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Excavations at the Tuiu iron-smelting site, Saaremaa

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INTRODUCTION

The article provides an overview of the fieldwork conducted at the Tuiu iron smelting site in northern Saaremaa (Fig. 1) in the summer of 2022 (Unt & Saage 2023). The goal of the fieldwork was to finish the archaeological experiment that began in 1988. During the work, the remains of the medieval iron smelting furnace and the remnants of the experimental iron smelting furnace built in 1988 were simultaneously explored and documented.

Fig. 1. *Tuiu on a map of Saaremaa.*
Jn 1. *Tuiu Saaremaa kaardil.*
Map / Kaart: Agnes Unt

The dunes and slag heaps located on the western side of Järise Lake and Pelisoo mire are known as *Tuiu Rauasaatmemäed* – Iron Slag Hills of Tuiu (Peets 2003, 99 and fig. 45). The Tuiu slag heaps were first excavated in 1962 (Kustin 1965), the same iron smelting site (A1) was fully excavated by Jüri Peets in 1986 and 1987; the size of the trench measuring at 372 m². The studies around the Tuiu area continued in the subsequent years (Peets 2003, 104–109 and figs 45, 47).

In the summer of 1988, the first test furnace was built at the archaeologically investigated iron smelting site A1. The reconstruction was based on the data of the remains of the iron smelting furnace discovered in the same place. The first smelting experiment took place in September of the same year. In the following year (1989), two more test furnaces were built for various tests, which were planned to be kept under light roofs as an outdoor exhibition. However, the first oven was left to the mercy of nature – it was destined to be an experiment lasting for decades. The experiment would aid in understanding ancient furnace remains, especially regarding the collapse of a furnace.

BACKGROUND ON TUIU

Located in northern Saaremaa, Tuiu is surrounded by dunes from Ancylus Lake and Litorina Sea periods of the Baltic Sea (Björck 1995; Peets 2003, 99–103, figs 45, 45a). The region has a long history of iron smelting, which started on a smaller scale between the 8th–11th centuries AD (Peets 1996, 31). The majority of the smelting took place between the 12th and 14th centuries, resulting in an estimated 1500–2000 tonnes of iron being produced in the area (Peets 2003, 135). More than 50 iron-smelting sites have been discovered in Tuiu, each containing one or more slag heaps. Each of the most voluminous heaps contains 30 to 40 tonnes of slag (Peets 1996, 30), thus making Tuiu the utmost bloomery iron-smelting center of Estonia in the late prehistoric and the beginning of the medieval period (Peets 2003, 99).

The Tuiu area was populated during the Late Neolithic (around 2000 BC) (Peets 2003, 105; Kriiska 1998). Cairns unearthed in the alvar pastures near Paatsa provide evidence of later settlement in the area, possibly in the form of stone-cist graves and *tarand* graves (Peets 1996, 36). Our own finding of a sherd of Late Stone Age pottery, a fragment of Corded Ware with spruce-twig motif (Fig. 2), further supports the early settlement of the given region. About 2 km west of Tuiu lies the Paatsa hillfort, and next to it a smithy site with very dark soil, where numerous remains of smithies were found – at least five or six buildings, dating from the 11th to the 17th centuries (Peets 2003, 181–190). It ought to be noted that no traces of permanent settlement have been found at Tuiu from the iron production period (Peets 1996, 36). An investigation into the vegetation history of the neighbouring Jõhvikasoo mire revealed a marked and rapid increase of the charcoal dust in the pollen diagrams, indicating a significant anthropogenic impact that started in the Viking Age. This has been linked to the iron industry in Tuiu, which required substantial quantities of wood (charcoal) for the smelting process (Hansson *et al*. 1996, 52–53, Peets 2003, 101–102).

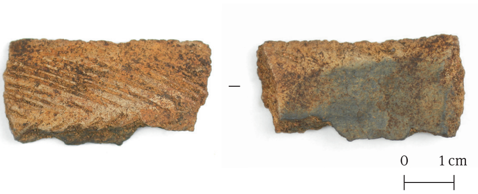

Fig. 2. *Corded Ware pottery with a spruce-twig motif from the iron smelting site of Tuiu.*
Jn 2. *Kuuseoksa motiiviga nöörkeraamika kild Tuiust.*
Photo / Foto: Agnes Unt

ARCHAEOLOGICAL FIELDWORK

Prior to the excavation, we were presented with an opportunity to learn what we would find. Thanks to the documentation (Peets 2003, plates III and IV), we understood the upper part of the furnace and its location at the site. The furnace (F2) we were about to excavate, was the best-preserved one found so far (Peets 2003, 108). Many construction details and measurements could be documented without breaking the furnace with excavations. Therefore, the possibility of exhibiting it in cooperation with Saaremaa Museum was considered, and the furnace was not fully excavated but was left as it was.

Another rare circumstance in archaeology was our opportunity to investigate the remnants of experimental archaeology – the iron smelting furnace that was built in 1988 and was used approximately ten times before allowing it to decay. We made two trenches, both 3 × 3 m – one on the F2 furnace and another on the experimental furnace.

The total of four finds were recovered from both trenches: three pieces of bloomery iron and a sherd of pottery, mentioned above (Fig. 2). Additionally, samples of soil, ore, slag and clay furnace remains were collected, along with slag from the experimental trench. Given the limited number of finds from the site, no further find analysis will be presented.

Furnace F2

We aimed to finish excavating furnace F2, so a square trench was measured with the furnace in the centre (Fig. 3). 1 × 1 m squares aided in marking down contexts of finds; however, a context-based method for digging was applied once it became apparent that this method made better sense for this furnace. The sand was sieved using 5 mm mesh sieves and a magnet was used to detect hammerscale and roasted ore. Finds, samples and marker locations for 3D models were measured using a total station.

The back wall of the furnace was built against a low hill (dune ridge) and was supported by stones, up to 20 cm in diameter, arranged in a horseshoe-like shape (Peets 2003, 106).

Fig. 3. *Ortophoto of the furnace F2. Made using Agisoft Metashape software.*

Jn 3. *Ortofoto F2 ahjust; valminud Agisoft Metashape programmiga.*

Photo / Foto: Agnes Unt, Ragnar Saage

During the excavation, the team cleaned and documented the debris-filled furnace F2, carefully removing stones from its structure while documenting each stage of the process. The main objective was to see the cross-section of the furnace's lower parts, especially the slag-tapping holes. These were unearthed on both sides of the 'mouth' of the furnace, where the furnace was most likely broken to remove the bloom.

The fieldwork uncovered a large *in situ* slag cake at the base of the furnace, with some slag near the furnace as well. It was apparent that the sand near the furnace had been subjected to high temperatures as it appeared much darker in colour than the sand in the second, 'experimental' trench (Fig. 4). Samples were taken both from the burnt and unburnt sand. The furnaces at Tuiu were repeatedly used in the same place and constantly repaired. This is further corroborated by the large amounts of slag in the area (see more on the amounts in Peets 1996, 32–33).

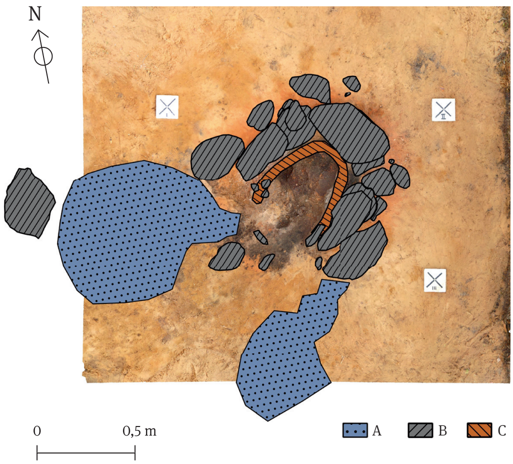

Fig. 4. *Furnace F2: A – slag-tapping holes, B – stones, C – clay wall of the furnace.*

Jn 4. *Ahi F2: A – lohud šlaki väljalaskmiseks, B – kivid, C – savist ahju sein.*

Photo / Foto: Agnes Unt, Ragnar Saage

Hammerscale originating from the initial forging of the bloom was found mainly from the southwest corner of the trench, as befits previous plans (Peets 2003, plate III, IV). The furnaces and hearths were typically in pairs, 2–2.5 m apart (Peets 1996, 32). Figure 3 shows the area rich in hammerscale in the bottom left corner.

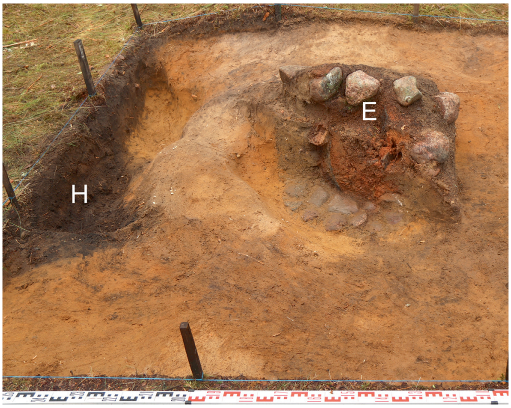

Fig. 5. *Slag heap (H) and the experimental furnace (E) in the process of being excavated.*
Jn 5. *Šlakiauk (H) ja eksperimentaalahi (E) kaevamiste ajal.*
Drawing / Joonis: Ragnar Saage

Trench E1

This was the 'experimental' trench – the furnace was used for experimental iron smelting by Jüri Peets in 1988 and 1989. The details of these experiments can be found in Arvi Lauringson's book on iron smelting in Estonia (Lauringson 1995) and are documented in the film 'Raua vägi' (1990). For the experiment, a furnace measuring 80–90 cm in height was constructed, with half of it in the ground (imitating the second type of Tuiu furnaces). The inner diameter of the furnace measured 30 cm, and the clay walls were 8–10 cm thick (Lauringson 1995, 85). Trench E1 was dug using the same methods as furnace F2. In addition to the furnace, we found an edge of a slag heap in the trench (Fig. 5). This contained slag and furnace remains, which originate most likely from the 11th–14th century, and a piece of Corded Ware pottery (Fig. 2). The slag heap was dug until only undisturbed sand could be seen.

POST-EXCAVATION ANALYSES

Photogrammetry and photos

We made 3D models from different stages in the excavation process – these helped to reach an all-including understanding of the furnaces. Agisoft Metashape 1.7.2 was used, as well as QGIS 3.10.3-A Coruña for the analyses. The 3D models were used to measure the height between the highest point of the slag-tapping holes and the bottom of the large slag cake still in place in the furnace F2. This was found to be around 8 cm.

Metallographical analysis and dating

In order to determine the properties of iron, a small iron nugget (<10 g) was chosen for metallographic analysis.[1] The cross-section of the iron piece revealed a porous, slag-rich surface. The iron was mainly eutectoid or hypereutectoid steel with 0.8% or higher carbon content (Fig. 6). This was supported by nine microhardness measurements from three areas across the cross-section. The microhardness varied from about 169[2] to 228 HV with an average of 195 HV. The piece of iron in question had most likely fallen off from a larger iron lump during the compacting of the bloom, and it was not picked up to merge it into the bigger iron lump. The shape of the pores in the iron suggests that the piece of iron was hammered from only one side before it fell, where the pores were elongated and in the same direction, while on the other side the pores were round. The carbon rich piece is another example of the good properties of the iron ore used in Tuiu, indicated by the lack of phosphorus (Peets 2003, 101). Previous metallographic analyses from bloomery iron lumps at the A1 smelting site in Tuiu

[1] The iron piece was cut with a precision saw, mounted in phenolic thermoset resin, grinded with diamond suspensions (45, 9, 3 and 1 μm), polished with aluminium oxide and colloidal silica paste, and etched in a 3% Nital solution (nitric acid in ethanol) for 6 seconds. The sample was examined with an optical metallographic microscope.
[2] The microhardnesses was measured with Wilson Tukon microhardness measurer under pressure of 500 g (HV0.5).

have revealed cast iron in two cases, five steel pieces and only one low carbon iron piece (Peets 2003, table 7 and fig. 71).

This piece of bloomery iron was also selected for radiocarbon dating. As the microstructure contained steel, it was possible to date the carbon that originated from the charcoal used as fuel in the smelting process. The analysis was done by the Tandem Laboratory at the University of Uppsala in Sweden. The piece of iron dates the furnace to 1279–1394 calAD with 95.4% probability.[3]

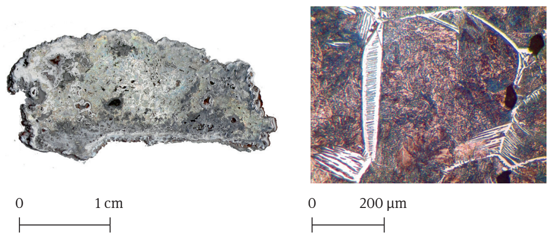

Fig. 6. *Etched cross section of the investigated bloomery iron piece (left) and microstructure containing hypereutectoid steel (right).*
Jn 6. *Uuritud rauatüki söövitatud ristlõige (vasakul) ja mikrostruktuur üleeutektoidse terasega (paremal).*
Photo / Foto: Kristo Oks

RESULTS AND DISCUSSION

The excavation of the experimental furnace offered valuable information on the collapse of an iron-smelting furnace. Due to being exposed to high temperatures, the clay had fallen apart; the upper part of the furnace had collapsed, helping to preserve the lower part of the furnace. As previously mentioned, our understanding of the furnace's structure is based on the documentation from the earlier fieldwork of 1986–1987. Excavating the experimental furnace helped us to interpret the furnace F2 better.

Prior to our fieldwork, the condition of the F2 furnace at Tuiu was thoroughly documented (Peets 2003, 108). According to this, the furnace was partly in the ground, with an open front. It was surrounded by granite stones (Peets 2003, plate III: 2: F2). The inner diameter of the furnace was measured to be between 28–30 cm, a measurement our work confirmed. The ventilation channel was located 14–15 cm from the bottom of the furnace, as evidenced by the imprint of the tuyere brick, with the side length of 11 cm, on the clay walls (Peets 2003, 108). Also, two slag tapping holes on both sides of the furnace were located.

The earlier trench extended to the south-west of the furnace, where the area of the forge could be observed. This was the dark area near the edge of our trench which we analysed with a magnet and discovered fragments of hammerscale still present in the soil (see bottom left corner of Fig. 3). It was noted previously that the forge's wall was made of stones that had crumbled in the heat; some had even melted on the surface (Peets 2003, 109).

The excavation yielded that the better-preserved slag tapping hole was located approximately 8 cm from the bottom of the furnace. This information significantly enhances our comprehension of the local bloomery furnaces and provides precise measurements for building the lower part of the furnace for iron smelting experiments. The most successful of such experiments conducted in Estonia have used the furnace F2 as an example and have employed

[3] Ua-78721: 658±32 BP calibrated with IOSACal v0.4.1; atmospheric data from Reimer *et al*. (2020).

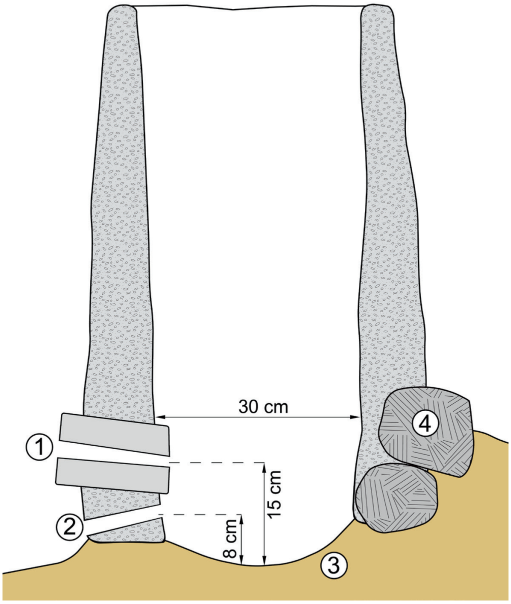

Fig. 7. *Dimensions of the smelting furnace. 1 – tuyère brick, 2 – slag tapping channel, 3 – sand, 4 – stones.*
Jn 7. *Ahju mõõtmed. 1 – lõõrik, 2 – šlakikanal, 3 – liiv, 4 – kivid.*
Drawing / Joonis: Ragnar Saage

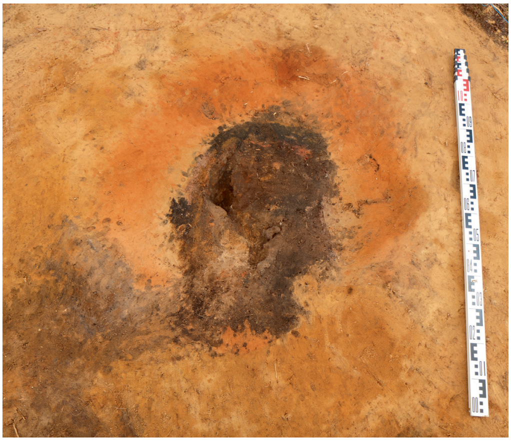

Fig. 8. *Burnt sand around the furnace F2 (vibrant orange). Viewed from SW.*
Jn 8. *Põlenud liiv ahju F2 ümber (erkoranž). Vaade edelast.*
Photo / Foto: Agnes Unt

its measurements (see Fig. 7 for the structure of such a furnace).

A burnt sand strait, 10–20 cm thick (which was originally about twice as wide), was observed around furnace F2 (see Fig. 8), suggesting repeated use of the furnace. The experimental furnace, which was used ten times, did not have such burnt sand around it. It also indicates that the experimental work was conducted differently from how it was done in the past. The primary difference was likely related to the charging of the furnace with charcoal and ore during the experiment, Peets was unaware at that time that the ore and charcoal should be added to the furnace in small, equal quantities. Instead, all the ore was added in one batch, resulting in a significant loss of heat, which also shortened the experiment.

The furnace construction process is summarised as follows: firstly, the tuyère brick was carefully moulded and dried. Next, the smelters dug a depression in the sand for the furnace's base, though it was not lined with clay. The back and the sides of the furnace were then lined with large stones, while the front was likely constructed using clay. Two slag tapping holes were left on either side of the front, and the tuyère brick was placed in the centre. Finally, the rest of the furnace was gradually built out of clay (Fig. 7).

During the smelting, both slag-tapping holes were used to drain the liquid slag from the furnace, but also a very large slag cake formed at the bottom of the furnace during the final smelt. The tuyère brick was probably broken during the removal of the bloom by the smelters. The furnace was then abandoned, and the upper part of the clay walls collapsed into the furnace, similar to what we observed in the case of the experimental furnace (Fig. 9).

Fig. 9. *The experimental furnace in different stages of excavation. Left: inside of the furnace full of debris. Right: empty inside of furnace.*
Jn 9. *Eksperimentaalahju kaevamise erinevad staadiumid. Vasakul ahi enne varingurusu eemaldamist. Paremal: tühi ahju sisemus.*
Photo / Foto: Agnes Unt, Ragnar Saage

SUMMARY

Tuiu in northern Saaremaa was populated as early as the Late Neolithic, as confirmed by our find of Late Neolithic pottery at the bottom of a slag heap. Around the 8th–9th centuries, iron-smelting began and continued up to the late 14th– early 15th century. We opened two 3 × 3 m trenches, one around the remains of a historical furnace, which was partially studied and measured by Jüri Peets in 1986 and 1987, but left intact. The other trench was made on the remains of an experimental furnace, used in 1988 and 1989. In the autumn of 1989, the test furnace was left to the mercy of nature to start an experiment expected to last for a few decades.

A metallographic analysis of a piece of bloomery iron was conducted, this showed a porous, slag-rich cross section, which was eutectoid or hypereutectoid steel with a 0.8% or higher carbon content. This enabled the radiocarbon dating of the iron piece and the furnace itself to the late 13th or 14th century. This result, coupled with the previous metallographic analyses, indicates that the bloomery smelting process at Tuiu produced iron with very little phosphorus. The most important result of our excavations were the measurements of the height of the slag-tapping holes in relation to the furnace's bottom – around 8 cm, and the inner diameter of the furnace, which was found to be about 28–30 cm. In addition, we gained valuable information regarding the collapsing of a furnace thanks to investigating the experimental furnace.

ACKNOWLEDGEMENTS

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VÄLJAKAEVAMISED TUIU RAUASULATUSKOHAL SAAREMAAL

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Tuiu on rauasulatuskoht Põhja-Saaremaal, kus esimesed asustusjäljed pärinevad neoliitikumist. Rauasulatus algas Tuius 8. sajandi paiku, selle hiilgeaeg oli 12.–14. sajandil. 2022. aasta suvel tegime Tuiu rauasulatuskohale kaks kaevandit. Esimene kaevand paigutati ajaloolise rauasulatusahju F2 kohale, mille kaevamine jäi 1980. aastatel pooleli. Teise kaevandi tegime Jüri Peetsi poolt ehitatud rauasulatuseksperimendi jaoks kasutatud ahju peale. Uurimismeetodid olid mõlemas kaevandis sarnased.

Ahju F2 kaevandist saime vajalikku informatsiooni Eesti rauasulatusahjude ehituse kohta. Ahju sisemine diameeter oli 28–30 cm – just sellise läbimõõduga ahjudega on toimunud Eesti kõige edukamad rauasulatuseksperimendid. Samuti saime teada, et šlaki väljalaskeavade kõrguse vahe ahju põhjaga on umbes 8 cm. Metallograafiline analüüs F2 ahju kõrvalt leitud toorraua tükist näitas, et tegu on eutektoidse või ülieutektoidse terasega, mille süsinikusisaldus on 0.8% või kõrgem.

„Eksperimentaalkaevandi“ abil selgitasime, kuidas rauasulatusahi laguneb. Märkimisväärne avastus oli põlenud liiva rant, mida ajaloolises kaevandis nägime, ent eksperimentaalses mitte. Erinevus tuleneb eksperimenteerimisel kasutatud rauasulatusmetoodikast, mis erines ajaloolisest ja põhjustas liigset kuumusekadu.