The Spell of Iron

Iron smelting experiments with stone box furnaces
of the Finnish Early Iron Age

Joni-Pekka Karjalainen

University of Oulu
Faculty of Humanities
Archaeology
Master’s Thesis / Pro gradu -tutkielma
Supervisor: Janne Ikäheimo
13.5.2016
CONTENT

1. INTRODUCTION ..................................................................................................................... 3

2. THEORETICAL FRAMEWORK ............................................................................................ 5

3. ARCHAEOLOGY OF THE STONE BOX FURNACES IN FINLAND .................................... 8
   3.1. Research history ............................................................................................................. 8
   3.1. Sites with stone box furnaces ....................................................................................... 10
   3.2. Furnace structures ....................................................................................................... 13

4. IRON SMELTING EXPERIMENTS ....................................................................................... 19
   4.1. Hypothesis and methods ............................................................................................. 19
   4.2. Building the stone box furnace and preparations for the smelts .................................. 20
   4.3. Experiments ................................................................................................................ 26
   4.4. Results ......................................................................................................................... 36
   4.5. Evaluation of the experiments ..................................................................................... 42

5. DISCUSSION ....................................................................................................................... 44

6. CONCLUSION ..................................................................................................................... 54

BIBLIOGRAPHY ......................................................................................................................... 55

APPENDIX 1. – SITE DESCRIPTIONS ...................................................................................... 1

APPENDIX 2. – EXPERIMENT DOCUMENTATION FORM (translated from Finnish version) 13

APPENDIX 3. – PHOTOS FROM THE EXPERIMENTS .......................................................... 17
1. INTRODUCTION
The coming of iron and iron production technology into Finland has always been an interesting, although to some extent neglected, topic in archaeological research. According to the newest research iron technology came both from the West and the East. The western and southern influences arrived to the coastal Finland from eastern Scandinavia and Estonia based on the artifacts found in Early Iron Age sites, but no smelting furnaces have been found. On the other hand, the eastern influences manifest in well surviving stone box furnaces and six of them have been excavated in eastern and northern Finland. The furnaces were built into a pit, which was lined first with stone slabs and then with clay. This thesis will study the existing Iron Age stone box furnaces in Finland through experimental archaeology and analyze them in an attempt to form interpretations on how they might have worked. Also the materials used in the furnaces are discussed, how they were used and why. By analyzing these aspects it is possible to gain new ideas and interpretations on technological and formation processes that took place in the Early Iron Age iron smelting sites.

In Finland there are few known iron smelting sites from the Early Iron Age, 500 BC–400 AD, and some of them have furnaces, which are made out of stone slabs into a box shape. These are so far the only confirmed structures related to early iron smelting in Finland, but they have not been researched or published systematically. Furthermore, the information about these furnaces has disappeared into excavation reports and, especially in the earlier cases, the documentation leaves much to be hoped for. Therefore, little is known about how they were used, what type of iron they produced and what type of actions were conducted around them. This leads to a situation where interpretations about these furnaces are difficult to make and one does not know what to look for in future excavations. The radiocarbon dates from the sites suggest that they were used during the Early Iron Age, 500 BC–400 AD. In order to understand the processes related to early iron production even more deeply, this thesis will take a more practical and hands on approach towards the questions at hand through experimental archaeology.

Moreover, iron smelting has not been researched much through experimental methods in Finland. The only reported or somehow published smelting experiments belong to Jouni Jäppinen and Jouko Pukkila. While Jäppinen has focused more on studying the shaft furnaces, Pukkila studied pit furnaces in his research. In addition, there are some individuals who have attempted and

---

2 Kotivuori 2013: 56–57.
succeeded in iron smelting with varying approaches. Only Hannu Kotivuori from the Provincial Museum of Lappland has done any experiments with stone box furnaces, but the experiment was not published.\(^5\) Therefore, there is a need and room for experimental research on this topic and this thesis will serve as a preliminary glance. Three experiments are reported, analyzed and discussed after which the results are compared to the archaeological sites and stone box furnaces in an attempt to see, what they have in common and if our knowledge on these furnaces could be increased with this approach. If nothing else, these experiments will provide new ideas on what to look for at archaeological sites with stone box furnaces.

The thesis has the following three aims.

1. To outline the archaeological data on the Early Iron Age stone box furnaces in Finland and analyse them as structures or artefacts.
2. To gain more information about the stone box furnaces through experimental archaeology.
3. To combine this data into archaeological data in order to answer how they were produced, used, modified, and discarded.

The thesis is composed of four main parts. The first part, Chapter 2, outlines the theoretical framework for experimental archaeology, which is the main approach used in this thesis. The second part, Chapter 3, studies the sites, where stone box furnaces have been found and analyses the structural elements of the furnaces building up towards the choices made for the experiments. Chapter 4 consists of a detailed report for the experiments and it outlines the hypotheses and methods used during the smelts. The majority of the chapter describes the experiments, how they progressed, results and eventually evaluates their value. The fourth part, Chapter 5, draws the observations and results from Chapters 3 and 4 together and compares the archaeological and experimental elements with one another. The conclusion outlines the results of the thesis. After bibliography the thesis has three appendices: Appendix 1 for site descriptions for the six sites studied here, Appendix 2 for the documentation form used in the smelts and Appendix 3 for pictures taken during the experiments.

\(^5\) Hannu Kotivuori 2014: pers. comm.
2. THEORETICAL FRAMEWORK

In academic research experiments are a major way to gain new information on wanted topics. It is a way to test hypotheses and prove them either false or true. In experimental archaeology the experiments carried can only give negative results, which means that they can only tell us how something was not made. At the best a positive result from a successful experiment implies how something might have been done, because there can be numerous other ways to reach the same goal. Some of them might not have anything to do with the experimental setting and especially with the processes that leave no traces in the archaeological record the difficulties are even greater. A variety of researchers have outlined basic requirements and definitions for experimental archaeology. For example, James Skibo has defined experimental archaeology in following way:

“Creation of an artificial system to explore archaeological material or processes. As the word experimental suggests, this subfield of archaeology performs tests to observe the relationship between human behavior and material culture (artifacts) throughout its life history. Experiments are performed to determine first how artifacts were produced, used, modified, and discarded and then to understand the processes that impact the material while in a depositional environment.”

Other famous researchers in the field include John Coles, who wrote down some of the first criteria for experimental research in his publications. Another important definition that James Mathieu has brought up is that experimental archaeology is used “… in order to generate and test hypotheses to provide or enhance analogies for archaeological interpretations.” That is, the aim is to create situations, in which comparisons between archaeological data and results from experiments can be made.

In Finland experimental archaeology has not reached wider interest yet and, thus, terminology and defining experimental archaeology is not as clear as it is abroad. Nevertheless, some advancement has taken place during the beginning of 21st century in the field of Finnish experimental archaeology. Kimmo Kyllönen has outlined and evaluated a handful of experimental studies carried out in Finland, while discussing the related theoretical aspects. In his thesis Kyllönen brings up the problem that due to vague definition of this sub-discipline,
experimental archaeology tends to be doubted as a method in Finland.\textsuperscript{13} He suggests that in order to make experimental archaeology more credible it has to be systematized and used as a method and a tool instead of using it as a research framework for individual case-studies.\textsuperscript{14} Although Kyllönen’s thesis is already over ten years old, the same problems can be observed today.

In the natural sciences experimental can be extremely rigorous with hundreds, if not thousands, of samples in order to form statistically meaningful results. The experiments are conducted under controlled circumstances usually in laboratories where each variable is carefully monitored to avoid biases.\textsuperscript{15} In addition to analyzable data, experiments can be used to obtain more experience about different aspects. The experiential knowledge allows one to gain information and practical skills on the researched topic. By making objects and by handling them one gains more information about how they can work and that can be used to ask more specific questions from them. Sometimes an object can work for many other purposes in addition to the primary function, which has to be taken into account as well.

While forming the hypotheses and the choosing the variables to be controlled, the limitations of natural environment compared to laboratories have to be acknowledged. While some of the variables in experiments reported here, such as rate of air blown into the furnace with bellows, can be thought to have remained fixed, they had limitations as well. For example, the amount of different people using the bellows, the tiredness of individuals towards the end of the smelts and even the stretching of the leather on the bellows affected the rate of air. Just like this aspect, not to mention many others, there are a lot of factors that changed over time and affected the experiments and the results undermining the nature of this study as experimental archaeology. Moreover, there were too few experiments to give statistically significant results and there were also biases in the experiments. The most severe bias was that we wanted to succeed with the smelts and, thus, we might have unconsciously changed our behavior in order to make it happen.

On the other hand, should we even try to conduct archaeological experiments as scientifically experimental as possible? In the earlier phase of experimental iron smelting, for example, Tylecote ran the majority of his experiments in laboratory settings in order to control all the variables, which has been criticised today.\textsuperscript{16} Today most of the smelts are run outside in a more organic setting without the use of electricity or other modern day tools. The more we move towards

\footnotesize{\textsuperscript{13} Kyllönen 2003: 7-8.  
\textsuperscript{14} Kyllönen 2003: 23.  
\textsuperscript{15} Ingersoll & Macdonald 1977: xii; Mathieu 2002: 7.  
\textsuperscript{16} Williams 2010; Doonan & Dungworth 2013a: 3.}
the laboratory setting and more detailed variables to control, the further we move away from the human aspect of archaeology. For example, with an air blower the air flow could have been kept constant in all the experiments. At the same time though, we would lose the physiological and behavioral aspects of human beings and is not it what archaeology attempts to study? Furthermore, we could have let the experiments fail if they seemed to go towards that direction, but would that have been what the smelters in the Iron Age would have done? Depending on the situation even failed experiments can even add a more information than a successful one.

While documenting and studying the physiological aspects of the iron smelting process, it is also important to study the behavior required from the smelters. What did they need to do to make a smelt successful and how did they go about in order to make it so? For instance, a simple action like clearing the tuyere\textsuperscript{17} from slag once in a while to maintain the airflow is extremely important for the smelt. The strength of this approach is that it takes the experiment a bit closer to the archaeological record, but we cannot pretend that we would be able to achieve the same level of information or to recreate the smelting process exactly as in the Early Iron Age. The limitation of this approach is the lesser control of the variables. Choosing how to conduct the experiment depends on what one wants to study through it. Is it the physiological and chemical processes of the smelt and the furnace or is it the process as a whole with the human trial and error involved in it? Taken to the other extreme, one could focus only in documenting the behavior of the smelters and ignore the furnace altogether. The experiments presented in this thesis attempt to do a bit of both.

Moreover, the division between experimental versus experiential archaeology is to a certain extent irrelevant. It should be seen more like a sliding scale, where one starts with the experiential and as more data and knowledge is gained, one starts to ask more specific questions with increasingly experimental set-up.\textsuperscript{18} Experience is needed before rigorous scientific experimenting.\textsuperscript{19} From this viewpoint, experiments presented here can be seen as experiential, because with every smelt more and more was learned about the stone box furnaces and how they worked, and also experimental, because they aimed to answer questions regarding formations processes and which “settings” give the best results.

\textsuperscript{17} A clay tube directing air from bellows into a furnace.
\textsuperscript{18} For discussion see eg. Kyllönen 2003: 37-40.
\textsuperscript{19} Hurcombe 2007: 537; Outram 2008: 3.
3. ARCHAEOLOGY OF THE STONE BOX FURNACES IN FINLAND

3.1. Research history
One of the questions regarding iron in Finland is that how intensively it was produced here during the Iron Age. It is assumed that a lot of iron was imported to a variety of areas in Finland, while local iron production always remained low. In particular this seems to be the case during the Middle Iron Age. While the assumption might be accurate, it seems odd, because the Finnish lakes are extremely rich in iron and there is ample evidence for iron smelting during the historical periods throughout Finland and especially in Kainuu region. Records from the 19th and 20th centuries show that lakes containing lake iron ore are distributed virtually throughout Finland and bog ore seems to be relatively common as well. In addition, a great number of archaeological sites with slag has been found around Finland. On the other hand, archaeological sites with slag are problematic at the best, because without any other material they give only limited amount of information. Radiocarbon dating from slag itself and charcoal embedded in slag is theoretically possible, but has not been done extensively as it is a costly method and not much attention has been paid towards slag as a researchable material. Furthermore, slag is an indirect indication of smelting activities, because it can also refer to other ironworking activities, such as blacksmithing and purification of iron blooms, as well. Identification of these differences can be difficult and requires knowledge on how different types of slag form.

According to the current research the iron production came to Finland from both the East and the West. The eastern route was through the extensive river networks that reach from the Russian Karelia all the way to the Bothnian Bay. This route had already been established during the Bronze Age and it is no wonder that technological ideas were also transmitted starting the transition towards Iron Age. For example, both Rovaniemi and Kajaani regions have evidence of Late Bronze Age connections to Ananjino-cultures in the East in the form of bronze axes and casting molds made of local soapstone. The former resemble the ones used Volga-Kama area, while the latter show that the technology was adapted to local resources. Moreover, the stone box furnaces found in Finland are analogous to the 18 furnaces, dating to 300 BC – 1500 AD,

---

23 Pukkila 2007: 34.
24 Puustinen 2002.
25 Nordqvist 2011.
27 Mäkivuoti 1983: 22; Buchwald 2005: Fig 74, 195.
discovered in the Russian Karelia.\textsuperscript{29} The furnaces in northern and eastern Finland do not seem to resemble the ones found from most of the southern Scandinavia and Estonia, where clay or stone lined bowl furnaces and shaft furnaces following the western European tradition were the most commonly used type of furnace.\textsuperscript{30} Moreover, few have been excavated even in Närke, Vestmanland\textsuperscript{31} and one in Kalix, Norrbotten,\textsuperscript{32} in Sweden. The origin of these furnaces possibly lies in the East as well and they make their appearance in the Late Bronze Age and Early Iron Age.\textsuperscript{33} No furnaces of this type have been found from Northern Norway.\textsuperscript{34} The amount of these furnaces suggests that the emergence of this type of iron smelting was not just an odd chance. Instead, the technology was spread through existing contacts and river networks from Karelia to Eastern and Northern Finland and even to Sweden.

Several Early Iron Age sites have been found from southeastern Finland with iron objects dating to this period, but no furnaces or furnace bottoms have been found yet. In contrast, slag has been found from these sites indicating iron smelting or at least ironworking. Lavento suspects that iron smelting might have begun in southwestern Finland already in 500 BC, which would therefore predate the use of stone box furnaces although the earliest archaeological evidence known to date is from 400 AD in Eura.\textsuperscript{35} The lack of furnaces might indicate that smelting technology was used along the

\textsuperscript{29} Kosmenko & Manjuhin 1999; Lavento 1999: 76.
\textsuperscript{32} Bennerhag 2009.
\textsuperscript{33} Buchwald 2005: 203; Bennerbag & Mattsson 2009: 54.
\textsuperscript{34} Jørgensen 2013: 79.
\textsuperscript{35} Lavento 2013: 93-96
coast or that sites with early furnaces have not been located yet.

3.1. Sites with stone box furnaces

Five definite and one probable stone box furnaces are known from the following sites in Finland: Riitakanranta and Kotijänkä in Rovaniemi,36 Kitulansuo D in Mikkeli,37 Äkälänniemi in Kajaani,38 Kilpisaari 1 in Lahti,39 and Neitilä 4 in Kemijärvi (Figure 1). These furnaces have been documented and discussed in literature and were chosen as the base for the experimental studies reported in this thesis.41

The sites with stone box furnaces are in the immediate proximity of lakes containing lake iron ore. The lake and bog iron ores were used as the main ore sources during the Finnish Iron Age and there is no archaeological evidence for the utilization of mined ore minerals such as hematite and magnetite.42 Therefore, the location of a furnace by a lake is logical as it was more sensible to transport finished iron instead of extensive amounts of ore. For example, Lavento noted during the excavations in Kitulansuo D that even today the bog nearby and the Lake Louhivesi contain iron ore the latter being 100 meters away from the site.43 In addition, Kehusmaa states that the vicinity of Neitilä 4 site had multiple possible sources for iron such as lake iron ore and magnetite sand.44 In the case of the other sites with stone box furnaces, the presence of iron ore in the nearby lakes has not been verified. Puustinen45 has compiled documentary evidence of mining and land claims in Finland during 1811 – 2001 and sites with lake iron ores are among them. 7800 land claims were made for sites with lake iron ore mostly in the Eastern Finland, although that does not mean that there would not be ore deposits outside these sites. These were the sites, which had enough quality

36 Kotivuori 1995; 1996.
38 Nieminen 1984.
40 Sarvas 1963.
41 In addition to the sites mentioned above, references to other stone box furnaces can be found from the research of Jouni Jäppinen and Rune Nygård. Their work group has studied the area of Kymlaakso in southern Finland in an attempt to find evidence of Iron Age habitation in the area. Jäppinen and Nygård found possible evidence for the use of stone box furnaces in four sites out of twenty; Koirankallio, Kärsäharju, Myllykylä and Viirankoski. For example, from these sites they found pieces of slate, which may have belonged to stone box furnaces. Unfortunately, there is no much further information about the sites or about the possible furnace structures at the given time. Therefore, these four sites are left outside this study. Jäppinen & Nygård 2014: 33–34, 37–39, 49–66. Register numbers from the National Board of Antiquities: Koirankallio (701010023), Kärsäharju (1000013517), Viirankoski (1000017615); Jäppinen 2014: 36.
44 Kehusmaa 1972: 84.
lake iron ore to uphold small scale industry during the 1800’s, while in Iron Age smaller quantities would have been enough.

Furthermore, it seems that being close to the ore resources was preferred instead of resources for furnace construction materials. For example, the area surrounding Kitulansuo D does not offer any natural stone material resources expect the exposed bedrock. Thus, all the stone found on the site have been brought there by the habitants. The largest stones of the furnace were roughly 30 x 20 x 10 cm in size, while considerably smaller stones had been used in its structure as well indicating that the stones might have been gathered from a wider area or that the builders were forced to build the furnace out of smaller stones, when ones big enough were not found in the vicinity. On the other hand, while there are no stones in the sandy beaches of Lake Sierijärvi in Rovaniemi, a tree covered hill Kurivaara is located to the south-west from the lake. The bedrock of the hill is partly mica schist, which breaks naturally into flat pieces. Kotivuori has confirmed that the material for the furnaces at Kotijänkä and Riitakanranta sites comes from Kurivaara. In the

![Figure 2. The Riitakanranta furnace in display in the Provincial Museum of Lapland. Reconstructed by Hannu Kotivuori. Photo by Laura Halvari.](image)

46 Lavento 1997: 8, 10.
47 Lavento 1997: 12.
presence of such well-suited material, it is no wonder that the Kotijänkä and Riitakanranta furnaces have survived so well and that the sites are in close vicinity to one another. Moreover, drilling samples from the nearby bog show silty clay, which has the same consistency as the clay used in the furnace structures found from the Riitakanranta site.\textsuperscript{49} Consequently, the sites seem to concentrate in areas, which have resources for both the building of a furnace and the smelts.

In addition to closeness of materials, the furnaces share other common characteristics in their placement within the sites based on a map survey. They are often located on the point of small capes and would have been right next to water at the time they were in use.\textsuperscript{50} Only the Neitilä 4 and Kitulansuo D sites do not seem to be located on a cape when observed from a map. Location on capes would have made them visible from the direction of the lakes and it might have helped to locate the sites when collecting ore with boats. Interestingly, the Kitulansuo D, Neitilä 4 and Kilpisaari 1 sites are located nearby dwelling sites of the same period\textsuperscript{51}, while the Riitakanranta, Kotijänkä and Äkälänniemi sites do not seem to have other sites of the same period close to them based on a map survey. The most likely explanation is that the dwelling sites have not been found, while it could also be that smelting sites were separated from dwelling sites. The earth on the sites is usually fine or coarse sand and the surrounding areas are boreal forests with pine as the main tree species\textsuperscript{52} with the exception of the Neitilä 4 site, where earth consisted of thick layers of silt brought by river floods\textsuperscript{53}. Both types of soil would have been easy to dig with shovels or even by hand. It is difficult to say whether the sites were amongst trees or if the forest areas around had been cut down, for example, for fuel.

The dating between the sites differs somewhat, but they all fall roughly into the Early Iron

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sample name</th>
<th>Date</th>
<th>Calibrated age (2σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Kotijänkä furnace</td>
<td>Hel-3173</td>
<td>1880 ± 110 BP</td>
<td>cal 156 BC–392 AD</td>
</tr>
<tr>
<td>The Riitakanranta furnace (inside)</td>
<td>Hel-2955</td>
<td>2090 ± 100 BP</td>
<td>cal 381 BC–81 AD</td>
</tr>
<tr>
<td>The Riitakanranta furnace (outside)</td>
<td>Hel-2956</td>
<td>1820 ± 110 BP</td>
<td>cal 53 BC–527 AD</td>
</tr>
<tr>
<td>The Kitulansuo D furnace</td>
<td>Hel-3837</td>
<td>1530 ± 80 BP</td>
<td>cal 356–657 AD</td>
</tr>
<tr>
<td>Slag (Äkälänniemi)</td>
<td>Hel-2098</td>
<td>2220 ± 100 BP</td>
<td>cal 536 BC–2 AD</td>
</tr>
<tr>
<td>Slag (Äkälänniemi)</td>
<td>Hel-2101</td>
<td>2180 ± 90 BP</td>
<td>cal 402–1 BC</td>
</tr>
</tbody>
</table>

Table 1. The radiocarbon dates from the sites with stone box furnaces. The dates are calibrated with OxCal-calibration programme (version 4.2. [Bronk 2009] using IntCal13-calibration curve[Reimer et al. 2013]). The dates are given with the precision of two sigmas (2σ).

\textsuperscript{49} Kotivuori 1995: 8.
\textsuperscript{50} Kotivuori 1995: 5–6; Nieminen 1983: 2; Poutiainen 2000: 1.
\textsuperscript{53} Kehusmaa 1972: 6–7.
Age, 500 BC – 400 AD. For example, the youngest layers in the Kilpisaari 1 site had textile ceramics, which were used to date the site to the Early Metal Period, 1900/1800 BC–300 AD.\textsuperscript{54} Moreover, the Sarsa-Tomitsa wares belong to the Early Metal period found from the Kitulansuo D site. Moreover, Luukonsaari wares most likely belong to this same period of use.\textsuperscript{55} The Neitilä 4 furnace has been dated to the approximately 100 BC – 200 AD based on Kjelmøy ware finds.\textsuperscript{56} The calibrated radiocarbon dates taken from the furnaces or objects related to them for the Kitulansuo D, Kotijänkä, Riitakanranta and Äkälänneimi sites can be seen in Table 1. Interestingly, the Kitulansuo D furnace seems to be relatively late and could indicate that the stone box furnaces were used until the beginning of the Middle Iron Age. As a group they can, therefore, be roughly dated to a time period of 400 BC–600 AD.

3.2. Furnace structures

All the stone box furnaces share the same characteristic of being formed into a rectangular box shape from slate slabs built at least partly underground. The stone slabs create a space in which the charcoal is allowed to burn and they also keep the heat inside the furnace. Building the furnace below ground level also improves insulation, but it also makes the structure more stable reducing the amount of materials needed to gather for a furnace. Slabs varying in size are used for the side and back walls to prevent the surrounding earth from collapsing into the furnace, while the front part of the furnace might have smaller stones that creates a narrow doorway into the furnace. If the furnace has suffered extensive damage, it can be difficult to identify these doorstones, although it is also possible that door structures were not used in all furnaces. The top side of the furnace was closed with one or several larger pieces of slate again to keep the heat and reductive gases inside. The most notable characteristics of the furnaces have been compiled into Table 2.

\textsuperscript{54} Poutiainen 2000: 33–36. The Early Metal Period has been used to describe the Bronze Age and the Early Iron Age inland. See more in Lavento 2015: 129.

\textsuperscript{55} Lavento 1997: 14, 16–18.

\textsuperscript{56} Kehusmaa 1972: 87.
In most cases one of the short sides has been left open or possibly narrowed with smaller stones. Riitakanranta (Figures 2 and 3), Kotijänkä (Figure 4) and Äkälänniemi (Figure 5) furnaces had stones on one of the short sides forming a door-like feature, which had a roughly two centimeter wide gap between them. The gap between the front stones would have allowed the slag to run out and it could have been easily blocked with clay or turf in order to keep the heat inside. In other cases the door stones were possibly mixed up with the stone debris around the furnaces or the furnaces never had them. In addition to the stones on the edges of the furnace pit, the Riitakanranta furnace also had a lid stone, which had broken into two pieces.

In some cases the stones were worked before they were used in order to fit them better on top of the structures. For example, Kotivuori found small pieces of slate from Riitakanranta, which belonged to the stone structures on the site, and the lid stone of the stone box furnace has been knapped into rectangular shape to fit perfectly on top of the furnace. Another possibility for the stone fragments is that some of the stones in the furnace broke down in use. No lid stone was found in the Kitulansuo D site, but some pieces of stone were uncovered on the northeastern side of the

<table>
<thead>
<tr>
<th>Location</th>
<th>Outside Dimensions (cm)</th>
<th>Slag pit</th>
<th>Roof stone</th>
<th>Clay inlay</th>
<th>Slag (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilpisaari, Nastola</td>
<td>77-85 x 43 x c. 23</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>-</td>
</tr>
<tr>
<td>Kitulansuo D, Mikkeli</td>
<td>70 x 50 x 20</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>9</td>
</tr>
<tr>
<td>Kotijänkä, Rovaniemi</td>
<td>40 x 50 x 25</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>170</td>
</tr>
<tr>
<td>?Neitilä 4, Kemijärvi</td>
<td>unknown</td>
<td>no</td>
<td>possibly</td>
<td>yes</td>
<td>230</td>
</tr>
<tr>
<td>Riitakanranta, Rovaniemi</td>
<td>65 x 32 x 25</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>23</td>
</tr>
<tr>
<td>Äkälänniemi, Kajaani</td>
<td>70 x 40 x 25</td>
<td>yes</td>
<td>possibly</td>
<td>yes</td>
<td>22,3</td>
</tr>
</tbody>
</table>

Table 2. The structural details of the stone box furnaces.

furnace and they could have formed the lid stone.\textsuperscript{59} Unlike the stones on the sides, the lid stones were difficult to line with clay and thus they were more vulnerable for the high temperatures and cracking.

Few of the stone box furnaces have evidence for the use of clay to protect the stones from damage caused by the intense heat inside the furnace. For example, in the excavations of the Kitulansuo D furnace clay was only found on the inside walls and on the floor of the furnace. The clay was burnt onto the stones indicating that it did not get there by accident. Unfortunately the thickness of the clay on the walls was not recorded or could not be verified, although Lavento reports that the amount of clay was not considerable.\textsuperscript{60} In addition, both the Äkälänniemi and Kilpisaari 1 furnaces had some burnt clay inside them when they were excavated.\textsuperscript{61} On the other hand, the Riitakanranta furnace was found filled with clay, but it was mostly unburnt. It seems to have collapsed into the furnace after the smelt as the clay inside the furnace was above the charcoal and only a small amount of vitrified clay was found at the bottom of the furnace. Kotivuori suspects that the furnace could have been covered with clay and turf in order to maintain the interior temperatures high enough.\textsuperscript{62} While the clay and turf would possibly suit for this purpose, it would also complicate the addition of charcoal and ore into the furnace during the smelt. Instead, the furnace could have been filled with the excess amount of clay used for the furnace and other metalworking activities at the site.

Furthermore, some furnaces had a slag pit dug in front of them.\textsuperscript{63} Therefore, it is possible that at least some of the furnaces

\textsuperscript{59} Lavento 1996: 68–69.
\textsuperscript{60} Lavento 1995: 68.
\textsuperscript{61} Nieminen 1984: 8; Poutiainen 2000: 4-5.
\textsuperscript{62} Kotivuori 1995: 22.
were planned to be run for a longer period of time, in which slag would have to be removed from the furnace. On the other hand, the smelts could have been short enough for slag to stay inside the furnace and in such cases a slag pit or the doorway for the furnace would not have been needed. Nonetheless, it is unknown how or where the slag was tapped or removed, if it ever was, in such cases. The tapping of slag out of the furnace, even with smaller quantities of iron ore, would have allowed the iron bloom to be purer from slag.

Bellows are difficult to research archaeologically, because very little material evidence remains of them. The earliest depictions of bellows in Fennoscandia come from the Viking Age. For example, the rock carving of Ramsundberget, Södermanland, dated to about 1000 AD shows a set of double bellows and a similar construction is seen on the wood carvings on the 12th century door frames of Hylestad Church, Setesdal. The double bellows allow a continuous air flow and the size shown in the depictions suggest that they can be transported easily. But these are not the only possible type of bellows. The simplest and probably the earliest bellows type can be a bag of leather and the more substantial ones can have a frame made of wood with leather as the airbag. One indirect type of evidence for the bellows are tuyeres and clay nozzles, which are used to focus the airflow and direct it into the desired spot inside the furnace. Tuyeres are usually clay pipes of varying length, diameter and thickness, which can withstand the high temperatures inside the furnace. Nozzles of the bellows, on the other hand, can be made of wood, horn, clay or even metal.

Few Finnish Iron Age sites have preserved some occasional clues about bellows in the form of clay tuyeres or discs. An example of the latter is a disc found in Rakannmäki, Tornio, which Mäkivuoti, has interpreted as a nozzle or a nozzle protector for the bellows, but this identification does not really give us much information about the bellows themselves. Furthermore, Hannu Kotivuori found small parts of pipe-like objects formed of slag from the Kotijänkä site with the outer diameter of 35 mm and inner diameter 20 mm, which could be tuyeres or air pipes connecting bellows to a clay tuyere. The problem with these though is the material, because slag can be brittle and it would have been an extremely curious choice, if they were used with that intention. Other possible materials used for air pipes could be leather, wood or even bone.

Furthermore, the location of tuyeres in the furnaces is difficult to evaluate. The Riitakanranta furnace had a small pit in front of the furnace for slag tapping. The front part of the

---

64 Buchwald 2005: Fig. 313, Fig. 318.
65 Merkel 2013: 57.
furnace was constructed with two stones so that roughly a two centimeter gap had been left between them, through which the slag came out. Kotivuori and Lavento have suggested that the bellows were also located at the front and the gap was used to pump air into the furnace. The problem with this idea is the difficulty for the air to reach the other end of the furnace. This type of setting would probably result in a hot spot located near the furnace mouth leaving the rest relatively cool. The more likely place for the bellows in the Riitakanranta site is the south-eastern side of the structure, where the stone lining has a gap and the surrounding soil was more compacted.

At the Riitakanranta site the western and south-eastern sides of the furnace had more compacted soil, which was a mix of sand, soot and dirt. These were possibly the sides where most of the work had taken place and one possibility is that the bellows were located on either or both sides. On the other hand, the individuals operating the furnace might have spent most of their time on these sides lifting the lid stones in order to add charcoal and ore. The front of the furnace, which was used to get the slag out, had a 2,5 meter long trail of soot and slag. One possibility is that the slag pit needed to be emptied in order to make room for more slag coming out. The second possibility is that the iron bloom did not form properly and everything in the furnace was dragged outside to find all the fragmentary pieces of iron.

While the marks resulting from iron smelting itself are relatively clear, the roasting of the ore does not leave much evidence to be seen in the archaeological record and from the sites discussed here only the Kitulansuo D site has some possible indications of it. As the site was first studied with geophysical methods archaeologists were able to locate the anomaly caused by the stone box furnace. The geophysical data showed another anomaly next to the furnace, but upon excavation no further structures were found. Still, Lavento points out that a large fire had been burnt on the spot and the archaeologists found bit of slag, burnt clay and pieces of burnt stones. One interpretation for the spot is that it was used to roast the iron ore for the smelting process. The temperature in a fire could rise surprisingly high creating slag from the sand and clay mixed in lake and bog ores. Nevertheless, no ore was found on the spot, which means that it was not used for roasting or that all the ore was carefully gathered and placed inside the furnace.

---

73 Lavento 1996: 68.
The Neitilä 4 furnace is the most ambiguous one of the six furnaces presented here. Stones have been scattered in a 5 x 3,5 meter area and only two stones seemed to be in their original places. The stones were 70 cm apart from each other and tilted away from each other. The pit between the stones reached 45–50 cm below ground level and 30–35 cm below the stones. It is difficult, if not impossible, to get a clear idea of how the furnace was built.\textsuperscript{74} One possibility is that the furnace was almost completely destroyed once it was put out of use\textsuperscript{75} and only the stones, pieces of burnt clay, slag and soot show that the site was used for smelting iron. Alternatively, it might have been a stone and clay lined bowl furnace as suggested by Lavento\textsuperscript{76}, in which case it does not belong to the stone box furnace tradition or it is a variation of it. Mäkivuoti has argued that it is possible that the presumed furnace spot might not be a furnace at all due to inconsistencies in Sarvas’s and Kehusmaa’s excavation report and Master’s Thesis respectively. While he agrees that iron was smelted at the site, he even claims that the actual furnace might not have been excavated at all and that it remained outside the excavated area.\textsuperscript{77} On the other hand, the finds showed evidence for the connections towards the East in the form of Ananjino cast moulds.\textsuperscript{78} Therefore, it can be assumed that the technological skill for iron smelting came from that direction as well, although in these uncertain circumstances it is difficult to say if it really was so. Nevertheless, the Neitilä 4 furnace has been included in this research as a possible stone box furnace, because it has enough common characteristics to create a link between the more reliable cases and it dates to the same period with them.

\textsuperscript{74} Kehusmaa 1972: 83–84, Liite 5.  
\textsuperscript{75} See for example Keränen et al. 1991: 5.  
\textsuperscript{76} Lavento 2013: 96.  
\textsuperscript{77} Mäkivuoti 1983: 64–69.  
\textsuperscript{78} Kehusmaa 1972: 65; Mäkivuoti 1983: 64, 68–69.
4. IRON SMELTING EXPERIMENTS

4.1. Hypothesis and methods
The main assumption for the experiments is that based on archaeological examination and research it is possible reach suitable conditions for producing iron using a stone box furnace. Because these furnaces have a rather large surface area, it was also assumed that placing the ore affects, for example, the unity of bloom and slag production. In the furnace structure and setting it was decided to choose the ore placement as a testable variable, while controlling the rest of the variables. Therefore, the hypotheses can be outlined as follows:

Research hypothesis (H₁): Ore placement affects the quality of iron produced with a stone box furnace.

Null hypothesis (H₀): Ore placement does not affect the quality of iron produced with a stone box furnace.

In total three smelts were undertaken and all the experiments were planned and conducted by the author and Juuso Vattulainen in Kierikki Stone Age Centre⁷⁹ in Yli-Ii, which is today a part of city of Oulu. The staff of Kierikki and occasional visitors assisted in the smelts as well by pumping the bellows. In the first smelt the ore was to be scattered in all areas of the furnace. Based on the experiences and results from the first smelt the placement of iron ore inside the furnace was experimented further. Therefore, we decided to use a different placement spot in rest of the smelts. We decided that in the second experiment the ore was to be placed on the edge of the hottest spot inside the furnace and in the third it was added into the hottest spot. Therefore, the ore placement was the only thing we aimed to change and then analyze the effects caused by the different scenarios and how they might manifest archaeologically.

On the other hand, we decided to keep all the other aspects fixed in order to receive more reliable results. This meant repairing the furnace back to its original shape after each smelt and keeping the airflow, equipment, temperatures and all other parameters same throughout all the experiments. Moreover, we used ten kilograms of lake iron ore lifted from Nerkoojärvi in Lapinlahti for each of the experiments. Instead of using specific amount of charcoal for each experiment, we decided to keep the furnace full of charcoal at all times in order to keep the heat as high as possible and only calculate the amount of charcoal used after the smelts. This also prevented us from adding ore into the furnace too quickly.

⁷⁹ From now on abbreviated as Kierikki.
The slag from the experiments was also documented and representative samples were gathered for further analysis. Slag can be used to identify, for example, if the furnace had a possibility for slag tapping or if all the slag gathered into the bottom of the furnace and stayed there until the end of the smelt. Moreover, the iron content of slag can be used as a clue to assess how successful the smelt or smelts might have been and what type of impurities, like manganese and phosphorus, could have made their way from ore into iron.\textsuperscript{80}

Smelting iron has multiple different stages and it requires specific conditions in order to transform iron ore into metallic iron or steel. Moreover, one has to go through multiple processes before the smelting is begun and after that it takes time and skill to create an object from the iron bloom. In our experiments we focused mainly on the processes related directly to smelting and avoided some of the other long processes like making charcoal and collecting clay from natural deposits by, for instance, buying the necessary materials.

4.2. Building the stone box furnace and preparations for the smelts
The planning process for the experimental furnace started with a thorough reading of the excavation reports for the six furnaces found in Finland. The results from the analyses can be found in chapter 3.3. We used the archaeological information to design our furnace, which we then built in Kierikki. Since the furnaces were all slightly of different sizes, we decided to use the mean size of the archaeological furnaces. Therefore, we decided to build our furnace 70 cm long, 40 cm wide and 25 cm tall, but to allow minor variation depending on the size and shape of the stones. As quite many

\textsuperscript{80} Keränen et al. 1991: 19–22.
of the archaeologically known furnaces are partly destroyed or altered by tree roots, we decided to use the one from Riitakanranta as the base example for the structural details. Clay lining was used in all the experiments to give better fire resistance to the stones. The only stones without clay lining were the lid stones.

We collected the stones from a harrowed forest area relatively close to Yli-Ii on two occasions. The harrowing machines used for forest cultivation had already broken bigger stones into more manageable sizes and exposed more stones from beneath the turf. Therefore, the area offered good opportunities for finding stones, which we would not have to work much. While this was not the most authentic approach, it allowed us to move straight into the experiments reducing the time for finding suitable stones. Slate was preferred as it was used in the archaeological examples. A single piece of granite was used for one of the sides, because we found it at the same place as other stones and it was suitably sized. On the first gathering trip we only took enough stones for the furnace, but a second trip was made after the first smelt as we realized that more stones were needed due to the stones cracking in the heat.

After the first stone gathering trip, we used the stones to build our furnace. The furnace was built at the furthest part of the Stone Age village of Kierikki, because we wanted to separate the Iron Age activities from the Stone Age milieu. The top turf was removed and piled aside with a shovel to prevent fire hazards. The earth was stony sand, which had been brought to the area when the first houses of the Stone Age village were built. The ground was also relatively wet due to a small swamp that started about ten meters from our furnace site. Archaeologically our site differed from the archaeological ones, but we did not have as much options. Firstly, a 15 cm deep pit was dug with a shovel and by hand for the stones (Figure 6). Digging by hand was actually easier due to the small stones mixed in the sand. They were placed into a rectangular form as tightly as possible by beating and stomping sand around them to give a firm place for them (Figure 7). The gaps between the stones above ground level were filled with the clay, which had been given to us by the local heritage society of Ylikiiminki. The clay was fine red-firing clay from a ditch bank and we tempered it with a lot of fine sand and some straw. In earlier smelt we had observed that straw binds the clay together better especially in the building phase. The upper edge of the stones rose to about 18 cm above ground level. Moreover, to the opening of the furnace we placed two narrow stones as door stones, which created approximately two centimeter gap for slag tapping. A slag pit with a diameter of roughly thirty centimeters was dug in front of the door stones following the examples of Riitakanranta, Kotijänkä and Kitulansuo D. The pit was not lined with clay at all, while the inside of the furnace was lined with one to two centimeter thick layer of clay (Appendix 3 Figure 3).
In order to help with slag flow, we left the back part of the furnace about five centimeters higher than the front so that the furnace floor sloped towards the gap between the door stones. We also added a small gutter from the tuyere to the gap for the slag to flow in. Furthermore, we used clay to level the top sides of the stones in order for the lid stone to fit properly on top of the furnace. Overall, the building process was easy and took only a day to build. Just in case, we built the furnace a week before the first experiment. The first smelt took place during OpenArc conference that concentrated on experimental archaeology.

On one of the long sides we knapped a gap between the stones in order to create an opening for the tuyere. The tuyere was at the center of the long edge both vertically and horizontally and we had it pointing slightly downwards to the center of the furnace. There is one possible case of this type of a gap between stones on one of the long sides from Riitakanranta furnace\(^{81}\), but it is difficult to say if the gap was done on purpose or as a result of use, decay or a combination of both. For instance, the Äkälänniemi and Kitulansuo D furnaces had several tree roots growing through the structures shifting the stones.\(^{82}\) The inner diameters of our tuyeres were two centimeters and length varied between 20 and 25 cm. The material for them was the same clay as the furnace lining. The tuyeres were made a week before the experiments in order to let them dry properly. We had noticed earlier that firing them separately was not needed and decided to leave that out.

As a precaution for the smelts, the lid stones were heated in a fire for a short while in order to drive out all the water from the possible cracks. Unfortunately already at this stage some stones

\(^{81}\) Kotivuori 1995: drawing in Liite 12.
\(^{82}\) Lavento 1997: figure Kuva 16; Nieminen 1984, 6.
started to crack as the heat from the fire reacted in different ways on the individual layers of the slates. Furthermore, some of the stones may have had inner cracks due to the harrowing machines. In extreme circumstances the stones could have exploded as the result of water steam expanding between the layers within the stones. Moreover, the different layers might have reacted, for example expanded, differently when heated due to water bound into the mica layers or due to different mineral compositions causing cracks and breaks. We did not preheat the stones on the sides, because they were lined with clay to protect the stones from extensive heat. Instead, once the stones and the clay were in place, a small fire was burned inside the furnace to drive out most of the moisture. The fire was primarily used just to dry the clay lining, but it was not enough to burn the clay. We also conducted a small test run with the furnace the day before the first experiment. We charged the furnace first with wood and then with charcoal and heated it up with the bellows until the charcoal was glowing red. That way we were able to confirm some ideas how the furnace would work during the smelts and to even see that it functioned as planned.

Before the experiments and building the furnace we had to process the lake iron ore. Within the borders of modern Finland lake and bog iron ores are the most common types of ore used for prehistoric iron making, while evidence for the use of mined rock iron ore is lacking. Both lake and bog iron ores are smelted in the same way and are both chiefly composed of mineral called limonite $\text{Fe}_2\text{O}_3\cdot\text{H}_2\text{O}$\textsuperscript{83}. We lifted the ore from Nerkoojärvi in Lapinlahti (Figure 8 and Appendix 3 Figure 1) in the early summer using a boat and two different hand nets with long handles. The other one was a commercial fishing hand net with knitted net, while we made the other one with poultry netting as the net and a long branch as the handle. Both of them worked equally well. Once we found a suitable spot in

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{roasted_ore.jpg}
\caption{The roasted ore. Note the more reddish colour compared to the unroasted ore in Figure --. Photo by the author.}
\end{figure}

\textsuperscript{83} Chatterjee 2007: 105.
the lake we were able to gather roughly 150 kg of ore in about four hours. We washed most of the sand and mud from the ore on the shore and then took all the ore to Kierikki, where we let it dry out for a week before further processing.

Then iron ore was crushed and roasted in a fire in preparation for the smelts. Roasting is extremely beneficial before a smelt in order to gain dry and pure ore, but it is not compulsory part of the process. Burning the ore in a substantially large fire drives out the possible moisture and burns all the organic matter trapped within the pieces of iron ore. We roasted the ore in two batches with wood available from Kierikki. During the process we added more wood into the fire until whitish smoke disappeared indicating that all the water had steamed out. Thereafter we piled the burning charcoal and ore into one pile and let it cool down. As the water evaporates from the chemical compound the limonite turns partially into hematite (Fe₂O₃) through the following reaction:

\[ 2 \text{FeOOH} \rightarrow \text{Fe}_2\text{O}_3 + \text{H}_2\text{O} \]

After roasting the ore (Figure 9 and Appendix 3 Figure 2) has a reddish colour to it and it has become magnetic, which is helpful when picking the best pieces of ore to be smelted. We used a magnet and a hand sieve for this purpose. This way we got rid of most of the small stones and sand making the raw material more homogenous, which helped to give more reliable results between the experiments. We could have done the ore extraction by sight as well, which was probably the method used in ancient times. Originally our lake iron ore was greyish on the surface and black with a blueish shine on the cracked inside surface. After roasting the overall color of the ore was light brown and the pieces, which were more attracted to the magnet, tended to be reddish in color and had a stronger shine on the cracked surfaces. Nevertheless, the magnet was faster and more convenient than extracting the material richer in iron by hand and by sight. The ore used during a smelt was weighed into batches of one kilogram and that was used as a base when documenting the consumption of ore.

In addition to iron ore, one needs also enough charcoal as the source of heat and materials for the furnace. Methods of making charcoal vary, but one of them is to place dry wood into a pit and cover it with earth. With this method the wood gains very little oxygen leaving only pure carbon behind. The process has a lot more nuances than described here, but the making of charcoal

---

84 Peets 2003: 36.
is not important for this research and thus will not be handled in detail.\textsuperscript{86} Charcoal for our smelts came from a local heritage society in Ylikiiminki that uses a charcoal kiln based on 18\textsuperscript{th} and 19\textsuperscript{th} century models. Birch charcoal was preferred due to its high temperature efficiency, although pine charcoal was used during the preheating of the furnace due to its lower price. Based on analyses in Scandinavia various mixes of charcoal were used although pine charcoal seems to have been the most commonly used.\textsuperscript{87}

The bellows (Figures 10 and 11) were made of plywood and the nozzle out of two pieces of clued plank, which was then drilled and chiseled into a funnel shape on the inside. The sides were covered with leather from Kierikki and drilled in place with screws using a small plank to make it air tight. The bellows had only a single chamber and no backup valve nor ribs on the leather. The bellows were able to give c. 15 liters of air per pressing and were pumped approximately 17 times a minute, which gives a rate of 255 liters of air per minute or 4.25 liters per second. While not completely authentic, these types of bellows were used in later periods and there is very little evidence on the actual bellows used in the Early Iron Age. The earliest signs from Fennoscandia are the examples mentioned in chapter 3.2., but they belong to Late Iron Age. The bellows had a 40 cm metal pipe, which led to the tuyere. We did not place the air pipe and tuyere

\textsuperscript{86} See for example Buchwald 2005: 94-96.

\textsuperscript{87} Buchwald 2005: 94, 199.
airtight in order to prevent hot gases from reaching the bellows chamber, where they might have combusted from a spark exploding the bellows apart.

4.3. Experiments
Each of the smelts began by preheating the furnace first with wood (Appendix 3 Figure 29) and then with pine charcoal. The time used for preheating with wood was roughly one and a half hour and it was designed to heat the clay slowly avoiding cracks. In addition, preheating created an ash bed on the floor of the furnace, which helped slag to flow more easily instead of getting stuck on the floor lining. Preheating with pine charcoal took about half an hour and at this stage the bellows started to pump air into the furnace, the lid was placed on top of the furnace and the doorway at the front was closed with clay to keep the heat inside. Last stage of preheating started when the first patches of birch charcoal were added by lifting the lid stone and heated for twenty to thirty minutes before first cycles were began. Once the flames coming from the furnace had a bluish-purple tint to

![Figure 12. The furnace in use during the first smelt. Note the metal pipe coming from the bellows and how it places in relation to the tuyere. They are not connected tightly in order to prevent hot gases reaching the bellows chamber and bursting into flame. Photo by the author.](image-url)
it, we knew that a reductive atmosphere had been established inside the furnace and this was the aim of preheating before adding any iron ore. In all of the experiments the flames grew stronger towards the end of the smelts as the heat grew higher inside (Figures 12, 13 and Appendix 3 Figure 4). At the very end of the first smelt we were also able to see some sparks coming out from the furnace, which according to Niko Hynninen, who is an expert in making Japanese iron and steel as well as wootz-steel, meant that the furnace was hot enough for the iron to burn. We measured temperatures only in the first smelt as we did not have our own measuring equipment, but Hynninen was kind enough to bring his infrared thermometer.88 Measuring points were the lid, the front gap of the furnace and the surface of charcoal above the hottest spot. We took measurements every once in a while, but not systematically.

During the smelts we added iron ore in cycles of one kilogram during the smelts. Every time when we added charcoal into the furnace by lifting the lid, we also sprinkled a bit of ore onto the decided spots in each smelt (Appendix 3 Figures 5 and 6). In the first it was scattered all over the furnace, in the second on the edge of the hot spot and in the third on top of the hot spot. The amount we added per lift was not measured, but it can be estimated to have varied from 100 grams to 300 grams. We probably could have added more ore, but we wanted to be sure that it was not done too quickly and cause too much slag build up. In the first experiment the time taken by one ore cycle ranged from fifteen minutes to one hour and ten minutes. In the beginning of the experiment the cycles took longer as we were more cautious and the furnace was still building up temperature. Halfway through the first smelt the cycles took approximately 25 minutes each. In the second experiment the cycles took from 50 minutes to one hour and 25

---

88 TROTEC TP9. The emission during the smelt was 1,0
minutes. The longer cycles were already a clear indication that the ore was not being reduced as planned and that the ore placement was not the best possible one. Nevertheless, we decided to continue as we had started in order to see the end results. In the third and last experiment the length of the cycles varied from 35 minutes to 50 minutes with the mean of 45 minutes. Scattering the ore all around the furnace resulted in faster cycles, because it descended to the bottom of the furnace quicker and the wind might have made higher temperatures possible. On the other hand, the smaller focused batches in the second and third smelt were easier to follow as they descended and took a bit longer to go below the charcoal level.

As mentioned above, we wanted to keep the charcoal level constant in order to maintain the maximum temperature inside the furnace. As the charcoal burns inside the furnace it starts to produce carbon monoxide, because the burning gains only limited amount of oxygen through the bellows.

\[ 2C + O_2 \rightarrow 2CO \]

Carbon monoxide then proceeds to react with iron ore reducing it first into wüštite and then into pure iron.\(^{89}\)

\[ \text{Fe}_2\text{O}_3 + \text{CO} \rightarrow 2\text{FeO (wüštite)} + \text{CO}_2 \]

\[ \text{FeO} + \text{CO} \rightarrow \text{Fe (metallic iron)} + \text{CO}_2 \]

Therefore, we added charcoal every time the charcoal layer had descended roughly 5-10 centimeters. We measured the consumption at the end of each smelt instead of cycles as we did with the ore. We added charcoal and ore into the furnace in alternating layers by lifting the lid with welder’s gloves. It could have been done with thick leather gloves or even with wooden poles. Nevertheless, we found that removing the lid by hand was easy and quick. Towards the end of the smelts the lids had cracked in the heat and we had to be more careful when lifting them. The consumption of charcoal is presented in Table 3. Unsurprisingly, the fastest charcoal consumption was in the hottest spot of the furnace, but the natural draft in the front gap burnt charcoal quickly keeping the front part of the furnace hot as well. Only the back part of the furnace seemed to stay relatively cool, because the charcoal smoldered there with only a mild reddish glow unlike the front part, where the glow was closer to bright red and orange. The hottest and brightest glow was visible through the tuyere where it was bright yellow and at the best almost white.

---

\(^{89}\) Buchwald 2005: 93.
We kept the bellows working throughout the experiments with only small pauses in pumping. Pumping began once the wood used for preheating had created a charcoal bed on the floor of the furnace, which also marked the moment we started inserting pine charcoal. Thereafter pumping was only stopped when we were adding more charcoal and ore, checking for slag flow or clearing the tuyere from slag. The halts prevented burns on the experimenters as the pumping caused considerable flames to come out. We took alternate shifts to operate the bellows in order to have somebody fresh operating them preventing the rate of air from changing too much for example due to exhaustion. People pumping the bellows were either the experimenters or occasional visitors at the experimentation site. When the last ore had been added into the furnace, we started a phase called afterburn, in which we increased the pumping speed in an attempt to get the bloom inside as hot as possible and to remove as much slag as we could.

Slag removal from the furnace proved to be an interesting aspect during the smelts and the placement of the ore caused considerable variation in how it behaved. As the iron ore turns into iron the reductive process also removes the impurities as slag. In the simplest representation the impurities can be represented as SiO$_2$, which can be sand, quartz or amorphous silica in bog and lake iron ores. The amount of pure iron and slag depends on the balance between Fe$_2$O$_3$ and SiO$_2$. In all experiments we attempted to remove slag occasionally by removing the clay plug from the gap at the front and poked into the furnace with a metal rod to clear a way for the slag to flow. In the first two experiments we did not succeed at all, but in the third we managed to get the slag to flow out nicely. In the first experiment the slag had pooled to the floor and back part of the furnace, but as the ore had been scattered to a wider area it did not flow out. The most likely reason is that the small pieces of bloom iron closed the route to the gap causing the slag to form liquid pools, which were visible when we opened the furnace and allowed the charcoal level to burn lower. In the second smelt the low amount of reduced ore might have prevented the slag to gain enough mass to

![Figure 14. Tapping slag during the third smelt. Photo by the author.](image)

---

90 Buchwald 2005 93–94.
flow out. After we had successfully tapped slag a few times in the third smelt (Figure 14), we noticed that the slag tended to gather into the same spot. By poking that spot a few times with the iron rod the slag flew out easily through the front gap into the slag pit. We let it gather into the pit and once no more came out, we placed the clay plug back in front of the gap and removed the slag from the pit.

Moreover, the tuyere tended to get clogged by the slag and vitrifying clay from the wall and tuyere itself. As some slag got in front of the pipe, the airflow from the bellows cooled it enough to solidify and hinder the rate of air reaching the furnace. Whenever this happened, we moved the bellows out of the way and opened the tuyere using a metal rod.

During each smelt we noticed quickly that due to the lack of clay lining on the lid stones, they were vulnerable to the high temperatures inside the furnace. The heat damage started as small cracks on the surface of the stones that continued to expand as the smelts proceeded. Fortunately there was no need to replace stones during any of the smelts. In all experiments the lid lasted to the end of the smelt, but in the last lift it usually broke into pieces and could not be reused for this purpose (Figure 15 and Appendix 3 Figure 30). Sometimes the side facing the interior of the furnace was partly fused due to the high temperatures in the furnace, and in the second smelt pieces of lid stone fell into the furnace and were found amongst the slag when we opened it. After the first smelt we gathered the pieces of lid stones and other broken stones into a pile near the furnace for

Figure 15. Pieces of lid stones after the experiments. Photo by Antti Palmroos.
possible reuse. For example, we chose the material for new door stones for the second smelt from this pile. Recycling and reworking broke the stones into smaller pieces. We decided not to reuse some pieces at all, because they were too cracked or damaged to be reused as raw material for the furnace or other purposes.

The furnace usually suffered the greatest amount of damage, when we took the bloom out to be hammered on a tree stump with a wooden mallet. The mallet is more gentle tool than a hammer to solidify an iron bloom when it is still in its spongy form. The hammering compresses the iron into single piece and removes slag from it. The lid broke every time at this stage beyond reuse, the clay lining suffered badly due to slag clinging onto it and through vitrification, and the door stones were knocked down in two of the smelts. The reason for knocking down the door stones in the first and third smelts was to get more room to extract the blooms. In both cases the door stones broke down and could not be reused. During the last stages of the second smelt a torrential rain prevent us from opening the furnace. Because of this, the door stones survived intact and we were

Figure 16. The tuyere and the blast zone after the third smelt. The clay around the tuyere had vitrified extensively creating holes in the lining. The nozzle of the tuyere is completely vitrified as well. The small slag bed shows the extent of the blast zone and the side opposite to the tuyere shows a curve, where the bloom had formed. Photo by the author.
able to use them in the third smelt.

Moreover, the clay lining was damaged as the blooms were taken out in the first smelt, because we used a crowbar to sever the bloom from the bottom of the furnace. The Iron Age equivalent for a crowbar could have been a wooden staff with an iron or steel chisel point. The hard hits produced a lot of cracks on the lining and some pieces fell into the furnace (Appendix 3 Figure 7). For this reason, we decided not to use the crowbar anymore, but instead took a meter long metal rod and forged a chisel head to the end of it. It proved to be a lot more gentle and precise when used with a hammer to gently chisel the bloom off the floor lining. The lining saw almost no damage except on the floor, where the bloom and slag bed had been, and front wall. The clay around the tuyere and the blast zone vitrified obtaining a glassy surface (Figure 16), as the temperature was constantly over 1000 °C in this area. After the first smelt we removed the vitrified clay and replaced with new lining where needed, but after the second smelt we smeared a thin layer of clay on top of the vitrified layer as it was otherwise intact. As a result the heat burned holes into the lining exposing the stones on the sides in few places around the tuyere during the third smelt. We also changed the tuyeres after each smelt, because the heat vitrified their nozzles almost completely.

After the third smelt we cleared the furnace of all loose clay, charcoal, slag and stone, because we wanted to document the furnace in its final stage. In the case of archaeological stone box furnaces, once the iron bloom was out and the furnace was not going to be used anymore, it would have been easier to leave all the debris inside unless the craftsmen wanted to extract every small piece of iron. After the experiments were completed the experimental furnace was abandoned without destroying it any more than what it had suffered during the last smelt. At the present, the furnace has stood unused and unmodified for almost two years, because we wanted to find out how badly the clay lining was broken by the freeze-thaw cycles and other natural processes.

The area surrounding the furnace was littered with debris from the smelts and working on the raw materials. For example, when emptying the furnace before documentation all the loose charcoal was cleared into the slag pit in front of the furnace and surroundings. Similarly, all the loose pieces of burnt and partially burnt clay, stone rubble and slag were placed into their respective

<table>
<thead>
<tr>
<th>Smelt No.</th>
<th>Duration (hours)</th>
<th>Ore</th>
<th>Materials (kg)</th>
<th>Outcome (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Charcoal (pine)</td>
<td>Charcoal (birch)</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>10</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>8.5</td>
<td>10</td>
<td>7.5</td>
<td>26</td>
</tr>
</tbody>
</table>

Table 3. The results from the experiments.
We examined the furnace again first a year and then two years after conducting the experiments and it gave some interesting results as well. On the first examination on May 2015 we immediately noticed that only within a year the furnace had suffered a lot of natural damage from the elements and possibly some visitors, especially children, in Kierikki might have damaged it as well. The clay lining had suffered greatly during the relatively rainy autumn and winter. Practically all the clay, which had not burnt into ceramics during the smelts, had disintegrated from their original place and turned either into sand or into natural clay (Figure 17). Only the baked clay on the inside had survived without disintegrating, but it had broken into small pieces so that there was no more clay lining inside the furnace. Clay on the outside of the furnace had fallen off the furnace and turned into sand. For instance, the back wall had no clay left on the outside. Moreover, the clay outside the furnace had dissolved and spread into the ground in the rain and melting snow leaving the sand used for tempering on top. The stones seemed withered, but otherwise they were not affected by the winter or the changes could not be seen on the surface. Cracks inside the stones caused by the heat are now potentially full of water, which would break the stones when expanding via warmth or freezing as time passes. Moreover, the inside wall where the tuyere was located still had the vitrified nozzle of the tuyere and its surroundings in place although the lining had cracked badly already at this stage (Appendix 3 Figures 36 and 37). The tuyere itself had broken into small pieces beside the furnace.
Three photos showing the decay of the furnace. The top photo shows the furnace right after the last smelt, the middle after a year and bottom after two years. Note the decay rate of the lining and how the stones have moved. Photos by the author, Juuso Vattulainen and Sami Viljanmaa respectively.
The second examination took place in April 2016 and yielded extremely interesting results. Only in two years’ time the furnace had decayed much more than expected (Figure 18 and Appendix 3 Figures 38 and 39). For example, none of the walls retained their lining, which had broken into small pieces and fallen to the bottom of the furnace. The vitrified nozzle of the tuyere had fallen off and apparently rolled into the slag pit leaving only some vitrified clay and stone on the wall. A stone on the wall itself had broken and fallen over and the stone next to it has signs that it has too broken into pieces along the natural layers of the slate. Another stone on the opposite wall had also fallen over creating a gap on the wall. Moreover, the unburnt parts of the lining had broken even more and sand had separated from the clay, which has descended to the ground level. The rest of the stones were standing in their original places. The most interesting observation was the speed in which the structure has withered with the seasons. At the moment the place of the tuyere is still noticeable with relative ease, but after a year or two more it might become harder to see. Nevertheless, the overall shape and structural elements are most likely easily observable as the stones will remain in place and pieces of lining are identifiable as well, although they might break into even smaller pieces.

The decaying of clay was an interesting aspect to observe over the years. The heat in the smelts, especially the last one, caused an uneven burn on the clay lining. Some parts had burnt yellow, orange or red, while some had remained grey. The grey lining was located on the coldest parts of the furnace like the floor and especially on the top edge, which was built to accommodate the lid stones. The floor lining had not burn through because slag covered it before thorough firing was able to take place. These parts had disintegrated already within a year after the smelts. Yellow- and orange-fired clay was found inside the furnace on the upper parts of the walls. These had started to crumble and disintegrate by the second year and some of them had turned back to grey clay. The red
clay was found mostly around the tuyere and on the opposite wall, where the air blast had hit. These sections had broken into pieces in two years, but did not show signs of disintegrating. If estimated correctly, the majority of the lining will turn back into clay over the years and only the red-fired parts will survive.

4.4. Results
The results from the smelts were rather encouraging, because all of the experiments produced some metallic iron although in rather small quantities. Nevertheless, they are a good start in the study of the stone box furnaces and how they might have been used to produce iron.

The first experiment produced slightly less than a kilogram of iron, but it came out in small fragmentary pieces. At the end of the smelt the individual fragments of iron could be seen as brighter spots on the floor of the stone box furnace (Figure 19 and Appendix 3 Figures 10, 13 and 14). The fragmentary nature of iron was due to the way how iron ore was added into the furnace as in the first smelt it was scattered all around the furnace without a specific concentration spot. None of the pieces would have been large enough to actually forge anything, but they could have been used as material for another smelt in the future. In addition to iron, the pre-experiment produced roughly six kilograms of slag. Most of the slag belongs to the type 1, because none of it was tapped during the smelt. Tapping was attempted few times, but these attempts proved unsuccessful possibly for the same reason why the iron was so fragmentary.

The second smelt was slightly more successful in the sense that the bloom weighing roughly 0.6 kilograms was now in one piece instead of small fragments. Clearly concentrating the feeding of ore into one place, in this case close to the center of one of the

---

Figure 20. The furnace after the second smelt. The bloom lies under the ore in the middle of the picture. The slag cake had formed into the blast zone (middle of the picture) and at the end of the smelt a small stream of slag had started to flow towards the front gap. Photo by the author.

---

91 We built a small shaft furnace in an attempt to smelt the pieces into one in a small scale smelting trial. Unfortunately, the trial was unsuccessful and all the iron burnt inside the miniature furnace leaving only slag behind.
long sides, helped in this aspect. While the bloom was in one piece, it nevertheless had quite a bit of slag and charcoal mixed in it, because the process ran relatively slowly and only five kilograms of ore was used for the whole smelt. Furthermore, as it was left to cool, the bloom was not consolidated right at the end of the smelt leaving the slag and charcoal into the bloom. Forging of the bloom was attempted later and some of it was forged into a small piece of usable iron. The weight of the forged piece was around 100 grams.

The unexpected torrential rain that started in the final stages prevented the furnace from being opened at the end of the second smelt (Appendix 3 Figure 15). Instead the furnace was left to cool over the weekend and it was opened in the beginning of the next week (Appendix 3 Figure 16). A decision was made to open it as “archaeologically” as possible and document each step of uncovering the inside of the furnace in an attempt to see the effects of the smelt more clearly.

The first step was to remove the lid stones and see what was inside. As we took away the clay plug from between the door stones, we could see some slag that had ran to and stopped at the plug indicating that slag had started to flow at some point of the smelt. During the smelt this had not happened. Apparently pumping the bellows without adding any ore had produced enough heat and slag for it to do so. Furthermore, we noticed few pieces of stone from the lid stones. One had fused into the furnace wall close to the tuyere and another had fallen on top of the slag bed. Both were partly fused and extremely withered by the heat stress (Appendix 3 Figures 23 and 24). Archaeologically these types of stones could possibly be used as indicators for prolonged heating of a furnace or a blacksmith’s hearth. Otherwise, it was difficult to see anything else clearly, because the charcoal ashes covered everything (Appendix 3 Figure 17). After the ashes had been removed as well, we noticed that at the spot, into which we had added all the ore, still contained a substantial amount of unsmelted ore. Around this spot were charcoal and few more pieces of burnt stone.

The second step was to remove all loose charcoal and to see how the ore, slag and bloom were distributed inside the furnace (Figure 20 and Appendix 3 Figure 18). The slag had formed a small stream, which had started to run towards the slag pit. However, the amount of slag was so small, that it had probably happened at the very end of the smelt. Moreover, the tuyere and its surroundings within 5-8 cm radius had vitrified almost completely and we could not see any clay in this area anymore. Only a small hole had remained open for the air to flow into the furnace. In all of the smelts the tuyere had to be poked open with a metal rod due to slag formation, but once the rainfall had started we stopped this action and the opening at the tuyere nozzle had the possibility to get smaller. A small slag bed had formed in front of the tuyere, but apparently it formed very
slowly. On the other side of the slag bed, close to the opposite wall from the tuyere, was the bloom. It was covered by unmelted ore and the side facing the tuyere seemed slaggy. Between the bloom and the furnace wall was a lot more unmelted ore. Apparently, once the bloom had formed some of the ore fell behind it and the air blast from the tuyere could not heat that part of the furnace well enough for reduction. During the smelt we had predicted that the chosen spot for ore addition was not very effective, since it took much longer for a cycle of ore to smelt than in the first smelt. Opening the furnace confirmed that the edge of the hottest spot inside the furnace was not hot enough to turn ore into metallic iron. Therefore, we chose to add the ore directly into the hottest spot in the third smelt.

The last steps of opening the furnace were the removal of all loose ore and then removing the bloom from the furnace (Appendix 3 Figures 19, 20, 21 and 22). The loose ore amounted to roughly to 2 kilograms, which is more than a third of the ore added into the furnace. Choosing the spot to add ore, therefore, is extremely important if you want to have the best yield from a smelt. Archaeologically this type of mistake is difficult to detect, because even if it happened, the ore could be used again. On the other hand, the bloom had started to form nicely thanks to the concentrated addition of ore unlike in the first smelt. Only a few small metallic pieces of iron were separated from the bloom. While the bloom was one entity, it still had a lot of slag attached to it, because the air blast was not strong enough to separate slag from the other side of the bloom. The top part of the bloom had a rough surface, which contained the most reduced iron, but the side

Figure 21. The iron bloom right after the third experiment. Note the curved shape caused by the air blast through the tuyere. Photo by the author.
facing the wall had pieces of ore embedded into the slag on the surface. The side facing the tuyere had a smooth surface, because the slag had flown out from the bloom on that side. Once the slag bed had been separated from the bloom it weighed 1.5 kilograms and the bloom approximately 0.6 kilograms. We attempted to forge the bloom into a bar in order to remove slag and to make the iron ready to be used. The slag content in the bloom was so high that the pieces of metallic iron (Appendix 3 Figure 25) in it were difficult to weld together and we ended up with a small piece of roughly 100 grams. From 5 kilograms of ore this is not much considering that about the third of the ore had not reduced at all. Nevertheless, the results from the smelt were extremely useful and gave a lot of insights into how the furnace works and how important ore placement is.

The third smelt proved to be the most successful of all the experiments. The whole batch of ten kilograms of ore were used and yielded a bloom of roughly 1.3 kilograms (Figure 21 and Appendix 3 Figures 31 and 32). It still contained some slag mixed with the iron, but not as much as with the second bloom. Placing the ore almost right over the hottest spot of the furnace proved to be the most efficient way of getting a good solid bloom with only little slag in it. Furthermore, as we removed the loose charcoal from the furnace, we did not find any ore, which had not reduced. The placement allowed the slag to separate from iron better and that also kept the slag hot enough to flow towards the door stones making it possible to tap slag. As a result, the inside of the furnace had very little slag inside when we inspected it once it had cooled down. The surrounding of the tuyere had vitrified from slagged clay. The area immediately in front of the tuyere had a slag bed covering the furnace floor, which had been formed from vitrified clay and slag from the ore. This

Figure 22. The bloom from the third smelt placed into the furnace to the place where it had formed. Note the slag stream running towards the front from the slag bed. This is the area we poked in order to tap slag. Photo by the author.
area showed the area of the blast zone as a depression caused by the air blast. On the other side of the slag bed the broken surface showed place where the bloom had been. Because the bloom was not hammered after it was extracted from the furnace, we could place it back into the cooled furnace and see how it had formed in it (Figure 22). Unfortunately, we did not have a chance to try to forge the bloom, which would give more information about its characteristics.

The slags were gathered from few of the smelts and assigned to typologies based on their visual and physical appearances. The typology formed by Jouko Pukkila\textsuperscript{92} and modified by Keränen et al.\textsuperscript{93} was used as the basis for the division:

Type 1) Slag, which forms a slag bed or cake inside the furnace. It is heavy and magnetic, the surface is mat and blue-grey. The breakage surface is bluish and metallic and it has bubbles of different sizes. Sometimes the slag cake takes the form of the bottom parts of the furnace.

Type 2) Slag is quite heavy as well and magnetic, but both the surface and breakage surface are shiny. Usually the surface is rough in the likeness of new year’s tin. This type of slag is often met amongst roasted ore and it is probably the first phase, in which the ore starts to change.

Type 3) Roasted ore. Roasted ore is red, light, fragile and slightly magnetic.

Type 4) Very light – some pieces even float on water – and dense slag. The breakage surface is glassy and often full of small bubbles. Slag is not magnetic and it can be divided into variants based on colour, of which the most usual ones are black and white. Usually it is formed when the furnace lining burns.

Type 5) Best characteristics are clear depressions from charcoal and multiple projections or signs that slag has ran and then solidified. Surface and breakage surface are both greyish with a metallic shine and the latter has some small bubbles. Magnetism of the pieces varies. This type of slag is usually tapped out of the furnace or it gathers under and around the slag cake.

The first smelt had mostly slags belonging to types 1, 2 and 4, where the type 1 slag had been solidified on the floor of the furnace right in front of the tuyere. The slag had formed a slag

\textsuperscript{92} Pukkila 1991: 65, 67.
\textsuperscript{93} Keränen et al. 1991: 17–18.
bed into which the pieces of iron were embedded. As we tried to take out the pieces of iron, the whole slag bed came loose with some of the floor lining along with it. The bed piece got completely destroyed as we tried to remove to pieces of iron from it (Appendix 3 Figure 8). Type 2 slag was found as small pieces amongst all the debris after we inspected the cooled down furnace, although they had a smooth surface (Appendix 3 Figure 12). As Pukkila states, this is probably iron ore, which has started to change from ore into wustite without reaching the point where it would have turned into metallic iron. Type 4 concentrated to surroundings of the tuyere, where the lining had vitrified in the heat (Appendix 3 Figure 11). Some small pieces of magnetic metallic iron were mixed into the slag and probably some miniature blooms, which did not attach to any larger pieces.

The second smelt had all of the ore types listed in the typology. Slag of type 1 had formed a slag bed in front and under the bloom, because slag had not started to flow out of the furnace. The bottom still has some floor lining attached to it (Appendix 3 Figures 26 and 27). Some parts of it on the edge can be assigned to types 2 and 5. The type 2 slag is located on the upper surface, while type 5 has gathered on the lower edges in liquid form and then solidified. The latter has pieces of charcoal embedded into it and charcoal imprints as well as some pieces of stone which fell off the lid stone. The small part of slag, which had started to run towards the front gap, but solidified into the gutter as the furnace cooled down, belongs to the type 5 as well (Appendix 3 Figure 28). If the smelt would have continued, we would probably have been able to tap the slag out of the furnace. Interestingly this example shows that it is possible to find slag which looks like it has been tapped from inside the furnace. Type 3 was found on and behind the bloom, where the ore had fallen without being affected by the reductive atmosphere enough to be even turned into type 2. Type 4 slag was again present at the surroundings of the tuyere due to slagged clay.

The third smelt consisted mostly of type 4 and 5 slags, because we managed to tap a lot of the slag out of the furnace (Appendix 3 Figures 33, 34 and 35). The type 5 slag was tapped out of the furnace every now and then when we felt that enough slag had built up inside the furnace for tapping. Parts of the slag are layered, because we let the slag to gather into the slag pit and removed it after we closed the furnace again. We noticed that the slag flowed better that way compared to when we removed the slag as it came out. Type 4 was, as usual gathered around the tuyere. We found some pieces iron, which had come broken off the bloom during extraction and they still contain some slag like the bloom itself. Some slag of type 2 with shiny surfaces was also found.

Once the smelting process has been completed the iron bloom is removed from the furnace and purified from slag by forging. This usually requires a lot of forging in order to remove as much
of the slag inclusions from the iron as possible. Depending on what the iron was made for it is then forged into tools or other implements and it is carburized turning the iron into steel and then forged into an object.

4.5. Evaluation of the experiments
Taken into account that these were the first experiments we have done with a stone box furnace, we gained a lot of new information on how the structure in question works and how it might be improved. Before these smelts our experience in making iron was a handful of smelts with shaft furnaces. Therefore, we were learning more and more about the furnace type as the experiments proceeded. The last smelt succeeded so well, because we had learned much of the characteristics of our stone box furnace and how we could achieve best outcomes with it. This is exactly the process how experimental and experiential archaeology can give us new insights into topics, which have not been researched before. Of course, it would have been better to do few smelts with the furnace beforehand in order to gain experience and only after that design three or more smelts with more experimental approach to them. Nevertheless, the experiments yielded interesting and useful results on how the stone box furnaces might work and how the placement of iron ore changed the way the structure behaved.

The weather between the smelts varied quite a bit, causing minor variation in how the furnace heated up. During the first smelt the temperature stayed under 10 °C the whole day and it was extremely windy. The impact of the wind was noticeable in the behavior of the stone box furnace. It caused the charcoal to burn quite well throughout the furnace as it got inside through the gaps between the lid stone and the upper edge. Even the charcoal at the back of the furnace was burning and smoldering, while in the later smelts we were not able to achieve the same effect. Moreover, the second smelt ended quite radically as a result of torrential rain and we were unable to open the furnace on that day. Opening of the furnace three days later once it had cooled down allowed us to study the inside of the furnace in more detail than would have been possible if the bloom had been removed as a part of the smelt. This yielded some extremely interesting results and was a great experience, although some might point out that the smelt itself was unsuccessful.

While documentation of the experiments allows us to follow what happened during the smelts, it could have been more consistent and taken into account more aspects than they did. For example, the slag from the smelts was weighed on a scale only during the last smelt, while it would’ve been useful to document the weight in all of the smelts. Weighing the slag would have
given interesting insights, for example, into how the slag forms inside the furnace and how it would possibly correlate to the amount of iron gained from a smelt and how much of clay turned into slag during the smelts. The idea for weighing the slag came up only during the third smelt, because we were finally successful in slag tapping and it was done in the spur of the moment. Furthermore, temperature measurements would have been extremely useful in all the experiments. Unfortunately, we were able to use an infrared meter only in the first smelt, because Niko Hynninen brought it with him when he visited to see our smelt. Measurements and documenting them would have confirmed if the temperatures were similar in all of the smelts or not. For instance, the extremely windy day during the first experiment helped to get the furnace hotter than in the rest of the experiments. Moreover, we do not know how much the stretching of the leather, resulting from the continuing use of same bellows, affected their air flow and, thus, the temperature inside the furnace. Nevertheless, after two years of the experiments it is still possible to follow them using the written experimentation form, pictures and video clips that we took during the experiments and afterwards and it would be possible to replicate the whole process.

Nevertheless, the temperature measurements during the first smelt revealed that the furnace worked better than expected. The first measurements about three hours after the fire was lit revealed that the surface temperature of the charcoal above the tuyere had risen up to 1085 °C. After six hours the temperature on the same spot was 1417 °C and at the same time the purple flames from gases formed during the reduction were visible even in sunlight. Unfortunately it was not possible to measure the temperatures in the middle of the charcoal, but it must have been higher than on the surface. Apparently the temperature did not rise over the melting point of iron as no pieces of cast iron were found from the furnace. One disadvantage of using only one set of bellows was that the back of the furnace did not heat up as much as the center and the front parts. In all smelts the charcoal on the back smoldered at the best instead of burning cleanly. The front part heated up better because of the natural airflow through the slag tapping gap. Another set of bellows might have been enough to heat up the whole furnace, but it is another question if it would be necessary. With the small amounts of ore that were used it is better to focus the ore to one spot in order to gain a better bloom instead of spreading it around the whole furnace as can be seen when comparing the first smelt to the second and third.
5. DISCUSSION
Currently the number of archaeological stone box furnaces is not high enough to define the extent in which they were used within Finland. Most likely the low number of found furnaces in Finland is due to lack of research as Jäppinen and Nygård have exemplified in their studies in the Kymijoki river valley. Few types of commonalities between the known stone box furnace sites making it possible to evaluate more possible sites. For example, more furnaces could be found from shores of lakes with iron ore along the water networks reaching from Kajaani to Rovaniemi, Kemijärvi and southeastern Finland. This would cover the areas, which have evidence for contacts with Ananjino-cultures and it would also hold the currently known sites. Their sporadic spread in Eastern and Northern Finland and vicinity to cities with provincial museums would make it reasonable that more furnaces could lie in the areas between them. Moreover, the known furnaces seem to be placed most often on the slopes or high points of capes extending towards the lakes. When in use the sites would have been most likely visible when viewed from the lakes. Interestingly, the evidence shows that stone box furnaces were used during a period lasting 500–1000 years according to the radiocarbon dates (Table 1). Based on the similarities of the structures it might be possible that they were relatively commonly used type of furnace in eastern and northern Finland indicating that there could be more furnaces to be found.

During the first smelt we noticed that adding the ore all over the furnace would only result in small fragmentary blooms. In the archaeological record the slag and other debris, which have been spread in the proximity of the furnaces, could be an indication of the very same result. Our solution for this problem was to collect all the pieces of iron with a magnet after the smelt, but obviously this was not the option for Iron Age craftsmen. Another valid solution would be to take out the contents of the furnace after the smelt and crush the pieces of slag in search of pure iron mixed with it. This could explain why, for example, at the Riitakanranta site there are no large pieces of slag, the trail of sand, soot and slag observed at the site could indicate the area where this type of process took place. Small pieces of iron are nearly useless if one attempts to forge them into anything as they are difficult to handle and burn easily. They could still be used in future smelts giving purer iron in the next smelting process. The dome shaped furnaces found in Riitakanranta and Kotijänkä sites could have been used for such purposes.

The stone box furnaces can be categorized as a type of pit furnace that differs somewhat from the shaft furnaces used especially during later periods. For example, in shaft furnace the reduction process takes place in the shaft as the iron ore stacked in alternating layers with charcoal

descends towards the hottest spot at the bottom. This allows the slag to separate from the ore while descending allowing better results. On the other hand, in box and bowl furnaces all the processes take place in the same space, i.e. in the pit, causing some of the iron oxides and metallic iron to flow out with slag when it separates from ore. This affects the productivity of the furnace. Buchwald was able to carry out SEM-EDAX analyses from few small pieces of slag from Äkälänniemi and Neitilä 4 sites. The results show that both of them are still rich in iron, containing respectively 69.1 % and 72.1 % of FeO. The pieces of slags had some pure iron blebs mixed into them and were rich in fayalite and wüstite. The latter two make slag heavier and give them a shiny surface. Furthermore, the tapping of slag can yield more slag free iron in a stone box furnace, but some iron is inevitably lost along with slag as noticed in the slags from the third smelt. In my experience, shaft furnaces are more effective with regard to slag tapping and easier to maintain during the smelt. Especially the feeding of ore is slightly easier, because one does not need to lift the hot cover stone before adding ore and charcoal. Additionally, the slags from pit furnaces have a wider range of melting temperatures than in shaft furnaces identified from their microstructure as the temperature is distributed unevenly from the blast zone. In a shaft furnace the blast zone is located at the bottom part and the temperature lowers steadily along the shaft. Therefore, the placement of the iron ore into a stone box furnace has to be more carefully planned in order to achieve as much pure iron as possible. This idea is supported by the experiments reported here, because in each case the different placement of the ore inside the stone box furnace gave slightly different results.

One of the questions remaining unsolved is related to the relatively big size of the stone box furnaces, because in our experiments the hottest zone remained relatively small. Was there more than one set of bellows feeding the furnace with air and thus creating larger reductive zone? The size could have allowed the furnace to accommodate more charcoal, as the temperature was kept higher around the hot spot allowing for the slag to run out better. While we decided to have only one tuyere placed in a gap between the stones on one of the long sides, it now seems that an alternative interpretation can be put forward.

---

96 Buchwald 2005: 195–196, Table 8.3.
97 The author has done nearly ten smelts with shaft furnaces.
At the Kilpisaari 1 site the furnace had a single long stone on each side of the furnace and both of them had a notch on the top of the stone. Both stones had cracked vertically in the middle of the notches. The notches might have been used as places for tuyeres, which were directed into the furnace from above. The burnt clay and stone, both of which had a glassy surface, surrounding the notches on the inside surface of the furnace support the idea that this area was the hottest spot. The same phenomenon was observed in our smelts as well, because the slag of type 4 was present only around the tuyere. Similarly, the furnace from the Riitakanranta site seems to have exactly similar notches, which can be seen in Figure 23. These notches are not mentioned in the excavation report. The stones have also cracked vertically at this point, which is a sign for extensive thermal stress. After realizing this, it was easy to see the same feature in furnaces from the Kotijänkä and Äkälänniemi sites as well (Figures 24 and 25). The notches on the Kitulansuo D furnace can be barely seen in Lavento’s picture, because the furnace was badly damaged and I was not able to inspect the furnace structure myself. Based on this observation it seems that the air was pumped into the furnace through these notches. Possibly the ends of L-shaped tuyeres lay on top of them directing the air blast downwards into the furnace. This would also suggest that the furnace was operated by two sets of bellows, possibly small leather hand bellows. This might have created more evenly spread blast zone inside, which would have allowed more ore to be smelted at a time. However, it is questionable if the air blast would have reached the bottom of the furnace without further experiments, but two sets of bellows might have been enough depending on their size.

Figure 23. The Riitakanranta furnace in the Provincial Museum of Lapland as reconstructed by Hannu Kotivuori. Note the notches on both of the stones on the long sides and the cracks running vertically. Photo by Laura Halvari.

100 Poutiainen 2000: 5.
101 Poutiainen 2000: 5.
and effectiveness.

Alternatively, the notches might have been used to add ore and charcoal into the furnace or even to help to lift the lid stone. A wooden beam or iron bar could have been inserted through the notches and used to lift the lid. Problems might arise if the lid stone started to crack during the smelt, because a beam or rod in the center of it would cause a lot of stress into a small part of the stone. The experiments showed that the thermal stress caused cracks in all of the lid stones and towards the end of each smelt they had to be lifted carefully. When two persons lifted the lid it was supported from four directions. With a beam and other support it could be one method of lifting the lid. In respect to ore and charcoal addition the notches are probably too small and difficult method insert them. A small ladle could have been used for the purpose when adding ore, but in case of charcoal this method would have taken time due to the amounts of charcoal needed during smelting.

Nevertheless, evidence that the stone box furnaces could be taken to extremely high temperatures is also found in the archaeological evidence. Unfortunately, temperatures reached by the archaeological furnaces are somewhat difficult to estimate, while our furnace reached the temperature of 1417°C as the highest recorded temperature. Fortunately there are other ways to assess the amount of heat inside the furnaces. For example, Kotivuori\textsuperscript{103} and Poutiainen\textsuperscript{104} found some partly fused slate from the Riitakanranta and Kilpisaari 1 sites implying relatively high temperatures. Similarly, in our first experiment the down facing side part of the lid stone had fused surface due to the heat (Appendix 3 Figure 9). In the second experiment few fragments of cracked lid stones had partly fused to the slag bed and to the clay lining of the furnace. Moreover, the stones on the long sides in the Äkälänniemi furnace had originally been single pieces, but they had cracked into several pieces and were withered by the

\textsuperscript{103} Kotivuori1995: 23.
\textsuperscript{104} Poutiainen 2000: 5
Similarly, the damage on the stones of our furnace could be observed especially two years after the smelts, because the clay lining had fallen off. Several of the lining stones had cracks or had broken into two or several pieces. Even the granite stone had broken. These examples indicate that the heat was hot enough to make the stones fragile, break them on the mineral structure or occasionally even melt stone.

For continued smelts spare stones especially for lids would have been necessary, but they are rarely found from the sites. The collection of slate slabs in the Neitilä 4 site could indicate that the craftsmen had collected spare stones for repairs. The big amount of slag would suggest that the site was used multiple times to produce iron making it essential to have building material for the furnace once it started to wear in use. The lack of spare stones at other sites could mean that these furnaces were used only once or few times and the craftsmen relied that the furnace could take the heat or that the stones were taken away as they could be recycled as construction material for another furnace. On the other hand, Äkälänniemi and Kitulansuo D sites had stones laying a short distance from the furnace structures. Lavento suspects that the pieces in Kitulansuo D are part of the furnace structure. The stones might have been collected there as spare parts of they could also be stones fragments from broken lids and other stone parts of the furnaces.

After a smelt the furnace lining often needed to be repaired or replaced before it could be used again. In this regard, the Riitakanranta furnace is a curious case, because the structure had been filled with unburnt clay after the smelt, which indicated by the charcoal layer found beneath the clay. Some clay was also found around the structure. While Kotivuori suspects that this represented the material covering the furnace during the smelt, the clay could also have been placed inside in order to store the clay for the next smelt, but for some reason the furnace was never

---

used again. On the other hand, the clay on the sides could be have been used to level the top of the stones as was done in the experiment reported here. Already after a year from experiments the clay had fallen from its place and disintegrated into a mix of sand and clay. Interestingly, no burnt clay was found lining the walls or the floor, but some vitrified clay was mixed in the charcoal at the bottom of the furnace and some burnt clay was found from the slag pit. Could the inside of the furnace have been customarily cleared from all material before placing the unburnt clay inside it causing the lack of burnt clay lining? If so, this would imply that the burnt lining was removed in order to add a new lining to the furnace, but it was never done. The furnace found in Haparanda had been used multiple times and was apparently emptied of most of slag and clay lining in preparation for a new lining, but was then abandoned. The furnace used in our experiments was fixed after the first smelt, because a lot of the lining had come loose. It did not take long to fix – unlike shaft furnaces, the stone box furnaces do not require a lot of clay. Therefore, it is safe to conclude that the furnaces were fixed between smelts, if they were used more than once.

One of the clearest indications that the furnace or smelting site was in continuous use is the amount of slag found, although the effects post-depositional processes has to be kept in mind as slag could have been placed, for instance, into burials. The amount of slag found vary radically between different sites. For instance, at Rovaniemi, where the two nearly identical production sites are located, roughly 23 kg of slag was found from Riitakanranta site and 170 kg from Kotijänkä site, at the latter site 115 kg was found near the furnace. In Äkälänniemi site roughly 32.5 kg of slag was found in total. In our experiments 10 kg of roasted iron ore produced 6-7 kg of slag in the first and third smelt and about 3 kg in the second smelt, when 5 kg of ore was used. In the last smelt we received a bloom weighing 1.3 kg, thus producing 0.2 kg of iron for each kilogram of slag. The closest parallel to our amount of slag comes from the Kitulansuo D site, 9 kg of slag, and it is possible that the stone box furnace there was used only once. Nevertheless, our suspicion is that even longer smelts can be carried out with the stone box furnace due to the possibility of tapping slag out. However, a smelt producing 115 kg, not to mention 230 kg, which is the quantity of slag found at the Neitilä 4 site, sounds excessively long and laborious. In the sites of Kotijänkä and Neitilä 4 the most likely explanation is that they were used for multiple iron production cycles.

110 Bennerhag 2010: 11–13
114 Compare Kotivuori 1996: 110.
with intermediate renovations when necessary. Unfortunately, the excavation report for the furnace in Kotijänkää has not been yet filed in making it difficult for us to research all the aspects regarding the site. On the other hand, the slag could have been transported away from the smelting sites, offering an explanation for sites with less slag, but this seems unlikely. Interestingly Vagn Buchwald states that it is difficult, if not impossible, to calculate the yield of a smelting process based on slag alone due to the huge variations within the quality of ores.\footnote{Buchwald 2005 93–94.}

Moreover, the tapping of slag seems to have been more or less successful at the sites. In our experiments some slag was left inside the furnace especially in the first and second smelts, because we did not manage to tap any slag. Similarly, at the Kitulansuo D site slag was found both inside and outside the furnace indicating that it was at least partially tapped.\footnote{Lavento 1997: 12.} At the Riitakanranta site the largest pieces of slag were found in the slag pit, but a small amount had remained inside the furnace as well. Kotivuori states that typologically almost all the slag was tapped slag\footnote{Kotivuori 1995: 22.}, which tells about successful slag tapping methods and skillful iron workers. Unfortunately, it was not possible to study the archaeological slags and compare them with the slag from the experiments.

With hindsight, the use of birch charcoal for higher heat might have been a mistake to some extent. Based on analyses on the ashes of different trees, it seems that deciduous trees, like birch, contain four times more phosphorus compared to coniferous trees, like pine.\footnote{Buchwald 2005: 96.} Phosphorus is also rather common element in lake and bog iron ores. This can cause various problems later when the finished objects are put to use, because phosphorus makes the iron brittle and it also prevents carbon migration into the iron when trying to turn it into steel.\footnote{Buchwald 2005: 178.} On the other hand, phosphorus makes the iron harder without adding any carbon into it\footnote{Gansum 2004: 42.} allowing the making edged tools even if steel was not available.

The insulation of the stone box furnaces has not received much attention in literature, but one of the most common statements is that they could have been covered with turf, clay and sand during the smelt.\footnote{Kotivuori 1995: 22.} On the other hand, the experiments showed that keeping a suitable atmosphere for iron reduction inside the furnace is possible just with the lid stones. Firstly, the experimental furnace reduced iron ore into metallic iron. Secondly, even during the smelts it was evident that the

\footnotesize
\begin{itemize}
  \item \footnote{Buchwald 2005 93–94.}
  \item \footnote{Lavento 1997: 12.}
  \item \footnote{Kotivuori 1995: 22.}
  \item \footnote{Buchwald 2005: 96.}
  \item \footnote{Buchwald 2005: 178.}
  \item \footnote{Gansum 2004: 42.}
  \item \footnote{Kotivuori 1995: 22.}
\end{itemize}

atmosphere was correct as the flames coming out of the furnace had a pale purple and bluish tint in them. The blue flame is an observable phenomenon for the combustion of carbon monoxide indicating that suitable reductive conditions have been achieved. This would have been the most visible cue for the ancient iron smelters that the process was working. The flame is at its most visible during night time, when the sun is not diminishing it.

The placement of the furnace in relation to ground level slightly differs between furnaces and in some cases it is not completely clear if a furnace was completely below ground level or only partly dug into the ground. Usually the top parts the furnaces excavated in Finland came into view immediately once the top soil had been removed or in the first excavation layer. At the Riitakanranta site signs of the furnace could be observed without removing the turf layer. This suggests that their top parts were at the ground level or slightly above it. At least at the Kilpisaari 1 site some finds were found right after removing the top soil, which suggests that the elevation of ground level has not changed much. Either the furnaces were constructed almost completely underground with only the top part at ground level or they were partly underground and the decomposing organic matter has raised the ground level slightly over the centuries. Moreover, the theory about the notches being used as entrance points for tuyeres would suggest that they were built underground, because it would be easier to direct the tuyeres and bellows, when the upper edge of the furnace was on the ground level. On the other hand, the furnace excavated in Haparanda, Sweden, was dug only partly into the sand and this is the method we decided to use for our furnace. In our opinion, this did not affect the insulation of the furnace, although further experiments with a fully sunken furnace would be needed to confirm this.

Eventually a furnace would face abandonment, destruction or recycling at the end of its lifecycle. In our case the abandonment was a rather easy choice, because we wanted to monitor the effects of decay on the furnace. For example, the furnace at the Riitakanranta site seems to have remained in operating condition except for the broken lid, but it was nevertheless abandoned. The hill Kurivaara next to Lake Sierijärvi offered an unlimited supply of stone material, which meant that there was no need to recycle the stones. Another possible explanation could be that the smelting took place close to the ore resources away from the settlement and the abandoning of the previous work space and moving just the tools to the new smelting site was the easiest option. Obviously, a

124 Merkel 2013: 56 Figure 4.
list of practical or even seemingly irrational ritual reasons can be suggested for the selection of smelting locations. The produced objects, sites and slag might have had qualities and attributes, which are difficult to study today. Nevertheless, iron production and iron tools were an essential and part of everyday life in the Iron Age allowing them to gain and create various meanings.

In addition to smelting, the furnace was noted to be a rather effective forge to heat the bloom again and then forge the slag out of it. The consolidation of the bloom from the second experiment was attempted in the furnace, but the bloom broke down into smaller pieces due to high slag content. Nevertheless, a small piece of pure iron was achieved, which could have been used to forge a small object. The test attests that a stone box furnace could have been used as a forge already in the Early Iron Age, although if a separate smithing hearth is found near the furnace, this was probably not the case. If not, this option has to be kept in mind while analyzing the slag as smelting and forging give different types of slag.

However, it is also the possible that the stone box furnaces were neither built nor used in the fashion presented in this thesis. Bennerhag suspects that the furnace found in Haparanda Sweden, might have had a short shaft. The stones lined with clay formed a base for the shaft, which rose from the center. The bloom would have formed into the base and the opening on one of the short sides could have been used to tap slag. Schulz makes similar claims based upon examples found from Northern Germany. This type of furnace with an underground stone lined pit and clay shaft have been excavated in Norway, Denmark and North Europe. With regard to Finnish furnaces this could, for instance, explain the unburnt clay inside the Riitakanranta furnace discussed above. However, the evidence from the other stone box furnaces in Finland does not support this idea. Moreover, the slag analysis from Äkälänniemi made by Buchwald suggests that due to high iron content in slag, it would more likely have been used as a bowl or pit furnace rather than as a short shaft furnace. Also, the lid stones found from Riitakanranta and Kotijänkä do not suggest that they had shafts, if the structure was already closed with a lid. Of course, it is possible that these stones were placed on top of the furnaces after use when the shaft had been destroyed, although this seems unlikely.

In regards to experimental and experiential archaeology, this study had multiple aspects that came into play. A lot of the experiential side was related to the methods of ore feeding, because

---

132 Buchwald 2005: 184, Fig 183.
133 Buchwald 2005: 195–196, Table 8.3.
the first smelt showed so clearly that scattering it around the furnace was not very effective. In addition, in the course of experiments we learned more and more about how the furnace works and eventually even managed to get slag flowing out of the furnace. The learning processes included learning through all our senses on various levels.\textsuperscript{134} For example, we observed multiple cues for the proper reductive atmosphere including the bluish-purple flame, the colour inside the furnace as observed through the tuyere and the sound of slag bubbling inside the furnace. At times some of these sensory observations were based on feel of the material. For example, this was the case when we mixed sand into clay in order to get the “right” consistency, which we had learned in our smelts with shaft furnaces. While temperature measurements with thermometers and other methods can give more concrete data on smelting process I find it also important to gain sensory cues from the material and structures, because these signs were equally accessible to the prehistoric iron smelters.

We also learned how precious failed experiments and accidents might be as a way of gaining more information via experimental archaeology. During the second experiment we allowed the smelt to fail, although it was clear that the process was not progressing as planned. The ore took a lot more time to descend into the furnace than in the first smelt and we immediately presumed that it was due to ineffective ore placement. Still we decided to continue as long as we could to see what would be the outcome. Without the torrential rain we would have opened the furnace with standard procedure only to find a smaller bloom inside and missed other significant aspects, which we noticed when the furnace was opened only once it had cooled down. As a matter of fact, we learned more from the second experiment when we allowed it to run its course and by sheer accident than we would have had, if we had changed the feeding of iron ore or if we had opened the furnace at the end of the smelt.

\textsuperscript{134} See Hurcombe 2007 for discussion about the importance of senses and perception and Light 2000 as an example how experience affects when working with iron.
6. CONCLUSION
This thesis included an archaeological analysis of six Early Iron Age sites with possible stone box furnaces used for iron smelting, three experiments with an experimental stone box furnace based on that analysis and finally a critical review of the archaeological material along with the results from the experiments.

The examination of the archaeological material showed that this furnace type came to Eastern and Northern Finland from Karelia during the Early Iron Age 500 BC–400 AD, while different type of iron smelting furnaces were synchronously being used in Southern and Western Finland. The stone box furnaces share numerous common characteristics such as being dug underground, having a clay lining on interior and namely being built out of flat slate slabs into a rectangular box shape usually accompanied with a stone lid or stones.

The experiments I conducted with Juuso Vattulainen gave new insights into how the stone box furnaces might have been used. We were also able to verify the fact that it is possibly to use this type of furnace structure to produce iron. The most important finding was the importance of ore placement within the furnace and how the placement affected both the slag tapping and the quality of the bloom. It was also noted that no upper structure, as suggested in previous research, is needed for the furnace to work and that a lid stone is enough for the process to succeed.

Moreover, the experiments gave a possibility to address the archaeological material and find indications on how the process of iron smelting might have taken place. Multiple similarities were found between archaeological and experimental data and especially some of the decaying processes can be looked from a new perspective. Some evident differences were observed as well. For instance, we did not dig our furnace completely underground and our decision to operate the furnace with a single tuyere placement differed from the discovery made only after the experiments had been carried out. The stone box furnaces seem to have been customarily equipped with two sets of bellows, from which the air was directed into the furnace through the notches on the top of the long sides.

In conclusion, these observations not only show what needs to be taken into account during the smelts, but also that in the Early Iron Age smelters had the knowledge and skill to operate this type of furnace successfully. Moreover, the study showed how useful experimental and experiential archaeology can be when researching technological processes such as iron smelting. This research also covered some new ground as only a few experiments with Early Iron Age stone box furnaces had been previously carried out in Finland.
BIBLIOGRAPHY

Unpublished literature


Personal communication

Published literature


APPENDIX 1. – SITE DESCRIPTIONS

1.

MUNICIPALITY: Kajaani

SITE: Äkälänniemi

Register number: 205010002

Year found: 1980

Topographic map: 343112 Kajaani

Coordinates: P: 7122497, I: 538413, Z: 145

Description

The site is located approximately 3 km east from the Kajaani city center on the highest spot of the Äkälänniemi cape. The geological settings are rocky and sandy boreal forest. Originally excavations were started at the site due to Stone Age finds, but an iron smelting furnace was also found.

The top part of the furnace was revealed in the first excavation layer. The 5 cm thick stones forming the long sides were still standing and some of them were burnt and weathered. Similar stones probably belonging to the roof structure were also found on the short sides, although they had been displaced by tree root action. More stones of the furnace were found from the adjacent excavation square. Charcoal, slag and burnt clay were found inside the furnace. A trail of soot and charcoal, containing a lot of slag was discovered on one of the short sides of the furnace.

Field research

1980, Survey, Mikko Perkko
1981, Excavation, Mikko Perkko
1982, Excavation, Eeva-Liisa Nieminen
1983, Excavation, Eeva-Liisa Nieminen

Literature

Keränen et al. 1991: 5.


2.

MUNICIPALITY: Kemijärvi
SITE: Neitilä 4

Register number: 320010104
Year found: 1962
Topographic map: 363204 Luusua

Description

The site is located 29 km south from the church of Kemijärvi on the shore of the Kemijoki river. Neitilä 4 is one of the sites excavated in 1963–4 due to construction of hydroelectric power plant and a dam. The area has been excavated thoroughly, because at the time it was going to be covered by water due to building of a power plant. Today the site is completely destroyed. The soil at the site was mostly fine sand.

The site yielded archaeological evidence from different periods all the way from the Stone Age to the Iron Age. The phases were easy to separate due to thick layers of mud caused by the floods of Kemijoki river.

The area producing evidence on ironworking site was about 5 x 3,5 m in size and contained several flat stones of about 25 x 50 x 5-11 cm in size placed against the ground. Kehusmaa suspects that these stones formed a floor, which acted as insulation against the soft muddy ground. Amongst these stones were two stones placed standing on their sides into a pit lining the walls and they leaned slightly outwards to opposite directions. Roughly 230 kgs of slag was found from the site.

Field research

1962, Excavation, Pekka Sarvas
1962, Survey, Pekka Sarvas
1963, Excavation, Pekka Sarvas
1964, Excavation, Pekka Sarvas
1989, Survey, Hannu Kotivuori
1997, Inspection, Hannu Kotivuori
2004, Inspection, Hannu Kotivuori

**Literature**

Kehusmaa 1972.
Keränen et al. 1991: 5.
Pukkila 1991: 60–62, 64.
3.

**MUNICIPALITY:** Lahti

**SITE:** Kilpisaari 1

**Register number:** 532010021

**Year found:** 1999

**Topographic map:** 311112 Arrajärvi

**Coordinates:** P: 6760783, I: 450950, Z: 80

**Description**

The site is located on the southern shore of a peninsula on the Lake Arrajärvi. This peninsula called Kilpisaari used to be an island, but due to land uplift a small strip of land connects the island to the mainland today. The dwelling site sits on a small terrace on the tip of the middle cape of the shore. The soil at the site is glacial fill with fine sand underneath. The slope descending towards the lake is rocky. The site is dated to the Early Metal Period based on the textile ceramics found at the site, but below Mesolithic finds have been found there. Therefore, two distinct periods of use have been identified.

The iron smelting furnace was discovered immediately in the first excavated layers with finds confirming that the structure had been used for iron smelting. The furnace itself was rectangular in shape with the dimensions of 85 x 43-44 cm on the outside and the interior measurements were 42 x 20 cm. Each of the long sides had been made out of one long stone and both had a gutter in the middle. Both short ends had a stone blocking the opening. Pieces of charcoal, clay and metal slag, burnt clay lining, burnt stone were found inside of the furnace. The clay had been used to seal the gaps between the stones. The gutters on the long stones had red burned clay, with fused stone and clay material. The sand surrounding the furnace contained small pieces of charcoal, burnt stone, clay and soot.

The smelting furnace was not completely excavated, because Poutiainen wanted to leave it there to be researched fully later on. Furthermore, part of the furnace continued into the wall of the excavation pit and the excavator did not have time to expand the excavation area. Therefore, the floor of the furnace and the ground below it have not been excavated yet.
Field research

1999, Inspection, Hannu Poutiainen
2000, Excavation, Hannu Poutiainen

Literature
Description

The site is located on a flat terrace on the south south-west side of the road leading from Ristiina to Suurlahti. The dwelling site is restricted by cliffs to the north and north-west and by a bog from south-east to west. The lake Louhivesi lies 100 meters to the north-east of the site. The lake is even today rich in lake iron ore. The bedrock is exposed partly in the area due to glacial action of the the Ice Age, but otherwise no stone material is available at the site.

The top part of the furnace was exposed immediately after the top soil had been removed. The first excavation layers contained large amounts of iron slag and some vitrified clay. The outside measurements of the furnace were 70 x 50 cm. The structure is closed on three sides, while the other short side had been left open. The largest stones in the furnace were ca. 30 cm long, ca. 20 cm high and with a maximum thickness of 10 cm, while smaller stones had been used as well. Burnt clay was found on inside surfaces of the furnace including the floor. The furnace did not have a lid stone in place, but more stones were found north-east to the structure and some of these might have been lid stones or they were spare stones. Slag was found both inside and around the open end of the furnace.

Nearly all the pottery finds from the Kitulansuo D site belong to Sarsa-Tomitsa, Sär 2 and Luukonsaari wares and these date the site to the Early Metal period. Moreover, five radiocarbon datings have been analyzed from the site during both years of excavation.

Field research
1992, Survey, Timo Sepänmaa
1993, Test excavation, E-L. and H. Schulz
1994, Excavation, Mika Lavento
1995, Excavation, Mika Lavento
2015, Inspection, Martti Koponen

**Literature**

Lavento 1996: 64–75
Lavento 1999: 75–80
5.

**MUNICIPALITY:** Rovaniemi

**SITE:** Kotijänkä

**Register number:** 699010469

**Year found:** 1987

**Topographic map:** 361210 Oikarainen

**Coordinates:** P: 7372287, I: 452217, Z: 82,5-90

**Description**

The Kotijänkä site is located 9 km east south-east from the church of Rovaniemi. It is defined from the south south-west by the Maununiemi bog and to from the north, east and south-east by the lake Sierijärvi.

The site has produced evidence on Stone Age and Early Iron Age habitation, iron smelting site and hunting as well as dwelling pits. The finds include different types of pottery, stone tools and tool fragments and clay and iron slag. Although the Kotijänkä furnace was partially destroyed, its dimensions of 40 x 50 x 25 cm indicate a volume of about 50 liters. The furnace also had a slag pit in front of the other short side.

The site also had a dome-shaped furnace structure built from sand tempered clay, which had been used to smelt iron. The structure was in relatively good condition, while at the Riitakanrantta site a similar structure was found broken.

The detailed information of the site and the furnace is rather limited, because the excavation report has not been filed in yet. Information given here is based on the excavation report of the Riitakanrantta site and other published literature.

**Field research**

1987, Survey, Hannu Kotivuori

1991, Excavation, Hannu Kotivuori
**Literature**


Kotivuori 2013: 55–58.
6.

**MUNICIPALITY:** Rovaniemi

**SITE:** Riitakanranta

**Register number:** 699010474

**Year found:** 1987

**Topographic map:** 361210 Oikarainen

**Coordinates:** P: 7371117, I: 455146, Z: 83-100

**Description**

The Riitakanranta site is located in the south-east part of the lake Sierijärvi, which is connected to the river Kemijoki by the smaller river Sierijoki. The ancient habitation is spread on terraces on different levels with finds from a wide time period. The site has evidence on both Stone Age and Early Metal period habitation with activities such as red ochre production, iron smelting. In addition, there are also remains of a Lappish cottage from historical period. The soil is composed of coarse sand and gravel. Pine is the dominate tree species with only a limited amount of fir and birch.

Some of the furnace stones could be observed amongst the top soil even before it was removed. A considerable amount of slag came into view immediately after the humus layer was removed. As the structure emerged, the slag pit also became visible on the side facing the lake. The first stones that became visible were the lid stones of the furnace. A piece of a lid stone had fallen into the furnace. Kotivuori was able to join this piece with another piece next to the furnace indicating that the stone had broken at some point of use. The dimensions of the Riitakanranta furnace are 50 x 25 x 25 cm, which gives it a volume of 31 liters.

In addition to the furnace structure, the site had few other structures probably related to metalworking. One was made of the same type of slate as the furnace on the ground level and it also included an unburnt clay wall in a horseshoe shape. Kotivuori suspects that this was an unfinished furnace a cooking oven or a hearth as the clay was unburnt. The measurements of the structure, 130
x 90 cm correspond quite closely to the confirmed smelting furnace. Another structure found at the site consisted of a single piece of slate with slag on top of it and especially around its edges. Burnt clay fragments forming a dome-shaped structure were found near the stone. Kotivuori suspects that the dome was built around the piece of slate and broken at the end of the smelt in order to extract the bloom. Similar furnace structure was found from the Kotijänkä site.

Other Early Metal period finds at the site include quartz and scrapers, flint, asbestos pottery and burnt bone. The asbestos pottery has been classified into Kjelmøy ware and Luukonsaari ware of the Sär 2 pottery group.

**Field research**

1987, Survey, Hannu Kotivuori
1989, Excavation, Hannu Kotivuori
1990, Excavation, Hannu Kotivuori

**Literature**

Kotivuori 2013: 55–58.
APPENDIX 2. – EXPERIMENT DOCUMENTATION FORM (translated from Finnish version)

**Documentation form for iron smelting experiments**

Date __________ Smelt/experiment n. __________ Place ______________________________

Smelters __________________________________________________________________________

Origin of the ore __________________________________________ Quantity (kg)____________

Description of the ore (type, colour, shape, grain size, selection etc. before and after roasting)

Furnace type________________________ Dimensions (cm, height-width-length, diameter)____________

Description of the furnace (materials, structural details, placement of the tuyere, bellows)

Charcoal type________________________ Quantity of charcoal (kg)_____________________

13
### Timetable of the smelt

<table>
<thead>
<tr>
<th>Time</th>
<th>Work phase / event</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ATTENTION!** Always make a note at the end of a cycle (cycle = a known amount of ore and/or charcoal used). Work phases eg. preheating the furnace (wood and/or charcoal, slag tapping, end phases, opening of the furnace.
**Results**

Wight of the bloom (kg)_______________  Weight of pure iron (kg)______________

Description of the iron bloom (size, shape, location in the furnace, slag content etc.)

<table>
<thead>
<tr>
<th>Time</th>
<th>Location of the measurement</th>
<th>Temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Type of slag (eg. slag cake, tapping slag)________________________________________

Total weight of slag (kg)_____________

Description of slag (running properties, colour, shape etc.)
APPENDIX 3. – PHOTOS FROM THE EXPERIMENTS

Figure 1. Breakage surface of dried lake iron ore from Nerkoojärvi. Photo by the author.

Figure 2. Breakage surface roasted lake iron ore from Nerkoojärvi. Note the red colour indicating the presence of hematite. Photo by the author.
Figure 3. Placing the clay lining on the door stones. Photo by the author.

Figure 4. The furnace in preheat stage during the first smelt with Jari Vähkyrää at the bellows. Photo by the author.
Figure 5. Lifting the furnace lid during the first smelt. Photo by Jari Vähkyrä.

Figure 6. Adding ore during the first smelt. Photo by Jari Vähkyrä.
Figure 7. Extracting the bloom with a crowbar in the first smelt. Notice how the lining has suffered due to the crowbar. The door stones have also been knocked down into the slag pit. Photo by Jari Vähkyrä.

Figure 8. The small pieces of iron had been attached to a slag bed, which in turn removed much of the lining when taken out. Photo by the author.
Figure 9. Some vitrified stone at the bottom of the lid after the first smelt. Photo by the author.

Figure 10. Small pieces of iron and some magnetic slag from the first smelt. Photo by the author.
Figure 11. Pieces of slag from the first smelt. The two on the left are slag of type 4 and they are still attached to the furnace lining. The marks left by straw in the clay are visible as well. The middle piece and upper right piece are slag of type 5 with imprints of charcoal visible on the left one. The last two pieces on the lower right corner are slag of type 2. Photo by the author.

Figure 12. Pieces of slag belonging to type 2. They are heavy with a shiny breakage surface indicating a high iron content. Photo by the author.
Figure 13. Piece of iron from the first experiment. The pieces was removed from the slag bed at the end of the smelt. It has been cut in two in order to see the quality of the piece. Photo by the author.

Figure 14. The piece of iron from the first smelt. The section shows high iron content in the piece, although it is probably too small to be forged. Photo by the author.
Figure 15. The end of the second smelt. The torrential rain started at the end of the smelt, but we continued to pump the bellows for a moment before leaving the furnace to cool down. Photo by Jari Vähkyrää.

Figure 16. The furnace three days after the second smelt before opening as viewed from the back. Photo by the author.

Figure 17. Inside of the furnace after the lid stones were removed. Most of the charcoal has burned and the center has a pile of slag, unburned ore and the bloom lies inside. Note the small piece of stone, which has vitrified to the furnace wall above the tuyere. Photo by the author.
Figure 18. The bloom is barely visible under the ore, which has fallen behind it, where the heat was not high enough to smelt it. Photo by the author.
Figure 19. The inside of the furnace after the removal of all loose material. The bloom has formed exactly where the ore was added. Photo by the author.

Figure 20. From left to right: the bloom, slag bed and vitrified tuyere. The unsolidified bloom laying on top of the slag bed has a rough surface, which consists of small pieces of iron. Photo by the author.
Figure 21. The bloom (top) and slag bed (bottom) after they have been taken out of the furnace. The slag bed had attached itself to the floor lining. The piece of slag weighed 1.5 kg after it had been removed from the bloom and it belongs to the slag type 1. Photo by the author.

Figure 22. The furnace after everything inside had been removed. Photo by the author.
Figure 23. Piece partly fused stone from the second experiment. Photo by the author.

Figure 24. Another piece of burnt stone, which was stuck onto the slag bed. Photo by the author.

Figure 25. Pieces of iron mixed with slag from the second smelt. Photo by the author.
Figure 26. The slag cake from the second smelt. The upper edge curves upwards indicating the extent of the blast zone and the bloom had formed on top of it. The cake belongs to slag type 1. Photo by the author.
Figure 27. The cross section of the slag cake from the second smelt. Interestingly the part, which has been in contact with the floor lining, shows more bubbles most likely caused by the clay turning burning into slag and getting mixed with the slag from iron ore. Middle part is relatively homogenous with only small bubbles and the top part has some rough surfaces, which are magnetic indicating high iron content. Photo by the author.

Figure 28. Slag of type 5 from the second smelt. This was found inside the furnace when it was opened. Photo by the author.
Figure 29. Preheating the furnace with wood in the beginning of the third experiment. Photo by the author.

Figure 30. The bigger lid stone broke into pieces when we lifted it the last time at the end of the third experiment. Photo by Jari Vähkyrä.
Figure 31. The bloom being extracted from the furnace. Photo by Sami Viljanmaa.

Figure 32. Few pieces of bloom, which fell off at the end of the third smelt. Photo by the author.
Figure 33. Pieces of slag from the third smelt removed from the slag pit. The four on the left are slag of type 5 showing clear signs of flow. The two on the right are type 2 with shiny surface indicating high iron content. Photo by the author.

Figure 34. Slag of type 5, which was tapped from the furnace in the third smelt. It is possible to see the slag build up as layers in the structure of the pieces. Photo by the author.
Figure 35. Slag of type 5 from the third smelt. The piece is in two pieces of which the left piece was outside the furnace and the right part inside. Photo by the author.

Figure 36. The furnace after one year since the experiments. The stones on the left have not changed much, but much of the lining has come off and fallen either into the furnace or on the outside. The clay has burnt only partially and its colour varies from yellow to red. Clay, which was not affected by the fire at all, has fallen off and spread on the ground leaving tempering sand on the ground level. The nozzle of the tuyere is still in place with the vitrified area around it. Photo by Juuso Vattulainen.
Figure 37. Detailed picture of the debris resulted from the withering process. The lining has broken into little pieces covering the floor. Photo by Juuso Vattulainen.

Figure 38. The furnace after two years. All the rest of the lining has broken into pieces and littered the inside. At this stage roughly one third of the furnace is full of pieces of baked clay or partially burnt clay. Few of the stones around the tuyere have fallen over and the tuyere nozzle itself has rolled into the slag pit. Photo by Sami Viljanmaa.
Figure 39. The partially burnt clay has started to turn back into natural clay, but the properly red-fired pieces survive. Moreover, the vitrified surroundings of the tuyere will survive for a long period of time. The heat has gone through the lining and vitrified parts of the stones. Photo by Sami Viljanmaa.