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Iron smelting or smithery: surveying the uncertain iron working sites in Estonia

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INTRODUCTION

Several iron smelting sites were surveyed in April and September 2024 to better apprehend their characteristics and function. The survey was quite brief and lasted three days. The main aim of it was to collect slag and iron from the sites for metallographic analysis and dating. The research was done as part of the research project 'Fundamental research for iron provenancing in Estonia.' The focus was on Estonian regions from where no confirmed smelting sites were known or there was no slag in the archaeological collections to sample and analyse. There are many sites in Estonia that are known to contain slag, but often it is unclear whether this originates from smithing, smelting or both (Oks 2025). In the following pages, we will focus on the smelting site of Patjala in Jõgevamaa County and three sites on the island of Hiiumaa: Kõpu, Prassi and Mägipe (Fig. 1). We also visited two known smelting sites, Kõmsi (Pärnu County, formerly Läänemaa) and Tindimurru (Jõgeva County), which were sampled for slag. These sites will not be discussed in the article. The results of the metallographic analysis were reviewed in detail in Kristo Oks' Master's thesis (Oks 2025), and the current paper summarises these observations. Metallographic samples (abbreviated as ML) are stored in the sample collection of the University of Tartu Department of Archaeology.

Fig. 1. *Investigated iron working sites.*
Jn 1. *Uuritud rauatöötlemiskohad.*
Map / Kaart: Ragnar Saage

METHODS

At the metalworking sites, 4–9 test pits were dug. The location of the test pit was determined by a metal detector signal. The leading principle was to gather enough slag, iron and clay pieces to identify the site as a smithy or a smelting site. Soil from the test pits was inspected

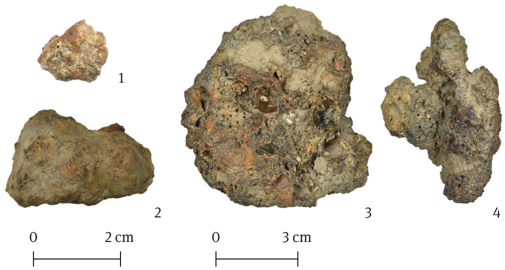

Fig. 2. *Finds from the Patjala iron smelting site: 1–2 – iron pieces, 3 – slag, 4 – melted clay.*
Jn 2. *Leiud Patjala rauasulatuskohalt: 1–2 – rauatükid, 3 – šlakk, 4 – sulanud savi.*
(TÜ 3387: 1–4.)
Photo / Foto: Ragnar Saage

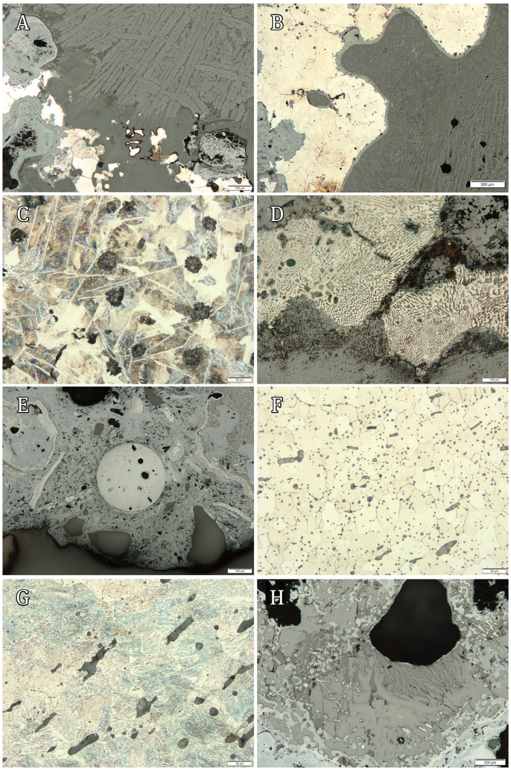

Fig. 3. *Microstructure of studied artefacts: A – ML 131, Patjala, B – ML 148, Patjala, C – ML 132, Prassi, D – ML 134, Kõpu, E – ML 135, Kõpu, F – ML 209, Mägipe, G – ML 210, Mägipe, H – ML 133, Mägipe.*
Jn 3. *Uuritud esemete mikrostruktuur: A – ML 131, Patjala, B – ML 148, Patjala, C – ML 132, Prassi, D – ML 134, Kõpu, E – ML 135, Kõpu, F – ML 209, Mägipe, G – ML 210, Mägipe, H – ML 133, Mägipe.*
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with a magnet for hammerscale and roasted ore particles. The ground was prodded with a long metal spike – a method that has worked well for archaeometallurgist Jüri Peets to locate slag deposits at large smelting sites such as Tuiu in Saaremaa.

Iron and slag finds were later metallographically analysed. The pieces were sectioned with a Buehler IsoMet 4000 precision saw, samples were mounted in thermoplastic in a Buehler Simplimet XPS1 mounting system, ground with a Buehler Automet 250 grinder-polisher, and investigated with an Olympus BX51 microscope. The iron finds were etched using a 3% nital solution. Microhardness testing was carried out with a Wilson Tukon 1102 tester on the Vickers scale, using a 0.5 kg load for 10 seconds.

RESULTS

Patjala site

The Patjala iron smelting site is in Jõgevamaa County, registered as a cultural monument in the National Registry (no. 9234). The site lies on a currently cultivated field and was first discovered by Ferdinand Sei, who invited archaeologist Kaarel Jaanits to the site in 1975 (Jaanits 1975). They collected slag and handmade pottery, possibly from the first millennium AD, from the site (AI 4848).

We returned to the site to get a better understanding of the activities there and identified an area with a significantly higher concentration of slag. From there, four large slag pieces, some melted clay, and smaller iron fragments were collected (Fig. 2). The soil samples contained magnetic hammerscale particles.

Metallographic analysis was carried out on two finds. The first piece (Fig. 2: 1; sample ML 131) contains slag, large iron accumulations and corrosion. Fayalite appears mainly as large, narrow flakes, and wüstite occurs only as very small dendrites between the fayalite flakes within the glass matrix (Fig. 3: A). Overall, the sample appears to be very glassy (silica-rich), which was visible under polarised light. The pores are often concentric and large to medium in size.

The second piece (Fig. 2: 2; ML 148) is highly porous and corroded. Ferrite appears in long, thin chains and does not contain carbon. Its microstructure strongly resembles the slag from the smelting site of Tindimurru: fayalite dominates and appears mostly as flakes (Fig. 3: B). Wüstite is also present, almost exclusively as very small dendrites within the fayalite-glass matrix, with visible wüstite bands like those in the Tindimurru sample. The slag matrix contains pores that are often perfectly round, indicating they formed in a very fluid slag (Oks 2025, 29).

A piece of charcoal was taken from one of the slag fragments (Fig. 2: 3) for radiocarbon dating, which dates the metalworking activity on the site to the 14th–15th centuries.[1] This would place the smelting site to a late stage of local iron production (Oks 2025, 65–66) at the very northernmost edge of the prince-bishopric of Tartu.

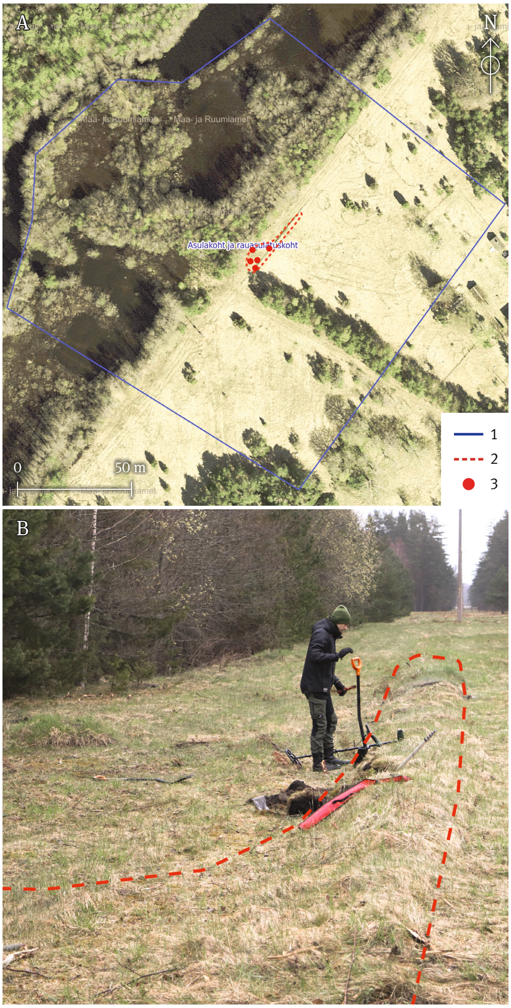

Fig. 4. *Location of the Prassi metalworking site (A): 1 – protected area of the settlement and smelting site, 2 – area with metalworking finds, 3 – test pits. The photo is taken towards the North-East (B).*

Jn 4. *Prassi metallitööpaiga asukoht (A): 1 – kaitse all oleva asulakoha ja rauasulatuskoha piirid, 2 – metallitööga seotud leidude ala, 3 – prooviaugud. Pildistatud kirde suunas (B).*

Map / Kaart: Estonian Land and Spatial Development Board; Photo / Foto: Ragnar Saage

Prassi smithy site

The Prassi settlement and iron smelting site have been under national heritage protection since 1997 (no. 8902). We received assistance from the landowner, Ain Piil, in locating the smelting site. Following his directions, we found a cultural layer containing slag in a very small area compared to the protected site (Fig. 4: A). According to the landowner, a road was constructed over the site leading to a quarry in the late Soviet era. The exact year it was dug remains uncertain, it happened after 1977, probably in the 1980s. During this process, part of the humus-rich topsoil was likely pushed aside with a bulldozer to clear the path, revealing a stonier subsoil that was suitable for a dirt road. As a result, the cultural layer was also exposed, and Ain Piil had already found slag there in his youth. Currently, vegetation has grown over the area. We found the highest concentration of finds in the long heap next to the

[1] Poz-189815, 550±30 BP, cal. 95.4% 1318–1360 AD, 1388–1434 AD; calibrated with computer programme OxCal v4.4.4 (Bronk Ramsey 2021); atmospheric data from Reimer *et al.* (2020).

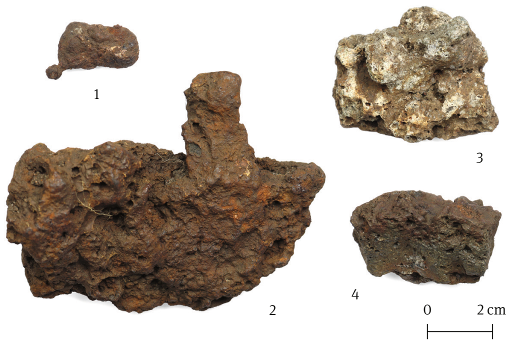

Fig. 5. *Finds from the Prassi metal working site: 1 – cast iron piece, 2 – slag with a piece of iron, 3 – melted clay, 4 – slag.*
Jn 5. *Leiud Prassi metallitöökohalt: 1 – malmi tükk, 2 – šlakk koos rauatükiga, 3 – sulanud savi, 4 – šlakk. (TÜ 3381: 1–4.)*
Photo / Foto: Ragnar Saage

road (Fig. 4: B). The finds included pieces of iron, slag, and melted clay (Fig. 5). One of the slag pieces had a piece of iron sticking out of it (Fig. 5: 2). In addition, a piece of copper alloy sheet metal was found with a metal detector.

Metallographic analysis was performed on one iron nugget (Fig. 5: 1; ML 132). The microstructure showed a very high carbon content, ranging from steel to cast iron. The edges of the sample had seen a significant reduction of carbon compared to the centre of the piece, which indicated a highly oxidising environment. The microstructure of the cast iron had spheroidal graphite in it (Fig. 3: C), which is something that we have not yet encountered in archaeological contexts. Such type of malleable cast iron was discovered in 1943 and patented in 1949 by Keith Millis. The same cast iron piece was radiocarbon dated, and the result was modern.[2] Hence, the finds collected from the Prassi site lack any evidence of ancient iron smelting. It is possible that the iron smelting site was destroyed by the quarry. However, the currently preserved metalworking remains indicate that this might have been a smithy site operating in the 19th–20th centuries.

Kõpu smelting site

Kõpu smelting site (no. 8929) is located on the island of Hiiumaa in the village of Kõpu on the Sepa (*Eng* Smith's) farm. It was identified as a smelting site by Vello Lõugas already in 1981, when the first slag finds were collected. Lõugas (1981, 3) wrote that the small slag pieces indicate a primitive and small-scale production. There was a smithy on the other side of the farmhouse, where blacksmithing and horseshoeing took place half a century ago. Hence, there might be some contamination from later iron-working activities.

The survey was done on a cultivated field, but unfortunately, about 10 cm of snow had covered the field during the previous night, so a metal detector was used to locate the iron working finds and four test pits were dug. The finds included slag, fragments of copper sheet metal, and nails. The soil was quite dark, and it contained large amounts of hammerscale, indicating intensive smithing in the area.

Two pieces were analysed metallographically. The cross-section of the first sample is heavily corroded and porous (Fig. 6: 1; ML 134). The shape and size of the pores vary. The sample contains a significant amount of cast iron, which appears as pearlite and ledeburite (Fig. 3: D), and includes graphite flakes. The microhardness of the cast iron ranges from 430 to 593 HV. In the slag, fayalite appears mostly as flakes, while wüstite appears both as dendrites and in irregular forms; there are also large areas where wüstite is absent. Radiocarbon dating was conducted on an analysed piece of cast iron, placing it in the 10th–12th century.[3]

[2] Ua-86018, 99±25 BP, cal. 95.4% 1809–1923 AD (calibrated with computer programme IOSACal v0.4.1 (Costa 2018); atmospheric data from Reimer *et al.* (2020).
[3] Ua-86019, 1008±49 BP, cal. 95.4% 973–1161 AD (calibrated as previous).

During this time, the production of cast iron was neither intentional nor desirable, because it is unmalleable.

The cross-section of the second Kõpu sample is highly porous, corroded, slaggy, and contains a significant amount of glass (Fig. 6: 2; ML 135). Wüstite appears as dendrites, and the fayalite in the background is uniform. At the edges of the sample, carbon-free iron is present, with a microhardness ranging from 135 to 150 HV. The carbon content increases toward the centre of the sample. In the centre, pearlitic steel is found with a microhardness of 244–268 HV. In some areas, a mixture of slag and ferrite is observed. Within the slag, there are hammerscale flakes and a rounded hammerscale sphere (Fig. 3: E), indicating forging, which means that this sample represents blacksmithing slag.

Based on the heterogeneity of the macrostructure in both samples, it is likely that Kõpu was a smelting site, where high-carbon iron – probably unintentionally also cast iron –, was produced during the Viking and Final Iron Age Iron Age periods. Sample ML 135 also provides evidence of local blacksmithing, which was standard practice at any smelting site for the initial forging of bloomery iron.

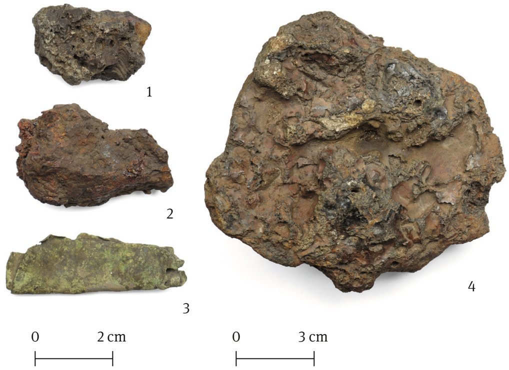

Fig. 6. *Finds from the Kõpu smelting site: 1 – cast iron, 2 – iron piece, 3 – copper sheet metal, 4 – slag cake.*
Jn 6. *Leiud Kõpu rauasulatuskohalt: 1 – malmi tükk, 2 – raud, 3 – vaskplekk, 4 – šlakikook.*
(TÜ 3382: 1–4.)
Photo / Foto: Ragnar Saage

Mägipe smelting site

Mägipe is recorded as a smelting site in the National Registry under no. 8933. There has been some confusion about the location of the monument. Previous archaeological fieldwork by Rivo Bernotas found no evidence of slag at the site, although there were some fragments of fired clay (Bernotas 2020). We returned to the site to get a slag sample, but faced similar issues as previous archaeologists. The only piece of heavily corroded slag was found from the easternmost test pit, while two larger iron pieces were found with a metal detector from the centre of the protected area. There was no hammerscale from the test pits. According to our assessment (Fig. 7), the metalworking site is in the eastern part or may even lie entirely outside the designated heritage area and its protection zone. Unfortunately, due to time constraints, we were unable to excavate test pits further to the east.

Two pieces of iron were analysed metallographically. The first was a round rod (Fig. 8: 2; ML 209), which displayed a layered macrostructure. The carbon content was generally quite low, but as an odd feature, there were small slag droplets all over the microstructure (Fig. 3: F). This indicates the manufacturing technique – the rod was probably rolled using heavy factory machinery and thus modern. The second piece turned out to be a steel bar (Fig. 8: 3; ML 210). The investigated cross section displayed an approximately 0.8% carbon content, but also pores and slag (Fig. 3: G). The carbon content was very even, which could mean it was made with modern steel production techniques. Both metal finds are likely not connected with ancient iron smelting.

Fig. 7. *Fieldwork on the Mägipe smelting site: 1 – protected area of the smelting site, 2 – possible location of the smelting site, 3 – test pits.*
Jn 7. *Välitööd Mägipe rauasulatuskohal: 1 – kaitse all oleva rauasulatuskoha piir, 2 – Mägipe rauasulatuskoha võimalik asukoht, 3 – prooviaugud.*
Map / Kaart: Estonian Land and Spatial Development Board / Maa- ja Ruumiamet; Ragnar Saage

Fig. 8. *Finds from the Mägipe smelting site: 1 – slag, 2 – iron rod, 3 – steel bar.*
Jn 8. *Leiud Mägipe rauasulatuskohalt: 1 – šlakk, 2 – rauast varras, 3 – terase kang.*
(TÜ 3383: 1–3.)
Photo / Foto: Ragnar Saage

The cross-sectional surface of the slag sample (Fig. 8: 1; ML 133) was highly porous, heavily corroded, and rich in slag, also containing a significant amount of vitrified clay. The pores are large and irregular in shape, with some concentric gas bubbles. The abundant corrosion on the edges and within the cross-section suggests that it once contained plenty of metallic iron, which has rusted (Fig. 3: H). Small ferrite clusters are present, which are carbon-free soft iron with a microhardness of 100 HV. Within the slag matrix, wüstite appears mostly as dendrites, although some irregularly shaped clusters can also be found. Overall, wüstite is sparse, and visible dendritic clusters occur as isolated islands. Fayalite in the background is mostly uniform, but there are areas with larger flakes.

In conclusion, the Mägipe sample appears to be ironworking residue that contains slag, vitrified clay, and iron, both in metallic and oxidised forms. Since the fayalite generally appears as larger crystals and the wüstite as dendrites, the slag piece likely cooled slowly, possibly inside a furnace or a forge. Because the sample also contains iron and round pores that closely resemble those in other iron smelting slags, it seems likely that the Mägipe site was also a location for iron smelting. However, further investigations and analyses are needed to confirm this hypothesis.

DISCUSSION AND CONCLUSIONS

During a few days of fieldwork, we successfully collected archaeological material required for laboratory analyses with minimal disturbance to the sites. At Patjala, we confirmed the presence of a medieval iron smelting and smithing site. The cultural layer, which contains metallurgical residue, is placed under heritage protection, and the designated area is sufficiently extensive to encompass this scientifically valuable context.

In contrast, the Mägipe ironworking site on the island of Hiiumaa yielded more ambiguous results. A heavily corroded slag fragment was recovered just outside the protected area, while two metal rods with modern microstructures and appearance were found within the protected zone. These findings suggest that further investigations are essential to accurately locate the historical smelting activity at this site.

A particularly informative sample, ML 134 from Kõpu, dates from the 10th–12th centuries and indicates iron production from local ores. It is unlikely that cast iron, unmalleable and of limited use in smithing, would have been imported to Hiiumaa during this period. Instead, the presence of cast iron points to local bloomery smelting, where cast iron was unintentionally produced as a by-product and then discarded. While recent discoveries of two 11th-century silver hoards in the Sarve village of Hiiumaa indicate trading and a possible harbour site (Reppo and Leimus, this volume), the smelting site of Kõpu provides evidence of local settlement and production activities. These new discoveries show that between the 10-12th centuries, the island of Hiiumaa was populated, its inhabitants were engaged in smelting iron and their trade networks reached other parts of Europe as well.

In contrast, the cast iron droplet from the Prassi site dates from the 19th–20th centuries, a period long after local iron production had ceased, i.e., by the 15th century. This suggests that Prassi was not an ancient smelting site but rather a modern farm smithy.

Our study demonstrates the potential of low-impact archaeological surveys to determine the function and chronology of ironworking sites. Cast iron has proven to be a valuable diagnostic indicator. There is no evidence of intentional cast iron use in Estonia before the 15th century (Saage 2020, 78, 98). However, cast iron frequently occurred as a by-product in bloomery smelting between the 1st and 15th centuries AD (Peets 2003, table 7; Peets 2014, 243). Moreover, the carbon contained in cast iron can be radiocarbon dated, providing a *terminus post quem* corresponding to the felling of trees for charcoal production, which was used as fuel for iron smelting. Since intentional cast iron production and bloomery smelting do not overlap chronologically, the dating of cast iron artefacts can help distinguish between these two technological processes.

ACKNOWLEDGEMENTS

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REFERENCES

Bernotas, R. 2020. Arheoloogiliste järeluuringute aruanne: Arheoloogiamälestis rauasulatuskoht (reg nr 8933) Süllasuranna kinnistu, Mägipe küla, Hiiumaa. *(Manuscript in MA.)*

Bronk Ramsey, C. 2021. OxCal v.4.4.4 [software]. URL: https://c14.arch.ox.ac.uk/oxcal.html *(last accessed 16.09.2025.)*

Costa, S. 2018. IOSACal: v0.4.1 [software]. Zenodo. https://doi.org/10.5281/zenodo.1243291 *(last accessed 16.09.2025.)*

Jaanits, K. 1975. Kassinurme rauasulatuskoht. Mälestise pass. *(Manuscript in MA.)*

Lõugas, V. 1981. Täiendusi Hiiumaa muinasajaloole. – Nõukogude Hiiumaa, 11.08.1981, no. 93, 3.

Oks, K. 2025. Eesti muistne rauatootmine: paigad, toodang ja protsess. Tartu. Master's thesis. *(Manuscript in the library of TÜAK.)*

Peets, J. 2003. The Power of Iron: Iron Production and Blacksmithy in Estonia and Neighbouring Areas in Prehistoric Period and the Middle Ages. *MT*, 12. Tallinn.

Peets, J. 2014. Raua tootmisest Siksäläs ja mujal Lõuna-Eestis. – Siksälä kalme. Muistis ja ajalugu. Ed. by H. Valk & S. Laul. Tartu, 239–244.

Reimer, P., Austin, W., Bard, E., Bayliss, A., Blackwell, P., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R., Friedrich, M., Grootes, P., Guilderson, T., Hajdas, I., Heaton, T., Hogg, A., Hughen, K., Kromer, B., Manning, S., Muscheler, R., Palmer, J., Pearson, C., van der Plicht, J., Reimer, R., Richards, D., Scott, E., Southon, J., Turney, C., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A. & Talamo, S. 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). – Radiocarbon, 62: 4, 725–757.

Saage, R. 2020. Metalworking Sites in Estonia during the 7th–17th Centuries. *Dissertationes Archaeologiae Universitatis Tartuensis*, 10. Tartu.

RAUASULATUS VÕI SEPATÖÖ: MÄÄRAMATA RAUATÖÖTLEMISKOHTADE UURIMINE EESTIS

Ragnar Saage ja Kristo Oks

Artikkel käsitleb nelja väheuuritud rauatöötlemiskohta Eestis, kus 2024. aasta aprillis ja septembris toimusid põgusad välitööd. Tööd võeti ette Haridus- ja Teadusministeeriumi rahastatava projekti „Raua päritolu määramise alusuuring Eestis" raames ning keskenduti aladele, kus olid ebaselge määratlusega rauatöö paigad. Peamine eesmärk oli koguda räbu ja rauaproove metallograafiliseks analüüsiks ning radiosüsiniku dateeringuteks. Uuritavad alad olid Patjala Jõgevamaal ning Kõpu, Prassi ja Mägipe Hiiumaal (jn 1).

Patjala asub haritaval põllumaal ning on kaitsealune mälestis. Seal tuvastati räbu, sulanud savi ja rauakilde (jn 2). Kahe proovi metallograafiline analüüs näitas rauasulatuskohale omaseid raua ja šlakistruktuure (jn 3). Ühe räbutüki külge jäänud söe radiosüsiniku dateering paigutas selle 14.–15. sajandisse, viidates, et Tartu piiskopkonna aladel asunud Patjala oli hiliskeskajal rauasulatus- ja sepatöökoht.

Prassi leiukoht näib sisaldavat hilisema metallitöötluse jälgi. Kuigi paik on arheoloogiamälestisena muinsuskaitse all, on selle kultuurkihti lõhutud nõukogude-aegsetel ehitustöödel (jn 4). Prassist pärit malmitükk sisaldas sfäärilist grafiiti, mida arheoloogilistes kontekstides ei leidu (jn 5). Radiosüsiniku dateering ja šlaki ning sulanud savi tükid viitavad sellele, et Prassi funktsioneeris 19.–20. sajandil talusepikojana.

Kõpu rauasulatuskohast leiti metallidetektori abil mitmeid rauatöötlemisega seotud jääke (jn 6). Kahest proovist tehti metallograafiline analüüs. Neist esimene sisaldas malmi, mis dateeriti 10.–12. sajandisse – perioodi, mil Eestis malmi sihipäraselt ei toodetud. See toetab tõlgendust, et Kõpu oli kohalik sulatuskoht, kus malmi tekkis soovimatu kõrvalproduktina sulatusahjus. Teine proov sisaldas lisaks rauale šlaki sisse kukkunud tagikuule ja -laaste, mis viitab kohapealsele sepatööle.

Mägipe rauasulatuskohta ei suudetud uuringutega määratleda. Kaitseala idaosast leiti üks räbutükk ning kaitsealalt kaks rauatükki, mis metallograafilise analüüsi tulemusel on pigem tööstuslikult toodetud (jn 7–8). Samas olid räbutükil rauasulatusšlakile omased tunnused (jn 3: H). See viitab võimalusele, et Mägipe oli rauasulatuskoht, ent selle täpne asukoht vajab täiendavat uurimist.

Hoolimata lühikest aega kestnud välitöödest, jõuti uuritud paikade rauatöötlemistegevuste tuvastamisel ja iseloomustamisel märkimisväärsete tulemusteni. Patjala dateeriti keskaegseks ja Kõpu noorema rauaaja sulatuskohaks. Seevastu Prassi tõlgendati ümber kui uusaegne sepikoda ning Mägipe kohta jääb alles esialgne hüpotees. Tehtu näitab, et ka väikese ulatusega uuringud võivad anda väärtuslikku teavet, kui need on ühendatud raudesemete metallograafilise ja radiosüsiniku analüüsiga. Oluliseks osutus malmi dateerimine, kuna Eestis puuduvad tõendid selle sihipärase tootmise kohta enne 15. sajandit. See tähendab, et 15. sajandist varasemad malmitükid pärinevad kohalikust rauasulatusest ja sisaldavad suurt potentsiaali tulevaste päritolu-uuringute jaoks.