as the source material.

The construction remains of four consecutive smithies were also found, out of which the three earlier smithies had been built out of logs without a foundation. The latest smithy had a row of stones for the foundation. The position of the smithy changed slightly each time it was rebuilt after the previous smithy had burned down, but in all cases the massive forge base was reused in same location.
The smithy of Käku more resembles the 14th century urban smithies at Haapsalu, than the 13th–14th century rural smithies of Paatsa. Hence, the smithy of Käku represents a new phase in Estonian metalworking history, where the ties to the Iron Age traditions had mostly been severed.
KASUTATUD KIRJANDUS / REFERENCES

Lühendid / Abbreviations
AI – Tallinna Ülikooli arheoloogia teaduskogu / Archaeological Research Collection of Tallinn University
AVE – Arheoloogilised välitööd Eestis / Archaeological fieldwork in Estonia
MKA – Eesti Muinsuskaitseamet / National Heritage Board of Estonia
PäMu – Pärnu Muuseum / Pärnu Museum
RAÄ – Riiksantikvarieämbet / Rootsi Muinsuskaitseamet / Swedish National Heritage Board
TLM – Tallinna Linnamuuseum / Tallinn City Museum
TM – Tartu Linnamuuseum / Tartu City Museum
TÜ – Tartu Ülikooli arheoloogia osakond / Department of archaeology of the University of Tartu

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Appendix 1. Image from the shooting sequence for the photogrammetric 3D model, using a 3D scale (the value of the third dimension is zero for all points).

Appendix 2. A cross section of a slag cake with a bloom inside it, from Võhma.

Lisa 5. Lihtsate lohkääside ja tõstetud ääsde tüpoloogia (Moilanen 2011 järgi): a) maasse süvendatud lohkääs; b) kividega vooderdatud lohkääs; c) kivide ja saviga vooderdatud lohkääs; d) kividest tõstetud alusega ääs; e) pinnase või liivaga täidetud puust raketisele ehitatud kividest ja savist ääs.

Appendix 5. Typology of simple pit forges and raised forges (after Moilanen 2011); a) a pit forge without lining; b) stone lined pit forge; c) stone and clay lined pit forge; d) raised forge with a stone foundation; e) raised forge on a wooden frame filled with earth or sand.


Appendix 6. Waste from brazing weights from the stronghold of Soontagana. PäMu 2767: 1241 (on the left), PäMu 2767: 1246 (three on the right).


Appendix 8. A casting mould from the Vabaduse Square excavations in Tallinn (AI 6860/IV: 211). A cross shaped pendant mould (left) and back sides with hoops for ornaments (right).
Appendix 9. The presumable osmund pieces from the village of Põrga in the county of Viljandimaa. TÜ 2701: 795, 796, 797 (from left to right).

Appendix 10. Ingots of pig iron from the village of Kehila on the island of Saaremaa.
Appendix 11. a) A reconstruction of a furnace for brass, side and top view (Drescher 1987); b) remains of a furnace from Lossi street in Tartu (Metsallik 1995).
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