DOCTORAL THESIS

Steel Making Hunter-Gatherers in Ancient Arctic Europe

Carina Bennerhag

History of Technology

LULEÅ UNIVERSITY OF TECHNOLOGY

Doctoral Thesis

Steel Making Hunter-Gatherers in Ancient Arctic Europe

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Abstract

Based on Norrbotten County Museum's c. 2010 findings in the vicinity of Sangis in Arctic Sweden of advanced iron and steel production in a hunter-gatherer setting dated to the pre-Roman Iron Age (c. 200–50 BC), the aim of this thesis is twofold. *First*, with a focus on know-how/established process stages, it investigates the possible wider geographical distribution of such production in Arctic Europe. The analysis is based on archaeometallurgical methods applied to materials from previously conducted and new surveys/excavations. *Second*, the aim is also to analyse the probable social/organizational conditions for the adaptation of iron and steel production among ancient Arctic hunter-gatherer groups. These breakthrough results reveal the extensive spatial distribution of advanced iron and steel production at more than 40 sites in present-day northernmost Finland, Sweden, and Norway more than 2000 years ago (i.e., contemporary with and even partly before the Romans). The geographical spread of advanced and early iron technology that emerges from these results should fundamentally alter traditional perceptions of the emergence of ferrous metallurgy, especially when societies traditionally considered less complex/highly mobile are addressed. Iron and steel production required long-term organization/balancing with other subsistence activities in the collected rhythm of activities in the strongly seasonally influenced (in terms of climate) landscape of ancient Arctic hunter-gatherer societies. In addition to advanced knowledge, the new metal-related activities required significant supplies of raw materials (including their extraction, transportation, preparation, and storage) and thus related labour. Overall, the results imply a significantly broader view of ancient Arctic hunter-gatherer societies in terms of specialization and complex organization, far above the traditional interpretative paradigm typically labelling prehistoric iron technology in the region as small-scale, import dependent, and underdeveloped or archaic. Furthermore, because some aspects of the process, such as the required production of charcoal, necessitated multi-year planning, the adaptation of, and investment in, iron technology in the rhythm of activities in the landscape reasonably and logistically bound these societies to specific locations in the landscape, implying greater sedentism than previously recognized for these groups. The research process forming the basis of this thesis (conducted by a small group of archaeologists, archaeometallurgists, and historians of technology) was strongly characterized by the fact the results completely contradict the larger international and Arctic European literature, implying both a lack of support for the interpretation of the results, and a perceived need to identify hidden assumptions in previous research to "make room" for the results. In addition, the process was characterized by the fact it took place in (and the ancient findings were made within) a region strongly marked by ethnopolitical forces and groups striving for identity building, where history (and particularly ancient findings) often plays a central role.

Acknowledgements

After 25 years as an excavating archaeologist at Norrbotten County Museum, I left the familiarity of work to begin my journey into the academic world. The years I have dedicated to doctoral studies have been among the most challenging but also stimulating and enjoyable years of my life, and I hope that this is just the beginning! Being welcomed as an archaeologist into the field of history of technology at Luleå University of Technology was a fundamental moment, and I cannot envision how different my academic career would have been if my path had led elsewhere. I consider myself incredibly fortunate to have had the opportunity to engage in this interdisciplinary work. While I initially started as an archaeologist, my journey has transformed me into a historian of technology. However, from now on I will never be exclusively one or the other. With my doctoral studies now almost complete, I want to express my deepest gratitude to all the individuals and institutions that have made this journey possible.

My most heartfelt thanks go to my primary supervisor, Kristina Söderholm, who has patiently guided me through my academic journey. Her high standards of scholarship and professionalism helped me accomplish things I had no idea I was capable of. Thank you so much for your intellectual stimulation and challenging questions that helped me transform my thoughts into coherent material during these years. Our journey through this thesis work has been marked by challenging moments, many laughs, creative ideas, and an amazing collaborative spirit, which, in the end, has given me the dearest friend.

My next and warmest thanks go to my assistant supervisor, Eva Hjärthner-Holdar, who generously shared her extensive knowledge of archaeometallurgy, making complex analyses comprehensible and initiating me into the practical world of iron through hands-on lessons in the laboratory and in the field. By introducing me to experimental archaeology, I also got the opportunity to immerse myself and experience the intricate art (and often dirty work!) of making iron. Eva's expertise in this regard has been extremely beneficial to this thesis and enriched my understanding of the technical processes and material residues embedded in the craft. Now I really understand that, "för att järnet ska bli bra, så måste slaggen må bra"!

I also owe the warmest thanks to Sara Hagström Yamamoto, my second assistant supervisor. As the former head of Archaeology at Norrbotten County Museum she encouraged me to pursue doctoral studies and engaged in numerous discussions on the narrative of ancient hunter-gatherers. The continuation of these discussions was essential during my doctoral work, helping me navigate the deeply rooted knowledge structures and various influences shaping northern archaeology.

The interdisciplinary nature of this thesis work included close collaboration with the Geoarchaeological Laboratory in Uppsala, Sweden (GAL) and Stilborg Ceramic Analysis (SKEA) which performed all the archaeometallurgical analyses. To Lena Grandin at GAL, who patiently answered my endless questions and engaged in discussions of the interpretation of analyses - you truly are a remarkable bridge between the natural sciences and the humanities! To Ole Stilborg at SKEA, who introduced me to the complex world of technical ceramics and refractories of clay, I want to express my warmest thanks for generously sharing your knowledge.

I would like to express my deepest gratitude to Norrbotten County Museum for fully supporting and facilitating my research. My former bosses all deserve my appreciation. Olle Mattson, who initially enabled me to conduct research during work hours and apply for funding for my research ideas, Sara Hagström Yamamoto, who encouraged and promoted me to realize my research efforts, and Nils Harnesk, who understood the value and benefits of collaborative research and always looked out for my best interests. To my new boss Ulf Renlund, I wish for fruitful future collaborations! To my current and past "archaeological" colleagues, Lars Backman, Jannica Grimbe, Tone Hellsten, Mirjam Jonsson, Hanna Larsson, Åsa Lindgren, Frida Palmbo, Daniel Sjödahl, and Olof Östlund, I thank you from the bottom of my heart for joining me in my various field adventures throughout Norrbotten. Thank you for effortlessly following my crazy ideas - for collecting hundreds of soil samples and then sifting them indoors in household sieves to find the tiniest fish bones, and with utmost accuracy clearing excavation surfaces for photography, and ensuring no footprints, roots, tree leaves, or even the tiniest pine needles were left! You are a fantastic group that makes things possible! A special thanks go to Annika Josbrant and Viktoria Lestander, the museum educational team, for their commitment to our mission of making the research results accessible to the school children and the general public in Norrbotten and Sweden. I want to sincerely thank the museum photographers Staffan Nygren and Daryoush Tahmasebi who have accompanied me in the field over the years, capturing amazing photos and making documentary films.

To my fellow doctoral students at Luleå University of Technology who joined me one by one and brightened my life: first Felicia, then Judit, Johan, and most recently Helena – I thank you for your valuable encouragement! A collective warm “thank you” is also directed to all the staff, past and present, at the Department of History.

For the excavation of the iron production site carried out in Vivungi it was crucial to be granted access to the site. For this, I express my warmest gratitude to the landowner Jan-Erik Lasu, and the locals for their fantastic support and interest. By clearing the site from timber, providing boats for ore prospecting in nearby lakes, showing clay locations, participating in Archaeology Day, engaging in experimental archaeology, and even pausing their elk hunting to attend a guided tour in the vicinity - they generously shared their time and their knowledge of the forest land around Vivungi!

As this work primarily focuses on material remains, it is essential to acknowledge the vital role of those who made samples from various archaeological assemblages available for my analyses. I am immensely thankful to the museum institutions that allowed me to analyse metallurgical materials. First and foremost, I would like to thank Norrbotten County Museum for granting me almost unlimited access to their rich archaeological materials and permitting invasive analyses. They allowed me to explore the collections, and open boxes and drawers in order to discover things not mentioned in reports. In Norway, archaeologist Roger Jørgensen at Tromsø University Museum made artefacts and related archaeological information available and generously shared his research. He also provided a substantial amount of bibliographical information, as well as unpublished documents, and assisted with analysis applications. In Finland, I extend my gratitude to the staff at the Finnish Heritage Agency Board, who greatly aided my study of archaeometallurgical remains in Helsinki. Special thanks go to Katja Vuristo, the head of collections, who facilitated access to archaeological collections, provided assistance with analysis applications, and supplied reports that had not yet been digitized, and to Jan-Erik Nyman who served as a bridge (crossing the language barrier) into the museum collection database.

I reserve a special warm thanks to the research funders. First, I thank the Berit Wallenberg Foundation for making my dream of a doctoral position a reality and for funding four of my years as a doctoral student. I would also like to thank the Swedish Research Council for enabling analyses and excavations. I would like to direct my gratitude to Jernkontoret, the Swedish iron and steel producers’ association, for their role in enabling my preliminary studies (before I started my doctoral work) by finding my project important and generously providing funding. They have contributed to the discovery of the first iron production site north of Jämtland County in Sweden and supported the analyses and radiocarbon dating in Vivungi that later enabled the excavations. They will also publish my thesis, and I am deeply honoured by their continued support.

Finally, I owe more thanks than I can express to my family. I would not have made it without your patience and support – I thank you unreservedly! First and foremost, to my parents whom

I’ve always been able to rely on when and if needed, and for always putting me and my family first. You have always supported me on my educational journey and stressed the importance of following my heart. Ever since I remember, you have been so proud of me and endlessly pointed out that what I do is good enough, even though I often worry about the opposite, setting way too high standards for myself. This thesis is for you! To my children Alva and Nils. Thank you for reminding me that there is more to life than work. For occasionally bringing me back to reality and for giving life its right proportions. And finally, to the love of my life Mattias, as we promised each other “in sickness and in health” the day we were married (23 years ago!). You have always stood by my side, through rain and shine, and provided me with a stable foundation when the ground was shifting beneath my feet. Together we have always found calm and peace out there in the forest enjoying each other's company – you often sitting on a stump relaxing, me roaming around looking in the ground for archaeological finds!

Antnäs, October 2023
Carina Bennerhag

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Paper II

Bennerhag, Carina, Sara Hagström Yamamoto, and Kristina Söderholm. "Towards a broader understanding of the emergence of iron technology in prehistoric Arctic Fennoscandia". *Cambridge Archaeological Journal* 33 (2023): 265–278.

Paper III

Bennerhag, Carina and Kristina Söderholm. "Ancient Arctic European hunter-gatherer steelmakers in the limelight". Under review (since May 2023) for *Journal of Interdisciplinary History*.

Paper IV

Söderholm, Kristina and Carina Bennerhag. "Reflections on an Arctic research process and the importance of the local place". Under review (since May 2023) for *Technology and Culture*.

Author contributions

Paper I

Bennerhag, Carina, Lena Grandin, Eva Hjärtner-Holdar, Ole Stilborg, and Kristina Söderholm. "Hunter-gatherer metallurgy in the Early Iron Age of northern Fennoscandia". *Antiquity* 95 (2021): 1511–1526. This paper is based on empirical evidence mainly collected by Bennerhag and on the authors' joint analysis. Bennerhag related the analysis to previous research and wrote the main part of the text.

Paper II

Bennerhag, Carina, Sara Hagström Yamamoto, and Kristina Söderholm. "Towards a broader understanding of the emergence of iron technology in prehistoric Arctic Fennoscandia". *Cambridge Archaeological Journal* 33 (2023): 265–278. Bennerhag was responsible for the main analysis and for most of the extensive literature review. Bennerhag wrote the main part of the text.

Paper III

Bennerhag, Carina and Kristina Söderholm. "Ancient Arctic Fennoscandian hunter-gatherer steelmakers in the limelight". Under review (since May 2023) for *Journal of Interdisciplinary History*. This paper is based on empirical evidence collected by Bennerhag, and on the authors' joint analysis. The main part of the text was written by Bennerhag.

Paper IV

Söderholm, Kristina and Carina Bennerhag. "Reflections on an Arctic research process and the importance of the local place". Under review (since May 2023) for *Technology and Culture*. The paper is based on the authors' joint analysis, with Söderholm having formulated the basic criteria for the analysis. The text was jointly written by Bennerhag and Söderholm.

Preface

After 12 years as a committed Stone Age archaeologist at the Norrbotten County Museum (in this section hereafter "the Museum"), I experienced my first encounter with prehistoric iron in 2006. As head of the excavations taking place in connection with the archaeological investigations preceding the railway construction of the Kalix–Haparanda railroad along the north Bothnian coast, I oversaw the discovery of the first known prehistoric iron production site in Arctic Sweden. Early on, in my quest to gain a deeper understanding of the finds, I was fortunate to come into contact with the Geoarchaeological Laboratory (GAL) in Uppsala, Sweden, the leading player in Scandinavia in terms of archaeometallurgical analyses of metal crafts. Extensive analyses were undertaken showing that advanced iron and steel technology was already an integrated part of the hunter-gatherer subsistence 2,200 years ago. Little did I know then that these finds would take me on this fascinating and extended journey into ancient Arctic hunter-gatherer metallurgy.

With encouragement from the Museum management (and supported by funding from Jernkontoret, the Swedish iron and steel producers' association), I proceeded to investigate the findings and their implications after completing excavations (for details, see *Table 1*). With a new head of archaeology at the Museum, Sara Hagström-Yamamoto, it eventually became relevant to initiate doctoral studies on the topic. Interdisciplinary collaboration was initiated between archaeologists at the Museum and historians of technology at Luleå University of Technology (LTU), with the aim of integrating the perspectives of both archaeology and history of technology, along with central elements of archaeometallurgy, to study the implementation of iron in ancient Arctic Europe. So, at the end of 2016, I became a doctoral student in the history of technology at LTU.

The work that forms the basis of this thesis took place within the context of two larger research projects involving, overall, a handful of researchers and interdisciplinary perspectives (the number of researchers has fluctuated over time, although I and my main supervisor Kristina Söderholm have formed a consistent core). These projects are *Ironworking in a Hunting Environment* (funded by the Swedish Research Council) and *Iron in the North* (funded by the Berit Wallenberg Foundation). The work has been founded on close collaboration with other researchers (i.e., historians of technology, archaeologists, and archaeometallurgists) in which I have always been at the heart of things, both in terms of being the main bridge between the different perspectives and in terms of having the main responsibility for the monumental collection of material and of having the most knowledge of the combined material (regarding my role in the respective publications, see the section "Author contributions").

Overall, I have been a doctoral student of the history of technology, dealing with archaeological materials and methods, in which technological–historical perspectives in combination with archaeometallurgical analyses have contributed to decisive openings in the understanding of the material.[1] It has been a very fruitful interdisciplinary collaboration based on a unique constellation of competencies, and as such contributing to a more comprehensive and nuanced understanding of the past. My overall central role in the research process – not least viewed from a material perspective – can be understood from my previous professional competencies and employment (as an archaeologist), making my doctoral studies reminiscent of those of an industrial doctoral student. Thus, for long periods, my studies have run parallel with continued part-time employment as an archaeologist at the Museum, which mainly entailed work on the ongoing public dissemination of the research results.

[1] A key part of my doctoral work entailed extensive archaeometallurgical training and schooling in the theories and methods of history of technology.

Introduction

Metals, especially iron, play a key role in national history narratives[2] as well as in the general global narrative of the development of nations/regions,[3] and particularly steel when it comes to the modern world.[4] Even in the contemporary narrative of how to achieve a climate-neutral society, (rare earth) metals play a leading role.[5] Focusing on Scandinavian, and in particular Swedish, iron and steel production, historians have mainly studied the rise and development of mining and related iron and steel production, typically from a business/ownership perspective, from the 18th century onwards in central and Arctic[6] Sweden.[7] In part, this literature focuses on the regional and national economic implications of the long-term performance of individual large-scale producers or of the producers in total in a region.[8] In part, it focuses on the construction of the necessary infrastructure, particularly for the 20th century's large-scale steel production in Arctic Sweden.[9] Other historical literature focuses on relationships and agreements in the 17th and 18th centuries between, on one hand, local iron and steel producers and, on the other, the local population.[10]

Considering, in turn, archaeological studies of Scandinavian iron and steel production, these have focused partly on the role of iron in Sweden's medieval modernization in terms of national administration, commercialization, and urbanization,[11] and partly on economic and power relations, such as in relation to the expansion of Nordic agrarian societies in central Sweden during the Migration Period/Viking Age (400/500s–700/1100s),[12] and in southern Norway during the Viking Age.[13] Further archaeological studies examine the introduction of iron in central Sweden as early as the Late Bronze Age (1000 BC),[14] although this ground-breaking research has not yet been fully embraced in the literature.[15] As far as archaeological studies of iron in Arctic Europe are concerned, these are scarce and largely constitute discussions of the ethnic dimensions of iron use.[16] To summarize, research on archaeological and historical iron and steel production predominantly concerns mining-related aspects, resulting in a limited understanding of iron technology in Arctic Scandinavia before the 18th century, which at a fundamental level motivates this study.

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2 Such as the Swedish and North American narratives (Karlsson and Magnusson 2015; Misa 1998).

3 Pleiner 2000.

4 Diamond 1997.

5 Buchert et al. 2009.

6 Exactly what the Arctic is and who has the right to define it are unanswered questions. Without clear borders, this vast area stretches across several states, three continents, several oceans, and unclaimed territory. According to the Arctic Council (the cooperation forum of the Arctic states), the southern border of the Arctic is somewhere between the Arctic Circle and 60 degrees north latitude, exactly where being up to each individual member state to decide. The Swedish Ministry of Foreign Affairs is working on a definition of the Swedish Arctic that includes Norrbotten County, Västerbotten County, and the Scandinavian Mountain Range (Nordiska Museet 2023). In this thesis, the term "Arctic" refers to the entire Arctic landmass, which is separated into the High Arctic, Low Arctic, and Subarctic according to the climate and vegetation. The concept of "subarctic" includes not only the area directly south of the Arctic Circle but also other regions in the Nordic countries with similar climatic and living conditions (AMAP 2023).

7 See, e.g., Hansson 1987; Strand 2005; Persson 2015.

8 Jonsson 1987, 1990; Olsson 2007.

9 Eriksson 1991; Hansson 1994; Viklund 2012; Hansson 2015.

10 Sjöberg 1993; Nordin and Ojala 2020.

11 Berglund 2015.

12 Magnusson 1986; Lindeberg 2009.

13 Rundberget 2013.

14 Hjärthner-Holdar 1993.

15 This concerns finds that do not fit the traditional diffusion framework, and that typically are questioned as being too old due to the contamination of radiocarbon dating; see, e.g., Bebermeier et al. 2016; Gassmann and Schäfer 2018; Hakonen 2021.

16 See, e.g., Sundquist 1999; Jørgensen 2010; Hansen and Olsen 2014.

Still, the detailed work on the formulation of research questions took off from interdisciplinary (i.e., history of technology/archaeology/archaeometallurgy) discussions rather than the previous international archaeological literature on iron. As illustrated in the section "Ancient iron and steel in the European Arctic", below, the focus of previous research and theories on origins and dualistic cultural interpretations has overall low explanatory value for the findings presented here. It was a long, exhausting, and discouraging process to gradually realize that, gauging solely from the literature, it would not really have been worthwhile to start the project at all – i.e., to search for additional finds or to analyse them in depth. As unsatisfactory as the literature study was, the discussions in the interdisciplinary team were a positive experience that led to decisive openings in our understanding of the findings.

Thesis aim

Based on Norrbotten County Museum's c. 2010 findings of advanced iron and steel production in a hunter-gatherer setting at the Sangis site in Arctic Sweden during the pre-Roman Iron Age (c. 200–50 BC), the aim of this thesis is twofold: *First*, with a focus on know-how and established process stages in iron technology, the aim is to investigate the possible wider geographical distribution of the observed pattern of ancient iron production covering the transnational area of Arctic Europe comprising today's northern Sweden, Finland, and Norway. *Second*, the aim is to achieve a more profound (compared with previous research, see further below) understanding of the probable social/organizational conditions for the implementation and further integration/adaptation of iron and steel production within/among ancient Arctic hunter-gatherer societies. In this context, "social/organizational" refers to the activities and knowledge practices (within local settlements and in their surrounding landscapes), alongside the planning and organization that the iron and steel production induced in local societies, not least how, where, and when the necessary ore, charcoal, clay, and other construction materials were mobilized.

The present breakthrough results concerning ancient, advanced iron and steel production in Arctic Europe provide an overall new picture of the hunter-gatherer societies that populated the area. The results concern the previously largely unexplored, especially in terms of metal handling, material produced by these societies across a geographically vast area. The overall goal is to deepen our understanding of ancient Arctic European hunter-gatherers through the lens of iron production. So far, we know little about these people. There are few previously known settlements from the period, and these have generally attracted little attention in archaeological research.[17] This thesis demonstrates that the social and organizational implications of the adoption of iron were an essential, but undervalued, aspect of their everyday lives.

[17] Despite the scarcity of data, the literature reveals a diversity in the economies of Early Iron Age local societies, which were mainly based on mobile groups with settlement movements primarily motivated by subsistence-related objectives dominated by hunting- (of seal and terrestrial animals) and fishing-based economies, but also including occasional small-scale agriculture and animal husbandry (evidenced in northern Norway from about 400 BC) (Damm and Forsberg 2014; Hansen and Olsen 2014; Arntzen 2015). Archaeological research has concentrated on explaining the large influence/contact spheres of the Arctic European population, with connections towards the east for inland populations and towards the south for coastal populations (for a review see, e.g., Ojala and Ojala 2020). Closely related to this dominant explanatory picture is a supposed marked split in ceramic technology in terms of typological variation and overall cultural contact explanations (Damm and Forsberg 2014). Under the strong impact of postcolonial currents (since the 1980s), interest has particularly been directed towards connecting the development of Sámi identity to ceramic developments, with pottery having become an ethnic idiom indicating different affiliations (Bennerhag et al. 2023). While the Sámi affiliations of many different types of archaeological sites in coastal areas are still in question, they are less contentious for most sites found in the interior and the northernmost areas (Salmi 2023). Recent literature has, however, directed interest towards climate change as the driving force behind the innovation of ancient ceramic technology (Jørgensen et al. 2023).

Temporally and geographically, this thesis concentrates on the pre-Roman Iron Age and the Roman Iron Age, c. 300 BC–AD 400 (assumed to constitute the initial phase of iron technology) in the transnational region of northern Norway, Sweden, and Finland, referred to as "Arctic Europe" to emphasize its significance in the context of Europe as a whole. In-depth archaeometallurgical examinations of both new and previous findings that were previously treated in "step-motherly" ways in terms of level of investigation and integration into more comprehensive understandings of prehistoric European iron are essential in pursuing the goal. These examinations partly involved attempts to trace the rhythms of metallurgical activities in the Arctic landscape, strongly seasonally influenced in terms of climate and characterized by coniferous forests, bogs, lakes, and mountains, in order to capture the social and organizational implications.

Methods and materials

This thesis features a detailed study of prehistoric metallurgical remains and their settings from Arctic Europe. It is the first ever in-depth analysis of prehistoric metallurgical material from this area, and it delivers ground-breaking results. Overall, it concerns a comprehensive material assemblage of 237 finds from 42 different prehistoric (i.e., Early Iron Age, 300 BC–AD 400) sites, including 26 in present-day Arctic Sweden, six in Finland, and ten in Norway (see *Fig 1* and *Appendix E-G* for details).[18] It has been crucial for the implementation of the in-depth analysis, and overall in the pursuit of the goal – to deepen our understanding of ancient Arctic European hunter-gatherers through the wider geographical distribution and local implementation of ancient Arctic iron and steel production – that the research was conducted using an interdisciplinary approach, combining perspectives from the academic fields of history of technology and archaeology, including archaeometallurgical analyses.

Overall, the primary source material of this thesis consists of traditional archaeological material (i.e., physical remains) deriving from archaeological excavations and surveys of hunter-gatherer sites carried out in Arctic Europe since the 1940s, including some newer excavations conducted (by the interdisciplinary team) in recent years. However, contrary to previous Arctic European iron research, which typically focuses on the types and morphology (i.e., the visually assessed shape and decoration) of the final products (which does not help much in explaining the local implications of iron production), this thesis recognizes that to understand the complexity of iron technology (i.e., specific techniques and technological practices, choices, and styles), including spatial and temporal variations evident in the metallurgical material, a more in-depth analytical approach is needed that includes all stages in the production of iron. Here, slags and other refuse materials are typically the most informative materials to study. Thus, most of the 237 finds consist of slags but remains from all production stages have been recovered in the material.

Also crucial for understanding the complexity of iron technology is the physical setting of the excavated sites. Here, archaeological reports containing drawings of the spatial distribution of finds alongside photos and descriptions have been studied to comprehend the layout of structures that are no longer accessible for direct study (e.g., due to lake regulation). Additionally, during the more recent field studies (regarding excavations and raw material surveys, see below), we were able to obtain a more comprehensive picture of the larger setting than was possible through previous excavations. This involved carefully examining the arrangement of social and technical structures manifested at the sites (also covering larger areas). The observations of geography and climate, and of eventual difficulties regarding the acquisition of raw material resources, are also important supplements in this context. Cooperation with local society in the research areas has been critical, demonstrating the importance of local situational knowledge.[19]

The secondary source material of this thesis can in turn essentially be divided into two parts: 1) archaeological/anthropological literature that helps to contextualize the primary source material in terms of placing the prehistoric iron technology in a wider social and economic context[20]; and 2) historical accounts, ethnographic literature, and experimental studies offering analogies to the traditional methods of collecting and preparing the raw materials and other processes that surrounded prehistoric ironworking.[21]

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[18] See papers I and III for an overview of the material assemblage.

[19] See, e.g., McAnany and Rowe 2015.

[20] See, e.g., Binford 1979; Olsen 1984; Forsberg 1985; Mäkivuoti 1987; Olsen 1994; Bergman 1995; Hesjedal et al. 1996; Lavento 1999; Sundquist 2000; Koryakova and Epimakhov 2007; Jørgensen 2010; 2011; Forsberg 2012; Kelly 2013; Hansen and Olsen 2014; see also papers I–IV.

[21] See, e.g., Naumann 1922 (regarding the collection of ore); Iles 2018 (regarding ethnographic examples of the use of different types of ores); Bergström and Wesslén 1915 (regarding charcoaling); Crew 2013 (regarding

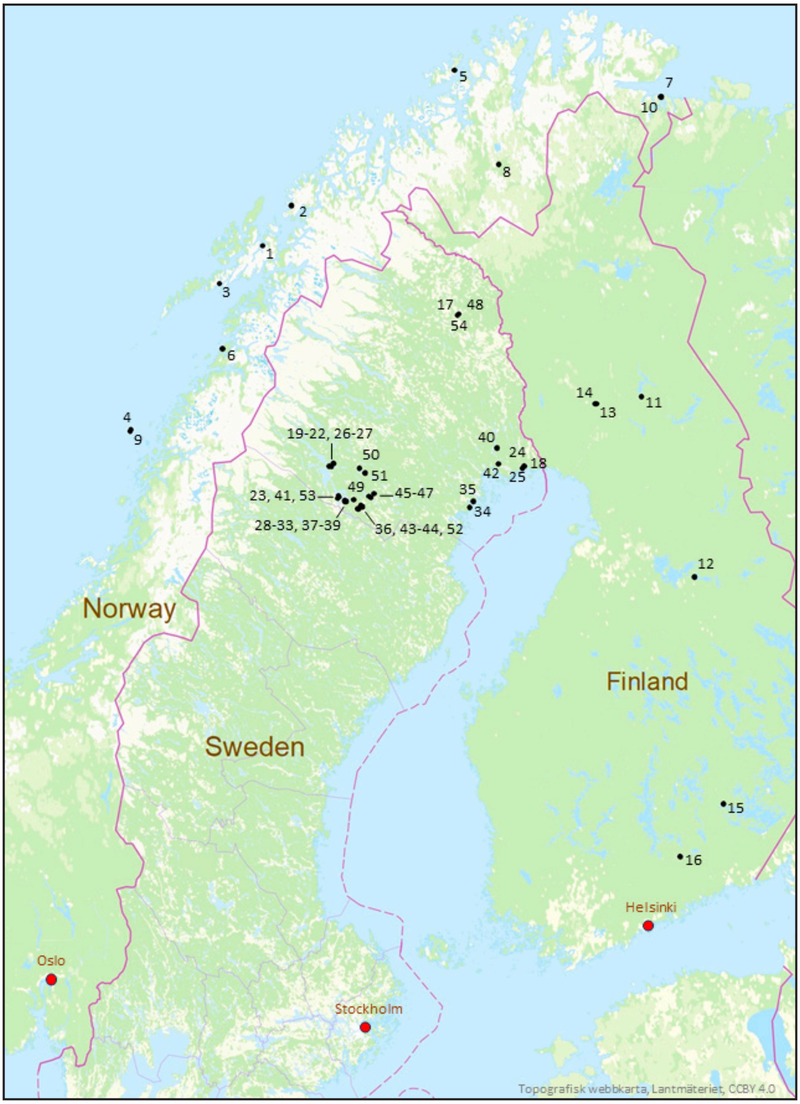

Figure 1. *Map of the studied area showing the location of the analysed sites. Numbers correspond to Appendix E (Table 2), Appendix F (Table 3-5) and Appendix G (Table 6-8).*

Norway: *1. Hemmestad Nedre; 2. Flakstadvåg; 3. Øvreværet; 4. Røsnesvalen; 5. Slettnes; 6. Fjære; 7. Makkholla; 8. Virdnejavre 112; 9. Hellervikjä; 10. Mestersanden*

Finland: *11. Kemijärvi, Neitilä; 12. Kajani, Äkälänniemi; 13. Rovaniemi, Riitakanranta; 14. Rovaniemi, Kotijänkä; 15. Mikkeli, Kitulansuo, Ristiina; 16. Lahti, Kilpisaari*

Sweden: *17. Vivungi, Jukkasjärvi 723; 18. Sangis, Nederkalix 842; 19. Nåttiholmen, SMA 4006; 20. Revi, SMA 929; 21. Revi, SMA 3319; 22. Revi, SMA 4131; 23. Hoppot, NA 36; 24. Sangis, Nederkalix 730; 25. Sangis, Nederkalix 797; 26. Rappasundet; 27. Revi Saxplats; 28. Sandudden, NA 53; 29. Sandudden, NA 54; 30. Sandudden, Ö Gottjärn, NA 55; 31. Sandudden, NA 80; 32. Sandudden, NA 82; 33. Sandudden, NA 83; 34. Vallen, Nederluleå 90; 35. Måttsund, Nederluleå 134; 36. S Holmnäs, NA 303; 37. Gottjärnmynnet, NA 69; 38. Snotterholmen, NA 71A; 39. Sandudden, NA 79; 40. Räktjärv, Töre 50; 41. Bergnäsudden, NA 16; 42. Kosjärv, Töre 510; 43. Månsträsk, NA 2145; 44. Notvik, NA 2153; 45. Tellek; 46. Masseviken, NA 357; 47. Nåludden, NA 397; 48. Vivungi, ore survey; 49. Vuolgamjaur, NA 202; 50. Abraur, NA1738; 51. Abraur, Åmynne, NA 36, Apl; 52. Skidträsk, NA 2179; 53. Ö Sguegesuolo, NA 48; 54. Vivungi, experiment*

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experimental studies in which bloomery furnaces, for example, have been reconstructed to fully comprehend the working parameters in the production of iron and steel); see also Paper III.

Methods

The research context forming the basis of this thesis included close collaboration with the Geoarchaeological Laboratory in Uppsala, Sweden (GAL) and SKEA Stilborg Ceramic Analysis in Borlänge, Sweden, which performed several archaeometallurgical analyses on the metal-related finds. Metallographic analyses were conducted on iron/waste to establish iron quality, i.e., whether finds were iron, steel, or, for example, phosphoric iron, and to define the extent to which the iron waste had been processed. In addition, petrographic and bulk chemical analyses were performed on samples of slag for the main purpose of defining the process stage during which they were formed and to determine their composition in terms of major, minor, and trace elements to allow the comparison of slags from various contexts (within and between sites) and to learn more about the ore types used. Also, samples of fresh iron ore were test-roasted and then petrographically and chemically analysed to assess the quality of the local ore and to determine possible prehistoric connections and use. Furthermore, technical ceramics (primarily furnace walls and hearth linings) were classified and specially recorded macroscopically. A selection of these ceramics was further analysed using petrographic microscopy and thermal analysis to establish raw material choices and gain insight into construction and curation strategies, along with the thermal and mechanical properties of the clays.[22]

The archaeometallurgical method provides great opportunities for material interpretation, not least regarding the first aim of the thesis, which is to investigate the possible wider geographical distribution. Hence, unlike previous ancient Arctic European iron research methods typically focusing on morphology alone (involving typologies, long chronologies, and linear processes), archaeometallurgical analyses along with radiocarbon dating and the *chaîne opératoire* concept can contribute to an in-depth understanding of the actual manufacturing technology in terms of know-how and established process stages at individual sites as well as in larger geographical areas regarding broader characterization and an eventual synchronic picture. The *chaîne opératoire* concept was originally developed out of the need to explicitly describe the methodology of lithic analysis in archaeological scholarship, which not least notes the logical order of the activities in the process/production chain through which raw material is transformed into a product.[23] In this regard, the archaeometallurgical method also provides important openings for the second goal of the thesis, which is to improve our understanding of probable social/organizational conditions for the implementation and further integration/adaptation of iron and steel production among ancient Arctic hunter-gatherer societies (see "Theoretical framework", below, for a more developed discussion).

In terms of previous analyses of the findings and publication of the results, only a few limited analyses of Finnish, Swedish, and Norwegian ironworking material were published before the papers connected to this thesis.[24] These mostly targeted small, selected samples of iron ore and slag pieces, typically mapping only a few of the key components to determine, for example, the quality of the ore. As a result, published archaeometallurgical work on Arctic European material has been restricted and sporadic, providing only a few comparative analyses. Considering the limited reference data, previous analyses have been reinterpreted in a major way using interdisciplinary approaches and in light of recent years accumulated knowledge of ancient iron production and smithing processes.[25] Regarding some finds, the residual pieces, but not necessarily the analysed samples, were re-examined (samples from as close as possible

[22] The analytical results are accessible in Papers I and III as supplementary material (the latter provided by the author on request until Paper III is published).
[23] Leroi-Gourhan 1993.
[24] Grälls 1986; Bartolotta et al. 1988; Hood and Olsen 1988; Bartolotta et al. 1990; Sundquist 1999; Buchwald 2005; Jørgensen 2010.
[25] Even at the time of publishing, interpretations of some of the analytical results were being questioned; see Espelund 1989.

to the prior samples' original locations were chosen) to facilitate the calibration of previous analytical results (with fewer elements).

This study also included an inventory of associated and available radiocarbon dates, and 19 of the 42 studied sites had undergone radiocarbon dating. This was done, for example, in relation to previously excavated prehistoric iron production sites in Finland and northern Norway (see also below) and within the framework of a few recent archaeological doctoral theses using so-called lake regulation material (see below). Still, never before had these sites been radiocarbon dated with regard to metals.[26] Most of the previously dated and selected sites have been assigned to the pre-Roman Iron Age. To obtain a more precise dating of the ironworking and to confirm the established chronology at the selected sites, this set of data was completed by performing new radiocarbon dating: of metallurgical remains at three of the previous sites having no direct dates; at seven of the previously dated sites using samples of charcoal trapped in slag (inclusions of charred wood can be extracted from slag specimens or from layers between them) and carbon extracted from iron/steel; and (when possible) of charcoal and burnt bones from excavated features connected to the production and manufacturing of iron. Overall, radiocarbon dating was applied to a variety of materials. Also, wood species and osteological analyses were conducted to assess the intrinsic age of the samples and any possible sources of error. Good results were obtained through this cross-dating, in which all radiocarbon dates rather consistently (including some dates considered less reliable) fall within the pre-Roman–Roman Iron Age period, except for a sample in Norway radiocarbon dated to the Viking Age (AD 800–1050) (see *Appendix G*).[27] Still, 20 of the selected sites are undated and their chronology is uncertain. Long-term use of these sites makes fine-scale chronological attributions challenging. This is especially true of interior sites that may have traces of habitation dating back over 10,000 years. The dating of the metallurgical material at these sites has, however, been approximated by the thorough examination of the contextual relationship to typologically dated archaeological material such as asbestos-tempered pottery (see below) with a chronological timeframe that makes it possible to classify these sites as belonging to the broader and more general Bronze Age/pre-Roman–Roman Iron Age period.[28]

Material composition and selection

Overall, the archaeological assemblage concerns diverse materials, such as slags, technical ceramics, ancient ores, iron, and artefacts, that have been collected over several decades, mainly from iron production sites and open habitation sites without visible structures (but sometimes including huts, shelters, and occasional hearth sites). Additionally, fresh ore samples from 11 different sites in northernmost Sweden have been examined. Much of the primary source material consists of previously collected although unexplored archaeometallurgical remains, typically forming parts of larger assemblages collected during archaeological inventories/surveys (surface collections), and in some cases parts of better-documented excavations from the early 1940s to recent times. Most of these surveys and excavations were not conducted primarily to study prehistoric metallurgy, but rather to document prehistoric dwelling remains, mainly in connection with the large-scale hydropower expansion in Arctic Europe in the second half of the 20th century (to some extent also in connection with other industrial exploitation, such as a gas line). Some remains derive from smaller excavations, typically conducted in connection with locally funded research projects. The material includes eight previously excavated and better-documented prehistoric iron production sites in Finland and northern Norway discovered between the 1980s and 1990s, excavated specifically to target iron production. Up to 2010, these were the only known prehistoric iron production sites in the entire Arctic.

[26] For an overview of radiocarbon dates and references, see Paper I (Bennerhag et al. 2021) and Paper III.

[27] See Paper III.

[28] Linder 1966; Hultén 1991; Jørgensen and Olsen 1988; Forsberg 2001; Nyman 2010; Jørgensen et al. 2023.

The selection of metallurgical material from previously excavated sites emerged from undertaking a major initial review/mapping of excavation reports, museum collection databases, and published works on archaeological sites. The review was motivated by the discovery of numerous step-motherly treated (i.e., unanalysed/unpublished) metallurgical finds in museum storage and reports throughout the region, as revealed by the literature review in parallel with the literature on ancient Arctic iron use and possible iron production. Since no previous studies had mapped this material, and the material covered such a vast geographical area, it was indeed time-consuming and, at times, challenging work due to linguistic barriers (i.e., the Finnish source material).

As a first step, for the northern-Swedish material, prehistoric sites documented in the Antiquities Register (Fornsök) were examined.[29] The information the Register provided was utilized to pinpoint as many locations as possible where metallurgical remains had been discovered, regardless of their type or historical period. In addition, the ADIN database[30] (i.e., an excavation database for northern Sweden), the Swedish History Museum find register,[31] the lake regulation reports,[32] and the Nordarkeologi inventory project reports[33] were reviewed. Individual survey and excavation reports from the Norrbotten County Museum register, as well as other published literature,[34] were used to augment the review. For the Norwegian and Finnish material, the data collection largely consisted of reviewing published literature documenting finds of metallurgical remains.[35] Information about the identified sites/finds (as well as information about additional finds) was obtained primarily from find catalogues such as UniMus[36] (the Norwegian University Museum collection database), the archaeological find register at the Arctic University Museum of Norway, and the Finnish Heritage Agency archaeological collection database,[37] along with information from excavation reports and information gained through personal communication with archaeologists and archival staff at the institutions/museums in the respective countries. For an overview of the review/mapping and the collection of metallurgical material, see *Table 1*.

The primary focus of the mapping was sites considered to represent the initial phase of iron technology, dating from the Late Bronze Age to the pre-Roman and Roman Iron Age, selected based on the criteria of artefact class (i.e., various finds that could be defined as metallurgical remains, e.g., slag, sintered sand, ore, burnt clay, metal fragments, and metal objects) and chronology. The latter was primarily based on available radiocarbon dating and a comprehensive contextual analysis of the depositional contexts of the metal assemblages[38] (for ambiguous contexts where an admixture of later material could be suspected), which were dated by the associated pottery and so-called Stone Age finds (i.e., certain asbestos-tempered pottery and lithics). Sites were also selected according to geographical spread (to cover the largest possible area) and, for the Norwegian material, according to contexts of so-called Kjelmöy and Risvik ceramics, associated in previous literature with hunter-gatherer and agrarian economies, respectively.[39]

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[29] The Swedish National Heritage database Fornsök, available at: https://www.raa.se/hitta-information/fornsok.
[30] Ramqvist 2000.
[31] The Swedish History Museum collection database, available at: https://samlingar.shm.se.
[32] For an overview, see Biörnstad 2006.
[33] Wigenstam 1969–1983.
[34] Serning 1960; Zachrisson 1976; Hulthén 1991; Mulk 1994; Bergman 1995; Forsberg 2012.
[35] Erä-Esko 1969; Olsen 1984, 1994; Mäkivuoti 1987; Hood and Olsen 1988; Sundquist 1999, 2000; Lavento 1999; Jørgensen 2010; Kotivuori 2013.
[36] The Norwegian University Museum collection database UniMus, available at: https://www.unimus.no.
[37] The Finnish Heritage Agency archaeological collection database, available at: https://www.kyppi.fi.
[38] This included determination of the spatial distribution of metallurgical finds at the sites by creating distribution maps using the coordinates of the individual finds.
[39] See Paper II, Bennerhag et al. 2023.

After this first selection, the prehistoric metallurgical material was studied[40] for the purpose of sampling at each of the archival institutions that held the metallurgical material: in Finland at the Finnish Heritage Agency in Helsinki; in Norway at the Arctic University Museum of Norway in Tromsø; and in Sweden at the Silver Museum in Arjeplog and the County Museum of Norrbotten in Luleå. The material was selected based on the visual (macroscopic) examination of the finds.[41] Slag samples were chosen to achieve a representative selection of the different morphological types in each find, allowing identification of different production processes. The macroscopically most common type of slag was chosen alongside samples of slag deviating in form, texture, and magnetism (the degree of magnetism indicates the type of slag). Iron fragments lost in the production process or parts of objects/semi-finished objects were especially targeted to establish the different types and qualities of iron used and produced. The most magnetic pieces were chosen with the aid of a magnet. Technical ceramics were also selected (based on identifiable shape and the macroscopic observation of a temperature gradient) to identify variation in raw materials (e.g., clay), construction details of furnace shafts and smithing hearths, refractivity, and firing temperatures. In some cases, the sampling was limited to only a few technical ceramic or slag fragments recovered from excavations. In addition, finds of fresh ore deriving from the area around the Swedish lakes Kakel and Storavan were sampled to determine whether they were suitable for iron production and to establish the raw material situation in the area. These ores were collected in connection with surveys of archaeological remains in the 1970s and 1980s in connection with hydropower expansion in the region and, at the time, were collected according to an unreserved sampling design, i.e., the collection of artefacts and deviant objects regardless of cultural or natural affiliation and period (sometimes also misidentified and referred to as “slag”).

Much of the prehistoric metallurgical material described above, and thus of particular importance as source material for this thesis, comprised the large metalworking assemblage collected from the 1940s to 1980s in Arctic Sweden, Finland, and Norway during surveys and excavations of ancient settlements related to lake regulation and hydropower expansion. Several doctoral theses have studied parts of this archaeological material, but without dealing with the metallurgical remains. Interestingly, the material was found at early hunter-gatherer sites alongside Stone Age finds (e.g., flakes, scrapers, and points of stone and pottery), indicating the early use of iron. Still, at the time of recovery, these sites were considered problematic due to tenacious evolutionary ideas related to the dichotomy between hunter-gatherers and farmers, and the heavily dominant chronological model of the Three Age System, with the assumed evolutionary stages inherent in the succession of the Stone, Bronze, and Iron ages.[42] Hence, the material context was not correlated with the evolutionary ideas, which is why the general idea of a “delayed Stone Age” was established, which in turn meant that the metallurgical remains found in these contexts were severely neglected (as they were not considered especially old) and that no methods were used for identifying the metallurgical material, such as archaeometrical analyses including the radiocarbon dating of carbon in steel and charcoal trapped in slag – methods long since established in European iron research.[43] In the course of reviewing this challenging material, the method outlined above, of searching out contexts likely belonging to the Early Iron Age, i.e., contexts with asbestos ceramics and stone material, was developed.

[40] The material was studied by the author in collaboration with assistant supervisor Eva Hjärthner-Holdar.
[41] The selection was also based on the spatial distribution of sites through the creation of maps using the Geographical Information System (GIS).
[42] Thomsen 1848.
[43] See, e.g., Serning 1960; Zachrisson 1976 regarding the idea of a “delayed stone age” and Van der Merwe 1969 regarding the radiocarbon dating of iron.

Table 1. *The process of material collection*

2006–2010, the Sangis site
- Excavation of the smithing site due to railway construction (coordinated by the author working at Norrbotten County Museum [NBM] in 2006–2007) - Metal detecting survey, discovery of the iron production site (initiated and coordinated out by the author working at NBM in 2009) - Rescue excavation of the iron production site (coordinated by the author working at NBM in 2010) - Archaeometallurgical analyses of the metallurgical remains (coordinated by the author working at NBM)
2015–2019, the Vivungi site
- Discovery of slag from the Vivungi site at NBM (by the author in 2015) - Archaeometallurgical analyses and radiocarbon dating of the discovered slag (indicating iron production during the pre-Roman Iron Age) (initiated and coordinated by the author working at NBM in 2015) - Metal detecting and magnetometer survey at the Vivungi site (coordinated by the author during doctoral work in 2017) - Excavation at the Vivungi site, leading to the discovery of two iron production furnaces (coordinated by the author during doctoral work in 2017) - Archaeometallurgical analyses of the metallurgical remains (coordinated by the author during doctoral work) - Clay and ore survey in the area near the Vivungi site (coordinated by the author in cooperation with archaeologists at NBM during doctoral work in 2019) - Experimental iron smelting using local ore discovered during the survey (coordinated by the author in cooperation with archaeologists at NBM during doctoral work in 2019)
2017–2018, mapping metallurgical findings (doctoral work)
- Swedish Antiquities Register (Fornsök), online - ADIN, northern Swedish excavation database, online - Swedish History Museum find register, online - Lake regulation reports kept at the Swedish National Heritage Board, Stockholm (Vitterhetsakademin) - Swedish Nordarkeologi inventory reports kept at Norrbotten County Museum in Luleå - Archaeological reports from 1960–2017 kept at Norrbotten County Museum in Luleå, Sweden - Searching find material (not listed in archaeological reports) in storage at Norrbotten County Museum - The find register at the Arctic University Museum of Norway, online - Norwegian University Museum collection database (UniMus), online - Archaeological reports at the Arctic University Museum of Norway, Tromsø - The Finnish Heritage Agency archaeological collection database, online - Archaeological reports at the Finnish Heritage Agency Board, Helsinki - Published literature covering northern Sweden, Norway, and Finland - Personal communications with archaeologists and archival staff at the Swedish History Museum in Stockholm; Silvermuseet in Arjeplog, Sweden; the Arctic University Museum of Norway in Tromsø; the Museum of Cultural History in Oslo, Norway; the Finnish Heritage Agency Board in Helsinki; the Regional Museum of Lapland in Rovaniemi, Finland
2018–2019, sampling metallurgical findings at archival institutions (doctoral work)
- Norrbotten County Museum, Luleå, Sweden (including permit application for analyses) - Silvermuseet, Arjeplog, Sweden (including permit application for analyses) - The Arctic University Museum of Norway, Tromsö (including permit application for analyses) - The Finnish Heritage Agency, Helsinki (including permit application for analyses)
2019–2021, archaeometallurgical analyses and radiocarbon dating (doctoral work)
- Norwegian metallurgical material - Finnish metallurgical material - Swedish metallurgical material

Field studies

In addition to previous excavation, the interdisciplinary team has more recently conducted archaeological excavations and archaeometallurgical analyses of two iron production sites and one smithing site in Swedish Sangis and Vivungi.[44] The coordination of these excavations and related analyses was made by the author partly before, and partly within the framework of the present thesis (see *Table 1*). The sites play an overall significant role in terms of forming the two key case studies in Paper I, as well as functioning as an underlying reference frame in the analysis of other sites. Some of the slags, technical ceramics (e.g., hearth linings), and iron waste from the Sangis site have further been re-examined and radiocarbon-dated in recent years. The two sites are examined more closely in the following.

Due to a planned railroad development along the Bothnian coast, the Sangis site was subject to excavation between 2006 and 2010 under the management of the author working as an archaeologist at Norrbotten County Museum.[45] The investigation was one of the most extensive in Arctic Europe since the initiation of large-scale hydropower expansion from the 1940s to the 1980s. It was also the first time extensive archaeometallurgical analyses were undertaken in Arctic Europe. Excavations and analyses at the Sangis site revealed the remains of a hunter-gatherer site including a large assemblage of smithing remains from both the primary smithing of blooms and secondary smithing of objects, along with several finished and semi-finished objects. At first, no signs of iron production could be established. Extensive archaeometallurgical analyses were carried out alongside a large set of radiocarbon datings of a variety of materials. Over 50 samples were radiocarbon dated (including pottery, burnt bones, charcoal in slag, and carbon in iron), establishing a fine-grained chronology at the site, resulting in two chronological horizons in the metallurgical material extending over 400 years. Based on the archaeometallurgical analytical results, it was hypothesized that iron production had been carried out in the immediate vicinity. In 2009, a field survey was launched and carried out in the nearby area by the author (and funded by Jernkontoret, the Swedish iron and steel producers' association) to search for potential iron production sites. Using a metal detector, a slag deposit was found 500 metres from the smithing site. Since the previously unknown slag deposit was located within the railway construction corridor, a rescue survey (funded by the Swedish National Heritage Board) was conducted in 2010, resulting in the discovery of the first-ever known prehistoric iron production site in all of the northern half of Sweden, dating back to the pre-Roman Iron Age. Extensive archaeometallurgical analyses were carried out at this new site. The scientific findings from Sangis were first published in Paper I, attached to this thesis.

The author of this thesis also directed the excavation of the Vivungi site in 2017 (funded by the Swedish Research Council, VR), as part of the doctoral work. The site was discovered during an inventory in the early 1990s when a deposit of a few slags was found. Undersigned had these slags analyzed in 2015 while working as an archaeologist at the Norrbotten County Museum with financing from Jernkontoret (the Swedish iron and steel producers' association), which revealed that they were associated with iron production from the pre-Roman Iron Age. The excavation in 2017 began with a survey followed by a metal detection and magnetometer examination intended to locate the slag deposit, all carried out by the author in collaboration with assistant supervisor Eva Hjärthner-Holdar. At least two concentrations of slag and possible furnace walls detected approximately 30 metres from each other, turned out to be two iron production furnaces. Archaeometallurgical analyses and radiocarbon dating were carried out on a wide variety of materials from the site.

As part of the Vivungi excavation, a survey was performed of the raw material supplies in the local surroundings of the excavated iron production site to find out more about the availability

[44] See paper I, Bennerhag et al. 2021.
[45] See Paper I, Bennerhag et al. 2021.

and quality of both local clay and ore. This work entailed close collaboration with locals, who participated in surveys and contributed invaluable situational knowledge of the local raw material sources known to them. The surveys revealed numerous sources of limonite ore in the local lakes, although it was quite challenging to find high-quality clays, with the nearest source being situated more than 15 kilometres away. Furthermore, experimental smelting in a bloomery furnace (based on local limonite ores) was conducted in collaboration with the locals.

Source criticism

The preconceived notions of Arctic Europe as a periphery with a relatively late settlement history have exerted a strong impact on interpretations of the metallurgical material recovered from previous excavations and surveys. The documentation of the material collected, furthermore, typically lacks contextual records. This is especially true of slags, as they have long been considered waste material bearing limited information, suggesting that many slag finds were not even collected. Moreover, there are several cases of misidentifications seriously affecting interpretations of the material, typically downplaying variation, i.e., almost all the metallurgical material has unilaterally been recorded as slag and, in some rare cases, burnt clay. Only a few archaeological features and structures of metallurgical activities have been identified along with the waste material. Nor are any hammer scales (i.e., magnetic flakes detached from the metal during smithing) present among the collected material, although they should have been part of the material based on the now-identified smithing activities. Several of the sites discovered in connection with lake regulation are now also submerged and exposed to erosion due to the building of dams and hydroelectric power stations (varying water levels), meaning that most of the microscopic evidence of production activity at these sites is forever lost. Conventional views are, furthermore, still reflected by the material-holding institutions, meaning that selection-related restrictions (e.g., on sampling) were occasionally imposed before the interdisciplinary team got to study the material or that parts of the collections were stored in inaccessible find magazines. The institutions were rather uncomprehending of the fact that slags could contribute interesting information, as they were still (according to the traditional view) considered waste/mass material.

The primary source material for this thesis comprises prehistoric remains collected over more than seven decades (including the most recent Sangis and Vivungi excavations), with all that this entails in terms of varying interpretative and methodological perspectives, practical research techniques, and levels of ambition. As a result, the collection includes archaeological material from both well-documented surveys and excavations, as well as from sites where a single find is the only evidence of metal craft. From this variation, we may conclude that the possibility of a representative interpretation is higher in certain regions than others. Still, individual finds from less surveyed sites can be interpreted with the support of information collected from sites that provide a more comprehensive, clearer picture of the craft and materials employed. This is particularly true of the Sangis and Vivungi sites. Although we have only analysed available artefacts from Sangis to evaluate how the smelted iron was formed into desired products, the related findings are largely corroborated by the overall evidence of the quality of smithing from a large number of sites. It should be noted that although smithing materials from Arctic Finland are not included in this study, the interdisciplinary team has sampled smithing material (for planned analysis) from this area as well. The aggregated material from all the sites suggests an extensive landscape of metalworking in which it is possible to start reconstructing an image of the production stages and draw the first tentative but substantial conclusions about the technology and organization involved, and this across a vast geographical area.

Ancient iron and steel in the European Arctic: a critical research review and paths forward

As stated in the introduction, we lack synthesizing long-term overviews of European Arctic metallurgical history since most historical literature on the theme focuses on pre-modern mining history only. Still, there is a rather large body of historical/archaeological literature that fragmentarily, and from different perspectives, more or less directly deals with earlier periods of Arctic European metallurgical history. Below follows an attempt to synthesize this literature in terms of major themes, particularly regarding different explanations and theories of the implementation of iron in Arctic Europe.

This partly concerns archaeological literature dating from the early–mid 1900s up to 2023, often written by archaeologists from the region, that deals with parts of prehistoric Arctic Europe where aspects of iron occur but without metals being the focus of study. This literature was reviewed by first studying archaeological doctoral theses, identifying and examining the references listed therein, and, in parallel, conducting a library search using various databases available at LTU. Most of the literature was found by conducting a "backward and forward search", i.e., to find the publications quoting one another. The studies considered in the review were written in Swedish, Norwegian, English, and, to a lesser extent, Finnish. Due to a dearth of recent literature on Early Iron Age metallurgy, the review eventually expanded to include more recent archaeological and historical studies addressing later periods, i.e., Late Iron Age–pre-Modern times, where a growing body of literature employs postcolonial perspectives, typically presenting new perspectives on mainstream narratives.

It was partly justified to also examine international literature in the search for perspectives on earlier periods of Arctic European metallurgical history. From this review, concerning the wider European area (including historical/archaeological literature dating from the mid-1900s up to 2023), the prevailing theoretical view and its long-standing influence on the field, consistently downplaying the role of iron in regions considered peripheral and societies considered low-complex, emerged. With the realization that these issues had broader implications for the study of ancient metallurgy, the review widened to include the critical examination of previous and recent scholarly studies of prehistoric iron metallurgy in non-agricultural contexts from a global perspective, which had received little attention in the European literature. Hence, the review also covers areas such as parts of Africa and Mongolia inhabited by nomads and pastoralists that have remained peripheral in discussions of Old-World metallurgical developments. In this context, it was also justified to examine whether the Arctic European situation was representative from an overall global Arctic perspective.

A critical review of previous research

In the overview below of partly international/general European and partly more specific Arctic European pre-historical literature, it becomes clear how research is always a "child of its time", which perhaps is less problematic as long as new ideas continuously break with outdated ones. Still, as will be shown below, outdated ideas about ancient iron and steel production continue to exert a significant impact on more recent research. Hence, a key theme in European research on ancient iron and steel is generally still an understanding of the origin and subsequent dispersal of iron technology through time and space closely related to the concept of "civilization" and ideas of the formation of stratified societies. It has been widely accepted since at least the mid-20th century that iron technology originated as a single invention in the Near East in the 2nd millennium BC (i.e., the classical birthplace of all important inventions),[46] and thereafter diffused by means of migration, trade, and conquest to central and eastern Europe,[47]

[46] Childe 1944.
[47] Pleiner 2000; Bebermeier et al. 2016; Zavyalov and Terekhova 2018.

Africa,[48] and eventually, at a much later date, northern Europe and the New World.[49] This diffusion is closely associated with distinct types of civilizations succeeding one another in time and space (i.e., the Greeks and Romans in ancient times and the European colonial powers in the 16th century), characteristically considered drivers of technological change, providing "less advanced" peripheral cultural groups with social and technological advances.[50]

The evolutionary view tied to this idea of metal technology as a significant milestone in human social progress further involves a periodized depiction of prehistory consisting of both chronological and developmental sequences for ancient cultures involved in technological and economic progress. This is not least firmly established within the conventional Three Age System, with the notion of one material technology unilaterally replacing another in connection with human evolution, from savage to barbarian and finally to civilized.[51] A strong impetus for these beliefs was the notion of separating and even dividing in a dichotomous manner civilized from primitive societies – typically farmers/sedentarists vs. nomads/pastoralists/hunter-gatherers – by routinely placing metallurgical knowledge at the forefront of social change and connected to farming/sedentary lifestyles exclusively.[52] Still, few studies have overall tried to investigate the level of knowledge of metals among nomads/pastoralists/hunter-gatherers.[53] Metallurgical remains in societies considered of low complexity, typically in the peripheral parts of Europe and beyond the Near East, are even still characteristically regarded (although at the same time generally methodologically and analytically neglected) as anomalies (e.g., as traces of imports or accidental products) or questioned as too old due to radiocarbon dating contamination effects.[54] Similar perspectives are held on the development of iron technology on the African continent and in the New World, where researchers typically argue over single or independent inventions or dispute essential technological and chronological data.[55]

Some researchers certainly claim that these older views have long been abandoned,[56] and new perspectives have rightly grown out of post-colonial perspectives and new scientific techniques since the 1960s. Many of these new perspectives are termed "bottom–up" in contrast to previous "top–down" and typically control-focused – in terms of "who has control over whom" – approaches. The bottom–up approaches typically seek to understand local societies and regions, identities, agencies, and individuals in prehistory,[57] for example, in terms of the local,[58] independent,[59] and indigenous[60] invention of iron. Still, despite increased general attention to the active role of local societies, traditional civilization narratives, alongside evolutionist and diffusionist theories as well as dichotomic discourse structures, have become a matter of assumption rather than investigation, being regenerated even within the new perspectives.[61] There is further a persistent focus on bounded cultures/identities, in which archaeological remains (according to typology and morphology) are assigned to different cultural groups and

[48] Killick 2009.
[49] Buchwald 2005; Charlton et al. 2010.
[50] Rudebeck 2000.
[51] Morgan 1877.
[52] This has previously been noted in the literature; see, e.g., Forsberg 2012; White and Hamilton 2018, and regarding ceramic technology, Jordan and Zvelebil 2009.
[53] For exceptions, see, e.g., Alpern 2005; Dyakonov et al. 2019; Park et al. 2023.
[54] Pleiner 2006; Bebermeier et al. 2016; Gassmann and Schäfer 2018; Hakonen 2021. This has previously been noted in the literature; see, e.g., Godfrey and van Nie 2004; Rijk and Joosten 2014; Janz and Conolly 2019.
[55] See, e.g., Zangato and Holl 2010; Killick and Fenn 2012.
[56] Killick and Fenn 2012; Erb-Satullo 2019.
[57] Layton 1994; Smith and Wobst 2005; Veldhuijzen and Rehren 2007.
[58] Mirau 1997; Renzi et al. 2013.
[59] Renfrew 1969; Wertime and Muhly 1980.
[60] Wertime and Muhly 1980; Higham 2004; Ramqvist 2007; Zangato and Holl 2010; Renzi et al. 2013; Yahalom-Mack and Eliyahu-Behar 2015; Kuusela et al. 2018.
[61] This has previously been noted in the literature; see, e.g., Díaz-Andreau and Champion 2014.

considered markers of ethnic identity.[62] Still, the reorientation towards identities in prehistory only means a shift in the objects of discourse from "civilizations" to other delimited objects.[63]

An in-depth review of the literature on Arctic Europe also reveals a strong bias towards origin, diffusionist, and evolutionary theories in iron research, offering little overall in terms of the interpretation of the findings. In fact, the assumed minor importance of iron technology for the ancient Arctic hunter-gatherers (albeit based on weak empirical grounds) has generally had a devastating impact on Arctic European research, above all regarding the fact the role of iron has been heavily underestimated (and little examined) in these societies. Long-standing tacit assumptions have simply held that the ancient Arctic hunter-gatherers did not possess the technical capabilities required to supply themselves with iron, and therefore relied on long-distance imports of raw iron or finished iron goods from sedentary societies, either in the east from the hierarchical societies in the Volga–Kama area near the Ural Mountains in present-day Russia, or in the south from the agro–pastoralist chiefdoms in the coastal areas of the South Scandinavian Peninsula. The eastern outlook has dominated archaeological research on the inland and northernmost parts of Arctic Sweden and Finland, and the southern view has been more prevalent in Norway. The presence of ironworking among the hunter-gatherers of the region is generally supposed to be yet another feature of the long-term stream of eastern influences on the development of prehistoric culture in the region starting in Late Neolithic times.[64] The process is further viewed as illustrating a one-directional, centre–periphery relationship in which the peripheral hunter-gatherer societies of ancient Arctic Europe are narrowed down to inferior/passive recipients of iron delivered by more progressive agricultural societies, typically with the application of dichotomies as a tool for separation.[65] An active phase in iron technology is not believed to have emerged in Arctic Europe until, more or less, the 17th century (through immigrating miners from the south), i.e., much later than elsewhere in central and northern Europe.[66]

The general lack of interest in knowledge and interpretation of findings regarding iron (including a strong bias towards origin, diffusionist, and evolutionary theories) is applicable to the entire Arctic region (see *Fig. 2*). Thus, in the vast area of Arctic Russia, there is only one known ancient iron production site (in Siberia) dating to 200 BC.[67] In the North American Arctic, the use of iron is not documented until AD 500, and iron production is first noted around AD 1000 (presumably introduced with the arrival of the Norse Vikings).[68] While much of the recent literature dealing with the prehistoric Arctic makes a significant and much-needed contribution to our understanding of iron and to the repositioning of ancient Arctic hunter-gatherer communities,[69] the literature still privileges traditional discursive dichotomies and evolutionary ideas, with discussions frequently centred on the down-the-line spread of iron through different metallurgical centres succeeding one another in time, for example, from the Caucasus via the Ananino cultural complex to Arctic Europe, western Arctic Russia, and Siberia,[70] and from Asian metallurgical centres (China) via Lake Baikal to eastern Arctic Russia, and further to the North American Arctic (via the Bering Strait/Alaska).[71]

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[62] See, e.g., Svestad and Olsen 2023 for the most recent reference.
[63] Wetherell 2010.
[64] Halén 1994.
[65] Sundquist 1999; Koryakova and Epimachov 2007; Jørgensen 2010.
[66] Norberg 1958.
[67] Vodyasov 2018.
[68] Cooper et al. 2016; Dyakonov et al. 2019; Janz and Connolly 2019.
[69] See, e.g., Jolicoeur 2019; Janz and Connolly 2019.
[70] Vodyasov 2018; Zavyalov and Terekhova 2018; Dyakonov et al. 2019.
[71] Cooper et al. 2016; Dyakonov et al. 2019.

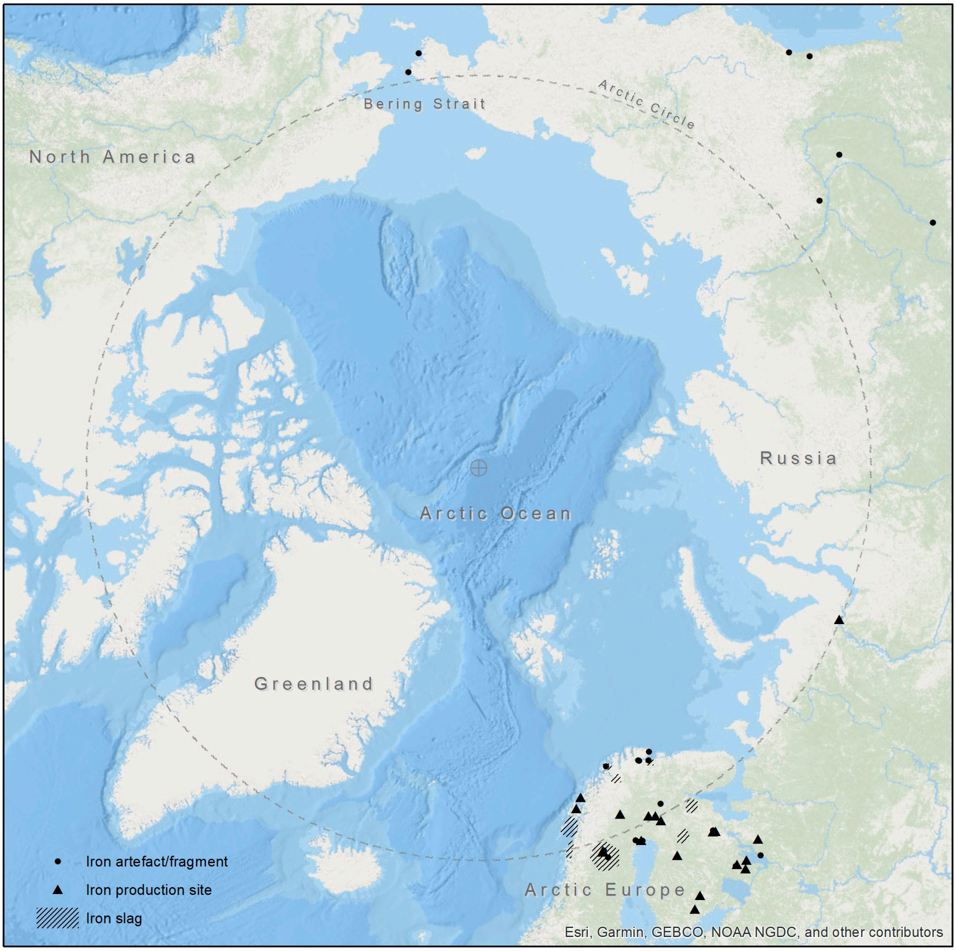

Figure 2. *Map of the Arctic area showing Late Bronze Age - Early Iron Age sites with metallurgical remains. Compilation of sites based on Erä-Esko 1969; Kehusmaa 1972; Huurre 1981; Schulz 1986; Jørgensen and Olsen 1988; Kosmenko and Manjuhin 1999; Lavento 1999; Sundquist 1999; Žul'nikov 2009; Jørgensen 2010; Kotivuori 2013; Lavento 2013; Saipio 2015; Cooper et al. 2016; Vodyasov 2018; Dyakonov et al. 2019; Bennerhag et al. 2021; Svestad and Olsen 2023; Bennerhag and Söderholm forthcoming.*

The assumed minor importance of iron technology for the ancient Arctic European hunter-gatherers has had a devastating influence on the selection (by archaeologists) of metal-related finds, which has long been generally dismissive, tendentious, and limited.[72] Even though large assemblages of iron objects and residues of metal products have been found at several prehistoric hunter-gatherer sites in Arctic Europe, not least in connection with surveys and excavations due to hydropower expansion and associated lake regulation starting in the 1940s, these have largely been interpreted as anomalies and therefore typically dismissed during cataloguing and research, or generally regarded (although without detailed analysis) as underdeveloped, primitive, low-tech (implying inefficient production and low organizational

[72] Serning 1960; Zachrisson 1976; Hakamäki and Kuusela 2013.

needs in relation to production), small in scale (implying little need for iron), and further implicitly reduced to mere knowledge of or only partial adoption of iron technology.[73] According to this reasoning, more or less all the way through the 17th century, the Arctic population was at best considered to have been able to manufacture and use iron (on a small scale) once it had been invented by more progressive agriculturalists. The scale of this population's own limited and substandard production has never been considered sufficient to meet even the small iron demands assumed for the hunter-gatherer groups, who consequently were continuously dependent on the import of iron.[74]

The general dismissal and limited selection of metallurgical finds in hunter-gatherer contexts in Arctic Europe can also be explained based on the unfortunate combination of the general stratigraphical problems of the region and the mental obstacle of the Three Age System, where finds of iron in parallel with "Stone Age" finds (i.e., stone-smithing) do not fit the expected stages of development. Tenacious social-evolutionary views were further maintained through the far-reaching neglect of available analytical tools such as radiocarbon dating and archaeometrical analyses (otherwise long applied in European iron research). Yet another layer of explanation for the exclusion of Arctic Europe and hunter-gatherer societies from the narrative of ferrous metallurgical developments consists of the general importance given to metals and metal technology in the civilization processes and creation of nation states in Sweden, Finland, and Norway (not least in Sweden). Metal handling and the extraction of metals were already crucial for these nations' economies and politics at an early stage of overall nation-building. Iron and iron technology formed the basis of industrialization, with industrial society finally, after a long time and through northwards migration, first of farmers and later of miners, making the Arctic part of the country "civilized".[75] In sum, the emergence of iron technology in Arctic Europe has long been a subordinate topic of archaeological research. Metallurgical remains are continuously ignored, and no comprehensive attempts have previously been made to analyse this material, meaning that the traditional view of the region as peripheral to Old World Ferrous metallurgical developments has been maintained.

Since the 1980s, in line with the bottom–up perspectives generally emerging from post-colonial perspectives in international/European literature since the 1960s, an ethnopolitical revitalization movement characterized by the increasing criticism and deconstruction of national history writings has developed within Arctic European archaeological research, particularly in terms of Sámi archaeology, which today forms a comprehensive part of Arctic European archaeological research. These movements have been accompanied by increased criticism and deconstruction of national history writings in many parts of the world, often alongside critical debates on the construction of cultures and ethnicity, and often with a focus on prehistoric local societies, agency, and the role of individual power strategies.[76] In Arctic Europe, these post-colonial theories strive to challenge nationalist and socio–evolutionary ideas, including the notion of the region as having retarded and inferior cultural development, typically by recognizing the active role of Arctic hunter-gatherer societies in the adoption and dispersal of technological innovations, not least concerning an early use of ceramic technology otherwise typically attributed to agricultural groups.[77] There are further examples of reversed centre–periphery perspectives concerning the role of hunter-gatherers in the production and

[73] See, e.g., Huurre 1982; Hood and Olsen 1988; Kosmenko and Manjuhin 1999; Lavento 1999; Sundquist 1999; Jørgensen 2010; Cooper et al. 2016; Vodyasov 2018.
[74] Hulthén 1991; Sundquist 1999; Jørgensen 2010; Svestad and Olsen 2023.
[75] Hagström Yamamoto 2010.
[76] See, e.g., Hodder 1986; Layton 1994; Smith and Wobst 2005; Ojala 2009; Hagström Yamamoto 2010; Spangen et al. 2015; Bruchac et al. 2016.
[77] Skandfer 2009; Damm 2012; Forsberg 2012; Jordan and Gibbs 2019a.

acquisition of metals (e.g., bronze and iron), challenging the top–down models that have dominated metallurgical research.[78]

All in all, this is an important development in archaeological research. Yet, iron is still typically seen as having been invented and passed on by the more complex agricultural societies, so the contact networks of trade or exchange with the more progressive agricultural societies continuously play major roles in explanations of the role of ancient Arctic hunter-gatherers in the production and acquisition of iron.[79] The identification of alternative explanations in terms of overcoming the discursive dichotomy and narratives of unidirectional developments and centre–periphery views is still a challenge. The dichotomic picture and asymmetrical relations are also maintained in historical research on Arctic Europe. Hence, in literature dealing with early modern times (i.e., 16th–17th centuries) and with the onset of mining, the migrationist view is perpetuated; with the local society (the Sámi) only acknowledged certain aspects of iron technology, such as knowledge of ore deposits,[80] even though historical accounts[81] give a much broader view of the metallurgical knowledge existing among the local societies living in the area.

The review of previous research shows how it, despite ever-growing archaeological evidence of more complex conditions, tenaciously perpetuates social-evolutionary narratives of centre–periphery and unidirectional developments and generally lacks substance on the role of perceived peripheries (e.g., the ancient Arctic hunter-gatherers) in the production and acquisition of iron.[82] Overall, the literature stands in stark contrast to the present findings and, consequently, has been of little interpretative value. The literature also displays a marked focus on the origin and the mere space–time pattern of the diffusion of technology (through general dispersal models or trade network mechanisms). The dispersal of metals is typically described as a unilinear sequence beginning with the introduction of metal objects arriving via trade networks, eventually followed by – through mere exposure to metal objects – actual knowledge of production and smithing.[83] Within Arctic European archaeological research, the space–time pattern focus has typically directed substantial attention towards the movement of finished objects (rather than production remains) based mainly on their form and stylistic type, and due to entrenched social-evolutionary views (particularly the Three Age System), this has been based mainly on objects of bronze and pottery. Hence, iron in early "Stone Age" contexts has not been considered relevant, with eventual iron finds unreflectively being assumed to be younger.[84]

The weak interpretative value of previous literature is also due to its persistent ambition to fit material culture into existing developmental trajectories or use it as a marker of cultural identity. With this focus on fitting findings into "ready-made" narratives about the emergence and development of cultures, attention is shifted away from other important areas, such as the local organization of crafting, and this is as common in Sámi archaeology as in traditional archaeological research. Other archaeological research focusing on Arctic Europe, mainly regarding ceramics, problematizes the equating of pots to ethnic and cultural groups.[85]

[78] Melheim 2012; Ramqvist 2012.
[79] Svestad and Olsen 2023.
[80] Nordin and Ojala 2020.
[81] See, e.g., Norberg 1958.
[82] Some recent scholarship challenges the old paradigms and highlights the agency and innovation of supposed peripheral or minority cultural groups around the world (Frachetti 2012), even when it comes to the use of metals in these societies (Alpern 2005; Park et al. 2023).
[83] See, e.g., Hood and Olsen 1988; Sundquist 1999; Jørgensen 2010; Kotivuori 2013.
[84] See, e.g., White and Hamilton 2018 who draw attention to the same problem regarding bronze metallurgy in Thailand.
[85] Regarding Arctic Europe, see Skandfer 2005; Damm 2012. Regarding other parts of the Arctic, see, e.g., Jordan and Gibbs 2019a.

The overall strong focus even in newer Arctic archaeological writing on ethnic and economic groups, along with origin/centre–periphery ideas (based, in turn, on outdated dualistic and social-evolutionary ideas), constituted a painful awakening. This awakening was, however, soon accompanied by a determination to shed light on the phenomena of interest within the framework of this thesis (see particularly papers II and IV), i.e., on how stereotypes have been created, constructed, and renewed even in the contemporary literature. The history and prehistory of Arctic Europe is far more nuanced and complex (and concerns a more diverse population) than the outmoded dualistic ideas and colonial relationships that contemporary literature tends to portray.

Theoretical framework: finding a path forward

As noted above, according to previous research, neither ancient Arctic Europe nor its hunter-gatherer population represent a place or type of subsistence lifestyle in which iron/steel production could have taken place. Still, the abundant evidence to the contrary presented here deserves to be interpreted in context. This is largely a matter of broadening the view of hunter-gatherers, both in terms of opening the concept to also accommodate advanced iron-making activities and in terms of seizing the opportunities offered by iron-making activities to understand more about the hitherto relatively unknown ancient Arctic hunter-gatherer societies. The following contends that central tools for finding a path forward in this regard should emanate in part from the empirical material on its own merits, which in this context mainly corresponds to an in-depth analysis of the technical findings through archaeometallurgical analysis. It is also partly about letting the landscape where it all unfolded, in terms of iron production- and other subsistence-related activities, emerge as a central tool in interpreting the social dimensions of technology.[86]

Social constructivist perspectives on technology,[87] not least in terms of technological choices, are rather widely adopted in archaeology in general[88] (although not much in previous ancient iron research). Although we may ask ourselves how we could possibly know why prehistoric persons/societies made particular technological choices – we cannot ask them why or watch them in operation, and they left no written explanations – social constructionist interpretations have been applied in archaeological research regarding, for example, Bronze Age/Iron Age ceramics/pottery[89] and lithics.[90] It has been suggested that social constructionist interpretations of prehistoric technology may be anchored in the archaeological evidence if the archaeological sites are well excavated and recorded in detail, where the careful reconstruction of *chaînes opératoires* and process-related experimental research are considered to contribute important insights. However, the material culture of hunter-gatherers is perceived as generally too sparse and insufficient to permit convincing social interpretations of technology.[91] Furthermore, while the ambition in archaeology to study technological choices has often led to topics such as the social identity, mobility, and interaction of potters, there has been less interest in studying organizational aspects.[92] In this thesis, a fundamental starting point is that the abundant technical findings related to iron and steel production – and provided that they are archaeometallurgically analysed, the *chaîne opératoire* is carefully reconstructed, and process-related experimental research has been carried out – enable the solid anchoring of social interpretations in the archaeological evidence regarding hunter-gatherers. Another central starting point is that a landscape perspective (see further below) can compensate for the

[86] Bijker 2010; Bijker et al. 2012.
[87] Technologies are socially constructed and never only ways to make things in a utilitarian sense, but also ways to fulfil social, political, religious, and symbolic needs.
[88] See Duistermaat 2017 for an overview.
[89] Jeffra 2011; Murphy and Poblome 2012; Duistermaat 2017.
[90] Högberg 2009.
[91] Killick 2004.
[92] Duistermaat 2017.

generally sparse material culture of hunter-gatherers, and even permit reasoning about organizational aspects.

Other recent interdisciplinary (i.e., archaeological/historical–archaeological/ecological) research on ancient hunter-gatherers in central Sweden also advocates empirically driven approaches and a broader perspective on hunter-gatherers and other overlooked groups in perceived peripheral areas. In these studies, as in this thesis, activities such as iron production (but also fur and tar production) and related resource-oriented uses of the landscape are also in focus.[93] Still, although the purpose is to create a more complex picture of these societies, the new research tends to end up in traditional categorical thinking, with the hunter-gatherer concept being depleted rather than expanded, and the local perspective being downplayed in favour of traditional extensive economic system/network perspectives according to which the periphery is still defined in relation to the centre, not on its own merits).[94] But what did these production activities and related uses of the landscape (and, for that matter, the participation in extensive economic systems) in fact *mean for the local groups*?[95] It is exactly this that the present thesis strives to investigate. The implementation and further integration/adaptation of ancient iron and steel production did not take place in a vacuum but had to be balanced against other (not least subsistence-related) activities of the small societies where it took place, and against the opportunities and limitations offered by the Arctic landscape and climate.

In the context of a landscape approach, Ingold's[96] "taskscape" concept, which treats landscapes not as meaningless backdrops but as arenas or mediators of human action, offers a useful approach. A taskscape is the array of rhythmic movements, tasks, and activities that humans and non-humans perform in the process of dwelling.[97] From distinguishing the different stages of ironworking through archaeometallurgical analyses and the reconstruction of the *chaîne opératoire*, we can explore the task of ironworking as an array of interrelated activities and relationships among the places and rhythms that formed the everyday lives of the individuals in the small ancient societies studied here. The concept allows us to incorporate the temporality of activities, a cyclical view of time tied to repeating patterns of activities in the landscape.[98] There is further reason to treat Ingold's[99] "skill" concept as a departure point. Rather than merely physical action or a mechanical process, Ingold considers skill the product of the craftsperson's intimate involvement in and active engagement with her tools and raw materials in a specific environment. In this thesis, the skill concept is expanded to encompass, in addition to the place of production and place of residence, the collection of raw materials in the wider landscape (i.e., the entire production cycle), such as, in the case of ancient iron and steel production, geological skills and skills in sustainable forest utilization. In the case of ancient Arctic activities, these skills were greatly shaped by climate and seasonal changes, which in

[93] Hennius 2021; Lindholm et al. 2021; Svensson 2022; Eriksson 2023; Wehlin et al. 2023.

[94] Recent archaeological research on the Bering Strait region and the North American Arctic applying a critical periphery perspective comparable to the Swedish neo-empirical literature – emphasizing a bottom–up view of the agency of hunter-gatherers by turning "the colonial nature of world-system theory on its head" (Janz and Conolly 2019:351) – unfortunately also downplays the local perspective in a way similar to the Swedish neo-empirical literature.

[95] See Paper II of this thesis for parallels in post-colonial research regarding northernmost Sweden focusing on indigenous groups. More locally focused studies paying attention to the resource-oriented use of landscapes and to the social components of technology have been called for by, for example, Swedish economic historians and agrarian historians in relation to agrarian studies of the 15th–18th centuries in Sweden (see, e.g., Hanssen 1952; Myrdal 1999).

[96] Ingold 1993.

[97] The dwelling perspective strives to reunite humans with the landscape by imagining the landscape as constantly unfolding and bearing witness to the passage of time and to everyone who lived there.

[98] Hadden et al. 2022.

[99] Ingold 2001.

turn required advanced organization and planning for the patterns to stay in rhythm.[100] Here it is likely advantageous for a researcher analysing the pattern of ancient activities in the landscape, to possess personal local knowledge and experience[101] of the European Arctic landscape and climate – which, incidentally, are similar to those of 2000 years ago.[102]

While exploring the task of ironworking, we further realize the shortcomings of the rather linear *chaîne opératoire* perspective, as several of the raw material preparation activities in fact take place over cyclically longer periods, both before, parallel with, and after the actual production and manufacturing process. This motivates us to supplement the *chaîne opératoire* perspective with a basic technical system perspective, in which the numerous interconnected "sub" production processes and technical systems of ancient iron production appear[103] and can be explored based on their actual "pattern size" in the landscape, i.e., the amount of time, geographical space, and planning/organizing tied to the pattern. In addition to charcoal production and ore preparation (i.e., roasting), the smaller production processes and technical systems in question include various smelting processes (depending on the desired product), bloomery furnaces, forging hearths, and various forging processes (again depending on the desired product).

The ambition is that, with the described theoretical framework and through a solid anchoring in both the empirical material and the landscape where it all unfolded, this thesis will be able to illuminate related social aspects in terms of the many individual activities (all, in turn, requiring numerous choices and decisions) involved in the successful transformation of ore into finished artefacts. These activities range from, for example, the processes of finding and deciding on the localization and most appropriate selection, transport, preparation, and storage of necessary raw materials, to deciding on and planning for the temporality of all these activities, i.e., when they were to be conducted alongside other livelihood activities and landscape/climate conditions. Social aspects further concern intentions, desires, and needs as driving forces of production. Hence, iron production did not take place independently outside the small societies and their inhabitants as they were the ones choosing, prioritizing, organizing for, and producing the iron.[104] This is an important theoretical contribution to research on prehistoric iron and metals, which all too often (due to a one-sided focus on origins, based on typological approaches, and simplified trade-related explanations) are treated in isolation from the involved local societies and people.[105]

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[100] This approach is inspired by other researchers also focusing on the interrelations between society, the landscape, climate, and technology; see, e.g., White 1996; Conneller 2000; Rajala and Mills 2017; Jordan and Gibbs 2019b; Erb-Satullo 2022; Berg-Hansen et al. 2022.
[101] Turnbull 2008.
[102] Seppä et al. 2009.
[103] Ingelstam 2002.
[104] Numerous anthropologists (Ingold 1990; Lemonnier 1992; Pfaffenberger 1992), modern historians and sociologists (Hughes 1983; Bijker 1995; Bijker et al. 2012), and archaeologists (Rehren et al. 2007; White and Hamilton 2018; Högberg and Lombard 2019) emphasize the socio–technical approach.
[105] Roberts 2009.

Overview/summary of papers

Paper I – "Hunter-gatherer metallurgy in the Early Iron Age of northern Fennoscandia" (Bennerhag et al. 2021, see *Appendix A*) presents the first in-depth analyses of prehistoric metallurgical remains from hunter-gatherer contexts in Arctic Europe. The role of ferrous metallurgy in the ancient societies of this area is poorly understood due, in part, to the widespread assumption that iron technology was a late introduction, passively received by local populations. Ancient hunter-gatherers have hitherto not been considered sufficiently advanced from the social and economic perspectives to be associated with iron. The paper is based on a study of two excavated hunter-gatherer sites near the villages of Sangis and Vivungi in northernmost Sweden. Radiocarbon dating and archaeometallurgical analysis of metallurgical remains were used to establish the various stages of the ironworking processes present at the two sites (including their chronology) and to contextualize the implementation of iron in these societies. The findings provide substantial evidence that iron technology (including bloomery steel production and the mastering of advanced smithing techniques) was already an integrated part of hunter-gatherer subsistence in Arctic Sweden 2200 years ago. Similar advanced knowledge and skilled craftsmanship have historically been linked to craft specializations in the Roman Empire in the first century BC. The traditional interpretative paradigm, labelling iron technology in Arctic Europe as small in scale, dependent on imports, and underdeveloped or archaic, is a simplification of a more complex situation and does not withstand evidence-based scrutiny. The paper's findings have implications from a global perspective and raise broader questions regarding the presence of ferrous metallurgy in societies considered less complex or highly mobile.

Paper II – "Towards a broader understanding of the emergence of iron technology in prehistoric Arctic Fennoscandia" (Bennerhag et al. 2023, see *Appendix B*) critically examines interpretations of Old World ferrous metallurgical developments with reference to their implications for Arctic European iron research. The traditional paradigm of technological innovation recurrently links the emergence of iron technology to increasing social complexity and a sedentary agricultural lifestyle, typically downplaying "peripheral" areas such as Arctic Europe and its hunter-gatherer societies. This is seen even in recent postcolonial research, in which the debate concerns the same recurrent questions. It is generally accepted that Arctic Europe's active phase in iron technology was established much later than elsewhere in central and northern Europe, typically first associated with the establishment of the mining industry in the 16th–17th centuries. Since the second half of the 20th century, archaeological excavations and surveys have been conducted in Arctic Sweden, Finland, and Norway in connection with lake regulation due to hydropower expansion, providing evidence potentially challenging this paradigm. This evidence has included extensive material in the form of metallurgical finds from hunter-gatherer contexts. Still, these occurrences have typically been regarded as anomalies, being continuously dismissed in iron research, typically by being described as underdeveloped, small in scale, and merely the result of long-distance contacts via trade or exchange. This paper concludes that earlier interpretative frameworks do not withstand scrutiny and that the role of iron in hunter-gatherer societies has been greatly underestimated. The new findings include substantial evidence that iron technology was already an integrated part of Arctic European hunter-gatherer subsistence economies during the Early Iron Age (c. 200 BC), revealing advanced knowledge of all the operational sequences of iron technology, including bloomery steel production and the mastering of advanced smithing techniques. Overall, the paper emphasizes the importance of dispensing with traditional ideas that do not help explain iron transfer and its implementation, and further calls for increased interest in the underlying mechanisms for knowledge distribution of iron to occur.

Paper III – "Ancient Arctic European hunter-gatherer steelmakers in the limelight" (Bennerhag and Söderholm, under review, see *Appendix C*) presents results of the analysis of metallurgical remains from as many as 42 different sites across present-day northernmost

Norway, Finland, and Sweden. This large assemblage of iron objects and residues of metalworking (including iron production) found at several prehistoric hunter-gatherer sites has largely been dismissed in previous iron research. Hunter-gatherer metallurgical knowledge has typically been interpreted as underdeveloped and implicitly reduced to mere knowledge of metals acquired through long-distance contact networks of trade or exchange. Archaeometrical analyses were employed in combination with an Arctic climate and landscape/taskscape lens to achieve new insights into what the implementation of iron knowledge and production meant for local groups of ancient Arctic hunter-gatherers, rather than, as is more common in archaeology, seeking to establish the origin of advanced knowledge. Results indicate widespread early knowledge of advanced iron production within the hitherto unthinkable cultural context of hunter-gatherers in Arctic Europe, critically challenging previous research. The striking similarities in iron technology regarding style, technological choices, and organization over much of the vast area of Arctic Europe indicate a well-established system that required extensive organization, workforce coordination/labour division, and balancing with other subsistence activities, not least in terms of the harsh climate and seasonal fluctuations. This balancing of tasks appears to have been done by aligning the locations of iron production with prosperous fishing grounds providing the bulk of food, which, combined with the extensive investment that iron production required, reasonably bound people to certain areas in the landscape. Taken together, these results not only indicate the far more multifaceted organization of the combined taskscapes of the ancient Arctic hunter-gatherers than previously assumed; rather, they also clearly contradict the strong emphasis on divided settlement patterns in previous research, suggesting that the Arctic's ancient hunter-gatherers lived a less mobile life than assumed. The paper demonstrates that it is time to expand our perspectives on hunter-gatherer societies in terms of their specialization and complex organization, bridging the dichotomic divide between farmers and hunter-gatherers. The paper further advocates for the broader use of archaeometrical approaches to identify peripheral locations/regions potentially possessing advanced and early metalworking other than Arctic Europe, arguing that the entire environmental and social "backdrop" (i.e., landscape, climate, and economy) must be examined to fully comprehend the implementation of iron and the underlying mechanisms behind the transmission and maintenance of iron technology.

While reflecting on a defined research process, the location of our interdisciplinary group's scholarly work and focus, Arctic Sweden, emerged as a powerful influencing factor causing significant deviations from the intended research path at multiple times. **Paper IV –** "Reflections on an Arctic research process and the importance of the local place" (Söderholm and Bennerhag, under review, see *Appendix D*) adopts a reflexive stance and examines the various paths taken during the research process and their underlying causes. By extension, the paper brings into focus the underlying perceptions, both old and new, of Arctic Sweden that strongly influence interpretations in the literature and public debate. In part, it is about the literature dealing with the place/region, a literature marked by persistent centre/periphery perspectives with which the findings of 2200-year-old advanced iron technology in the hands of ancient Arctic hunter-gatherers are totally at odds. The research process was influenced by the region's historical and partly ongoing marginalization (compared with the rest of Sweden) alongside long-term and extensive national (and, to some extent, international) natural resource exploitation, which not least has affected the indigenous Sámi and other minorities of the region. Today, their need for recognition has given rise to strong ethnopolitical currents. This is often expressed in ambitions to rewrite or fill the gaps in history writing, which is why historians and archaeologists may face challenging expectations to create particular historical narratives. Notably, peripheral cultural groups striving for recognition through historical writings is a global postcolonial phenomenon. Finally, this paper underlines the advantages of interdisciplinary research as a way forward when the literature has too little to contribute to the interpretation of finds. By combining archaeological and historical methods, sources, and theoretical perspectives (including key aspects of archaeometallurgy), insights can be gained that broaden and enrich our understanding of the past.

Discussion

Through the reactivation and analysis of previously and newly recovered metallurgical finds, **this study has enabled an in-depth examination of the potential contemporary wider distribution of advanced know-how in iron and steel production** (including smithing) evident at the Sangis site during pre-Roman and Roman times. Remarkably, the new data support the existence of the widespread presence of similar contemporary advanced production at more than 40 different sites (including Sangis) spanning the transnational borders of Arctic Norway, Sweden, and Finland. Although the amounts of metallurgical remains at these sites are small compared with those at the larger-scale production sites in Europe in later times, and not all find categories are represented in all places, the analysed material – considered as a group of formally related remains – unambiguously suggests an extensive ironworking landscape in Arctic Europe already present during the Early Iron Age (most of the sites are radiocarbon dated to the pre-Roman and Roman Iron Age) (see *Appendix G, Table 6-8*), i.e., almost two thousand years before the first mining extraction started in this area. The contemporary dating of the studied sites (spanning the 300 BC–AD 400 period) suggests that knowledge of and skill in iron technology spread rapidly across the vast area of Arctic Europe and were maintained for centuries. Based on comprehensive contextual studies, including radiocarbon dating of the analysed sites, there is no doubt that the manufacturing and use of iron can be linked to hunter-gatherer contexts. Most sites show evidence of a diversified hunter-gatherer economy with heavy reliance on fishing and on the hunting of small-game mammals (e.g., squirrels, beavers, and martens) and birds. Also, most of the metallurgical remains are found amidst stone tool assemblages, also including asbestos-tempered pottery, which are essential of ancient Arctic hunter-gatherer settings of the Early Iron Age. The archaeometallurgical analyses further demonstrate the production of numerous kinds of iron alloys – especially high-carbon steel – using several different lake and bog iron ores. Most of the analysed artefacts further derive from advanced smithing techniques, including various heat treatments to enhance the material properties. In several ways completely at odds with conventional views, this study shows that iron and steel production, and the related manufacturing of objects (alongside their widespread use), was an integral aspect of the Arctic hunter-gatherer subsistence economy contemporary with the Roman Empire, i.e., around 100 BC.[106]

In other words, this thesis highlights the significance of Arctic European iron metallurgy in the global history of technology, and thus firmly exposes and challenges the interpretative paradigm of European iron research in two major ways. To start with, the present findings problematize the preoccupation with questions of origins and linear diffusion models that tacitly assume that prehistoric Arctic European iron metallurgy was generally a late phenomenon. Not only do the analyses show quite the opposite – that metallurgy was an early phenomenon – but they also highlight the possibility of moving away from simplified diffusion explanations typically framed in terms of trade, in favour of an increased focus on the local implications of the new technology. Second, closely related and no less important, the present findings contradict the deeply rooted categorical distinctions between hunter-gatherer and farmer societies established by European archaeologists in the 19th and 20th centuries (that still exert major global influence on the literature), including the central diffusionist idiom of Old World ferrous metallurgical developments in which metals are considered the invention of more complex farming societies, spread as commodities through long-distance trade. Tacit assumptions have long influenced the interpretation of prehistoric Arctic European iron metallurgy in a devastating way, i.e., as a late, underdeveloped, and small-scale technology, while its socio–economic, technological, and environmental complexities have been completely ignored.

[106] Pleiner 2000.

Regarding the distribution in Arctic Europe of advanced know-how in iron and steel production, analyses demonstrate apparent conformity in terms of both spatial organization and technical choices. Thus, there is conformity in ensuring basic landscape- and raw material-related prerequisites in terms of the settlements' distinct clustering (when plotted on maps) around larger water bodies in forest landscapes, i.e., in relation to primary resources in terms of ore and wood needed for fuel. There is conformity and at the same time distinctiveness in the spatial distribution of the workshops as well. This is partly in terms of the complete metal production cycle apparently having taken place in the same local context, i.e., both smelting and smithing, which is unusual in the Early Iron Age from a global perspective[107] and unique when it comes to hunter-gatherer contexts. Also, the complete *chaîne opératoire* – from smelting to smithing – seems to have already been established at the inception of iron. The smithing workshops are, moreover, spatially connected to large known settlements, and as a rule also to other craft activities, such as lithic technology, pottery, horn/bone crafts, and skin/fur crafts. Ancient Arctic ironworking seems integrated with the existing material technologies and organizationally incorporated with other residential activities, contrary to assumptions that ironworking was a secluded practice hidden away from everyday life.[108]

When it comes to technical choices, the selection of both raw materials (e.g., clay and ore) and curation strategies, as well as "standardization" concerning the mastery of excellent smelting and smithing operations, indicate well-established and apparently uniform technology throughout Arctic Europe. At most of the sites, the same general (although not easily available, see further below) quality of clay was used in constructing the bloomery furnaces and hearths, with the large proportion of sand (dominated by quartz, increasing refractory properties and the physical stability) meaning that the constructors had to deal with limited plasticity. To cope with the insufficient plastic qualities, curation strategies were adapted by repeatedly repairing cracks and applying layers of clay between the runs instead of rebuilding the furnaces. Reuse was accompanied by relining with fresh clay on the inside, often in the blowing zone where the furnace shaft was most exposed to high temperatures, particularly around the air-inlet hole(s). After each repair, the furnace would be used for a further number of runs. Overall, this attests to widespread knowledge of how to handle this type of clay, as well as uniformity of technological tradition.

Concerning the smelting and smithing operations, where archaeometallurgical analyses find evidence of advanced technological know-how in all operational sequences alongside the deliberate production of steel directly in the bloomery furnace[109] as early as the Early Iron Age (200–50 BC), slag analyses imply various ores of different element compositions, each of crucial importance to the quality of the manufactured iron. The steel can be followed through all stages of the metallurgical process, implying widespread demand among the hunter-gatherer societies for products of high-quality steel as a key iron alloy, i.e., a tough material that can withstand substantial deformation without breaking. This attests to iron production skills that are traditionally associated with the Roman Empire.[110] The presence of phosphoric and ferritic iron at some sites suggests demand for other alloys as well, requiring ores of different element

[107] However, in France there are two examples, one associated with a Celtic agglomeration during the pre-Roman Iron Age (Berranger and Fluzin 2014) and the other a 4th-century Roman workshop with all stages of iron processing including the smelting and refining of blooms and smithing of objects (Dieudonné and Glad 1997).

[108] This assumption is related to the notion that excellent smithing techniques were kept as "professional secrets" by local craftsmen to prevent them from spreading (Pleiner 2006; Zavyalov and Terekhov 2018) and to occasional ethnographic evidence that smelting took place in secluded areas away from settlements because of its link with reproduction (Chirikure 2015).

[109] The use of manganese-rich ores is usually associated with the production of steel in the Roman Empire (i.e., the *ferrum Noricum*), facilitating the direct production of steel in the bloomery furnace (Truffaut 2014; Hjärthner-Holdar et al. 2018). The use of manganese-bearing ores is also evident at the analysed sites, directly connected to the production of steel.

[110] Pleiner 2000, 2006.

compositions. While phosphoric ores can contribute to a ductile, but somewhat hard, iron, manganese-rich ores facilitate harder products (i.e., high-carbon steel) with the potential for various heat treatments that further improve the material properties.[111] There are further examples of the different types of iron being accumulated together, a phenomenon frequently observed in specialized craft contexts during the Late Iron Age (often interpreted as under elite control).[112] The productivity of iron production has not previously been calculated in terms of hunter-gatherer economy. However, based on the estimated iron consumption of a Late Iron Age farm (2–5 kg/year) and the calculated yield of Swedish limonite ore (i.e., 10 kg of ore produces 5 kg of slag and 5 kg of iron metal),[113] the scale of production at each furnace (i.e., 9–230 kg iron) would have exceeded the consumption of a single household even over several years. This shows that iron was no less important in hunter-gatherer societies than in sedentary, agricultural societies.

The artefacts[114] illustrate the use of welding techniques combining different steel and iron (both phosphoric and soft ferritic iron) qualities into multilayered tools, enhanced by various heat treatments including quenching and tempering. In the analysed objects, the hardest steel was consistently used for the edges, indicating a desire for tough and hard cutting tools. The fabrication techniques and iron alloys used were thus tailored to the specific tool types. In one of the analysed knives, there is also evidence of a desire for visual and stylistic effects using lamination techniques (i.e., combining different layers of steel and phosphoric iron). This requires skills usually considered the most challenging for ancient European smiths.[115] The difficulty is related to the fact that the different iron alloys to be attached to one another often have different optimum smithing temperatures,[116] resulting in small time windows for attachment and, in turn, making the ancient blacksmith's skill in determining the temperature with his/her own senses (e.g., through the colour of the glowing metal) decisive. In the literature, these skills are considered to have been attempted in central Europe) as early as 500 BC, but without becoming more widespread until Roman times and first reaching northern Europe in the Middle Ages (but never really its Arctic parts).[117] Still, our analyses show that advanced smithing techniques were maintained in ancient Arctic Europe for at least 400–500 years.[118] Overall, the successful implementation of iron technology would not have been possible without a thorough understanding of the entire operational chain, including knowledge of the raw materials, characteristics and properties of iron alloys, and thermo–mechanical treatments used. The fact that iron technology shared common practices over a large geographical area underscores the hunter-gatherers' shared achievement of a uniformly high level of technological mastery.

Analyses of the Sangis smithing site further show that the blooms[119] used in manufacturing originated from several different furnaces, possibly running in the area simultaneously.[120] At several other smithing sites (e.g., the Swedish lake Storavan and Kakel sites), the processing of various types of iron, indicated by analysis of iron waste (originating from blooms) possibly also suggests several different furnaces running simultaneously. Whether these furnaces were

[111] See, e.g., Crew et al. 2011; Bennerhag et al. 2021.
[112] See discussion in Erb-Satullo 2022 and references therein.
[113] Hjärthner-Holdar et al. 2018.
[114] So far, only artefacts from the Sangis site have been analysed.
[115] Gilmour 2017.
[116] Güder et al. 2017.
[117] Pleiner 2006. This book is considered a seminal work in European ancient iron research, and maps depicting the spread of advanced smithing techniques in Europe do not even include the Arctic.
[118] Radiocarbon dating reveals chronologies spanning several hundred years (pre-Roman–Roman Iron Age) at additional smithing sites, including the Swedish Lake Kakel region (in addition to Sangis). However, no artefacts from these sites have yet been examined.
[119] Analyses show that the primary smithing of blooms was in fact carried out at the smithing sites, a fact rarely mentioned in the literature (for an exception, see Dieudonné and Glad 1997).
[120] This has been established by conducting chemical analyses of slag inclusions in the iron.

operated more or less in parallel by different groups of people supplying a single smithing site with blooms, or that a group of people, and perhaps their descendants, at a site gradually built new furnaces and used new ore deposits to supply the smithing site with blooms, it is justifiable to regard the smithing workshop as the very heart of the ancient iron production system (not least illustrated by the spatial connection of the smithing workshops to places of settlement and other residential activities).[121] Still, in the literature, attention and authority are typically directed to the smelting sites.[122]

This study has further enabled an in-depth examination of the social/organizational implications of iron in hunter-gatherer societies. Through the application of archaeometallurgical methods and the *chaîne opératoire* perspective in conjunction with the landscape/taskscape and climate/seasonal perspectives, this thesis arrive at a basic understanding (generally at odds with the literature[123]) of ancient Arctic metalworking, no matter how small in scale, as requiring organization and planning throughout the year as well as the investment of numerous participants at the collective level. The production of iron and the manufacture of artefacts was a labour-intensive process involving multiple materials and several different production steps (involving different areas of specialized knowledge). Ores had to be prospected and roasted, wood was required to produce charcoal, and building materials (clay and stone) were required for the construction/repair of furnaces and smithing hearths. For all these steps and areas of knowledge, the landscape and climate/seasons played a major role.

The strong seasonality of the Arctic European landscape, including significant climatic variation, created fundamental challenges for the ancient people living there. Merely surviving required skills and far-reaching planning. Planning and activities related to hunting, fishing, and gathering are often highlighted,[124] although there is reason to also emphasize tasks related to, for example, the preparation of clothing and housing suitable for the Arctic climate, and now also metallurgical activities. The seasonal variations had major impacts on the temporality of the different taskscapes of the Arctic hunter-gatherer societies and required well-adapted strategies and the complex organization of tasks and of landscape use to balance the different tasks. Basic prerequisites for these groups to engage in iron production were, in addition to access to primary resources such as ore, clay, and wood, that they could engage in activities other than primarily food collection. By coordinating the locations of iron production with productive fishing grounds, necessary conditions seem to have been in place.

The taskscapes related to ancient iron production had the greatest labour intensity and parallel need for division of labour in the local society during bare-ground season, and especially during the summer months. This was not only about the necessity to carry out much of the preparation for iron production – in terms of prospecting for, collecting, and preparing primary resources – but also about the construction and running of furnaces, which required bare-ground season. Also, the construction of forging hearths required bare-ground season, although the forging may have been carried out year-round in dedicated huts. Some tasks were spread out over several years, for example, the drying of wood for charcoaling. Concerning the acquisition of clay, this task may have been spread out over several seasons, as the clay had to be dug up during bare-ground season after the frost had left the ground and before too much vegetation had taken hold, and, due to its weight, was possibly transported during winter. In general, iron making was influenced by the landscape in terms of the location of primary resources (including geologic,

[121] The presence of several furnaces situated around the same lakes at the Swedish Vivungi and Finnish Rovaniemi smelting sites further corroborates this hypothesis. Still, smithing activities have not yet been found in the areas near these sites.
[122] See, e.g., Pleiner 2000, 2006.
[123] The literature typically states that small-scale technologies did not call for complex social organization; see, e.g., Jørgensen 2011.
[124] Bergman 1995; Bergman and Ramqvist 2017.

hydrologic, and woodland conditions) and the climatic/seasonal fluctuations determining when tasks could be conducted alongside other livelihood activities and conditions.

The implementation of iron-making tasks alongside other life rhythms necessitated the division of labour to accommodate them. Only those societies that were able to integrate the lengthy metal production sequence into the wider pattern of the settlement system would have been able to benefit from the adaptive advantages of iron. Mobilizing this social effort would have required advanced planning and workforce coordination, especially considering the rather small-scale societies probably concerned (i.e., 25–50 people[125]). Basic conditions were in place through the very location of the settlement, with rich access to aquatic food resources (indicated by the abundance of fish bones discovered at the settlement sites) alongside primary resources of ore, fuel, and building material. This spatial coordination demonstrates that iron technology was an integrated part of these societies' exploitative strategies.[126] Furthermore, the spatial location of iron production within the settlement, being clearly integrated with existing material technologies, such as lithic technology and other residential activities, demonstrates that it was successfully integrated into the organizational structure. It should be pointed out here, regarding subsistence economies, the localization of settlement sites[127] and the lithic tradition, that there are no signs of broader socio–economic change at the time of the inception of iron technology. Rather, there was continuity well before and after, in turn indicating that a necessary surplus for the adoption of iron technology was in place at these locations even before the introduction of iron. Also supporting this is the rapid inception of iron technology over a large geographical area.

The spatial clustering of the different process stages within or near the settlements indicates that iron production was part of the same cooperative organization of labour that the literature typically assumes for hunting and gathering societies.[128] Not to mention, given the small scale of the prehistoric hunting-gathering groups in Arctic Europe, the long-term investments and sometimes labour-intensive tasks related to the manufacturing of iron reasonably required the consent of more or less the whole society. The activity required an extensive knowledge base in the hands of rather small groups of people, and the spatial clustering of the different process stages within or near the settlement would have facilitated collective control over and responsibility for the complete metal production cycle – the entire *chaîne opératoire*. This, in turn, could explain why ironworking in ancient Arctic Europe was not a secluded practice, detached from everyday life, which otherwise constitutes the typical description of ancient iron production in the literature.[129] These results indicate that rather than assume power relations and elite control, in this case it is more rewarding to discuss the organization of iron production in terms of a) major societal involvement – possibly of the entire society, if considering the entire *chaîne opératoire*, including skilled artisans belonging to a geographically broad technological knowledge community; and b) actual local conditions regarding landscape, climate/seasonal variations, and other everyday activities influencing the conditions for ironworking.

Taken together, this attests to a far more advanced and multifaceted organization of the combined taskscapes of the ancient Arctic hunter-gatherers than previously assumed, and overall shows that iron production played an important role in their socio–economic activities. Furthermore, the aggregation of metallurgical sites close to rich aquatic resources, which suggests that societies were tied to specific sites and resource areas, and the way iron production claimed extensive time investments at specific places in the landscape, reasonably tied the people to certain areas for longer periods. Fisheries were understandably of major importance

[125] Kelly 2013:171.
[126] Binford 1979.
[127] See, e.g., Hakamäki and Kuusela 2013; Seitsonen and Viljanmaa 2021.
[128] Kelly 2013.
[129] See discussion in Erb-Satullo 2022.

in this context, for creating surplus and the prerequisites for increased sedentariness. Finds at the Sangis and Kosjärv sites (which include metallurgical remains) of bone fragment patterning indicating dried fish (i.e., chewed vertebra) imply a strategy of conserving and managing surplus resources and practising a delayed-return lifestyle. Such optimal locations close to aquatic resources creating conditions for increased sedentariness have also been suggested to facilitate the introduction of pottery.[130] In addition, all the human-made and maintenance-requiring capital investments in workshops, furnaces, storerooms/sheds (for drying wood, charcoal, and roasted ore), and other equipment related to iron production attest to the increased sedentariness of these ancient Arctic iron-making societies, and to the sophisticated melting and forging techniques obviously requiring continuity in the artisans' line of work, i.e., remaining close to their workshops. Still, sedentariness is totally at odds with the literature on ancient Arctic Europe, which strongly emphasizes divided settlement patterns and, more recently, even increased mobility.[131]

The way this thesis deconstructs (in various layers) the traditional paradigms of European iron research – including the strong bias in favour of origin, diffusionist (i.e., centre–periphery), and evolutionary theories – means that it contributes important methodological and theoretical lessons. This thesis reduces knowledge gaps and presents wider perspectives regarding ancient European iron use and the ancient Arctic hunter-gatherers, providing considerable knowledge of their daily lives through the in-depth analysis of iron and steel production. The hunter-gatherer concept is thus expanded – and yes, they were still hunter-gatherers who, in addition to iron and steel production, hunted/trapped and gathered for their livelihood. The interdisciplinary approach (combining history of technology/archaeology/archaeometallurgy) was central to finding paths away from traditional paradigms, where the solution was anchored in the empirical material and the landscape/climate where the phenomena of interest unfolded. In this context, undersigned emphasize the importance of archaeometallurgical analyses and radiocarbon dating of the full metallurgical assemblage (including residual products of slag, technical ceramics, and iron waste). Although this archaeological material displays huge potential, it has been largely overlooked. The methods and perspectives should be relevant and applicable to other regions considered peripheral (in relation to conventional centres) and, in general, to small-scale/less-complex societies, as these typically exhibit "invisible archaeologies" and generally poor possibilities for the preservation of archaeological artefacts.[132] The methods should also be useful for later time periods, for example, in archaeometallurgical analyses of industrial history complexes, as they could provide information not usually available in historical sources.

[130] Jordan and Zvelebil 2009.
[131] Eidlitz Kuoljok 1991; Mulk 1994; Bergman 1995; Karlsson 2006; Aronsson 2009; Hansen and Olsen 2014; Wallerström 2020; Jørgensen et al. 2023.
[132] Seitsonen and Viljanmaa 2021.

Final remarks

It was a long series of more-or-less random events (ranging from authority decisions about railway lines to meetings between out-of-the-box thinking individuals) that led to the ground-breaking results presented here.[133] It is really against the odds they were produced at all. While the results concern, from the perspective of conventional centres, a peripheral place on earth with "invisible" archaeology, they simultaneously concern a region that a national slogan describes as something of an eternal Future land, a frontier to conquer. This region has long been and still is exposed to large-scale natural resource extraction, meaning continuous large-scale assaults on the region's cultural heritage. Even though attempts are often made in parallel with large-scale resource extraction to preserve cultural heritage, only a selection is preserved, and the preservation attempts are carried out within a limited period, guided by limited knowledge and a limited social outlook – with all that implies. It therefore cannot be emphasized enough that it was essentially detective work even to find the residual products of ancient ironworking in the storage boxes that are still preserved (but that may soon be culled) at institutions around Sweden, Norway, and Finland containing remnants of Arctic Europe's ancient cultural heritage collected from where they once lay along unregulated rivers. Today, many of the 42 analysed sites of ancient iron and steel technology discussed here are submerged under water as a result of large-scale hydropower development in the region, and many important aspects of ancient iron making have been lost (in comparison with the Sangis and Vivungi excavations) as we cannot visit these sites and examine them. How many additional sites of ancient iron making, or other yet unknown ancient pioneering activities, are there not even traces of in the preserved storage boxes? Considering how little the region has been archeologically researched overall, it is remarkable how many sites this study has identified. Without a doubt, this research has only scratched the surface. The results highlight the importance of valuing the cultural heritage of the Arctic region as highly as that of more southern regions.

Closely related to the problems described above are the abuses of several of the region's minorities throughout history, due to the strong national interest in the region's natural resources. In recent years, this has contributed to a powerful post-colonial reaction, partly expressed in strongly ethnically and culturally marked history writing by many of the region's archaeologists and historians. This movement, in terms of both minority representatives and professional historians/archaeologists, has placed expectations on the research project within which this doctoral work was carried out, to put ethnic labels on the findings. There is a danger in a strong ethnic focus in history writing, particularly in a region that still possesses limited history writing about earlier periods. An ethnic focus therefore often means a lack of attention to the rich multilingualism and diversified resource utilization that for a very long time have de facto characterized the region.[134]

[133] See Paper IV for a closer overview of the process.

[134] Some recent research in Sweden, does indeed, aim to broaden the perspectives; see, e.g., Bergman and Hörnberg 2015; Fjellström 2020.

Further research

While the contemporary dating of the studied sites suggests that knowledge of and skill in iron technology spread rapidly across the vast area of Arctic Europe, it would be justified to continue to explore possible explanations for this transmission, and at a far deeper level than offered by traditional trade/exchange network explanations. The traditional explanations add little to our understanding of such a broad contemporary engagement in advanced knowledge that required long-term collective commitment (which may also have contributed to a changed/more sedentary settlement pattern). Also, the small societies in question did not have very many unique products to exchange with one another due to the relatively similar landscape and related main subsistence conditions, i.e., located at fishing lakes in forest landscapes with good access to small-game mammals and birds. Overall, the seemingly rapid spread of iron technology in Arctic Europe, rather than its origins, is crucial to explore further. To dwell a bit more on the similar landscape situation, there is cause to reason about the importance of landscape and climate variables for technology transfer in this context.[135] It would further be useful to explore several types of contemporary crafts, such as ceramics, lithics, and iron and steel production, to seek more robust models of the implementation of new technologies in ancient societies.[136] These technologies are contemporaneous and take place in the same landscape and social contexts. Overall, the landscape perspective has the potential to open up the framework of apprenticeship systems (i.e., formal learning), to instead consider learning processes as continuously taking place within the taskscape.[137] Furthermore, the multiple craft approach alongside the landscape perspective has the potential to open up the importance long attributed to cultures, closed groups, and ethnicities, to instead talk about "communities of practice".[138] Here, again, the so-called lake-regulation material would be interesting – and relevant – to study. Unfortunately, however, it is a fact that, during the last few years, despite repeated requests, the interdisciplinary group has been prevented (with reference to internal organizational problems) from accessing this material by the largest Swedish institution holding lake-regulation material, the Swedish National Historical Museum, Department of Collections, in Stockholm. It is bad enough that the cultural heritage of northernmost Sweden is partly submerged and partly stored in boxes at archival institutions far from the original contexts of the material collection, but it is completely unacceptable that it is made inaccessible to research as well.

[135] Other researchers have also recently considered the landscape and climate in explaining the distribution/transfer of lithics and ceramics; see Centi et al. 2023; Jørgensen et al. 2023.
[136] Miller 2020; Jørgensen et al. 2023.
[137] See, e.g., Riede et al. 2023.
[138] Lave and Wenger 1991; Wenger 1998.

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Appendix A

Paper I

Hunter-gatherer metallurgy in the Early Iron Age of northern Fennoscandia

Bennerhag, Carina, Lena Grandin, Eva Hjärtner-Holdar, Ole Stilborg, and Kristina Söderholm

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Research Article

Hunter-gatherer metallurgy in the Early Iron Age of Northern Fennoscandia

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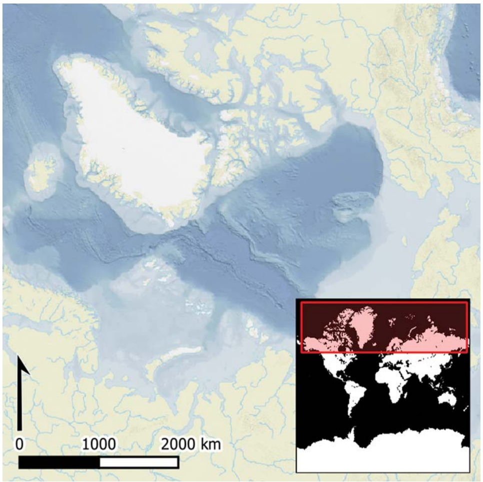

The role of ferrous metallurgy in ancient communities of the Circumpolar North is poorly understood due, in part, to the widespread assumption that iron technology was a late introduction, passively received by local populations. Analyses of two recently excavated sites in northernmost Sweden, however, show that iron technology already formed an integral part of the hunter-gatherer subsistence economy in Northern Fennoscandia during the Iron Age (*c.* 200–50 BC). Such developed knowledge of steel production and complex smithing techniques finds parallels in contemporaneous continental Europe and Western Eurasia. The evidence presented raises broader questions concerning the presence of intricate metallurgical processes in societies considered less complex or highly mobile.

Keywords: Circumpolar North, Fennoscandia, Iron Age, iron technology, hunter-gatherer subsistence

Introduction

The introduction of iron technology to the Circumpolar North has been a neglected topic of archaeological research and considered peripheral to Old World ferrous metallurgical developments (Wertime 1973; Pleiner 2000). The region has typically not been included in broad narratives of prehistoric iron technology, and it is generally accepted that the latter was established much later in this region than elsewhere in Eurasia. According to the prevailing diffusion model, iron technology began as a single invention in the Near East in the second millennium BC. From there it is believed to have spread westwards around 1200–500 BC, only reaching the peripheral areas of the Circumpolar North during the Viking Age

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or pre-modern times (AD 700–1600) (Pleiner 2000; Peets 2003; Buchwald 2005; Koryakova & Epimachov 2007; Zavyalov & Terekhova 2018). This diffusionist model is often associated with evolutionary perspectives that link technological progress with societal complexity (Childe 1944). Hence, iron technology is strongly connected to the emergence of stratified societies and a sedentary way of life based on agriculture. Consequently, the role of iron technology in societies defined as less stratified or highly mobile (e.g. hunter-gatherers, nomads and pastoralists) is generally underestimated in metallurgical research, these being considered insufficiently complex to be associated with iron.

In recent decades, several studies have questioned this interpretation (for a review, see Erb-Satullo 2019), but they have not had a significant impact on iron research in Europe. For example, although there have been numerous finds of iron objects and evidence of metalworking at prehistoric hunter-gatherer sites in Northern Fennoscandia (i.e. the Scandinavian and Kola peninsulas, Finland and Karelia), and in the Russian Arctic and the Bering Strait region (Figure 1) (Huurre 1981; Hood & Olsen 1988; Kosmenko & Manjuhin 1999; Lavento 1999; Sundquist 1999; Jørgensen 2010; Cooper *et al*. 2016; Vodyasov 2018) (Figure 1), these finds are predominantly understood along traditional interpretative lines, and are thus disregarded as anomalies. Consequently, none of these sites has been subjected to archaeometallurgical analyses, except for a few chemical analyses of slag (Buchwald 2005; Vodyasov 2018). This paucity of research has limited our understanding of early iron technology in the Circumpolar North and sustained the assumption that metallurgical knowledge was underdeveloped and archaic, or reduced to a simple acquaintance with metals that reached the region as imports via trade or exchange (Koryakova & Epimachov 2007; Jørgensen 2010; Cooper *et al*. 2016). The use of iron is further typically interpreted as small-scale, for domestic use only and based on a small-tool tradition associated with a hunter-gatherer mode of subsistence (Hood & Olsen 1988; Kosmenko & Manjuhin 1999; Sundquist 1999; Jørgensen 2010).

To increase our knowledge of early iron metallurgy in the Circumpolar North, we adopt an alternative perspective that goes beyond these assumptions and works towards an understanding of the mechanisms of transmission and technological change. This is based on evidence from two recently excavated sites near Sangis and Vivungi in northernmost Sweden, and builds on recent research on the development of metallurgy (Roberts *et al*. 2009) and other technological innovations (Jordan 2015; Grøn & Sørensen 2018). While several Eurasian and Scandinavian researchers have highlighted the role of social networks of skilled practitioners in the initial transmission of metallurgy, their findings have yet to have an impact on European iron research (e.g. Chernykh 1992; Hjärthner-Holdar & Risberg 2009; Forsberg 2012; White & Hamilton 2018). Likewise, here, we too emphasise the importance of actor networks, including experienced metalworkers and active apprenticeship—rather than mere exposure to metals—for the transmission of the knowledge of iron metallurgy to Northern Fennoscandia.

This article introduces the sites of Sangis and Vivungi, which provide extensive evidence that iron technology was already integrated in hunter-gatherer subsistence strategies in Northern Fennoscandia during the pre-Roman Iron Age (*c*. 200–50 BC). By combining archaeometallurgical analyses and archaeological research, we reconstruct the *chaîne opératoire*. The craftsmanship at these sites was elaborate, including the mastery of bloomery-steel production

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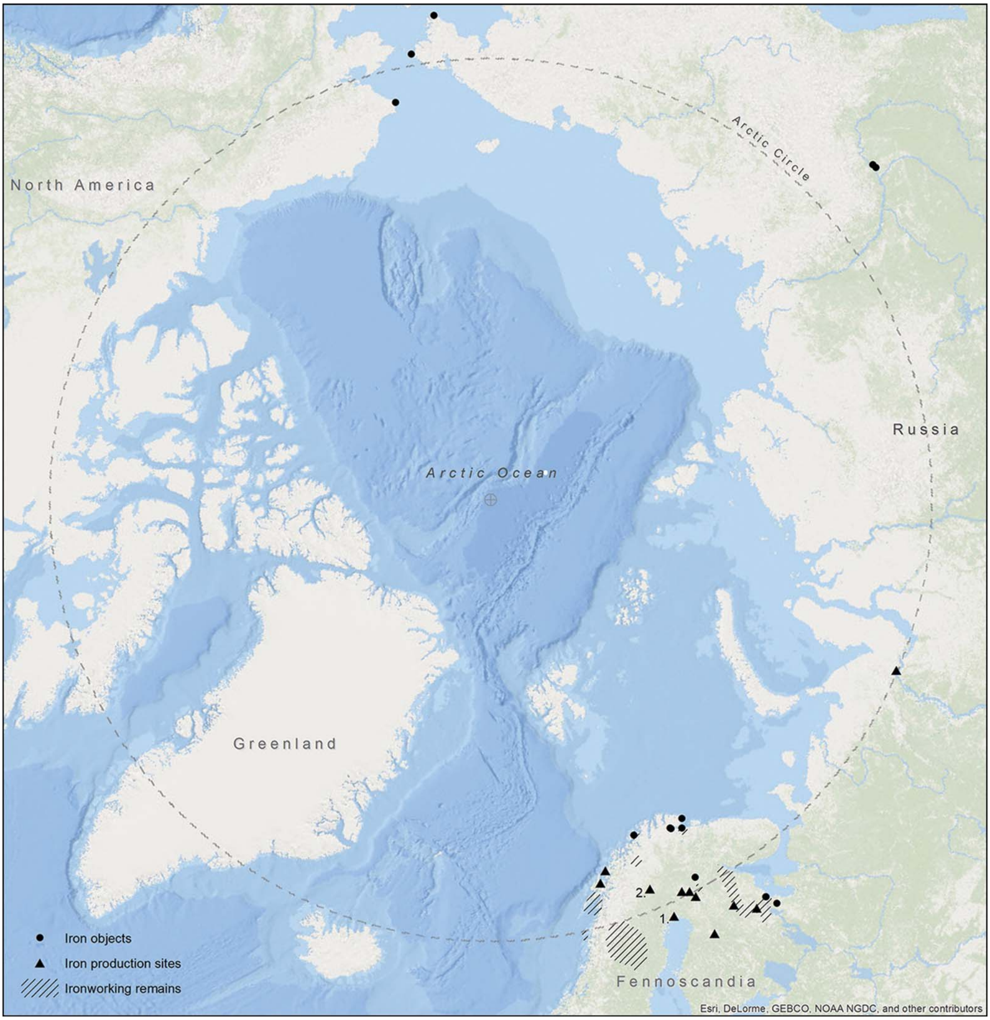

Figure 1. Published iron objects and metalworking remains in the Circumpolar North from the Late Bronze Age to the beginning of the first millennium AD: 1) the Sangis site (Sangis 730 and 842); 2) the Vivungi site (Vivungi 723) (figure by C. Bennerhag © Norrbottens Museum).

and advanced smithing techniques traditionally associated with craft specialisation in Transcaucasia *c*. 1200 BC and the Roman Empire in the first century BC (Pleiner 2000, 2006; Zavyalov & Terekhova 2018) (for further information on methodology, see the online supplementary material (OSM)).

Archaeological setting

The sites of Sangis and Vivungi, named after the villages closest to them, are located in the Arctic and Boreal zone of north-eastern Sweden: Sangis lies close to Lake Storträsket in the

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coastal area of the Bothnian Bay and Vivungi in the interior, approximately 140km north of the Arctic Circle (Figure 1). At both sites the landscape is characterised by coniferous forests, lake systems and vast mires—optimal conditions for the procurement of aquatic foods and the resources required for iron production (e.g. fuel and limonite ore).

In 2006–2007 and 2010, rescue excavations in advance of a railway expansion were carried out at Sangis by archaeologists from the County Museum of Norrbotten (directed by Carina Bennerhag). The investigations opened an area of around 7000m^2, constituting one of the largest archaeological excavations in northernmost Sweden to have taken place in the last 50 years. Analyses have included the first comprehensive archaeometallurgical study of prehistoric remains in Northern Fennoscandia. The excavations revealed an iron-smelting site (Sangis 842) and a hunter-gatherer habitation site (Sangis 730), less than 500m apart, the latter including both primary smithing (consolidation of blooms) and secondary smithing of iron objects. The smelting site (Sangis 842) consisted of one bloomery furnace (Figure 2) and debris from iron smelting, comprising slags, technical ceramics (i.e. furnace wall lining) and iron waste. Radiocarbon analyses of furnace remains, charcoal embedded in slag and carbon extracted from iron (steel) waste indicate that iron production took place between *c*. 200 and 50 BC (Figure S146 & Table S5.1). The furnace area at Sangis 842 was associated with contemporaneous hunter-gatherer habitation remains (Table S5.2), including domestic hearths, lithic debitage, asbestos-tempered pottery, as well as faunal remains—mainly fish but also reindeer antler, some of the latter showing cut marks made with a metal blade.

The hunter-gatherer habitation site (Sangis 730) yielded archaeological finds dating from the pre-Roman Iron Age to the Viking Age (*c*. 500 BC–AD 900). Radiocarbon-dating reveals four consecutive occupational phases (Table S5.2). More than 50 features were identified, consisting of household and smithing hearths and cooking pits, along with large quantities of lithic debitage, ceramic fragments, metallurgical finds and debris (iron and copper alloys), and faunal remains. Zooarchaeological analyses show that the inhabitants' diet was dominated by freshwater fish in all phases, emphasising the importance of aquatic resources.

Figure 2. Left) the bloomery furnace at the Sangis site (Sangis 842); right) the lower part of the furnace shaft left in situ. *Note the two blasting holes for the air inlet in the furnace wall and the groove on the flat stones for mounting the bellow (photographs by C. Bennerhag © Norrbottens Museum).*

The faunal remains also include small game mammals (hare, marten and squirrel) and fragments of worked antler (probably from reindeer), indicating crafts such as the handling of furs and horn working. Evidence for smithing activities was concentrated in the central part of the habitation site, and consisted of five features, including at least three smithing hearths; the associated assemblage comprised plano-convex slags, hammerscale, iron waste and several finished and semi-finished items of iron and steel. A bronze buckle (F1784) (Figure 3) was also found, as was slag with copper droplets on the surface, which indicates that different types of metals were worked on site. Radiocarbon-dating of metallurgical remains, including charcoal and burnt bones from structural remains, charcoal embedded within slag and carbon extracted from iron (steel) objects and iron waste, show that metallurgical activities began shortly after 200 BC and continued until around AD 200 (Figure S147 & Table S5.1).

The excavations at the Vivungi site were carried out in 2017 by researchers from Luleå University of Technology in northern Sweden, in collaboration with archaeologists from the Sangis excavations and archaeometallurgists at the Swedish National Historical Museums. Initial metal detecting and a magnetometry survey identified three potential production areas close to the shore of Lake Vaihkojärvi, two of which were excavated. Excavations uncovered the remains of two bloomery furnaces (furnaces two and three; Figure 4) approximately 30m apart. These yielded smelting slag, technical ceramics, and iron ore and waste. Unlike the Sangis site, no evidence of smithing activities was found. Radiocarbon

Figure 3. Bronze buckle (F1784) from the Sangis smithing site (Sangis 730). Charred organic material (resin?) was found next to the bronze buckle, radiocarbon-dated to c. *50 BC–AD 115 (Poz 23733) (photograph by S. Nygren © Norrbottens Museum).*

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Figure 4. The bloomery furnaces at the Vivungi site (Vivungi 723) (left: furnace two; right: furnace three). A charcoal feature was found inside furnace two (bottom), showing that the inner part of the furnace shaft was oval (photographs by C. Bennerhag © Norrbottens Museum).

analyses of furnace remains, charcoal embedded within slag, and carbon extracted from iron (steel) waste indicate that iron production started at Vivungi around 100 BC, with overlapping dates around 50 BC–AD 50 (Figure S148 & Table S5.1). Scattered occupation remains

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were also found in each furnace area, comprising debris from lithic procurement and ceramic fragments, along with faunal remains mainly of fish, beaver and reindeer. Due to their thin vegetation cover and slow soil-formation processes, prehistoric sites in northern Sweden are generally not stratified, making it difficult to date the occupation remains at sites with mixed functions. Radiocarbon-dating of a representative sample of faunal remains from both furnace areas reveals at least four periods of habitation, indicating repeated hunter-gatherer occupation from the Mesolithic period to the Middle Ages (*c*. 5300 BC–AD 1600) (Table S5.2). None of the dated faunal remains, however, was contemporaneous with iron smelting at the Vivungi site.

Archaeometallurgical results

Iron production at the Sangis and Vivungi sites

The furnace structures at the Sangis and Vivungi sites were shaft furnaces with underlying slag pits, intended for multiple firings. They all share similar features and consisted of a rectangular frame of vertically set stone slabs leaving one side open, and a shaft of clay built within and partly on this frame. Metallurgical debris in front of every furnace comprised slag, technical ceramics (wall fragments) and iron waste, as well as iron ore at the Vivungi site (see S1–4 in the OSM).

The curvature of the furnaces' wall fragments and field observations of the structural remains suggest that the furnace shafts were round (Figure 4), with an inner diameter of 0.25–0.35m and estimated heights of about 0.5–0.7m above the blowing zone, taking into account the technical aspects of the process (see S2.3 & S3.4). Air inlets, measuring 20–40mm in diameter, indicate that the furnaces were bellow-blown (Figure 2). Ceramic analyses show that the furnace shafts were made of local clay with good refractory qualities, but with differences in raw material selection and curation both within and between the sites (see S2.3 & S3.4). At the Sangis site and in one of the Vivungi furnaces (furnace two), coarse-grained clays with very poor to poor plastic qualities were used. These furnace shafts were repaired more frequently than is usual in Scandinavian Iron Age contexts. The other furnace at the Vivungi site (furnace three) used a more workable and finer-grained clay; the shaft was probably demolished and rebuilt after every two to three smelts, suggesting differences in the availability and hence procurement of suitable clays in the local surroundings.

The slag assemblages consist exclusively of smelting slag (see S2.1 & S3.1), characteristic of slags known from contemporaneous bloomery iron production sites—not least a relatively high bulk iron content (Table S3) and a clear, but somewhat variable, presence of manganese. A general feature of lake and bog iron ores is their highly variable manganese content. The use of manganese-rich ore (defined by Pleiner (2000) as exceeding 3.5 wt% MnO) is reflected in the slags at the Vivungi site (approximately 3.4–5.1 wt% MnO), and further confirmed by the lake and bog iron ores found next to the furnaces (>5 wt% MnO). No iron ore was found at the Sangis site, although the adjacent wetland and nearby lake's geological conditions are favourable to ore formation. The slag analysed from this site, however, indicates that ores containing manganese were used here (approximately 1.5–2.2 w% MnO). The composition of the slag from the Vivungi site deviates from that of Sangis, reflecting natural geological

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variations. The Vivungi slag can further be distinguished by variations in other minor and trace elements (Table S3), thus suggesting that the smelters there exploited several different ore sources.

Several pieces of irregular, magnetic lumps, characteristic of iron lost during iron production, were found adjacent to all the Sangis and Vivungi furnaces (Figure 5; see S2.2 & S3.2). Remarkably, most of the samples consist of homogeneous steel with a quite high carbon content (0.7–0.8 per cent); some are even cast iron (>2 per cent carbon). This suggests that high-carbon steel was produced intentionally during the smelting process. At the Sangis site carbon-free (ferritic) and low-carbon iron have also been identified, indicating knowledge of the techniques for producing different types of iron.

Evidence for smithing at the Sangis habitation site

The workshop area at the Sangis habitation site contained metallurgical debris comprising predominantly smithing slags. Analyses have identified homogeneous and heterogeneous slag (see S1), indicating that both primary smithing of blooms and secondary smithing of objects took place there. This is further confirmed by the presence of unconsolidated pieces of iron waste, suggesting that iron blooms were brought to the smithing site without prior forging, and by highly magnetic hammerscale associated with the smithing hearths, formed during hot forging on an anvil.

Chemical analyses of slag inclusions within iron waste and objects at Sangis show somewhat high but varying manganese contents (see S4, Tables S1 & S3), suggesting that the smithing site was supplied with various types of iron, probably from different iron-smelting systems. Several furnaces were operating simultaneously in the area, as attested by the chemical analyses of slag from the nearby smelting site (Sangis 842). Although the analyses so far show no direct linkage between the smelting and smithing sites, they do demonstrate that the raw materials at both sites originated from the same geological area. This strongly suggests that contemporaneous furnaces supplying the smithing site were probably operating nearby.

The artefact assemblage from the Sangis habitation site comprised tools (mainly knives), along with an axe and several semi-finished objects. Metallographic analyses show that steel is present in both the iron waste and the finished and semi-finished objects (see S1.2), indicating that the smiths used bloomery steel as a starting point in the forge. Ferritic iron was also observed among the finds (mainly in the iron waste, and more rarely in the objects), as was phosphoric iron (see S1.2). The objects' composite construction (welding and possibly lamination) and the combination of different qualities of iron and steel demonstrate extensive knowledge of different smithing techniques. Various heat treatments, such as quenching and annealing, were also applied to enhance material properties.

Two unidentifiable objects (F1559, F2771) were made of multi-layered steel, with variable carbon contents. One (F1559; Figure S24) was quenched, while the other (F2771; Figures S30–31) was annealed. The latter is radiocarbon-dated to *c.* 40 BC–AD 150 (Ua-59597; Table S5.1). Multi-layered structures were also identified in two knives (F878 and F2021). One (F878; Figures S21–23) has several alternating bands running from the edge to the ridge, resembling lamination techniques; the central band has a higher carbon content than the outer parts, indicating that the hardest steel is at the edge. Such smithing techniques

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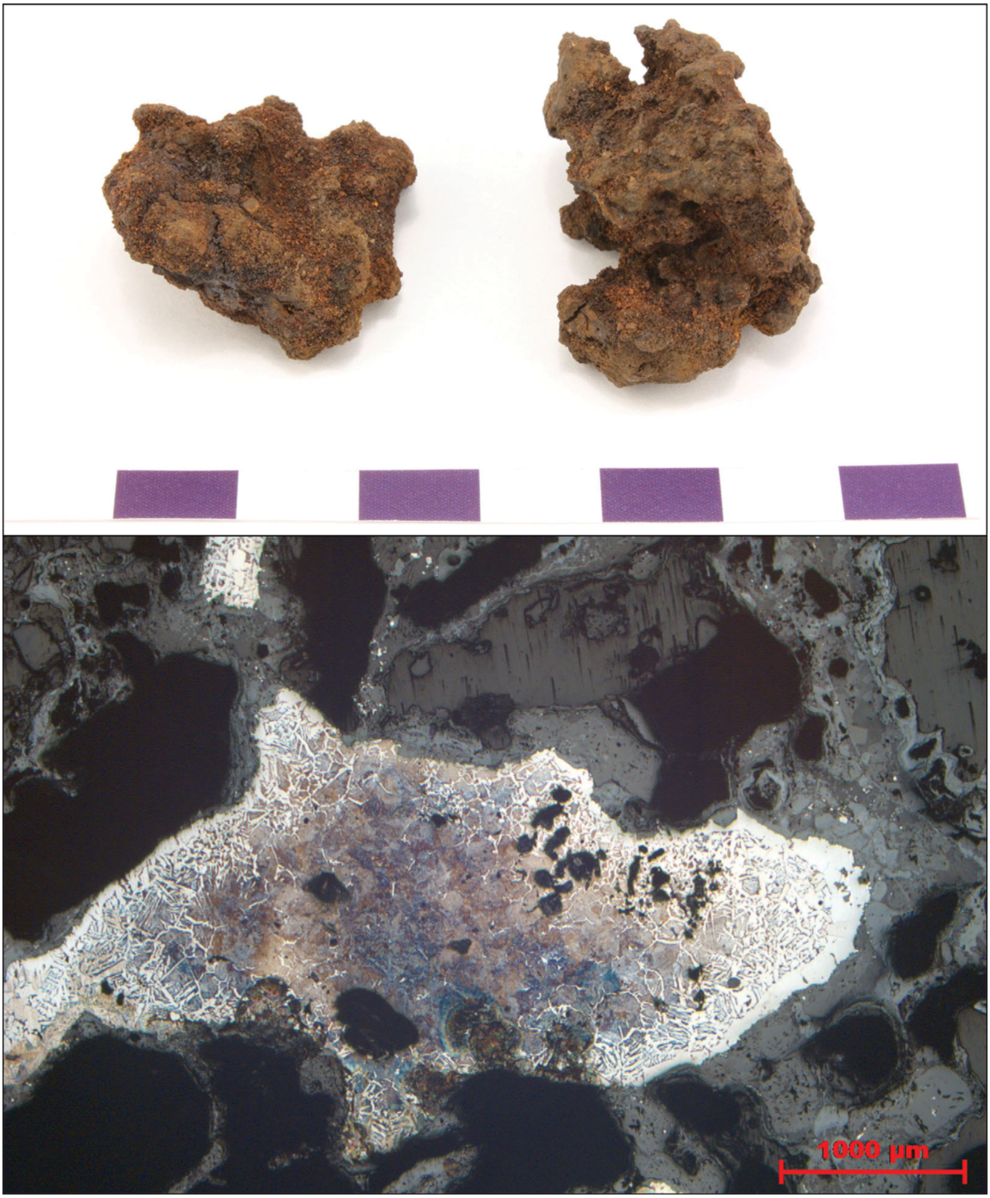

Figure 5. Iron waste from the Vivungi site (Vivungi 723). The etched sample shows a pearlite texture, which demonstrates a high carbon content (photograph and micrograph by E. Ogenhall © The Archaeologists, Swedish National Historical Museums).

are usually associated with the Late Iron Age (*c.* AD 500) (Pleiner 2006), yet the knife is radiocarbon-dated to *c.* AD 120–330 (Ua-59594; Table S5.1). The other knife (F2021; Figures S25–26) is made of several bands of phosphoric iron and low-carbon steel, resembling pattern welding—another common technique in the Late Iron Age. Given its low

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carbon content, this knife could not be radiocarbon-dated, but its context suggests a date contemporaneous with the other finds. Another object showing advanced forging techniques is a socketed axe (F2684; Figure 6: FS27–29) with a multi-layered structure of steel of different strengths. It was heat-treated in several steps using quenching and annealing. Its radiocarbon date range of *c*. 340–50 BC (Ua-36295; Table S5.1) makes it one of the earliest heat-treated steel objects in Northern Europe.

Discussion

Cutting-edge technology

The archaeometallurgical analyses of the Sangis and Vivungi sites reveal the inhabitants' advanced knowledge of metallurgy. At an early stage, different types of iron, including soft ferritic iron and high-carbon steel, were produced. The numerous finds of high-quality steel waste at both sites indicate that smelting processes at high temperatures had been mastered, including the use of extreme temperatures in the furnaces (Crew *et al*. 2011), as attested by the presence of cast iron. Combined, this evidence suggests that the smelters were aware of the refractory properties of clays, as it is critical to maintain the structural stability of the furnace shaft during the high-temperature smelting process. Furthermore, differences in maintenance strategies between the furnaces at the Sangis and Vivungi sites indicate that the smelters were well acquainted with a variety of raw materials and aware of their properties.

In European iron research, the intentional production of bloomery steel is generally linked to the mastery of Roman iron technology starting around 100 BC. This is particularly well attested in the Roman province of Noricum (present-day Austria), where steel is believed to have been produced directly in the smelting furnace (Pleiner 2006). Finds of droplets and small pieces of high-carbon steel of an earlier date have, however, been found at several production sites in Europe (see Crew *et al*. 2011), and in Scandinavia there is evidence of steel production as early as 800–700 BC (Hjärthner-Holdar 1993). This suggests that crucial steps towards deliberate steel production were also taken outside the Roman Empire. While manganese-rich ores were understood to be an important prerequisite for the production of bloomery steel in Noricum, enabling carbon to be alloyed with the metallic iron (e.g. Buchwald 2005; Crew *et al*. 2011; Hjärthner-Holdar *et al*. 2018), such ores are common throughout Europe (Rostocker & Bronson 1990). Indeed, the correlation between manganiferous ores and the intentional production of steel is evident at the Sangis and Vivungi sites, where analyses of smelting slags show the use of these ores to produce steel. This is further evident in the limonite ores at the Vivungi site (with >5 wt% MnO) and in several steel artefacts at the Sangis smithing site, which show extremely high quantities of manganese (up to 32 wt% MnO) (Table S1). Overall, this evidence suggests that the northern bloomery smelters graded the ores; they possessed extensive knowledge of the properties of the raw materials and used them to produce iron and steel of different quality.

The intentional production and demand for various qualities of steel are confirmed by the numerous steel objects found at the Sangis smithing site, which are made of several different steel alloys (and combinations thereof) that produced very hard and tough edges. Other types of iron were also used, including relatively soft, ferritic iron and phosphoric iron with a higher

Figure 6. Socketed axe from the Sangis smithing site (Sangis 730) with a multi-layered structure indicating steel. The micrograph cross-section shows light lines indicating welding seams (photograph by S. Nygren © Norrbottens Museum; micrograph by L. Grandin © The Archaeologists, Swedish National Historical Museums).

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ductility than carbon steel. Overall, the smiths had a thorough knowledge of the properties of each alloy and which materials were suitable for different tools. Furthermore, the forged artefacts show advanced craftsmanship, including forge-welding and heat treatments in several steps. Pattern welding—observed on one of the Sangis knives—is an example of a highly advanced, composite structure exploited for its decorative potential. This technique was widely used during the Late Iron Age, requiring years of training (Gilmour 2017).

Steel artefacts and advanced smithing techniques are strongly associated in European iron research with the Roman Empire, and thus considered unusual beyond the Roman frontiers (Sim & Ridge 2000; Buchwald 2005; Pleiner 2006). Similarly, in Eurasian iron research, the mastery of advanced smithing techniques is associated with Transcaucasian metallurgy, which was already operating around 1200 BC and is believed not to have spread beyond this region (Zavyalov & Terekhova 2018). In South India, there is evidence of lamination techniques at around 1000 BC (Gullapalli 2009), while in the Ananino Culture in the Ural region of North-western Eurasia, eighth- to sixth-century BC burial finds include examples of heat-treated steel objects manufactured by welding (Koryakova & Epimachov 2007), similar to the techniques observed at the Sangis smithing site. In central Sweden, Estonia and Slovakia, there is further evidence of welded steel objects ((Hjärthner-Holdar 1993; Mikhok & Pribulová 2003; Peets 2003), showing that advanced forging techniques were known outside the Roman Empire from as early as the fifth century BC to the second century AD. The tendency within iron research has, however, been to treat these examples as exceptional, or to consider them as imports. There are few published metallographic analyses of iron artefacts from beyond the Roman frontiers (Goodfrey & Nie 2004), and iron research has generally focused on the later Iron Age, with higher or more extensive iron-production levels attributed to the Roman world.

Technological networks

Our archaeometallurgical analyses illustrate the homogeneity of the metallurgical remains from the Sangis and Vivungi sites, indicating a shared or common technological tradition over a large area. Mastery of a craft, such as metallurgy, generally presupposes both theoretical knowledge and physical training, including apprenticeship and practical guidance from a skilled person (White & Hamilton 2018). The analyses illustrate a general lack of experimentation, as would be expected when practitioners attempt to copy products from another context (White & Hamilton 2018). This in turn indicates that the technology was introduced as a full package including objects, smithing and smelting techniques—all arriving at the same time, presumably through direct contact with experienced metalworkers. The transmission and maintenance of iron technology probably involved the agreement and commitment of many actors, given the labour-intensive extraction and preparation of the raw materials and the collective nature of the iron-production process. Hence, the technology could only have been introduced and accepted within a consenting social environment and a community that appreciated the advantages of its adoption (see Hjärthner-Holdar & Risberg 2009). This, in turn, implies that the hunter-gatherers of the Circumpolar North were active partners in a reciprocal process, rather than passive recipients.

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In addition, we also observe design similarities over a large geographic area. The Sangis and Vivungi furnaces are morphologically similar to contemporaneous production sites in Finland and Russian Karelia (Kosmenko & Manjuhin 1999; Lavento 1999) and some Late Bronze Age iron-production sites in central Sweden (Hjärthner-Holdar 1993), whose rectangular stone-frame construction is a notable feature. The identical furnace design across this vast area is striking, as the rectangular shape is not required for the process. We interpret these similarities as a manifestation of a shared or common technological tradition, in which production practices and design ideas result from relatively far-reaching social interactions (Jordan 2015).

A number of Bronze Age finds of eastern origin, related to the Seima-Turbino phenomenon and the Ananino Culture in north-western Russia, show clear evidence that the hunter-gatherers of Northern Fennoscandia formed part of technological networks as early as the beginning of the second millennium BC (Forsberg 2012). Although the nature of these networks has yet to be fully explored, the geographic distribution of the stone-frame furnaces and the Bronze Age finds (Forsberg 2012) suggests extensive continuity and contacts. It appears that previously established local and regional technological networks made the rapid spread of iron metallurgy in the Circumpolar North possible.

The discovery of a bronze buckle at the Sangis smithing site (Figure 3), whose moulding technique and style are most closely paralleled in the Pyanobor Culture (300 BC–AD 200), a direct successor of the Ananino Culture, indicates that the eastern contacts were still active when iron was being processed at our Fennoscandian sites. That the Pyanobor Culture is characterised by specialised knowledge in iron technology, including steel production and advanced forging techniques (Koryakova & Epimachov 2007), is intriguing, as is the link between the Ural area and northern Scandinavia during the second half of the first millennium BC revealed by genetic studies (Ingman & Gyllensten 2007). These aspects require further detailed investigation.

Organisational structure

The archaeometallurgical and archaeological data from the Sangis and Vivungi sites provide, for the first time, comprehensive evidence for an iron-smelting system in the Circumpolar North. Knowledge of iron smelting in prehistoric societies, which are assumed to be less complex and highly mobile, is unusual (for an exception, see Agatova *et al.* 2018), although a growing body of research on African nomadic and pastoralist societies that combines archaeometallurgical and ethnographic/ethnohistoric approaches suggests that our evidence may not be entirely atypical (e.g. Iles 2018). The Sangis site represents a notable archaeological context, however, in that the full *chaîne opératoire* is present, including the smelting of iron, primary smithing of blooms and secondary smithing of objects. Such sites are unusual in the Early Iron Age, and very rare in hunter-gatherer contexts. The Sangis site therefore offers an excellent opportunity to examine the spatial and organisational structure of an iron-smelting system, and the integration of new technology into hunter-gatherer communities.

At Sangis, the chemical analyses suggest a local exchange network consisting of several decentralised production units operating simultaneously in the area, supplying the smithing site with iron. This implies an organisational structure within which multiple households were stakeholders in the production process, with the smithing site centrally positioned in the distribution chain. This pattern can also be discerned at the Vivungi site, where several local furnaces were in use at the same time, although so far smithing has not been documented. Overall, this suggests a more extensive production and more complex organisation of iron technology than previously assumed for the Circumpolar North.

The scale of production is further demonstrated by the furnaces themselves, which were used several times. The productivity of iron production has not previously been assessed in terms of hunter-gatherer economies. Based on Hjärthner-Holdar *et al.*'s (2018) estimated iron consumption of a Late Iron Age farm (2–5kg/year) and the calculated yield of Swedish limonite ore (10kg of ore producing 5kg of slag and 5kg of metal), the scale of production at each of our furnaces (ranging from 9–80kg of iron) would have exceeded the consumption of a single household, even if spread over several years. Thus, iron was of no less importance to the hunter-gatherer community than to more sedentary farming societies.

The production of iron and the manufacture of artefacts was a labour-intensive process, involving multiple materials, several production steps and specialised knowledge. Ores had to be prospected and roasted, wood was required to produce charcoal, and clay and stone were needed to build and repair the furnaces and smithing hearths. The collective nature of this endeavour required organisation and planning throughout the year, and the investment of numerous participants at a collective level. This further implies that a sedentary mode of life was required over extended periods in various optimal locations close to important resources.

The availability of raw materials (i.e. ore, fuel and building material) was key to the location of the production and manufacturing sites. The abundant freshwater fish remains found at the Sangis and Vivungi sites imply that access to nearby aquatic food resources was of equal importance for the establishment of the sites. The conjunction of different resources suggests that iron technology had become an integral part of the exploitative strategies (Binford 1979) of the Northern Fennoscandian hunter-gatherers during the pre-Roman Iron Age. Remains of craft activities such as horn- and bone-working, and evidence of metallurgy involving copper/bronze and lithic procurement alongside the smithing remains at the Sangis site, further suggest that iron metallurgy had become organisationally incorporated with other residential activities. This is reinforced by the fact that smelting and smithing were sustained over a considerable period. Such an endeavour seems unlikely without a well-established socio-economic structure.

Conclusion

Our research has uncovered new evidence that iron technology formed a substantial part of the hunter-gatherer subsistence in the Circumpolar North more than 2000 years ago. The greater mobility of hunter-gatherer societies should no longer be considered an obstacle to appreciation of their complex social organisation. Moreover, the spatial and organisational nature of the processes involved in iron production suggests a higher degree of sedentism than previously recognised in this context. Overall, the traditional interpretative paradigm—labelling iron technology in the Circumpolar North as small scale, dependent on imports and underdeveloped or 'archaic'—is a simplification of a more complex situation. In a global perspective, our results have important implications regarding the emergence of ferrous metallurgy in societies seen as less complex or highly mobile.

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Supplementary material

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Appendix B

Paper II

Towards a broader understanding of the emergence of iron technology in prehistoric Arctic Fennoscandia

Bennerhag, Carina, Sara Hagström Yamamoto, and Kristina Söderholm

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Towards a Broader Understanding of the Emergence of Iron Technology in Prehistoric Arctic Fennoscandia

Carina Bennerhag, Sara Hagström Yamamoto & Kristina Söderholm

The article critically examines interpretations of Old World ferrous metallurgical developments with reference to their consequences for Arctic Fennoscandian iron research. The traditional paradigm of technological innovations recurrently links the emergence of iron technology to increasing social complexity and a sedentary agricultural lifestyle, typically downplaying 'peripheral' areas such as Arctic Fennoscandia and its hunter-gatherer communities. Even in postcolonial research of recent years, the archaeometallurgical record of Arctic Fennoscandia is interpreted and organized within the traditional frameworks on the time, course, and cultural context of the introduction of iron technology in Europe, where Arctic Fennoscandia is not considered to have any noteworthy role. However, current archaeological research with new data in Arctic Fennoscandia disputes prevailing ideas in European iron research and shows substantial evidence that iron technology was an integrated part of hunter-gatherer subsistence already during the Early Iron Age (c. 200 BC*). Archaeometallurgical analyses reveal advanced knowledge in all the operational sequences of iron technology, including bloomery steel production and the mastering of advanced smithing techniques. Therefore, we urge dispensing with traditional ideas and call for an increased interest in the underlying mechanisms for the transfer of iron.*

Introduction

Current archaeological research with new data disputes prevailing ideas in European iron research and shows substantial evidence of elaborate craftsmanship, including bloomery steel production and the mastering of advanced smithing techniques, as an integrated part of the Arctic Fennoscandian hunter-gatherer subsistence already during the Early Iron Age (*c.* 200 BC) (Bennerhag *et al.* 2021). The emergence and dispersal of iron technology is a long-term theme in socio-evolutionary views and a hallmark of European industrialization and civilization, with emergence being closely connected to social complexity and significant economic change, i.e. typically farming societies and a sedentary lifestyle. These views marginalize the use of iron in hunter-gatherer communities and make the advanced production of steel in such societies a highly unlikely phenomenon. The main purpose of this article is to shed light on the far-reaching and constraining influence of long-standing diffusionist and evolutionist views in European iron research on investigation of Arctic Fennoscandia and its prehistoric hunter-gatherer communities. This is manifested partly in a sharp (both temporal and spatial) under-estimation of the role of iron in hunter-gatherer societies of the region, even in recent iron research, and partly in the fact that a rather extensive range of prehistoric iron finds in the area (including iron-production sites) are largely unanalysed. Overall, although there is literature dealing with aspects of the introduction of iron to the

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region, there is little that can contribute to a greater understanding of the findings of elaborate craftsmanship during the Early Iron Age.

It is a global phenomenon that archaeological finds in more peripheral areas of nations/regions/continents are under-researched (Killick & Fenn 2012; White & Hamilton 2018). At the same time, these same areas often strive for restoration in the literature on prehistoric societies defined as less stratified or highly mobile, which makes it urgent to reframe old narratives and explanatory models in new ways. We live and work geographically as researchers in such an area. Here the indigenous Sámi, and also other minorities, live alongside a Swedish majority and strive to formulate a long-neglected past, where our archaeological finds automatically have acquired a highly topical ethno-political value.

Influenced by a new direction in archaeological research (metals as well as other archaeological materials) drawing on innovative theories of transmission (Damm 2012; Jordan & Zvelebil 2009; Skandfer 2009) and an analytically integrated *chaîne opératoire* approach (Roux 2019; White & Hamilton 2018), we have come to a realization of the great possibilities offered by archeometric analyses for the understanding of the underlying mechanisms for the transfer of iron, to move beyond arrows on maps and simplistic explanations of diffusion and trade (Roberts 2009). Discussions of paradigms, methods and theories are needed for assessment of the significance and meaning of the finds in a contemporary framework. This is how we can make inferences about the rather weakly researched prehistoric Arctic Fennoscandian hunter-gatherer communities and their involvement in the introduction of iron.

In what follows, we will present the new findings and the long-standing views in European iron research. Thereafter we go in depth into Arctic Fennoscandian iron research with focus on the far-reaching influences of long-standing diffusionist and evolutionist theories in European iron research on this literature, and how it fails to explain our new findings. Finally, in the Discussion and conclusions of the article, the most important restraining influences are summarized, and we will further exemplify how, through archeometric analyses of our finds, we can reach a more comprehensive understanding of the human dynamics involved in the emergence of iron in prehistoric Arctic Fennoscandia.

New findings

Between 2010 and 2019, archaeological excavations were carried out by the research group behind this article in coastal (Sangis site) and inland (Vivungi site) areas of northernmost Sweden—about 200 kilometres apart, as the crow flies—resulting in finds of a breakthrough character including both prehistoric iron-smelting sites (containing features of shaft furnaces, reduction slag, technical ceramics and iron waste) and a smithing site (with residues from primary and secondary smithing, iron waste and iron objects). Radiocarbon analyses at both sites place the production of iron and manufacturing of objects around 200 BC–AD 100 (Bennerhag *et al.* 2021).

Notable are the characteristics of similar technological traits between the sites, where archaeometric analyses show a rather consistent picture of the technological system across the area. Numerous finds of iron waste from the smelting process consisting of iron with high levels of carbon indicate the preference for high-quality steel and even production of cast iron. This reflects the mastering of successful smelting processes, including high-temperature operations and extensive knowledge of the refractory properties of clays (as one of the most critical passages while allowing high temperatures is to maintain structural stability of the furnace shaft throughout the process). Also indicated through analysis is the usage and preference of manganese rich ores, facilitating the absorption of carbon into the iron. This suggests the deliberate grading of ores and specialized knowledge of their different properties. The smelters' acquaintance with a variety of raw materials, including their possibilities and limitations, is further evident through observed differences in curation strategies between the furnaces at the two sites, demonstrating the handling of a rather difficult raw material situation of suitable clays.

The deliberate production of different steel qualities is confirmed from numerous steel objects (knives and an axe) found at the Sangis smithing site, showing several different steel alloys and combinations thereof, suitable for hard and tough edges to be produced. Phosphoric iron with a higher ductility than carbon steel was also used, as well as soft ferritic iron. The forged artefacts show advanced craftsmanship, including skills in forge welding of composite constructions and techniques of altering the properties of the iron (i.e. heat treatments in several steps), traditionally associated with the Roman Empire in the first century BC (Pleiner 2000; 2006). Overall, the findings show the hunter-gatherer smiths already at this early stage had thorough knowledge about the properties of each alloy, and which materials were suitable for different products.

Regarding the organization of iron production and the manufacture of iron products, variations in

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the chemical analyses of slag inclusions in iron waste and objects suggest the Sangis smithing site was supplied with various types of iron originating from different iron-smelting systems, based, however, on ores from the same geological area. This in turn suggests a workshop-based system featured by several shaft furnaces operating simultaneously in the nearby area, supplying the smithing site (the centre of the distribution chain) with various types of iron. Several aligned shaft furnaces can be discerned also at the Vivungi site, where at least two furnaces were operating simultaneously (including several indications of additional but not yet further investigated furnaces).

Considering economy and scale of production, analyses show each furnace was run several times. Productivity in iron production has not previously been calculated in terms of hunter-gatherer economies; however, based on the estimated consumption of a Late Iron Age farm (2–5 kg/year) (Hjärthner-Holdar *et al.* 2018), the scale of production at each furnace (ranging from 9 to 80 kg iron) would have exceeded the consumption of a single household, even if spread over several years. Overall, this shows iron technology most likely was a community undertaking, and further, as important to hunter-gatherer societies as to more sedentary and agriculturally based societies (Bennerhag *et al.* 2021).

Long-standing views in European iron research

Understanding the origin of iron technology and its subsequent dispersal through time and space is a key theme in European iron research. Over time, two basic models have formed the core of discussions, i.e. the idea of a single centre of invention (from which iron diffused to the rest of the world) and of multiple centres of independent invention (for a review, see Killick & Fenn 2012). In the single invention model, the origin of iron technology is placed in the Near East in the second millennium BC (according to the earliest dated iron objects and written evidence), from where it is assumed to have spread by different routes to central and eastern Europe (Bebermeier *et al.* 2016; Pleiner 2000; Zavyalov & Terekhova 2018), Africa (Killick 2009) and eventually northern Europe and the New World (Buchwald 2005; Charlton *et al.* 2010). The long-lived notions of V. Gordon Childe (1944) have had a profound impact in viewing the Near East as the primary centre of important inventions.

The diffusion of iron constitutes an essential element in central narratives of the civilization and industrialization processes of the west (Engels 1972; Pleiner 2000; 2006; Wertime & Muhly 1980), with succeeding civilizations in time and space (Rudebeck 2000). In European iron research, and with persistent and massive referencing typically to Childe (1944), the Near East, Greece, and the Roman Empire are considered drivers of technological change, providing 'less advanced' peripheral cultural groups with social and technological advances in a one-directional way.

Pleiner (2000; 2006) has been extremely influential in the history of European iron technology, typically narrated from a viewpoint of a Roman centre with the *limes* as the 'iron curtain' working as a cultural filter dividing the inner and outer Roman world. From this viewpoint, some skills, such as producing high-quality steel and advanced forging, are considered extremely rare outside the *limes*. Roman large-scale production is further the non-questioned point of departure for all other production. Although it has been pointed out that the strongly Romano-centric perspective contributes a general methodological and analytical neglect of iron remains found outside the Roman centre due to preconceived notions about low production levels (Rijk & Joosten 2014) and low quality (Godfrey & van Nie 2004), early finds of steel and high-quality objects are continuously interpreted as imported objects, accidental products or questioned as too old due to radiocarbon dating contamination effects (e.g. Bebermeier *et al.* 2016; Gassmann & Schäfer 2018; Pleiner 2006). These views are further accentuated in relation to metallurgical remains in societies considered as of low complexity and peripheral (such as nomads, pastoralists and hunter-gatherers), where early prehistoric metals typically are regarded as anomalies (considered as imports) and continuously dismissed in iron research (Alpern 2005; Dyakonov *et al.* 2019; Janz & Conolly 2019; Jørgensen 2011).

In this sense, the discourse structure of European iron research has been tightly packaged with nineteenth-century social-evolutionary frameworks with general schemes of technological progress as markers of social and economic change (Morgan 1877). Routinely, connections are made between knowledge of metallurgy and modes of subsistence, with iron technology predominantly linked to farming societies with a sedentary lifestyle, and hunter-gatherer/pastoralist societies considered incapable of mastering the production of metals from raw materials, although few studies overall have been conducted in this regard.

The socio-evolutionary ideas are not least firmly established within the conventional Three-Age

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system (Thomsen 1848), with the notion of one material technology unilaterally replacing the other in connection to human evolution from savage to barbarian and civilized (Morgan 1877). Even though this has met criticism (e.g. Kanjanajuntorn 2020), it is still influential in metallurgical research (see, for example, recent research on the abandonment of metal tools by North American hunter-gatherers) (Bebber *et al.* 2021). Hence, there is a non-questionable departure in much of the literature that iron technology is guided by a pre-existing understanding and knowledge of bronze and copper (see recently Eliyahu-Behar *et al.* 2013). It is further common in historical overviews on metallurgical developments to emphasize the progressive and linear view in terms of an 'increased importance' of iron, 'higher proficiency' and 'larger production levels', over time leading to the 'True' or 'Fully-fledged' Iron Age, and ultimately to industrialized society. Progression is considered a later phenomenon in the periphery and is in its initial phase often referred to as small-scale and experimental, and typically contrasted to the 'True' Iron Age (Karlsson & Magnusson 2020; Pleiner 2000; Wertime 1973).

Even though some researchers claim these views are long abandoned (Erb-Satullo 2019; Killick & Fenn 2012), we maintain that described civilization narratives, evolutionist and diffusionist theories and dichotomic discourse structures (Diaz-Andreau & Champion 1996) have become naturalized knowledge and are regenerated even within new perspectives. This is exemplified, not least, in the fact that although evidence has emerged that the actual smelting of iron in the Near East is dated to the first millennium BC (Veldhuijzen & Rehren 2007), which is contemporary with the oldest known evidence of iron smelting in Scandinavia (central Sweden) (Hjärthner-Holdar 1993), several researchers within European iron research consider the Scandinavian datings highly problematic, and do not acknowledge the finds, since they do not fit the traditional diffusion framework (see e.g. Bebermeier *et al.* 2016 and references therein; Gassman & Schäfer 2018).

Similar dismissive attitudes (Alpern 2005) have been applied also towards alternative perspectives that grew out of post-colonial theories and new scientific techniques since the 1960s of multiple (*versus* single) centres of invention (for a review, see Killick & Fenn 2012). Hence, through radiocarbon dating and general archeometallurgical development enabling more detailed, systematic, or contextual archaeological research, interest has been directed towards an understanding of local societies and regions, identities, agencies and individuals in prehistory (Layton 1994; Smith & Wobst 2005), such as towards local (Mirau 1997; Renzi *et al.* 2013; Veldhuijzen & Rehren 2007), independent (Renfrew 1969; Wertime & Muhly 1980) and indigenous (Higham 2004; Kuusela *et al.* 2018; Ramqvist 2007; Renzi *et al.* 2013; Wertime & Muhly 1980; Yahalom-Mack & Eliyahu-Behar 2015; Zangato & Holl 2010) invention. These (more or less) new perspectives consider iron innovation from the perspective of individual subregions and often—as post-colonial counter-reactions to the top-down discourse structures on evidence of iron technology in societies defined as less stratified or highly mobile—extend the analysis to 'non-complex' societies. Although this has been a global trend in archeological research over the last decades (covering Africa and Eurasia and, as we will see below, Arctic Fennoscandia), it has not had any profound impact within central or north European iron research. Overall, the alternative perspectives have had greater impact in Bronze Age (rather than Iron Age) metallurgical research (White & Hamilton 2018).

Unfortunately, and as we will develop further below considering counter-reactive literature to the tenacious downgrading of iron technology in Arctic Fennoscandia, the overall orientation towards identities and ethnic groups in prehistory really only means a change of focus in the objects of discourse, from 'civilizations' to other delimited objects. Archaeologists continuously typically classify archaeological remains of iron technology according to the 'cultural context' in which they are found, and hence with a tendency to marginalize important aspects of actors, knowledge and activities in the complex processes of iron technology. In what follows, we will go in depth into how the older framework still features the scientific literature of northern Fennoscandian iron history. Hence, only through insight into how traditional ideas on the origin and adoption of technological innovations still recur in much of the literature on iron history can we develop explanatory models in more balanced ways.

Iron research in Arctic Fennoscandia

Ancient Arctic Fennoscandia and its hunter-gatherer communities is considered peripheral in much European archaeological research, and the region's active phase in iron technology is considered established much later than elsewhere in Europe. Arctic Fennoscandia is geographically vast, and although it is highly unexplored archaeologically, it is a fact that since the middle of the twentieth century,

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archaeologists have come across quite a lot of iron finds, and since the 1980s, also several (largely neglected) iron-production sites (Forsberg 2012; Jørgensen 2010; Kotivuori 2013).

Relatively extensive archaeological surveys and excavations were carried out in Arctic Fennoscandia in the 1940s to 1980s due to hydropower expansion and connected lake regulations, which in turn yielded large amounts of metallurgical remains in prehistoric hunter-gatherer contexts from various steps in the production and processing of iron, including slag, technical ceramics and metal objects (Forsberg 2012). Still, due to a general perception of a 'delayed stone age' (Loeffler 2005) alongside a general neglect of available analytical tools (such as radiocarbon dating), the metallurgical remains were heavily overlooked. Slag residues from iron working especially have been consistently neglected in Arctic Fennoscandian archaeological research as they have been considered waste material with limited chronological information.

The perception of a 'delayed stone age' is strongly related to the tenacious evolutionary ideas inherent in both the dichotomy of hunter-gatherers *versus* farmers and the succession of stone–bronze–iron. Hence, as a general lack of stratigraphies on the multi-strata sites in Arctic Fennoscandia makes chronological systematization of the metallurgical record problematic—especially with a parallel general neglect of radiocarbon dating—the presence of iron in the same contexts as typical Stone Age finds (knapped lithics, scrapers, points of stone and pottery) has simply been interpreted as evidence of unfulfilled stages of development. Overall, despite abundant archaeological evidence indicating a widespread knowledge and practice of iron, tenacious social-evolutionary views have long resulted (and still do) in a general dismissal/tendentious and limited selection of metallurgical finds in early hunter-gatherer contexts. Archaeologists have instead typically focused solely on chronologically significant artefacts from later periods (e.g. Hakamäki & Kuusela 2013; Henriksen 2019; Serning 1960; Zachrisson 1976).

Northern metals, industrialization and the creation of nation states

The exclusion of the Arctic area and the hunter-gatherer communities in the narrative of ferrous metallurgical developments should partly be understood in the light of the general importance given to metals and metal technology in the civilization process and creation of the nation states in Sweden Finland, and Norway (not least in Sweden; see Hagström Yamamoto 2010). Metal handling and the extraction of metals (which generally takes place right in the Arctic parts of these countries) were already at an early stage of central importance for the nations' economies and politics and overall nation-building. In line with this, the Swedish state recurrently, at least until the middle of the twentieth century, identified Arctic Sweden as an area in need of modernization, civilization or 'Swedishization', for defence-policy, nationalist and/or economic reasons. Iron and iron technology formed the basis for industrialization, where industrial society finally, after a long time and through southern immigration (first of farmers and later of miners), made the Arctic part of the country 'civilized'. In relation to the grand industrial narrative of the region, the indigenous Sámi population of the area was often treated as a timeless 'Other' (Hagström Yamamoto 2010; Ojala 2009; Ojala & Ojala 2020). In recent publications (Karlsson & Magnusson 2020), iron production in terms of the establishment of the mining industry in the seventeenth–eighteenth centuries is still highlighted as *the* process creating preconditions for the building of societies in Scandinavia. Early iron technology by hunter-gatherers is totally at odds with this narrative.

Explanatory frameworks of the emergence of iron technology in Arctic Fennoscandia

Three explanatory frameworks emerge in the literature on prehistoric iron technology in Arctic Fennoscandia: (1) a *migrationist view* which is partly connected to the economic and political expansion of the Nordic society during Late Iron Age/Early Middle Ages (Magnusson 1987; Stenvik 2003), partly to the establishment of a considered full-scale knowledge in iron production (equated with large-scale production and considered as the true Iron Age/industrial stage in the developmental scheme of Pleiner 2000) in the seventeenth–eighteenth centuries (Norberg 1958); (2) A *diffusionist view* based on trade-network mechanisms and center-periphery relations with eastern and southern agricultural societies during the Late Bronze Age/Early Iron Age (see a review in Forsberg 2012). The initial iron phase (Late Bronze Age/Early Iron Age) is overall considered to have had little impact on Arctic Fennoscandian society compared to the fully fledged industrial phase; (3) a *localizationist view* (Amzallag 2009), where the emergence of iron technology in Arctic Fennoscandia since the 1980s is explained also from partly new perspectives in postcolonial, ethno-political and revitalizing archaeological

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research focusing on local power strategies/individual agency and ethnicity. Below is first a presentation of the migrationist, diffusionist and localizationist views, followed by an analysis of the implications of long-standing European views on Arctic Fennoscandian iron history, in particular related to our new findings.

The migrationist view

The emergence of iron production in Arctic Fennoscandia is typically regarded a late phenomenon, much later than elsewhere in central and northern Europe. During the Migration period (AD 400–500), a first industrial-like large-scale production connected to a Nordic economic and political expansion and colonization is considered to be represented in the southern part of Sweden's widely spread Norrlandic area (in mid-Sweden, Jämtland, and in mid-Norway, Tröndelag) (Magnusson 1987; Stenvik 2003). In the peripheral areas of northernmost Arctic Sweden, the knowledge to make iron and steel is not considered to have begun until the seventeenth and eighteenth centuries, with the establishment of the mining industry (Hansson 1987). Both explanations are based on migration/colonization; during the early phase of Nordic expansion of agrarian societies from the south, and during the later phase of migrating miners from the south (Hansson 1987; Magnusson 1987; Norberg 1958). Early archaeological research in Arctic Fennoscandia long maintained the migrationist (from the south) view alone—clearly in line with the highly influential developmental schemes of Childe (1944), explaining the spread of metals through migrating metallurgists.

The diffusionist view

During the second half of the twentieth century, the migrationist view was supplemented by the diffusionist view, where some stray finds of metal contributed to the perception that Arctic Fennoscandia nevertheless experienced an initial phase (Late Bronze Age/Early Iron Age) of iron technology through diffusion of iron objects (in the early phase) and technological knowledge (later) that spread from one culture to another via trade. The dispersal of iron as a gradual process in several stages based on the mere exposure of iron is indeed a typical description in iron research. The early phase of iron technology is generally considered manifested by a single find (considered imported) of curved iron daggers in Finnish Lapland with Scythian appearance, typologically dated to 700–600 BC (Erä-Esko 1969; Kotivuori 2013). Iron fragments and horn/bone implements with rusty marks (fishing hooks, knife handles) found in northern Norway and dated (stratigraphically) to *c.* 780–420 BC, have in turn been taken as evidence for early use of iron, starting already during the Late Bronze Age (Sundquist 1999). Early finds of iron working, such as slags, are overall interpreted as evidence of a certain knowledge in forging reaching the area during the Early Iron Age. With finds of iron-production sites from the 1980s onwards, some small-scale iron production has been acknowledged, however with the assumption that the main need for iron was still met by imports from outside. Finds of slag and iron-production sites are still overall unexplored (Forsberg 2012). Neither has the question *how* knowledge of forging and production reached Arctic Fennoscandia been further investigated.

Based on the distribution of certain types of archaeological material (such as stylistically assigned metal artefacts and different ceramic types), there is a strong tradition of considering Arctic Fennoscandia as long-term exposed to cultural elements from eastern and western cultural spheres (see e.g. Kuusela 2020 and references therein)—and the spread of iron is no exception. Current explanations look either east to hierarchical societies in the Volga-Kama area near the Ural Mountains in present-day Russia, or south to agro-pastoralist Nordic societies in southern Scandinavia. The eastern outlook has been attested for societies in the inland areas and northernmost parts of Arctic Sweden, Norway and Finland, while the southern outlook has been a more prevalent explanation for coastal areas (especially the north Norwegian coast).

Researchers persistently emphasize eastern influence on the region, initially during the Stone Age (about 5000 BC), when the first metals reached Arctic Fennoscandia (Nordqvist & Herva 2013), and later through Seima Turbino (about 2000–1000 BC) and the Ananino culture (about 800–200 BC), where iron eventually was yet another (inevitable) feature in the long-term stream of eastern impulses (Forsberg 2012; Ojala & Ojala 2020). Several scholars point to the Ananino culture of the Volga-Kama region in Russia as an area from where impulses of iron to Arctic Fennoscandia originated, manifested by stylistic interpretations of finds of certain types of asbestos ceramics and copper-based finds of eastern origin found at hunter-gatherer sites in the same contexts as iron (Hansen & Olsen 2014; Hood & Olsen 1988; Ramqvist 2007).

The eastern connection is considered confirmed also by the so-called stone frame furnaces for iron production found in eastern and northern Finland (Kotivuori 2013; Lavento 1999; Peets 2003), and Russian Karelia (Kosmenko & Manjuhin 1999),

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dated to 300 BC–AD 1500. These types of furnaces have been found also in central Sweden, radiocarbon dated to the Late Bronze Age (Hjärthner-Holdar 1993), and in recent years (through our own research) also in northernmost Sweden (Bennerhag *et al.* 2021). Typologically (based on the rectangular stone frame feature), these furnaces are considered to lack analogies with the European shaft furnace tradition and are therefore considered to constitute an eastern type (Kotivuori 2013; Lavento 1999; Peets 2003), although no analogies have been demonstrated with iron-production furnaces further east than Karelia (Kosmenko & Manjuhin 1999). The westernmost finds of these furnaces further predate the eastern finds (highlighted by Kotivuori 2013). This anteriority of the western finds, seemingly suggesting a punctuated diffusion, has not been problematized further in north Fennoscandian archaeological research, except for a few remarks related to ceramic research (Jørgensen & Olsen 1987).

When it comes to the southern explanation, contact networks with agropastoralist (typically referred as Germanic) societies in southern Scandinavia are considered crucial to the emergence of iron technology in the coastal areas (predominantly along the north Norwegian coast). As in the eastern explanation, this connection is based solely on stylistic assignations of a ceramic type—Risvik-type, found in the same contexts as iron-working remains (slag and furnace remains dated to about 400–200 BC)—and not the metallurgical material itself (Jørgensen 2010). The ceramic type is overall considered to define the affinity of the hunter-gatherer groups along the coastal area with southern Germanic/Nordic agropastoralist societies (Hansen & Olsen 2014; Jørgensen 2011). Furthermore, as in the eastern explanation, the southern connection is considered to have begun already during Bronze Age, materially manifested through the occurrence of burial cairns and settlement structures (including two- and three-aisled long houses) of (presumed) southern Scandinavian origin (Andreassen 2002; Arntzen 2015). Although the archaeological remains of burial cairns and two- and three-aisled long houses have been found also further north along the Swedish (Lindqvist & Granholm 2016; Ramqvist 2017) and Finnish coasts (Holmblad 2010), connections have not been as pronounced between early iron handling and southern contacts. This is probably due to a greater scarcity so far of early metallurgical finds in these areas. Some researchers have problematized the geographical linear view and questioned the Scandinavian origin of the Bronze Age burial cairns since radiocarbon datings contradict that the cairn tradition is older in the south compared to the north (Damm & Forsberg 2014; Ramqvist 2017).

The localizationist view

Since the 1980s, a postcolonial, ethno-political revitalization movement has striven to challenge the nationalist and socio-evolutionary ideas of Arctic Fennoscandia as having a retarded and inferior cultural development (Hagström Yamamoto 2010; Loeffler 2005; Ojala 2009). Focus has been directed towards local societies, agency and the role of individual power strategies in prehistoric research (for a review, see Ojala 2009; Forsberg 2012). The movement has particularly resulted in a strong growth of research on the indigenous Sámi of the area, and particularly on the emergence of a Sámi ethnicity—Sámi archeology has even emerged as scientific field in northern Scandinavia (e.g. Hansen & Olsen 2014). The movement has been influential; broad groups of researchers today nominate the prehistoric hunter-gatherers as the ancestors of present-day Sámi (Forsberg 1996; Hansen & Olsen 2014). Others criticize the movement of being unreflectively self-glorifying and exclusive in a political context, questioning the plausibility of a now-living ethnic group to claim it was first (e.g. Wallerström 2006).

In the same way as previous national history writing placed metals at the forefront of discussions, metals still play an important role in the formulation of (Sámi) identity and ethnicity. The overall agreement within Sámi archeology is that the Sámi identity process had already started in the Late Bronze Age, when hunter-gatherer communities in Arctic Fennoscandia intensified their long-distance contacts with metal-producing agricultural societies in the Volga-Kama area, through which bronze and iron are considered to have spread to the hunter-gatherers in exchange for furs and other hunting products. The elements of the emergence of a Sámi ethnicity are influenced by theories on ethnicity as a social construction shaped by a practical need to arrange coexistence/interaction between two groups and communicated mainly through symbols expressed in the material culture (Hansen & Olsen 2014). Hence, contact with the eastern metal-producing agricultural societies is suggested to have triggered the hunter-gatherers´ discovery of distinctive cultural characteristics and differences. The process is suggested also to be related to the above-described increased southern (and agricultural) contacts of coastal hunter-gatherer communities, which over time displayed great contrast to the remaining inland hunting-gatherer communities further north (Hansen & Olsen 2014).

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The discovery of distinctiveness is manifest in the split of the former uniform textile ceramic tradition of Arctic Fennoscandia into the geographically complementary Risvik and Kjelmöy ceramics. The stylistic traits of the ceramics are considered the most important ethnic marker/symbolic language of the hunter-gatherers in their transactions to secure access to metals and overall in their interaction with metal-producing farming societies (Hansen & Olsen 2014; Jørgensen & Olsen 1987). The growing supply of iron in the Roman Iron Age has been suggested as contributing to a specialization in resource utilization by hunter-gatherer communities (towards reindeer hunting), involving the transition from stone to metal technology, and over time from hunting/fishing as main subsistence to domesticated reindeer herding during the Late Iron Age (Bergman *et al.* 2013; Mulk 1994; Storli 1993; see Ojala 2009 for further background on the emergence of Sámi ethnicity). Hence, in the same way as in the emergence of farming, and based on basic evolutionary and progressive explanatory models, iron is attributed with the ability to cause revolutionary socio-economic change.

With parallels to the role ascribed to local Mediterranean societies in recent iron research, Sámi archaeology has further presented several new perspectives regarding metals and related contacts and power relations of Sámi/hunter-gatherers from the Bronze Age onwards (Jørgensen 2010; Kuusela *et al.* 2018; Melheim 2012; Ramqvist 2012). Regarding iron technology, and through their eastern contacts with the Ananino culture, Sámi/hunter-gatherers have, for example, been attributed the role of local/indigenous developers of iron technology during the large-scale iron production in inland middle Sweden in the Migration period (AD 400–500) (Ramqvist 2012). In fact it is suggested that the Sámi/hunter-gatherers produced and delivered iron and fur to farming chiefdoms along the coast. The farming chiefdoms are considered as refiners of the iron, functioning as middlemen in the trading of iron and fur further south (Ramqvist 2012). Similar perspectives have recently been suggested regarding non-hierarchical relations between Sámi/hunter-gatherers and power centres operating in the Baltic sphere during the Middle Ages (AD 1000–1520), involving trade actions of metals and fur (Henriksen 2019; Kuusela *et al.* 2018).

Influence of long-standing European views

An in-depth review of the literature on the emergence of iron technology in Arctic Fennoscandia reveals that explanations are recurrently understood and organized within the conventional framework of the time, course and cultural context of the introduction of iron technology in Europe, instead of challenging it. This also applies to postcolonial and ethnopolitical research of recent years, which has had a particularly strong impact on Arctic Fennoscandian iron research. Hence, to this day, the predominant scholarly opinion is that the Iron Age hunter-gatherer societies of Arctic Fennoscandia did not play any noteworthy role in metal technology on a broader European scale. The tenacious influence of the conventional framework in terms of a strong bias for origin and dualism in connection with diffusionist and evolutionary theories has made it almost impossible to interpret the northern finds in any other way. Archaeologists have been locked into an explanatory context where some aspects have simply been excluded from further investigation.

A basic example of how the narrative structure of evolutionary frameworks still implicitly recurs in interpretations of the emergence of iron technology in Arctic Fennoscandia consists of the idea of how the emergence of iron (from initial to fully fledged phase) follows a unilinear progressive development similar to the conventional explanatory models of European iron research. The diffusion is considered to begin with the introduction of metal objects arriving via eastern and southern trade/exchange networks, later followed by the appearance of actual knowledge of iron technology (e.g. Hood & Olsen 1988; Jørgensen 2010; Kotivuori 2013; Sundquist 1999). Similar arguments have been put forward regarding metal objects found in other parts of the northern circumpolar area, such as in northern Siberia and Alaska/Canada (Cooper *et al.* 2016; Dyakonov *et al.* 2019; Janz & Conolly 2019). Our findings from the Sangis and Vivungi sites, however, fit poorly with these explanations as there seems to have been no preceding phase where metal objects were imported before the skills to produce and manufacture iron was acquired. What we see is that all stages in iron technology were in place from the start, including skills in prospecting/collecting raw material (clay and ore) and in smelting and smithing iron.

The eastern and southern diffusion ideas are still more closely linked to the universal and progressive scheme of the Three-Age system, where bronze precedes iron in the diffusion from the east and the south and where it is assumed that some prior knowledge of bronze handling is required to be able to handle iron. But hitherto, north

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Fennoscandian bronze craft is completely unexplored and undated. We do not know which process steps were performed in copper/bronze handling or even if it really preceded iron handling. Further, extensive stone smithing occurs in parallel with iron technology at both the Sangis and Vivungi sites, overall demonstrating the ramification of the evolutionary sequences of the Three Age system.

The spread of iron is further described as a one-directional, centre-periphery relationship where the peripheral communities of the arctic Fennoscandian hunter-gatherers are narrowed down to inferior/passive recipients of iron rather than active agents of iron and technological knowledge, typically with the application of dichotomies as tool for separation. Hence, the emergence of iron technology is inevitable linked to complex farming populations, regardless of temporal scale. In the same dichotomic way, early (to the mid twentieth century) Scandinavian archaeology typically treated the northern parts of Scandinavia as something separate, different and liminal in relation to the 'national' and 'southern Scandinavian/Nordic' (Hagström-Yamamoto 2010; Ojala & Ojala 2020). Likewise, the Arctic has been treated as something separate and different in relation to the Nordic (Bakka 1976), and inland as something separate from coastal Arctic Fennoscandia (Hansen & Olsen 2014; Jørgensen 2010; Sundquist 1999).

The center-periphery relationship relates to evolutionary-based models of different modes of trade associated with different types of societies (Renfrew 1975), generally taken as exclusive categories. Hence, while the exchange of the egalitarian hunter-gatherers typically is expressed in the form of reciprocity, the exchange of the hierarchical farming populations is expressed through redistribution. And we see parallels in the division of labour, in that the assumed occupations/know-how of the hunter-gatherers typically include forging, decorating and distributing rather than producing (from raw materials) metals.

The discursive dichotomy between farmers/centres and hunter-gatherers/periphery is maintained within recent research on the emergence of a Sámi ethnicity. Hence, the hunter-gatherers/ Sámi, although suggested producers (smelting the ores), are still not refiners or consumers, and they are still recipients of knowledge of metal technology from outside (Ramqvist 2012). There are parallels in the view of Romans and so-called barbarians in European iron research, where producers and refiners-consumers typically are regarded as belonging to different groups, with corresponding distance from perceived cultural centres (Pleiner 2006). Our finds of elaborate craftsmanship among Arctic Fennoscandian hunter-gatherers in both coastal Sangis and inland Vivungi already during the Early Iron Age, and including both bloomery steel production and the mastering of advanced smithing techniques, fit poorly with one-directional, centre-periphery views and related evolutionary-based models.

With the assumed forging, decorating and distribution, rather than production of iron, follow further small-scale assumptions, where no extensive organization was needed, and where iron working therefore easily could be managed by a few persons (e.g. Jørgensen 2011). These assumptions further include interpretations of a small-tool tradition, and thus a lesser need of iron (Jørgensen 2010; Sundquist 1999). This long-prevalent idea of early iron production as primitive and low-tech, implying low efficiency and a limited amount of iron obtained at each run, means Arctic Fennoscandian iron research has typically been directed towards quantity rather than quality of iron. Conclusions have been based on the seemingly small amounts of residual products in the form of slag and their morphological appearance.

It is one thing that we do not find support in literature to explain our findings, and far more distressing to consider the extensive consequences of the long-time marginalization (on behalf of the broad history of iron technology) of important aspects and actors in the complex processes of iron technology in Arctic Fennoscandia. The assumed diminutive role of iron technology in hunter-gatherer contexts (albeit based on weak empirical grounds) has had a devastating influence on archaeologists' attitude even towards finds of actual iron-production sites in such contexts (since the 1980s), and although they in fact are radiocarbon-dated to the Pre-Roman Iron Age (Jørgensen 2010; Kotivuori 2013). Hence, these finds have been rather neglected, and without actual attempts to determine the characteristics behind the objects or the metallurgical remains. According to this essentialist reasoning, the scale of Arctic Fennoscandian production has not been considered sufficient to meet even the small iron demands of the hunter-gatherer groups, who consequently were dependent on the import of iron (Hulthén 1991; Jørgensen 2010; Sundquist 1999). Again, these inferences stand in stark contrast to our finds in Sangis and Vivungi, implying a rather comprehensive organization on a societal level and a production in parity with the assumed need of iron in a farming context.

While much recent literature dealing with the prehistoric Arctic north makes a significant and

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much needed contribution to the knowledge and repositioning of ancient Arctic hunter-gatherer communities, regarding the introduction of ceramics, metals and cultivation which otherwise typically is attributed to agricultural groups, the literature still lingers with traditional discursive dichotomies, centre-periphery diffusion and evolutionary ideas. Hence, e.g. recent Stone Age research (Alenius *et al.* 2013; Nordqvist & Herva 2013) implicitly focuses on trying to confirm that the northern area advanced towards neolithization (through established evolutionary sequences) at an earlier stage than previously thought. In the same evolutionary vein as the interpretative framework of the emergence of iron technology and on weak contextual/archaeologically empirical ground (there is a general lack of actual archaeological traces of cultivation practices), the (assumed) small-scale finds of pollen evidence of cultivation, copper metals, semi-sedentary settlements and ceramics are taken as evidence for a long-term and initially small-scale/sporadic neolithization process (Alenius *et al.* 2013).

Other recent literature that strives to reposition the Arctic north and which generally criticizes the dichotomic picture and asymmetrical relations/passive role typically ascribed to northern hunter-gatherers (Forsberg 2012; Janz & Conolly 1919; Kuusela 2020; Kuusela *et al.* 2018; Melheim 2012; Ramqvist 2012), despite its general focus on the active role of local societies, is still locked in world system theory with a persistent focus on centre/periphery relations. There is further a persistent focus on bounded cultures/identities in much of this literature, where archaeological remains (according to typology and morphology) are assigned to different cultural groups and considered markers of ethnic identity. Hence, northern Fennoscandia as a border zone between western and eastern cultural spheres is a strong notion in Fennoscandian literature (e.g. Nordqvist 2018; Sørensen *et al.* 2013), along with the division of the coastal and inland communities of northern Fennoscandia into two different cultural and economic systems (based typically on the distribution of ceramics and metals), with inland societies considered proto-Sámi and coastal societies proto-farmers, antecedents of the Scandinavian/Germanic population (Ojala & Ojala 2020). Lately, since the archaeological material nevertheless show great diversity even within small regions (Kuusela 2020), archaeologists have divided Arctic Fennoscandia into even smaller systems (Ramqvist 2007; 2012), and further contributed to interpretations of the appearance of hybridity cultures in the form of, e.g., 'Sámi practising cultivation' (Bergman & Hörnberg 2015).

With the persistent ambition to fit material culture into existing developmental trajectories, or use it as markers of cultural identity, follows a lack of focus on *how* technology transferred, of the social content and form of exchange pathways and of the local adoption and maintenance of new technologies. This has recently been highlighted in archaeological literature (Ojala & Ojala 2020), such as the problems of applying find-categories in local contexts to large, homogenous Sámi (and Germanic) ethnic categories, and on weak empirical grounds (Ojala 2014). Although we reaffirm the importance of formulating a long-neglected past, regarding ethnic categorized historiography in northern Fennoscandia of recent years, we join Wallerström (2006) and question the exclusion to which it contributes in a political context. We do not want to limit the possibility for anyone/any group to experience connections to our findings. Hence, for us, it would be equally out of the question to denominate the ancient hunter-gatherers proto-Swedes, proto-Sámi, or some other proto-ethnic/cultural identity, both for exclusionary reasons and for the limitations shown through this article from the traditional classification of remains.

Also other archaeological literature, in part focusing on Arctic Fennoscandia (Damm 2012; Skandfer 2005) and other parts of the circumpolar north (see e.g. Jordan & Gibbs 2019) (preferably concerning ceramics), problematizes the equation of pots with ethnic and cultural groups, and further tries to overcome simplified models of the past from focusing on networks of contacts and common practices. In our interpretation of our findings, we are inspired by this research where overall there has been little prior focus on iron. We are further inspired by recent literature on Southeast Asia (Thailand) regarding metal technology (copper and bronze), which integrates (natural) scientific methods to increase the social knowledge of prehistoric societies (White & Hamilton 2018).

Discussion and conclusion

Our analysis of Arctic Fennoscandian iron research reveals a strong dominance of evolutionary frameworks based on asymmetrical relations, framing the Fennoscandian hunter-gatherers as passive recipients rather than active agents of iron and technological knowledge. It is a general situation in much iron research that while the origin framework has become more differentiated in recent decades, much research is still characterized by socio-evolutionary ideas. Such ideas have had a devastating influence on the attitude towards iron finds in Arctic Fennoscandian

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archaeological research, with serious consequences for overall understanding in European iron research. Hence, when we now for the first time in this region analyse metal finds in depth, not only do we reveal early iron handling far from perceived centres, but also that iron was a substantial and integral part within the hitherto unrecognized context of the prehistoric hunter-gatherer community.

In terms of the spread of iron, diffusionist models have played a central role in Arctic Fennoscandian iron research—with metals and fur playing major roles in defining centres and peripheries—and with a strong focus on bounded cultures/identities with ceramics and metals defining the cultures and their geographical borders. Explanations further persistently build on the trade idea, where innovation/emergence of iron is understood as the outcome of the very interaction of different regional groups and the mere exposure of (metal) objects emanating from early metal-producing centres.

Overall, it is about a long list of explanations that simplify the complexity of transferring metals technology between societies (White & Hamilton 2018), and which limit the possibility to investigate *how* the metals really transferred. Hence, with polarization, bounded cultures/identities and progressive sequences in focus, fluidity and variety is easily lost. Not all communities would have followed the same trajectory in the adoption of innovations/technologies. There would have been many different strategies, which motivates us to explore the underlying mechanisms of the transfer of technological knowledge, possible exchange pathways, and how the inception of iron transformed society. Even though the exchange networks of an eastern origin have long been the focus of north Fennoscandian archaeologists, broader discussions over these relations are generally lacking, and the eastern contacts still play the role of the unknown and unexplored. Theories that have been put forth have not led to any in-depth studies of the material culture of the communities in the Volga-Kama region, or of the character of long-distance contacts (Ojala & Ojala 2020).

It is generally conceived a challenge for archaeologists to identify the social content and form of exchange pathways and networks, and the underlying mechanisms for the adoption and maintenance of a technology. Variables used mainly concern morphological and stylistic attributes of artifacts where similarities are taken as proxy for links between sites. These attributes, however, tell us nothing about the actual type of interaction (Roux 2019). Here archaeology has a lot to gain from an increased focus on the technological aspects through an archaeometric approach, to reconstruct production methods and techniques (the *chaîne opératoire*) and get clues as to what levels of knowledge/skills and equipment would have been required to perform each identifiable transformation stage from ore to metal. This would open up a detailed identification of social processes and activities, and overall provide important insights into the adoption and role of metal in Arctic Fennoscandia and Europe. It would further lead to a systematic and sophisticated addressing of the transfer of metallurgy. Instead of bounded cultures and identities, material culture repertoires (technological style and knowledge) would in various ways work as common elements of shared cultural practices (Damm 2012; Skandfer 2009), or as Brosseder & Miller (2018, 16) put it, reveal the cultural 'weft' of connectivity across the 'warp' of distinct, yet interwoven societies.

To exemplify further through our findings, archaeometric analyses give us clues about the nature of the knowledge transfer, which in turn opens new perspectives on the networks of the Early Iron Age hunter-gatherers in Arctic Fennoscandia. Hence, archaeometric analyses reveal great similarities in the technological practices between our sites (despite the vast distance) and a general lack of experimentation in the metallurgical material. This indicates the transmission of technology as a full package—including objects, smithing and smelting techniques—all transferring at the same time, in turn implying the existence of distinct technological learning networks of skilled practitioners (Hjärthner-Holdar & Risberg 2009). Hence, the mastery of a craft such as metallurgy presupposes both theoretical and practical knowledge taught through guidance from an experienced person (White & Hamilton 2018), i.e. it would require a process of learning at an exploitable ore source to communicate the various stages of metal production through visual demonstrations and verbal explanations for the multifaceted knowledge transfer to occur.

The skilled and extensive metal production further opens new perspectives on the organizational ability and probable habitation patterns of the small communities, as well as of their desires and metal use. Much of the prospection and extraction (of clay, stone, ore and wood), and processing (coal production, furnace construction, roasting and smelting of ore, forging) reasonably required collective commitment by the small communities (White & Hamilton 2018), and even more so, as well as far-reaching and long-term planning, when we take the Arctic climate into consideration. Hence, with frost, ice and snow in combination with coldness and darkness during half the year, extensive planning and

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organization of the small community is needed to succeed in implementing iron production in parallel with other necessary livelihood-/survival measures within the time frame allowed by climate. A crucial part of the iron-production work (many individuals for many hours) must take place while the ground is bare and thus start up in parallel to when winter supplies dried up and extensive effort was required (also many individuals for many hours) to manage food supply (typically fishing and the collection of berries and plants during summer). All in all, this probably required more permanent cohabiting than previously thought (see e.g. Skandfer 2009 for a similar discussion regarding Stone Age ceramics).

There was no inherent functional reason why metal objects or metal production should be adopted by the Early Iron Age hunter-gatherers in Arctic Fennoscandia, and it was thus not only up to the metal producers for the transfer to occur. Hence, in addition to the collective aspects of metal production described above, it also required the desires of the communities who adopted the metallurgical skills, and further circulated and used the metal objects. Transmission was the consequence of the desire to participate in networks of socio-cultural interaction, networks whose existence already depended on the regular movement of individuals and groups (Roberts & Vander Linden 2011). With such a perspective there is not a single line of development trajectory, but we get a punctuated transmission sequence reflecting a mosaic of community traditions, in part depending on the networks and cross-cultural affiliations between otherwise distinct and disparate societies. In sum, it is high time to recognize the Early Iron Age hunter-gatherers in Arctic Fennoscandia as early adopters of iron technology and active network participants. We have both material and methods for this.

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Appendix C

Paper III

Ancient Arctic European hunter-gatherer steelmakers in the limelight

Bennerhag, Carina and Kristina Söderholm

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Ancient Arctic European Hunter-Gatherer Steelmakers in the Limelight

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Abstract

The article presents results seriously challenging conventional frameworks on the time, course, and cultural context for the introduction of iron and steel in Europe, these for the major narrative of the development of civilizations indeed important metals. It concerns 2000-year-old finds from as many as 42 different sites across the national borders of present-day northernmost Norway, Finland, and Sweden in Arctic Europe, of advanced iron and steel production (i.e., contemporary with Roman steel production) within the hitherto unthinkable cultural context of hunter-gatherers. Due to insufficient frameworks for the undersigned as historian and archaeologist to interpret these findings through, we used archeometric analyses in combination with an arctic climate- and landscape/taskscape lens to reach new insights into the ancient arctic iron- and steel-making hunter-gatherers. These turned out to be particularly fruitful perspectives for gaining insights into the previously overall weakly explored social/organizational aspects of early ironmaking, as well as for the overall inadequately explored ancient arctic hunter-gatherers. We urge other historians and archaeologists to use similar methods to possibly uncover additional ("unthinkable") locations/regions with advanced and early metalworking.

Keywords: Ancient iron and steelmaking, Hunter-gatherers, Arctic Europe, Arctic climate, Landscape

1. Introduction

The introduction of metals and their importance for the development of civilizations constitute a major historical narrative. Still, especially when it comes to the introduction of iron, the narrative is strongly marked by conventional frameworks on time, course, and cultural context, with a strong bias for origin in connection to diffusionist- and evolutionary theories. With such explanatory models, perceived peripheral areas, such as the ancient Arctic, are at a great disadvantage. Hence, the predominant scholarly opinion still in recent research is the ancient hunter-gatherer communities in Arctic Europe did not play any noteworthy role in metal technology on a broader European scale, and that full-scale iron production was first introduced during the 17th and 18th centuries by immigrating miners from the south. Archaeologists seem locked into an explanatory context where some aspects merely are excluded from further investigation, or it is almost impossible to interpret arctic metallurgical finds in any other way. Thus, although Arctic Europe is geographically vast and highly unexplored archeologically, it is a fact that since the middle of the 20th century, archaeologists have uncovered large assemblages of iron finds, and since the 1980s, also several, however largely neglected iron production sites. Hence, as a rule, these have been interpreted based on morphology alone (and rather tendentiously) resulting in the selective use of available analytical methods, such as archeometallurgical analyses and radiocarbon dating.[1]

In this article, and totally at odds with the conventional scholarly opinion, we present results indicating a widespread knowledge of advanced early iron production among hunter-gatherer communities in Arctic Europe, critically challenging previous research. It concerns finds (partly newly discovered, partly previously surveyed and excavated, however, neglected in research) of iron and steel production at 42 different pre-Roman/Roman hunter-gatherer sites distributed over the national borders of northernmost Sweden, Finland, and Norway (Figure 1).[2] It was critical with an interdisciplinary approach to arrive at these results, and to be able to interpret them in a way truly freed from conventional theories, to advance knowledge. Through archaeometric methods – such as petrographic and bulk chemical analyses of slag (a by-product from metallurgical processes) and iron ore; metallographic analyses of iron; ceramic analyses of technical ceramics (typically hearth linings and furnace walls); and radiocarbon dating analyses of metallurgical remains – historians, archaeologists, and archaeometallurgists could jointly establish the widespread ancient arctic advanced knowledge in iron and steel working. Further, through a combined arctic climate- and landscape lens, historians and archaeologists then got tools to reach new insights into the organization of the (overall weakly explored) ancient arctic hunter-gatherers involved in iron and steel production. Here the historical-scientific contribution was critical, hence, through the fundamental interest in the human/social it became natural to focus on what the implementation of iron knowledge/-production meant for the local group of ancient arctic hunter-gatherers rather than, as is more common in archaeology, seeking to establish the origin and distribution of the advanced knowledge like arrows on a map. The Arctic Europe landscape is characterized by mountains, bogs, and coniferous forests, alongside marked seasonal changes. The climate (which was similar to that of today) is characterized by harsh, snowy, and long (November-March/April) winters; springs half as short compared to southern Scandinavia, but with a fifth season in the form of spring winters when the sun begins to warm a little during the day but when snow is still deep; and, finally, short (June-August) but often sunny summers. Reasonably, the seasonal fluctuations impacted the organization and rhythm of the ancient Arctic metalworking activities.

The conventional scholarly opinion is the Arctic European hunter-gatherers (ever since the Bronze Age) only secured access to bronze and iron in exchange for furs and other hunting products through long-distance trade with metal-producing agricultural societies in eastern and central Russia (typically the Volga-Kama region), respectively in southern Scandinavia.[3] Thus, they are not considered complex enough to produce and organize iron production themselves.[4] Although rather extensive trade is suggested, we further lack discussions on the significance of the exchange of goods for means of production and division of labor, or in general for social organization on the part of the hunter-gatherers (admittedly, several researchers suggest there was higher mobility in society and utilization of terrestrial resources due to the increased importance of fur exchange[5]). Hence, there is a maintained view of the hunter-gatherer economy as characterized by collective ownership of resources. Only at the time of the Viking Age (AD 800 - 1050) it is suggested they had become socially differentiated, partly due to ”the inherent dynamics of (reindeer) pastoralism,”[6] and partly reflected in the tax then claimed by Norwegian chieftains from the hunter-gatherers/the Sami[7], which appears differentiated according to status/position.[8]

Although the literature thus in many ways lack underlying explanations regarding the contacts, exchanges, and direct effects, metals (first regarding bronze and later also iron) are still typically attributed a kind of super (driving) power for process changes in terms of ethnic (and assumed closely related basic economic) differentiation.[9] Hence, particularly in Sami archaeology[10], and essentially related to the supply of metals, there is a strong notion of a division between coast and inland groups, with inland hunter-gatherer societies considered proto-Sami and coastal societies considered proto-farmers and antecedents of the Scandinavian/Germanic population.[11]

By presenting this wealth of archaeological material from the larger part of Arctic Europe (excluding Russia), alongside reaching new insights regarding the organization of the ancient arctic hunter-gatherers' involvement in iron and steel production (through archaeometric methods and a combined arctic climate and landscape lens), we hope to contribute to archaeology and history writing once and for all refrain from the old conventional views of the ancient arctic hunter-gatherers' (rather lack of) involvement with iron. We are historians of technology, archaeologists, and others collaborating in the research project that forms the basis of this article, and we believe our interdisciplinary approach has been central to our line of focusing on the local implementation (rather than origin) of iron, and going deeper into its organization (i.e., beyond trade and power relations) than what is common among archaeologists.

2. To add Context – the Ironmaking of pre-Roman Arctic Hunter-Gatherers

To examine the organization and technology of ironworking in ancient Arctic Europe we need to establish the production process and the various metal-related activities taking place. Through archeometric analyses of the material, we unravel the technical framework (including variations) of the iron produced (such as in terms of qualities/necessary knowledge, temperatures, raw materials, and the origin of ore). Through the concept of *chaîne opératoire* we further disentangle the condensed records of sequences of purposeful human activities encapsulated in the material.[12] Hence, iron technology involves a complex series of processes, each step revealing manufacturing choices and allowing room for variables.[13]

Already prior to ironmaking, a series of highly knowledge-dependent choices/activities must be conducted in terms of (a) prospecting and collecting viable, and for the different products most suitable ores (regarding Fe content, P content, MnO content); (b) prospecting and collecting clays with refractory properties and suitable plasticity; (c) collecting stone building material; (d) constructing furnaces and forging hearths; and (e) produce charcoal. The production of iron from iron ores by the direct, bloomery process is in turn a long procedure that can be roughly divided into three main stages: (1) the smelting (reduction) of the ores to produce a bloom; (2) the refining of the bloom (primary smithing) to produce a more compacted metal (a bar ingot); and (3) the forging of the end product (secondary smithing). All these stages can be performed continuously at the smelting site. Alternatively, iron in the form of the bloom or a bar is transported to iron smithies for further refinement, where primary/secondary smithing is carried out until the final product is formed. In iron research, it is often assumed that the bloom with its rough form was not fit for transportation and therefore was compacted and refined from slag at the smelting sites. However, at the ancient arctic smelting and smithing sites examined here (see further below), the blooms seem to have been transported to the iron smithies for further refinement.

Examining the technical practices across the different production stages allows for a more nuanced and sophisticated reconstruction of the behavioral influences of the local production than those afforded by the (within archaeology) conventional one-sided focus on morphological and stylistic affiliation. In this study, we conduct such reconstruction of the technical practices/characteristics across a larger region, Arctic Europe. Highlighting the expertise and choices of smelters and smiths further facilitates a factual discussion about how the craft in one area relates to that in another, i.e., beyond the assumption of imitation.

The taskscape approach[14] in turn allows us to explore the task of iron-making as an array of interrelated activities and relationships among the places and rhythms that form everyday life. It allows us to incorporate the temporality of activities, a cyclical view of the time tied to repeating patterns of activities in the landscape.[15] Hence, the task of iron making was influenced by the localization of raw material in the landscape, as well as by climate/seasonal fluctuations regulating when tasks could be conducted alongside other livelihood activities and conditions. Reasonably, the implementation of the iron-making task alongside other rhythms required some reorganization, to create space for it. Overall, the taskscape approach adds depth and complexity to our understanding of the strategies employed by the ancient Arctic iron-making hunter-gatherers.

In line with the taskscape approach, however, without subscribing to it, Bergman points to the crucial importance of the marked seasonal changes of the ancient Arctic population for resource supply activities, and in extension for settlement patterns. [16] She suggests the settlement pattern during the pre-Roman and Roman Iron Ages followed an annual cycle where autumn and winter were characterized by aggregation at a base settlement in the forest land and spring and summer of division into several different camps. She points to the decisive importance of fishing and hunting (moose, reindeer, and small game) for settlement patterns as the harvest period of the animal resources mainly falls during autumn/early winter due to the spawning season. Moose and reindeer then wander along given routes from the mountains down to the forest area, and marten, fox, and wolverine are easy to track in the snow. Overall, this meant a great opportunity for large catches to be frozen and stored. Hence, Bergman suggests autumn was the time of year when several local groups converged into so-called microbands (of about 25-50 people[17]) for joint work, whereas spring (March-May) probably was the most difficult time of year supply-wise due to depleted stores. In addition, transport, hunting, and fishing were more difficult in spring due to light snow (poor bearing capacity) and water on the ice. Hence, Bergman points to the lack of conditions for larger joint settlements from spring-winter to summer, when instead a division of the microbands into smaller units was the most advantageous form of resource utilization. She suggests the need to secure fuel (wood), especially for the winter months, and still reduce the risk of overexploitation, speaks in favor of such division. Bergman points to the influence of seasonal changes also for the disposition of activities within the settlement area to the extent that, e.g., in the cold and dark winter, tool maintenance could only be carried out in a heated (and lit) dwelling, but during the bare ground season on optional places all over the settlement area.[18]

Like Bergman, also Wallerström[19] deals with multilayered resource supply activities in relation to seasonal fluctuations, both however lack the perspective of iron working. This is generally the case in previous rather inadequate literature on the arctic hunter-gatherers during the pre-Roman and Roman Iron Ages, exclusively focusing on subsistence activities (hunting, fishing) and gathering of raw materials (for stone tools and pottery).[20]

3. Materials and Method

This article presents ground-breaking datasets resulting from the first-ever implementation of extensive archaeometallurgical analyses of archaeological material from the Arctic European area. The datasets concern a diverse material – ranging from slags, technical ceramics, ores, iron, and artifacts – stemming from as many as 42 different prehistoric sites in Arctic Europe (of which 31 have been analysed in more detail), including 26 in northern Sweden, 6 in Finland and 10 in Norway (for an overview, see Table 1 and Figure 1). Find contexts primarily include iron production sites and multiperiod habitation/dwelling sites, often without visible structures but in some cases with huts, and occasional hearth structures (for details, see Table 1). Additionally, samples of fresh ore from 11 different sites have been examined through test roasting (of which 4 have been analysed in more detail). The metallurgical finds form part of larger assemblages collected during archaeological surveys or derive from well-documented excavations between the early 1940s to recent times. Most finds derive from surface collections and occasional excavations conducted in connection to the large-scale hydropower expansion in Arctic Europe in the second half of the 20th century, and to other industrial exploitation (such as a gas line). Some finds derive from smaller excavations, typically conducted in connection with locally funded research projects. For more detailed information on conducted sampling and analyses (in addition to what is presented here, in Section 3), please see *Supplementary, S.1*.

Prior to our study, only a few analyses were overall published on Finnish, Swedish, and Norwegian ironworking material.[21] These mainly targeted iron ore and slag pieces (between 2.5 - 10 cm), and typically mapped a few of the major elements of importance to judge the quality of the ore. In some cases, bulk chemical analyses were also conducted. Hence only a few comparable analyses with reference data are overall available. We have reinterpreted some of the micrographs and descriptions in a major way due to our interdisciplinary approach and related extensive knowledge of iron production and smithing processes.[22] Regarding some finds, the residual pieces, but not necessarily the analysed samples, have been re-examined (samples as close as possible to the site of the previous samples were selected). These new analyses facilitate the calibration of old analytical results (comprising fewer elements) with the new results.

More recently, two iron production sites and one smithing site in Swedish Sangis and Vivungi were investigated archaeologically and subject to archaeometallurgical analyses by us, signed, together with fellow researchers.[23] Here we applied the same methods as in the current study which allows for direct analytical comparison. Hence, the results of the Sangis and Vivungi sites function as an underlying reference frame, and some of these slags, technical ceramics (hearth linings), and ancient ores of the Sangis and Vivungi sites have also been re-examined in the current study. The sites have been subject to investigation since at least 2006.[24]

3:1 Chronology

Previously, radiocarbon dating of charcoal samples from and around construction remains has been carried out at 19 of the 42 studied sites (mainly iron production sites, although the sites at the time of the dating were generally not yet known as either smelting or smithing sites), with the majority of sites attributed to Pre-Roman Iron Age, representing the initial phase of iron technology in Arctic Europe (Table 2, 3 and 4). In this study, we have completed this set of data with new radiocarbon datings on metallurgical remains at three of the previously undated and seven of the previously dated sites through sampling of charcoal trapped in slag and carbon extracted from iron (steel) to get a reliable dating of the actual iron working and confirm the established chronology (Table 2, 3 and 4). Still, 20 of the analysed sites are undated (with respect to archaeometric analyses) and the chronology at these sites is uncertain. Fine-scale chronological attributions are made difficult by the sites' long-term use. This is especially true for the interior sites which, due to land uplift, can contain traces of settlements extending back over 10,000 years. The dating of the metallurgical material at these sites has therefore been approximated through a careful analysis of the contextual relation to typologically dated asbestos-tempered ceramics (see further below). Hence, these sites are assigned to a broader Late Bronze Age/Pre-Roman – Roman Iron Age phase.

3.2 Data Collection, Sampling Strategy, and Constraints

A stepwise strategy was used to collect data, starting with a review of excavation reports, museum collection databases, and published works of sites including prehistoric metallurgical material in Arctic Europe. The primary focus was sites considered to represent the initial phase of iron technology dated to the Late Bronze Age – Pre-Roman and Roman Iron Age. The initial selection method was primarily based on available radiocarbon dating and the depositional contexts of the finds, which were dated by the associated pottery and so-called "stone age finds" (certain asbestos-tempered pottery and lithics). Sites were also selected according to geographical spread (to cover the largest possible area), and to contexts of so-called Kjelmöy and Risvik ceramics which in previous literature are associated with hunter-gatherer and agrarian economies respectively.[25] Subsequently, material studies were conducted at the archival institutions that held the metallurgical material; in Finland at the Finnish Heritage Agency in Helsinki, in Norway at the Arctic University Museum of Norway in Tromsø, and in Sweden at the Silver Museum in Arjeplog and the County Museum of Norrbotten in Luleå.

We based our selection at each institution on a visual (macroscopic) examination of the finds. Slag samples were chosen to achieve a representative selection of the different morphological types in each find (to identify different production processes). The macroscopically most common type of slag was chosen alongside samples of slag deviating in form, texture, and magnetism (the degree of magnetism indicates the type of slag). Iron fragments lost in the production process or parts of objects/semi-finished objects were especially targeted to establish the different types and qualities of iron used and produced. The most magnetic pieces were chosen with the aid of a magnet. Technical ceramics was also selected (based on identifiable shape and the macroscopical observation of a temperature gradient) to identify variation in raw materials (clay), construction details of furnace shafts and smithing hearths, refractivity, and firing temperatures. In some cases, the sampling was limited to the only few technical ceramic fragments overall recovered from excavation.

In addition, finds of fresh ore deriving from the area around the Swedish lakes Kakel and Storavan were sampled to determine whether they were suitable for iron production. The ores were collected in connection to surveys of archaeological remains in the 1970s-1980s due to hydropower expansion in the area and were at the time collected according to an unreserved sampling design, i.e., a collection of artifacts and deviant objects regardless of cultural or natural affiliation, and period (sometimes also misidentified and referred to as slag).

As part of our study, we have also performed a survey of the raw material supplies in the local surroundings of the excavated iron production site in Vivungi, Sweden. We wanted to know more about the availability and quality of both local clay and ore. This work entailed a close collaboration with locals who participated in surveys and contributed invaluable knowledge about the local raw material sources known to them from participating in modern taskscapes. Our surveys revealed numerous sources of limonite ore in the local lakes, but it was quite challenging to find high-quality clays, with the nearest source being more than 15 kilometers away.

Of particular interest for our sampling was the large assemblage from metalworking collected in the 1940s to the 1980s in Arctic Sweden, Finland, and Norway during surveys and excavations of ancient settlements related to lake regulations and hydropower expansion. While the number of slag fragments found at each site was limited, the aggregated material from all the sites represents an extensive landscape of metalworking. Interestingly, the material was found at early hunter-gatherer sites alongside Stone Age finds – such as flakes, scrapers, and points of stone and pottery – indicating an early use of iron. Still, at the time of recovery, these sites were considered problematic due to tenacious evolutionary ideas related to the dichotomy between hunter-gatherers and farmers, the heavily dominating chronological model of the Three-Age system, and the assumed evolutionary stages inherent in the succession of Stone, Bronze, and Iron Age. Hence, the material context did not correlate to the evolutionary ideas, why a general idea of a "delayed stone age" (rather than an "early iron age") was established, which in turn meant the metallurgical remains were severely neglected, and no methods were used for the identification of the metallurgical material, such as archaeometrical analyses including radiocarbon dating of carbon in steel and charcoal trapped in slag - methods since long established in European iron research.

The preconceived notions of the Arctic parts of Scandinavia as a periphery with a relatively late settlement history have exercised a strong impact on interpretations of the lake regulation metallurgical material. The documentation of the material collection further typically lacks contextual records. This is especially true of slags as they were considered waste material with limited information, meaning some slag finds were not even collected. Moreover, there are several cases of misidentifications seriously affecting interpretations of the material, typically downplaying variation, i.e., almost all the metallurgical material has unilaterally been recorded as slag, and in some rare cases burnt clay. Only a few archaeological features and structures of metallurgical activities are identified along with the waste material. Nor are any hammer scales (magnetic flakes detached from the metal during smithing) present among the collected material, although they should have been part of the material based on the now-identified smithing activities. Several of the sites are now submerged under water and exposed to erosion due to the building of dams and hydroelectric power stations, meaning that much of the microscopic evidence for production activity is forever lost. Conventional views are still reflected among the material-holding institutions, typically meaning selection-related restrictions (such as sampling) were occasionally imposed before we got to study the material and that parts of the collections were stored in inaccessible find magazines. In fact, the institutions were rather uncomprehensive by the fact that slags could contribute interesting information as it (according to the traditional view) was considered waste/mass material.

Overall, we have studied material collected over a period of 70 years (including our own excavations in recent years) with all that this entails in terms of varying interpretative and methodological perspectives, practical research techniques, and levels of ambition. We find it intriguing that we, despite the serious limitations, have succeeded in distinguishing both reduction and smithing slag alongside technical ceramics (furnace wall and hearth lining), ore, iron waste, and iron fragments for a larger geographical area. The aggregated sites represent an extensive landscape of metalworking where it is possible to start to draw the first tentative but substantial conclusions about the technology and organization involved. Slags and other refuse are far more informative about the metal craft than the morphology of the final products, which was the previously typical focus in North Scandinavian iron research. Hence, this material provides an important synchronic perspective on Early Iron Age metallurgical traditions in the Arctic European area.

3.3 Set of Samples, Methods, and Detailed Analyses

In total, 237 finds were selected for the present study, 65 from Finland, 33 from Norway, and 139 from Sweden (of which several included more than one underlying find item and several different material types) (for details see *Supplementary S.5—S.7*). Most of the finds consist of reduction or smithing slags (the latter including both primary and secondary smithing) and technical ceramics (from furnace walls and hearth linings), but even iron waste, fragments of iron objects, fresh and ancient ores, heat-affected stones, stones with slag cover and red-brown magnetic particles and lumps are included.

Initially, a visual inspection and morphological description was carried out on all the sampled material, with a special recording of technical ceramics, and a characterization of slag finds with respect to the degree of magnetism. Based on these observations, and in collaboration with archaeometric fellow researchers, we selected samples for more detailed analyses.

We used archaeometric analyses to extract relevant metallurgical information about the metal smelting and smithing material and the technologies used to reconstruct the respective craft practices, and in extension to get as many insights as possible on the economic organization, resource acquisition and overall social context of metal technology. The clarification of the production processes is fundamental to establishing the various activities and practices related to the organization of the iron production at each site, and we can begin to understand how metalworking was adapted and embedded in the organization of society and the overall spatial patterning of the crafting landscape.[26] Also, variations in resource acquisition and production practices may suggest different participation of distinct social groups between different communities.

Several analytical methods were used for the metallurgical finds. Metallographic analyses were conducted on iron/waste to establish iron quality, i.e., whether it is iron, steel, or, e.g., phosphoric iron, and to define the extent to which the iron waste had been processed. In addition, petrographic and bulk chemical analyses were performed on samples of slag with the main purpose to define the process stage during which it was formed, and determining the composition in terms of major, minor, and trace elements to allow a comparison of slags from various contexts (within and between sites), and to learn more about the ore types used. Also, samples of fresh iron ore were test-roasted, and petrographically and chemically analysed to assess the quality of the local ore and determine possible prehistoric connections and use. Further, technical ceramics (primarily furnace walls and hearth linings) were classified and specially recorded macroscopically. A selection of these was analysed further (petrographic microscopy, thermal analyses) to establish raw material choices and get insights into constructions and curation strategies, along with the thermal and mechanical properties of the clays (see Table 1 and *Supplementary, S.4*).

Radiocarbon dating has been performed on iron/waste and on samples of charcoal included in slag. Prior to the dating of charcoal included in slag, wood species analyses were conducted to assess the intrinsic age of the sample and possible sources of error. All radiocarbon dates rather consistently (including some considered less reliable) fall within the period Pre-Roman to Roman Iron Age, except for a sample in Norway radiocarbon dated to the Viking Age (AD 800 - 1050). Table 2, 3, and 4 contains a compilation of all radiocarbon dating samples, as well as previous radiocarbon dating from the excavated iron production and smithing sites.

4. Results

Although the amount of slag at each site is small compared to the more large-scale production in Europe in later times, and not all find categories are covered in all places, the analysed material (and its spatial distribution), considered as a group of formally related remains, unambiguously suggest an extensive iron working landscape in Arctic Europe already during the Early Iron Age (our sites, both smithing and smelting, are almost exclusively radiocarbon dated to Pre-Roman and Roman Iron Age). We see a high degree of conformity between the sites, where all parts of the technological *chaîne opératoire* seem to have been established already at the inception of iron. For more detailed information on the results of archaeometallurgical analyses (presented in Section 4), please see *Supplementary, S.2—S.4*.

4.1 Iron Smelting

Analytical results confirm the production of iron at the 10 previously excavated production sites[27], with 16 furnaces spread throughout Arctic Norway, Sweden, and Finland with radiocarbon dating spanning the period from 300 BC to AD 300 (Figure 1, Table 2, 3, and 4). These include the Hemmestad and Flakstadvåg sites in Norway, the Sangis and Vivungi sites in Sweden, and the Riitakanranta, Kotijänki, Kemijärvi, Äkälänniemi, Mikkeli and Lahti sites in Finland. Two additional smelting sites have been confirmed in the Lake Kakel area in northern Sweden (the Revi site, SMA 3319 and the Nåtti site, without number) through detailed petrographic and chemical analyses of stearin-like slag. These sites, which so far lack any traces of furnace constructions, belong to the lake-regulation material (the sites are immersed today) and are not further excavated. The Revi slag has been radiocarbon dated (through charcoal inclusion in the slag) to Pre-Roman Iron Age (Figure 1, Table 4).

The interpretations in the literature of iron smelting in the Arctic European area have revolved around a dichotomic division of furnace remains into a western and eastern cultural sphere (attributed to different smelting technologies/traditions), mainly argued from reconstruction models of the furnaces based on insufficient knowledge regarding necessary criteria for the smelting process to function (such as that a furnace shaft with a certain height is fundamental from an aerodynamic perspective, as well as certain room above the slag-mass for the bloom to form). While the eastern furnaces (in our study including the north Swedish and north Finnish sites) typically are attributed to a relic and archaic bowl-furnace technology (without superstructure) and seen as part of a hunter-gatherer economy, the western furnaces (here including the Norwegian sites) are seen as part of a (superior) European shaft furnace tradition.[28] Still, based on substantial evidence of clay-built furnace wall remains identified at all our smelting sites, and at odds with literature, we establish the same smelting technology (including the basic furnace construction) at all sites, i.e., from Finland in the east to Norway in the west. It should be mentioned that in recent years the overall validity of the typological division of furnace constructions has been questioned and discussed at a general European level. Hence, this tendency to downgrade furnace types for certain groups has not only affected Arctic Europe.[29]

Analyses of process-related parameters at sites with construction remains demonstrate, at odds with literature, smelting operations took place in small bloomery furnaces (inner diameter of app. 0.3 m) with an upright cylindrical shaft made of clay, and with a rectangular stone framed base and underlying slag pit, in a few cases lined with clay. Analyses further demonstrate the same furnace was used several times. Roasted limonites in terms of lake- and bog ore along with charcoal (as fuel) from pine and birch were used in the smelting process; the charcoal provided the high temperatures and the reducing atmosphere needed for the iron ore to reduce into metallic iron. Air-inlet holes, visible on furnace wall fragments were further identified at all sites with construction remains, indicating air was provided using bellows. These were most likely placed at the bottom of the furnace shaft, mounted at the stone frame, the hottest zone of the furnace with temperatures slightly exceeding 1250°C. In this zone, the liquefied slag separated from the solid iron and accumulated at the bottom part of the furnace in the slag pit. Afterward, the slag was removed through an arch in the stone frame. Since the smelting took place below the melting temperature of iron, the iron formed in a solid state into a spongey mass (a bloom) just below the blowing zone. From a global perspective, blooms are very seldom found in the archaeological material, however, at 7 of our 12 smelting sites, small fragments of iron waste (detached parts of blooms showing no signs of additional consolidation/mechanical processing) were found around the furnaces. Overall, the ancient Arctic furnace technology is the shaft furnace technology, i.e., the same basic technology as other contemporary and later furnaces for iron production.[30]

4.2 Iron Smithing

Evidence from smithing is more abundant than evidence from iron smelting in the analysed material and indicated at 27 of the 42 studied sites, a major part spatially connected to large settlement sites and spread across a vast geographic area covering northernmost Norway and Sweden (Figure 1, Table 1). Regarding Finland, language barriers and lack of time have contributed to the fact that the Finnish smithing material (although smithing finds are abundant also in the Finnish material) has not yet been selected and analysed.

Physical remains of ancient smithing hearths are rare, and there is overall limited knowledge in the literature on the organization of northern European iron workshops/roofed forges from the Early Iron Ages.[31] Focus has been on the exchange and trade of metal objects rather than on the organization of metal production. If there are physical remains these are generally limited to the spatial distribution of slags, iron waste (bloom pieces), hammering scales (indicating the location of the anvil), and remnants of the clay lining of the slag pit. Against this background, our rather abundant finds of smithing installations in Arctic Europe are remarkable.

We have distinguished several types of smithing remains, with slag cakes – each corresponding to one work session – as the most common type of debris (in both Sweden and Norway). Most of the slag cakes are the result of the fabrication of objects and, consequently, show oxidizing conditions.[32] Consistently, however, we also find smithing slag cakes with reducing conditions along with separate lumps of metallic iron (or as concentrations in slag) indicating bloom consolidation (primary smithing)[33] took place at the smithing sites, i.e., implying the supply of iron blooms as raw material rather than, as suggested in the literature, currency bars.[34] Hence, both primary and secondary smithing is spatially separated from the smelting. The smithing and smelting sites are, however, situated in close proximity to each other. Such nearby location of smithing (primary and secondary) and smelting is confirmed through our analyses at three of the 27 studied smithing sites (the Swedish Revi, Nåtti, and Sangis sites). Here smithing and smelting is separated by only about 10-500 m. Hence, blooms are unwieldy to transport longer distances. We also want to highlight the logistical advantages of placing forging and production in the same location due to the difficulty of transporting charcoal (risk of shattering). Both primary and secondary smithing requires a blacksmith hearth in terms of repeated heating of the iron in a charcoal bed (hearth).

At two of our excavated sites, Sangis and Vallen, there is even evidence of hearth installations (oval features including charcoal), where (even more remarkably) one is found within the remains of a hut. Hence, the Pre-Roman Vallen site now represents the oldest known remains from a roofed forge in all of Scandinavia. The previously oldest known iron workshop (Roman Iron Age) is located in southern Sweden, about 1000 kilometers south of Vallen.[35] Only a small number of metallurgical contexts with evidence for installations have overall previously been excavated in all of Arctic Europe, and then from later periods (AD 400-).[36] Workshops are not even mentioned in the literature on Arctic Europe in earlier periods. Finds of smithing slag have simply been explained as evidence for the maintenance of tools.[37] Roofed forges have not even been considered or looked for. Still, we emphasize the decisive importance of controlled light for the ancient Arctic blacksmiths to observe color changes of the iron (for the understanding of the temperature and behavior of the metal during heating), which in turn strongly suggests forging took place under a roof to shield it from direct sunlight and rain, as well as from arctic winters. This is reasonably valid also for the smelting, i.e., also the smelter required good conditions to monitor the process.[38] Since several of our sites are now submerged under water due to the building of dams it is, however, difficult for us to prove this further in terms of our sites.

Finished metal artifacts have been discovered at several Swedish and Norwegian smithing sites. Knives make up most of these finds. So far, two knives and an axe from Sangis – where the chemical composition shows they were made from local ores – have been analysed and radiocarbon dated spanning the period from 200 BC to AD 100. Based on the context, it is likely that the yet-to-be-dated knives also originate from this period.

4.3 Raw Materials

The knowledge and availability of raw materials have significantly influenced the technological choices and *chaîne opératoire* of the ironworking process. This is especially true for pyrotechnical ceramics (furnace walls and hearth linings), the functionality of which is significantly constrained by the thermo-mechanical properties of the clay in terms of plasticity and refractoriness (i.e., the performance at extremely high temperatures). Hence, the choice/supply of clay that could endure high temperatures while still being plastic enough to allow for the construction of a maintainable shaft was an important (but in literature frequently overlooked) aspect of the manufacturing of iron.[39] An enclosure used to smelt iron ores (mostly wholly or partly built of clay) must withstand temperatures up to 1200-1300°C for a prolonged time. Most natural clays in Scandinavia have a refractivity sufficient for the bloomery process temperatures. Exceptions are calciferous clays and clays with large iron oxide concentrations or iron-rich rock fragments which may cause instability and, in the worst-case collapsing furnace walls. Refractivity can be improved by tempering the clay with non-plastic often silicate-rich materials (quartz).

Procurement analyses demonstrate a complex raw material composition at many of our sites, with conscious selections of clays with special characteristics. The Finnish Neitilä, Äkkälänniemi, and Riitakanranta smelting sites show close similarities with the Swedish Sangis and Vivungi melting sites, where the smelters used medium to very coarse-grained clays for the furnace shafts. The furnace builders in these locations seem to have opted for the same general quality of clay with a high volume of sand (dominated by quartz increasing the physical stability), however, having to deal with a limited plasticity consequently. Still, we would need more information about the types of clay available in the areas around the sites for a closer understanding of whether choices (of clay) were based mainly on a shared craft tradition or determined by a shared geology. Analyses, however, indicate curation strategies were adapted to cope with the insufficient plastic qualities by repeatedly repairing cracks and applying layers of clay between the runs instead of rebuilding the furnaces. Re-use was accompanied by the relining with fresh clay on the inside, often in the blowing zone where the furnace shaft was most exposed to high temperatures. After each repair, the furnaces were used for a further number of runs. This attests to a widespread knowledge of handling this type of clay. This is further supported by the fact the sintering interval of the clays exhibits deformation and melting between 1150 and 1250 °C, showing small temperature windows for the metallurgical processes to be carried through. Thus, the ancient smelters balanced the working temperature to the very edge of the thermal capability of the furnace. Interestingly, almost all analysed smithing sites with refractory remains in terms of hearth linings, i.e., all Swedish- and about half the Norwegian smithing sites, show the same use of coarse-grained clays as for the furnaces, i.e., clay suited for high-temperature operations.

Analyses reveal alternative choices of clay at the Swedish Vivungi and the Finnish Neitilä sites, where also finer-grained clay with higher plasticity (but maintained refractivity) were used, in turn indicating a different curation strategy where the furnace shaft was torn apart and re-built after only a few smelts. While the direct simple reason might have been the furnace builders managed to find a larger/closer clay bed with better plasticity, the fact they could readily shift to a different curation strategy further testifies to a solid knowledge of the raw material.

At the Hemmestad and Flakstadvåg sites in Norway, and the Lahti site in southern Finland, clays with clearly low-refractory qualities were used, such as calciferous clay, and clay stone, both unsuitable for high temperatures (which further is confirmed by slag analyses indicating leakage of oxygen into the furnaces). Even though the furnaces of the Hemmestad and Flakstadvåg sites have been used several times, there are further no signs of repairing the troublesome cracks appearing in the furnace walls. The use of clays with low-refractory qualities together with the lack of curation strategies at these sites overall suggests a partly different technological system compared to the north Swedish and Finnish smelting sites. In an upcoming article, we intend to explore whether this, e.g., may be interpreted as partly different knowledge acquisition.

The availability of viable ores was another essential component of the smelting technology. Ancient ores are rarely found in the excavation of iron production sites, and this is also the case in this study (with the Vivungi site as an exception40). Still, bulk chemical analysis of slag recovered from the various iron smelting sites offer a good possibility to get information on the type of ancient iron ore used in the furnaces. These show exclusively limonite ores (generally highly frequent/distributed in the Arctic European geography41) were utilized at all 12 smelting sites, and we infer it is mostly lake ore. Hence, all 12 sites are situated by lakes/water courses with a likely supply of lake ores, which further have the advantage (in comparison with bog ores, which can be depleted) it renews every 25-50 years.42 We further sampled and analysed fresh ores (often mistaken for slag) collected in connection to the lake regulation surveys, showing some of these were viable as iron ores (with high iron oxide content, more than 70 %, and the presence of manganese, 2-4 % MnO). Also, the chemical composition of ore which we collected from the lake next to the Vivungi site, correlating with bloomery slags from that site, confirms the ancient smelters collected ores from the lake.

Slag analyses further imply the ancient smelters employed ores with different element compositions with crucial importance to the quality of the manufactured iron. Hence, the Finnish Neitilä, Äkälänniemi, Riitakanranta, and Mikkeli sites used phosphorus ores (up to 1.7 % P2O5), and the Swedish Sangis and Vivungi sites, together with the Finnish Neitilä, Äkälänniemi, Riitakanranta, and Mikkeli sites used manganese containing ores (between 0.4 - 5 wt % MnO). While a phosphorus content can contribute to ductile, but also somewhat hard iron, manganese facilitates the direct production of steel in the bloomery furnace,43 i.e., a harder product with the potential for various heat treatments that will further improve the material properties. This is not only evident at our analysed sites but was also common elsewhere in Europe at the time.[44]

4.4 Iron Alloys

We gain good insight into what was possible to achieve/produce in the furnaces from the small fragments of iron waste (detached parts of blooms, 10-40 mm in size) recovered at seven of the 10 smelting sites with construction remains. Up to over one kilo of iron waste was found at each of these seven sites (all of them in Finland and Sweden). At the other three smelting sites – the Finnish Lahti and the Norwegian Hemmestad and Flakstadvåg sites – and possibly due to the problems observed in the reduction process, no metallic iron debris was found.

At all seven smelting sites with iron waste, metallographic analyses demonstrate a highly similar pattern in terms of high levels of carbon (more than 0.8 % C). Hence, this study establishes the presence of high-quality steel as a key iron alloy. At six sites (Swedish Sangis and Vivungi, Finnish Neitilä, Äkälänniemi, Riitakanranta, and Mikkeli), this can be related to the use of manganese-containing ores (evidenced through chemical analyses of slag), indicating the deliberate production of steel directly in the bloomery furnace. Even cast iron (more than 2 % C), usually associated with blast furnace production (but also claimed to be an inevitable by-product of high carbon steel production in bloomery furnaces[45]) is revealed in a few lumps at the Swedish (Vivungi) and Finnish (Riitakanranta and Mikkeli) sites. The iron waste discovered at six (Sangis R730 and R797, Sandudden NA 54 and NA 82, Hoppot NA 36 and Vallen R 90) of the 16 confirmed Swedish smithing sites (Table 1), all of which most likely originated from primary smithing, provide additional evidence of steel as a desired product. Moreover, phosphoric iron, observed at two of the Finnish (Riitakanranta and Mikkeli) smelting sites, suggest a demand also for hard and ductile metals. This is also confirmed by the chemical analyses of slag at these, as well as at two other Finnish sites (Neitilä and Äkälänniemi), showing the use of ores with a phosphorus content. The production of phosphoric iron in the Arctic European region is indicated also through the recovery of an iron knife at the Swedish Sangis smithing site combining phosphoric iron and steel.

4.5 Fabrication and Composition of Artifacts

Another key element of the technological system is how the smelted iron was formed into the desired products. The most typical fabrication techniques, as shown by our analytical results, were comparable to the most cutting-edge technology in Europe at the time in terms of expertise and specialization. Analyses of artifacts at the Sangis smithing site show welding techniques combining different steel and iron (both phosphorus and soft iron) qualities into multilayered tools, further enhanced by various heat treatments including quenching and tempering. The analysed objects (mainly knives and an axe) show the hardest steel was consistently used for the edge, indicating the desire for tough and hard cutting edges. Thus, the fabrication techniques and iron alloys used were tailored to the specific tool types. In one of the analysed knives, there is also proof of the intent for visual/stylistic effects using lamination techniques (combining different layers of steel and phosphoric iron).

In literature, the welding and laminating procedures we now see in ancient Arctic Europe are overall considered the most challenging endeavors of ancient European smiths.[46] The difficulty is related to the fact that the different iron alloys to be attached often have different optimum smithing temperatures[47] (resulting in small temperature windows for attaching). Hence, the ancient blacksmith's skills in determining the temperatures with his/her own senses, such as through the color of the glowing metal, become decisive. In previous literature, these methods are said to have been attempted in Europe (in its central parts) as early as 500 BC, but did not become more widespread until Roman times, reaching the northern European continent first in the Middle Ages (however, never really to its Arctic parts).[48] The present study, however, shows that more than 2000 years ago, the advanced smithing techniques were established in Arctic Europe, and were maintained over 400-500 years (documented at the Swedish Sangis site and in the Kakel and Storavan areas).

4.6 Similarities in Style and Technological Choice

A comparison between our studied sites reveals striking similarities in style and technological choices between the north Swedish and Finnish smelting sites and between the north Norwegian and Swedish smithing sites (Finnish smithing material has not yet been selected and analysed). Hence, analyses demonstrate conformity in technological features including the use of raw materials (clay and ore), curation strategies, and the finished products (raw metal and artifacts). There are furthermore only minor chronological differences between the sites. This "standardization" concerning the mastering of excellent smelting and smithing operations identified at each workshop strongly indicates a well-established and recognizable technology (including a technological network) across a large geographical area in Arctic Europe.

Overall, our data allow us to reconstruct, for the Early Iron Age (200-50 BC), and thus at odds with literature[49], the deliberate production of steel directly in the bloomery furnace. Steel can be followed through all stages of the metallurgical process, strongly indicating a widespread demand for steel as a product. The identification at some sites of phosphoric iron indicates the demand also for other alloys. The predominant choice of coarse-grained clays and the repair technology in the north Swedish and Finnish smelting sites further suggest a conformity in technological tradition. Repairs as such are not a characterizing element of a particular craft tradition, but the notion that furnace shafts with necessary repairs could be used repeatedly testifies to an established technological tradition. A more significant and possibly characterizing detail is the apparent focus on the repair of the area around the air-inlet hole(s). Coarse-grained clays were also employed by the ancient arctic smiths, evidenced through the remnants of hearth linings at both the Swedish and Norwegian smithing sites. Interestingly, this indicates a knowledgebase that may have been different from the smelters in the Norwegian area, using much finer clays and different curation strategies.

While our results show a shared complex technological system across a large geographical area in Arctic Europe, it does not preclude individual or local differences in technical choices. Thus, morphological characteristics point to certain differences regarding constructions of the smithing hearths on both local and regional scales, such as regarding the placement of the clay lining (wholly lined hearths at the north Norwegian sites and both wholly lined and just upper lined hearths at the Swedish sites). Further, the varying sizes of and the variations in contact material (sandy subsoil or charcoal bed) for the slag cakes found at the Swedish smithing sites, indicate various solutions for the hearth constructions. This is further evident in the various dimensions of the hearth lining remnants.

4.7 Landscape Structuring and Organization

The apparent conformity not only concerns technological features but also the spatial distribution of iron production and smithing operations. When plotted on maps, distinct clusters can be distinguished around larger lakes and water bodies in forest landscapes, i.e., in relation to primary resources in terms of ore and wood needed for fuel. The spatial organization of the smelting and smithing processes is particularly distinctive in Arctic Europe where, in fact, the complete metal production cycle often seems to have taken place in the same local context. A spatial clustering of the different process stages would have facilitated the control of the complete metal production cycle/the entire *chaîne opératoire*, from ore selection to the manufacturing of finished objects. It overall concerned an extensive knowledge base in the hands of the rather small-scale ancient Arctic hunting-gatherer communities (25-50 people[50]). Variants of a clustered organization are suggested also at Siberian iron workshops during Iron Age (1st-3rd century AD)[51], as well as in Mongolia, northern Germany, and Denmark in Pre-Roman time.[52]

The water bodies further typically contained (and still do) an abundance of fish, and we have found large amounts of faunal remains from freshwater fish at the sites where we had access to material context (Sangis and Vivungi). Overall, this points towards coordination of iron production and good supply/utilization of fish. All the Swedish and the Norwegian smithing sites are further spatially connected to large known settlement places, and as a rule also to other craft activities, such as lithic technology, pottery, horn-bone, and skin/fur-craft. Hence, ironworking seems integrated with the existing material technologies and organizationally incorporated with other residential activities.[53] Regarding the lithic tradition, we see no signs of a broader technological change at the time of the inception of iron but rather a continuity well before and after. In addition to dismantling the Three-Age system, this indicates iron was integrated and incorporated seamlessly into the social and economic organization of the Arctic hunter-gatherers.

5. Discussion

In this article we establish a comprehensive geographical distribution of advanced and early ironworking across the national borders of present-day northernmost Norway, Finland, and Sweden in Arctic Europe, and without division between coast and inland. At the 42(!) different known sites, from Finnish Lahti in the east to Norwegian Tromsö in the west, hunter-gatherer groups engaged in advanced production of iron and steel already during the Early Iron Age, providing an important synchronic perspective of metallurgical traditions in the Arctic European area. We see conformity in terms of a complete and highly specialized technology that seems to have spread quickly (suggested by contemporary dating) over the vast area, and which was maintained (without major alterations) for at least 500 years (within the time span of 300 BC-AD 200).

The fact it concerns hunter-gatherers who got involved in advanced iron production as early as the Romans, that it took place in the Arctic, and that knowledge (to produce iron) seems to have diffused quickly over a large region, overall, demonstrates the need to strongly question the typical center-periphery way of thinking, focusing on power relations and necessary social developmental stages. Hence, such interpretations still strongly influence historical writings on the diffusion of iron around the world. Now it is high time to focus on what is considered the periphery, and on what one means by using such terms.

Below, and through a combined *chaîne opératoire*- and taskscape/landscape/climate approach to our results, we will discuss how the task of iron production influenced the everyday lives of the ancient arctic hunter-gatherers. We will discuss this as if they were a unified group although it is important to remember that of course, they consisted of several local groups with local variations, which we also see indications of in the material.

The strong seasonality, including significant climatic variations and related environmental constraints, created fundamental challenges for the people living in ancient Arctic Europe. Only to survive required skills and far-reaching planning. Planning and activities related to hunting, fishing, and gathering are often highlighted[54] although there is reason to also emphasize tasks related to, e.g., the preparation of clothing and housing suitable for the arctic climate, and now even metallurgical activities. The climatic variations and environmental constraints had a major impact on the temporality of the different taskscapes of the hunter-gatherer communities and required overall a high degree of the complex organization of tasks and landscape use to balance the different tasks. Basic prerequisites for these groups to be able to engage in iron production were, in addition to access to primary resources such as ore, clay, and wood, that they could engage in activities other than primarily food collection. By coordinating the locations of iron production with productive fishing grounds, necessary conditions seem to have been in place.

Tasks related to the acquisition and preparation of ores and clays are fundamental to the production of iron. Lake iron ores occur mainly at depths of 1.5-4 m at the bottom of lakes, whereas bog iron ores (and clays) are covered with layers of vegetation, meaning good knowledge of its occurrence is required before it can be found. It is reasonable to believe people gained knowledge about the presence of lake ores from catching ore in their nets, as many arctic fishermen still do today. Overall, the location of iron smelting close to productive fishing grounds is understandable from several perspectives. There are historical records from southern Sweden in the 19th century describing how lake ores were collected from specially constructed rafts during summer, alternatively were harvested from the bottom of waterways during winter (through holes cut in the ice).[55] We do not know during what season lake ore collection was carried out by the ancient arctic hunter-gatherers, only that if it was a winter activity it did not take time away from the many activities that had to be carried out during summer. Bog iron ores were preferably collected during summer, and like clay, this was done within a short time window after the frost had left the ground but before the growth of vegetation. After drying, the ores had to be roasted, and both steps had to be carried out during bare ground season; the drier the ore, the less fuel was needed for roasting.

It is an implicit assumption in the literature that clay appropriate for the construction of ironworking furnaces and hearths was commonly available and adjacent to production sites. However, a clay survey conducted in 2019 with the help of locals in the surroundings of the Vivungi site revealed the closest source of suitable clay was likely located rather far from the production site. Hence, closeness to clays of sufficient quality was seemingly not prioritized in the location selection for production sites. This is further confirmed by ethnographic data regarding arctic pottery, showing people were willing to travel some distance to acquire the best clays.[56] Hence, the acquisition of clay was probably a larger investment in terms of transportation compared to ores. Still, perhaps it enabled a more spread-out task/activity over the year as the clay – although it had to be dug up during summer – with advantage (due to the weight) was transported on a sled during winter. In addition, investments in specialized facilities were required for the acquisition and preparation of ores and clays; for lake ore, long shovels to rake the ore from the bottom of the lake, and a special container with a sieve to allow water to flow through, and for bog ore and clay, various digging, and transportation equipment. Reasonably, both ore and clay were further stored under some form of roof to protect them from precipitation.

Wood consumption for fuel production formed, overall, a substantial part of the subsistence of the ancient arctic hunter-gatherers. While, in addition to general heating and cooking, large quantities of charcoal were needed in the manufacturing process of iron, both for smelting and smithing, we particularly stress the importance of the localization of the production sites close to lakes in forest areas. At odds with literature typically suggesting the need to secure fuel (and still avoid deforestation) speaks in favor of divided settlement patterns,[57] we suggest the waterways in forest areas offered unique transport possibilities counteracting local deforestation. There is other recent research which, in line with our reasoning, indicates that ancient hunter-gatherers engaged in sustainable forestry, i.e., that they consciously chose 30-40-year-old trees.[58]

After the timber was cut it had to dry for 1-2 summer seasons before it was used for general heating/charcoaled in pits (it is not possible to fire with sourwood). Thus, we would like to point out the necessity of strategies for stockpiling wood at all settlement sites (regardless of whether they are temporary or not, whether iron is produced there or not). Charcoaling had to take place during the bare ground season. Each batch preparation took 1–2 weeks, and a couple of days after completion the charcoal was torn out of the pit, preferably in the evening when humidity is higher and the charcoal cools faster. Reasonably, the charcoal was thereafter stored under a roof to protect it from precipitation. The overall high level of investment, temporality, and technical competence required in the charcoaling process prevents it from being a side business conducted spontaneously when needed. Hence, it required far-reaching planning.

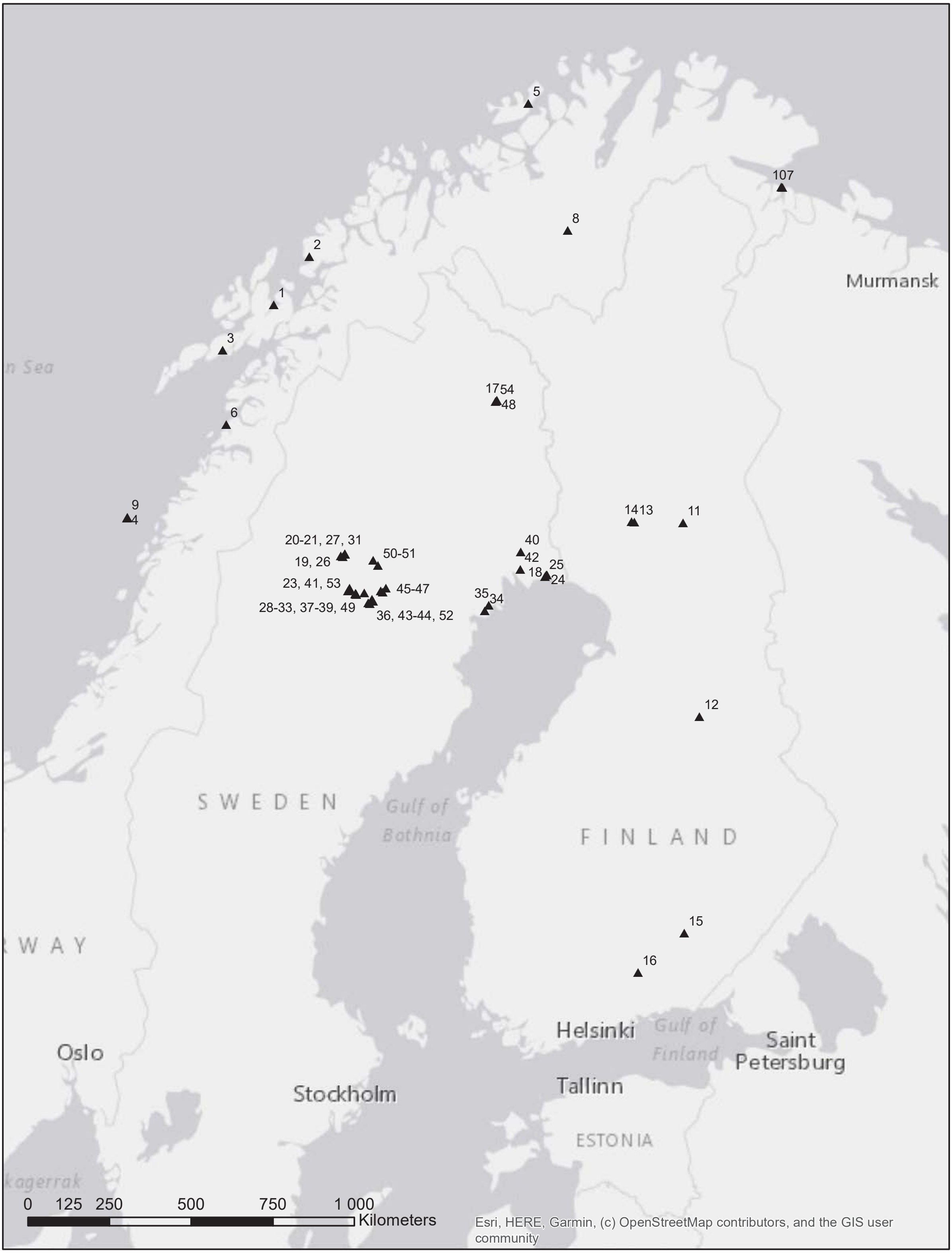
The taskscapes related to iron production overall followed a clear seasonal pattern, with the greatest labor intensity and parallel need for division of labor in the local community during the bare ground season, and especially during the summer months. In addition to the necessary carrying out of a major part of the preparation of iron production during the bare ground season – in terms of prospecting, collecting, and preparing primary resources – also the construction and running of furnaces required bare ground season and perhaps less, but more specialized, work efforts. Also the construction of forging hearths required bare ground season although the forging may have been carried out all year round in specially intended huts. Hence, the bare ground season was required for the smelting, or the shaft would cool down. Overall, integrating metalworking into the economy required advanced planning and workforce coordination/labor division. The spatial location of iron working within the settlement and, especially, the clear integration with the existing material technology along with other residential activities demonstrate that ancient Arctic iron technology was successfully integrated into the organizational structure.[59]

Taken together, this not only speaks for a far more advanced/multifaceted organization of the combined taskscapes of the ancient arctic hunter-gatherers than previously assumed. It also speaks clearly against the strong emphasis on divided settlement patterns in previous research, particularly during summers. Hence, we rather perceive an aggregation/cooperation during bare ground season considering the many iron-related taskscapes which needed to be carried out then. Overall, the way iron production claimed extensive investment in time at specific places in the landscape, tied the people there. It is reasonable to believe this led to increased sedentariness. Additionally speaking for stationary rather than divided settlements is reasonably all the man-made capital investments in workshops, furnaces, storerooms/sheds, and other equipment related to iron production, all in turn requiring continuous maintenance. In addition, the sophisticated forging techniques attest to a required continuity in the blacksmith's line of work, i.e., to remain close to the workshop.

We consider the fishery as an important prerequisite for the increased sedentariness and apparent rapid interception of iron working by these groups, and then in terms of creating the necessary surplus. This reasoning is supported by the abundance of fish bones discovered at the settlement sites. Finds at the Sangis and Kosjärv sites of bone fragment patterning indicating dried fish (chewed vertebra) further overall imply a strategy to conserve/manage a surplus of resources. There is a complete lack of signs of reorganization after ironworking was taken up, furthermore indicating the fishery/surplus was already in place. Transmission studies suggest the introduction of pottery coincided with a significant shift towards exploitation and processing of aquatic resources, in turn creating conditions for increased sedentariness.[60] Hence, primary resources of pottery production are often in easy access by lake and river edge settings (as are primary resources of iron production).

Overall, our research so far shows that rather than in terms of power relations/control of production and specialization – with the most advanced skills organized by an elite[61] (such as migrating specialized smiths[62]), which is the typical way in literature to discuss the organization of iron technology – in this case it is more rewarding to discuss the organization in terms of actual local conditions as regards landscape, climate and economy. From doing that we gain an understanding of the reasonably necessary major community involvement (possibly the entire little community if considering the entire *chaîne opératoire*), and thus, reasonably necessary common agreement in the community to produce iron, flanked by a common need/desire for iron. They were hunter-gatherers with an economy centered on small game hunting and fishing rather than farmers –which is otherwise strongly emphasized in literature as a prerequisite for iron production – and had reasonably (due to landscape, climate, and economy) good use of, e.g., knives and axes. In addition, the production and manufacturing of iron (including the collection and preparation of primary resources) reasonably created a need for various new essential equipment, such as devices for moving the melt from the furnace to the hearth, and equipment and containers for quenching and annealing. At Sangis, estimates indicate a production amount of 80 kg of iron, to be compared with the estimated yearly iron consumption of a Late Iron Age farm, 2–5kg.[63]

In conclusion, our research shows it is time to significantly broaden the perspectives on hunter-gatherer communities in terms of specialization and complex organization, and so far, we haven't even touched upon the fact that maintaining technology over generations certainly required long-term organization and balancing with other subsistence activities. To ascribe to iron a merely symbolic value for these communities, as is common in the literature so far, is to seriously simplify. Hence, it is a global problem/phenomenon that only symbolic value is attributed to metals in overall poorly explored perceived peripheral areas.[64] We call for expanded use of archaeometrical methods to possibly uncover peripheral locations/regions other than Arctic Europe with advanced and early metalworking. We further propose, to fully comprehend the implementation of iron and the underlying mechanisms behind the transmission and maintenance of iron technology, that the full environmental and social setting (landscape, climate, and economy) must be considered.[65]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Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Caption, Figure 1

Figure 1. Analysed sites in northern Fennoscandia.

Norway: 1. Hemmestad Nedre, 2. Flakstadvåg, 3. Øvreværet, 4. Røsnesvalen, 5. Slettnes, 6. Fjære, 7. Makkholla, 8. Virdnejavre 112, 9. Hellervikjä, 10. Mestersanden

Finland: 11. Kemijärvi, Neitilä, 12. Kajani, Äkälänniemi, 13. Rovaniemi, Riitakanranta, 14. Rovaniemi, Kotijänkä, 15. Mikkeli, Kitulansuo, Ristiina, 16. Lahti, Kilpisaari

Sweden: 17. Vivungi, Jukkasjärvi 723, 18. Sangis, Nederkalix 842, 19. Nåttiholmen, SMA 4006, 20. Revi, SMA 929, 21. Revi, SMA 3319, 22. Revi, SMA 4131, 23. Hoppot, NA 36, 24. Sangis, Nederkalix 730, 25. Sangis, Nederkalix 797, 26. Rappasundet, 27. Revi Saxplats, 28. Sandudden, NA 53, 29. Sandudden, NA 54, 30. Sandudden, Ö Gottjärn, NA 55, 31. Sandudden, NA 80, 32. Sandudden, NA 82, 33. Sandudden, NA 83, 34. Vallen, Nederluleå 90, 35. Måttsund, Nederluleå 134, 36. S Holmnäs, NA 303, 37. Gottjärnmynnet, NA 69, 38. Snotterholmen, NA 71A, 39. Sandudden, NA 79, 40. Räktjärv, Töre 50, 41. Bergnäsudden, NA 16, 42. Kosjärv, Töre 510, 43. Månsträsk, NA 2145, 44. Notvik, NA 2153, 45. Tellek, 46. Masseviken, NA 357, 47. Nåludden, NA 397, 48. Vivungi, ore survey, 49. Vuolgamjaur, NA 202, 50. Abraur, NA1738, 51. Abraur, Åmynne, NA 36, Apl, 52. Skidträsk, NA 2179, 53. Ö Sguegesuolo, NA 48, 54. Vivungi, experiment

Table 1. Analysed sites in northern Fennoscandia

No	Country	Site	Site Id	Context	Production step	Material
1	Norway	Hemmestad Nedre	No number	Production site	Smelting	Slag, furnace wall
2	Norway	Flakstadvåg	No number	Production site	Smelting	Slag, furnace wall
3	Norway	Øvreværet	No number	Dwelling site	Smelting/primary smithing	Slag with metal inclusions
4	Norway	Røsnesvalen	26980	Hut	Smelting/smithing	Hearth lining or furnace wall, slag (?)
5	Norway	Slettnes	No number	Hut	Secondary smithing	Slag, iron fragment, iron object
6	Norway	Fjære	No number	Dwelling site	Secondary smithing	Slag, hearth lining
7	Norway	Makkholla	150901	Dwelling site	Secondary smithing	Hearth lining, slag
8	Norway	Virdnejavre 112	No number	Dwelling site	Smithing?	Sandstone with slag layer
9	Norway	Hellervikjä	46967	Hut	Finished object	Fragment of iron object (knife?)
10	Norway	Mestersanden[1]	56557	Dwelling site	Finished/semifinished objects	Iron fragment, bone with metallic iron
11	Finland	Kemijärvi, Neitilä	320010104	Dwelling site	Smelting	Slag, furnace wall, iron waste
12	Finland	Kajani, Äkälänniemi	205010002	Dwelling site	Smelting	Slag, furnace wall, iron waste
13	Finland	Rovaniemi, Riitakanranta	699010474	Dwelling site	Smelting	Slag, furnace wall, iron waste
14	Finland	Rovaniemi, Kotijänkä[2]	699010469	Dwelling site	Smelting	Slag
15	Finland	Mikkeli, Kitulansuo, Ristiina	696010026	Dwelling site	Smelting	Slag, lining (slag pit), iron waste
16	Finland	Lahti, Kilpisaari	532010021	Dwelling site	Smelting	Slag, lining (slag pit)
17	Sweden	Vivungi, Jukkasjärvi 723	L1994:8821	Production site	Smelting	Ancient ore
18	Sweden	Sangis, Nederkalix 842	L1992:9207	Production site	Smelting	White metal, clips
19	Sweden	Nåttiholmen, SMA 4006	L1995:364	Dwelling site	Smelting & smithing	Slag, lining
20	Sweden	Revi, SMA 929	L1995:53	Dwelling site	Smithing	Slag, lining
21	Sweden	Revi, SMA 3319	L1996:9978	Dwelling site	Smelting	Slag
22	Sweden	Revi, SMA 4131	No number	Dwelling site	Smithing	Slag, lining
23	Sweden	Hoppot, NA 36	L1996:9593	Dwelling site	Smelting/primary smithing	Metallic iron
24	Sweden	Sangis, Nederkalix 730	L1992:6497	Dwelling site	Primary & secondary smithing	Slag, lining
25	Sweden	Sangis, Nederkalix 797	L1992:8588	Dwelling site	Primary/secondary smithing	Slag, lining, metallic iron
26	Sweden	Rappasundet	L1996:9944	Dwelling site	Smithing	Slag, lining
27	Sweden	Revi Saxplats	No number	Dwelling site	Smithing	Slag, lining
28	Sweden	Sandudden, NA 53	L1996:9040	Dwelling site	Smithing	Hearth lining, lining
29	Sweden	Sandudden, NA 54	L1996:8099	Dwelling site	Primary & secondary smithing	Slag, lining, metallic iron, stone
30	Sweden	Sandudden, Ö Gottjärn, NA 55	L1996:8103	Dwelling site	Smithing	Slag, lining, stone
31	Sweden	Sandudden, NA 80	L1996:7942	Dwelling site	Smithing	Slag
32	Sweden	Sandudden, NA 82	L1996:8958	Dwelling site	Primary/secondary smithing	Slag, lining, metallic iron
33	Sweden	Sandudden, NA 83	L1995:4248	Dwelling site	Smithing	Slag
34	Sweden	Vallen, Nederluleå 90	L1992:5168	Hut	Primary/secondary smithing	Slag, metallic iron, stone
35	Sweden	Måttsund, Nederluleå 134	L1992:918	Dwelling site	Smithing	Slag
36	Sweden	S Holmnäs, NA 303	L1995:2336	Dwelling site	Smithing?	Lining
37	Sweden	Gottjärnmynnet, NA 69	L1996:8638	Dwelling site	Smithing?	Slag, lining
38	Sweden	Snotterholmen, NA 71A	L1996:8026	Dwelling site	Smithing?	Lining
39	Sweden	Sandudden, NA 79	L1996:7938	Dwelling site	Smithing?	Lining, fresh ore
40	Sweden	Räktjärv, Töre 50	L1992:3598	Grave	Finished object	Knife, iron
41	Sweden	Bergnäsudden, NA 16	L1996:9129	Dwelling site	?	Slag (?)
42	Sweden	Kosjärv, Töre 510	L1992:5683	Dwelling site	Semifinished/finished objects	Slag(?), metallic iron, needle
43	Sweden	Månsträsk, NA 2145	L1995:3887			Fresh ore
44	Sweden	Notvik, NA2153	L1995:3875			Fresh ore
45	Sweden	Tellek	No number			Fresh ore
46	Sweden	Masseviken, NA 357	L1995:3605			Fresh ore
47	Sweden	Nåludden, NA 397	L1995:2182			Fresh ore
48	Sweden	Vivungi, ore survey	No number			Fresh ore
49	Sweden	Vuolgamjaur, NA 202	L1995:2480			Fresh ore
50	Sweden	Abraur, NA1738	L1995:6070			Fresh ore
51	Sweden	Abraur, Åmynne, NA 36, Apl	No number			Fresh ore
52	Sweden	Skidträsk, NA 2179	L1995:6955			Fresh ore
53	Sweden	Ö Sguegesuolo, NA 48	L1996:9549			Fresh ore
54	Sweden	Vivungi, experiment	No number		Experimental smelting	Slag, metallic iron

[1]From the Mestersanden site in Norway only one find was available during our research visit.
[2]From the Kotijänkä site in Finland only a minor part of the find material was available during our research visit, with the result that only one find was sampled. This find had previous been interpreted as part of a ceramic bellow tube, but our analyses indicate that this is slag formed in connection to the air-inlet.

Table 2. Radiocarbon dating, Finland

Site	Sample	Context	Material	14C-age (BP)	Lab id
Kemijärvi, Neitilä	KM 16145:68	1.5 m outside the furnace	Charcoal in slag	2074 ± 33 BP	Ua-64344[1]
Kemijärvi, Neitilä	KM 16145:1678	1 m outside the furnace	Carbon extracted from steel	1968 ± 31 BP	Ua-66062[1]
Kajani, Äkälänniemi	KM 21213:55_1	Furnace, slagheap	Charcoal in slag	2195 ± 31 BP	Ua-64343[1]
Kajani, Äkälänniemi	KM 21213:55_2	Furnace, slagheap	Carbon extracted from steel	1970 ± 28 BP	Ua-67778[1]
Rovaniemi, Riitakanranta	KM 26172:391	3.5 m outside the furnace	Carbon extracted from steel	2048 ± 28 BP	Ua-66063[1]
Rovaniemi, Riitakanranta	KM 25374:107_2	Furnace	Carbon extracted from steel		Undatable[1]
Mikkeli, Kitulansuo, Ristiina	KM 28960:1749_2	Furnace	Carbon extracted from steel	1722 ± 42 BP	Ua-67779[1]
Mikkeli, Kitulansuo, Ristiina	KM 28960:2224	Furnace, slagheap	Carbon extracted from steel		Undatable[1]
Kajani, Äkälänniemi			Charcoal	2220 ± 100 BP	Hel-2098[2]
Kajani, Äkälänniemi			Charcoal	2180 ± 90 BP	Hel-2101[2]
Rovaniemi, Riitakanranta		Furnace	Charcoal	2090 ± 100 BP	Hel-2955[3]
Rovaniemi, Riitakanranta		Furnace	Charcoal	1820 ± 110 BP	Hel-2965[3]
Rovaniemi, Kotijänkä			Charcoal	1560 ± 90	Tku-034[3]
Rovaniemi, Kotijänkä			Charcoal	1750 ± 90	Tku-035[3]
Rovaniemi, Kotijänkä		Furnace	Charcoal	1880 ± 110	Hel-3173[3]
Mikkeli, Kitulansuo, Ristiina		Furnace	Charcoal	1530 ± 80 BP	Hel-3837[4]
Lahti, Kilpisaari I		In connection to the furnace	Charcoal	AD 550	Unpublished[5]

[1]This study; [2]Schulz, Eeva.-Liisa. "Ein Eisenverhiittungsplatz aus der alteren Eisenzeit in Kajaani," Iskos 6 (1986):169-173.; [3]Kotivuori, Hannu. "Pyytiijistli kaskenraivaajiksi," in *Rovaniemen historia vuoteen 1721: kotatulilta savupirtin suojaan, e* d. M. Saamisto et al. (Jyviiskylii, 1996), 34-125.; [4]Lavento, Mika. "An iron furnace from the Early Metal Period at Kitulansuo in Ristiina, in the Southern part of the Lake Saimaa water system," Fennoscandia archaeologica XVI (1999): 75–80.; [5]Saipio, Jarkko. "Nastola Kilpisaari 2 – Esihistoriallisen röykkiön elämänkaari," Muinaistutkija 1 (2015): 2–18.

Table 3. Radiocarbon dating, Norway

Site	Sample	Context	Material	14C-age (BP)	Lab id
Hemmestad Nedre	11225C	Structure I (furnace)	Charcoal (pine)	2300 ± 30	Ua-67109[1]
Hemmestad Nedre	11225B	Furnace II	Charcoal in slag (coniferus tree)		Undatable[1]
Slettnes	9433e	Smithing	Charcoal on iron (deciduous tree/birch?)	1189 ± 29	Ua-67108[1]
Øvreværet	11297:2	Smelting/primary smithing	Carbon extracted from steel included in slag	281 ± 26	Ua-67777[1]
Hemmestad Nedre		Furnace I	Charcoal (pine/birch)	2344 ± 69	T-14761[2]
Hemmestad Nedre		Furnace I, slagheap	Charcoal (pine/birch)	2360 ± 89	T-14762[2]
Hemmestad Nedre		Furnace II	Charcoal (birch)	2351 ± 67	Tua-2662[2]
Hemmestad Nedre		Furnace II, below furnace (slag pit?)	Charcoal (pine/birch)	2255 ± 68	Tua-2663[2]
Hemmestad Nedre		Charcoal kiln	Charcoal (foliferous trees)	2247 ± 70	T-14763[2]
Flakstadvåg		1 m outside the furnace	Charcoal (pine)	1747 ± 37	T-13126[2]
Flakstadvåg		Furnace	Charcoal in slag (pine)	1793 ± 34	Wk-20639[2]
Slettnes		Tuft F204	Charcoal	1160 ± 70	Beta-52220[3]
Slettnes		Tuft F204	Charcoal	1250 ± 80	Beta-52219[3]
Øvreværet			Charcoal	2296 ± 70	T-4296[4]
Øvreværet		Tilv. 1981/43, F56	Organic material adhered to ceramics	2380 ± 55	TUa-2448[5]
Fjære			Ceramics	2860 ± 110	T-6151[6]
Makkholla		Felt II, rute 42x, -3y, lag 2	Reindeer antler	2280 ± 100	T-4815[7]
Makkholla		Felt III, rute 5x, -1y, lag 3	Charcoal (birch)	2400 ± 110	T-4814[7]
Mestersanden		Cultural layer, area 3	Fishbone	1650 ± 90	T-1728[8]
Mestersanden		Cultural layer, area 3	Fishbone	1700 ± 90	T-1729[8]
Mestersanden		Cultural layer, area 4	Reindeer antler	1770 ± 90	T-2743[8]
Mestersanden			Ceramics	2550 ± 100	T-6147[6]
Mestersanden			Ceramics	2170 ± 90	T-6472[6]
Mestersanden			Ceramics	2450 ± 120	T-6474[6]

[1]This study; [2]Jørgensen, Roger. *Production or trade?: the supply of iron to North Norway during the Iron Age*. (PhD diss, Universitetet i Tromsø, 2010).; [3]Hesjedal, Anders, Damm, Charlotte, Olsen, Björnar and Storli, Inger. *Arkeologi på Slettnes: dokumentasjon av 11.000 års bosetning* (Tromsø, Tromsø museum 1996). [4]Jørgensen, Roger. "The early metal age in Nordland and Troms," *Acta Borealia* 3, no 2 (1986): 61-87.; [5]Andreassen, Dag Magnus. *Risvikkeramikk. En analyse av teknologisk stil på Nordkalotten i sein steinbrukende tid.* (Master's thesis, Universitetet i Tromsø, 2002).; [6]Jørgensen, Roger., & Olsen, Björnar. Asbestkeramiske grupper i Nord-Norge:2100 f. Kr.-100 e. Kr. *Tromura*, Kulturhistorie nr. 13. Universitet i Tromsø, Institutt for museumsvirksomhet (1988).; [7]Olsen, Björnar. *Stabilitet og endring. Produksjon og samfunn i Varanger 800 f. Kr. – 1700 e. Kr.* (PhD diss, Universitetet i Tromsø, 1984).; [8]Helskog, Knut. 1980. "The chronology of the younger stone age in Varanger, North Norway. Revisited," *Norwegian Archaeological Review* 13, no 1 (1980): 47-54.

Table 4. Radiocarbon dating, Sweden

Site	Sample	Context	Material	14C-age (BP)	Lab id
Sandudden, NA 82	No 30	Smithing	Charcoal in slag (pine)	1747 ± 30	Ua-69699[1]
Sangis 797		Smithing	Charcoal in slag (pine)	1676 ± 36	Ua-69700[1]
Revi	SMA 3319	Smelting	Charcoal in slag (pine)	1955 ± 30	Ua-69701[1]
Sangis 842	F13:1	Furnace, slag heap	Charcoal in slag (pine)	2295 ± 35	Ua-38706[2]
Sangis 842		Furnace, slag heap	Charcoal (birch)	2025 ± 30	Ua-40588[2]
Sangis 842	F759	Furnace, slag heap	Carbon extracted from steel (iron waste)	1994 ± 31	Ua-57787[2]
Sangis 842		Furnace, slag pit	Charcoal (birch)	1950 ± 32	Ua-40589[2]
Sangis 730	F1112	Smithing hearth A4	Charcoal in slag (pine)	2980 ± 100	Ua-36293[2]
Sangis 730	F7045	Smithing hearth A4	Carbon extracted from steel (iron waste)	2186 ± 29	Ua-59598[2]
Sangis 730		Smithing hearth A4	Charcoal (pine)	2125 ± 30	Ua-33335[2]
Sangis 730	F925	Smithing hearth A4	Carbon extracted from steel (iron waste)	1981 ± 77	Ua-59595[2]
Sangis 730	F2768	Structure A27	Pottery	2740 ± 30	Poz-23960[2]
Sangis 730		Structure A27	Burnt bone	2720 ± 110	Poz-23611[2]
Sangis 730	F1784	Structure A27	Charcoal (organic residue next to bronze buckle)	1990 ± 30	Poz-23733[2]
Sangis 730	F2771	Structure A27	Carbon extracted from steel (unidentified object)	1966 ± 34	Ua- 59597[2]
Sangis 730	F3010	Structure A27	Carbon extracted from steel (iron waste)	1895 ± 30	Ua-36296[2]
Sangis 730		Structure A29	Charcoal (crowberry, small twigs)	1885 ± 30	Poz-23737[2]
Sangis 730		Structure A29	Burnt bone	1850 ± 50	Poz-23610[2]
Sangis 730	F3763	Smithing hearth, A45	Charcoal in slag (pine)	2430 ± 75	Ua-36294[2]
Sangis 730		Smithing hearth A45	Burnt bone	2115 ± 35	Poz-23608[2]
Sangis 730	F1840	Smithing hearth A53	Carbon extracted from steel (iron waste)	2150 ± 30	Ua-59596[2]
Sangis 730	F913	Smithing hearth A53	Charcoal in slag (pine)	1915 ± 35	Ua-36292[2]
Sangis 730	F2684	Single find within site	Carbon extracted from steel (socketed axe)	2115 ± 30	Ua-36295[2]
Sangis 730	F878	Single find within site	Carbon extracted from steel (knife)	1831 ± 41	Ua-59594[2]
Vivungi 723		Furnace 2, slag pit	Charcoal (pine)	2076±32	Ua-57488[2]
Vivungi 723		Furnace 2, slag heap	Charcoal (pine, twig/branch)	1962±31	Ua-57487[2]
Vivungi 723	Id 392	Furnace 2, slag heap	Carbon extracted from steel (iron waste)	1899±32	Ua-57788[2]
Vivungi 723		Furnace 2, slag heap	Charcoal (pine)	1820±32	Ua-57491[2]
Vivungi 723		Furnace 3, slag heap	Charcoal (pine)	2124±32	Ua-57489[2]
Vivungi 723		Furnace 3, slag pit	Charcoal (pine, twig/branch)	2035±32	Ua-57490[2]
Vivungi 723	Id 1759	Furnace 3, slag heap	Carbon extracted from steel (iron waste)	1998±31	Ua-57789[2]
Vivungi 723		Single find within site	Charcoal in slag (birch)	2097±29	Ua-51279[2]
Töre 50		Grave	Chremated human bones	1761 ± 39	Ua-51569[3]
Nederluleå 90	Kp 6	Dwelling site, house	Charcoal	2000 ± 35	Ua-36800[4]
Nederluleå 90	Kp 16	Dwelling site, house	Organic material adhered to ceramics	2035 ± 30	Ua-36801[4]
Nederluleå 90	Kp 13	Dwelling site, house	Charcoal	2060 ± 35	Ua-36802[4]
Nåttiholmen	128	Dwelling site	Organic material adhered to ceramics	2 286 ± 30	Ua-72702[5]
Nåttiholmen	131	Dwelling site	Organic material adhered to ceramics	2 177 ± 30	Ua-72703[5]
Nåttiholmen	237	Dwelling site	Organic material adhered to ceramics	2 413 ± 31	Ua-72704[5]
Nåttiholmen	304	Dwelling site	Organic material adhered to ceramics	2 321 ± 30	Ua-72705[5]
Nåttiholmen	308	Dwelling site	Organic material adhered to ceramics	2 313 ± 30	Ua-72706[5]
Kosjärv		Dwellingsite	Burnt bone	2280 ± 40	Ua-33179[6]

[1]This study; [2]Carina Bennerhag, Lena Grandin, Eva Hjärthner-Holdar, Ole Stilborg and Kristina Söderholm, Hunter-gatherer metallurgy in the Early Iron Age of northern Fennoscandia, Antiquity 95(384) (2021): 1511–26.; [3]Bennerhag, Carina. *En brandgrav från romersk järnålder . Arkeologisk räddningsundersökning av Raä Töre 50:1, grav- och boplatsområde.* Norrbottens museum rapport 2015:16. Luleå: Norrbottens museum, 2015.; [4]Bennerhag, Carina. *En boplatsvall från förromersk/romersk järnålder. Delundersökning av Raä 90, Nederluleå socken, Norrbottens län* . Norrbottens museum rapport 2012:6. Luleå: Norrbottens museum, 2012.; [5]Nils Harnesk, Norrbottens museum, E-mail to author, March 23, 2023; [6]Östlund, Olof, Palmbo, Frida and Jonsson Mirjam. *Mötesstation Kosjärv, Bondersbyn 2:2, Töre sn, Norrbottens län, Västerbotten* . Norrbottens museum dnr 384-2006. Luleå: Norrbottens museum, 2006.

[1] Carina Bennerhag, Sara Hagström Yamamoto, and Kristina Söderholm, ”Towards a Broader Understanding of the Emergence of Iron Technology in Prehistoric Arctic Fennoscandia,” *Cambridge Archaeological Journal 33*(2) (2023): 265-279.

[2] In 2021 we published results of steel production at two pre-Roman hunter-gatherer sites in the coastal and inland areas of northernmost Sweden, see Carina Bennerhag, Lena Grandin, Eva Hjärthner-Holdar, Ole Stilborg and Kristina Söderholm, Hunter-gatherer metallurgy in the Early Iron Age of northern Fennoscandia, *Antiquity* 95(384) (2021): 1511–26.

[3] Roger Jørgensen, “Production or Trade? The Supply of Iron to North Norway during the Iron Age” (PhD diss., Tromsö University, 2010); Lars Forsberg, “Assymetric twins? Some reflections on coastal and inland societies in the Bothnian area during the Epineolithic and Early Metal Age,” in *Local Societies in Bronze Age Northern Europe*, eds Nils Anfinset and Melanie Wrigglesworth (Sheffield: Equinox Publishing, 2012), 31–5; Lars Ivar Hansen and Bjørnar Olsen, *Hunters in Transition: An outline of early Sámi history* (Leiden: Brill, 2014).

[4] Roger Jørgensen, “Prehistoric iron production in north Norway,” *Acta Archaeologica* 82 (2011): 97–128; Øyvind Sundquist, “Traces of iron in prehistoric Finnmark,” *Fennoscandia Archaeologica* 16 (1999): 47–57.

[5] See, e.g., Hansen and Olsen, *Hunters in Transition*, 43; Erik Norberg, “The Meaning of Words and the Power of Silence” in *The Indigenous Identity of the South Saami*, eds Håkon Hermanstrand, Asbjørn Kolberg, Trond Risto Nilssen and Leiv Sem (Springer, Cham, 2019): 65–89.

[6] Ingela Bergman, Olle Zackrisson and Lars Liedgren, “From Hunting to Herding: Land Use, Ecosystem Processes, and Social Transformation among Sami AD 800–1500,” *Arctic Anthropology* 50, no. 2 (2013): 25–39.

[7] The Sami live mainly in Sweden, Norway, Finland, and Russia (and constitute indigenous people in the three first-mentioned nations), and they form one of several minorities in northernmost Sweden. Swedish archeology and history writing often interpret the advent of reindeer pastoralism (in archaeology evidenced by a change in settlement patterns around AD 800) as being linked to Sami group formation. Archeology further shows that, in addition to reindeer herding, other economic activities (such as early cultivation and livestock keeping) existed in northernmost Sweden at the same time (Kristina Söderholm and Carina Bennerhag, “Reflections over an Arctic research process and the importance of the local place”, forthcoming).

[8] Hansen and Olsen, *Hunters in Transition*, 53f.

[9] Lars Forsberg, ”Forskningslinjer inom samisk förhistoria (Research lines within Sami prehistory),” Arkeologi i Norr 6/7 (1993/94): 165–86; Hansen and Olsen, Hunters in Transition, 39ff; Norberg, The meaning of Words, 68.

[10] Sami archaeology has emerged among parts of the Arctic European archaeologists since the 1980s in the wake of rather strong postcolonial and ethnopolitical movements in the region.

[11] Karin Ojala and Carl-Gösta Ojala, “Northern Connections: Interregional Contacts in Bronze Age Northern and Middle Sweden," *Open Archaeology* 6, No. 1 (2020): 151-171; Charlotte Damm and Lars Forsberg, “Forager–Farmer Contacts in Northern Fennoscandia,” in *The Oxford Handbook of the Archaeology and Anthropology of Hunter-Gatherers*, eds Vicki Cummings, Peter Jordan and Marek Zvelebil (Oxford University Press, Oxford Academic, 2014): 838–56.

[12] Andre Leroi-Gourhan, *Gesture and Speech* (translated by Anna Bostock Berger). (Cambridge: Massachusetts Institute of Technology, 1993).

[13] Olivier Gosselain, “Social and technical identity in a clay crystal ball,” in *The archaeology of social boundaries*, ed Miriam T Stark (Washington: Smithsonian Institution Press, 1998): 78–106; Pierre Lemonnier, *Elements for an Anthropology of Technology* (University of Michigan Press, Museum of Anthropological Archaeology, 1992).

[14] Tim Ingold, “The temporality of the landscape,” *World Archaeology* 25, No. 2 (1993): 152–174.

[15] Carla S. Hadden, Gregory A. Waselkov, Elizabeth J. Reitz and C. Fred T. Andrus, “Temporality of fishery taskscapes on the north-central Gulf of Mexico coast (USA) during the Middle/Late Woodland period (AD 325–1040),” *Journal of Anthropological Archaeology* 67 (2022): 101436.

[16] Ingela Bergman, ”Från Döudden till Varghalsen. En studie av kontinuitet och förändring inom ett fångstsamhälle i övre Norrlands inland, 5200 f. Kr – 400 e. Kr. (From Döudden to Varghalsen. A study of continuity and change within a hunter-gatherer society in the upper Norrland hinterland, 5200 BC – 400 AD)” (PhD diss., Umea university, Umea, Sweden, 1995): 194ff.

[17] Robert L Kelly, *The Lifeways of Hunter-Gatherers: The Foraging Spectrum* (Cambridge, Cambridge University Press, 2013): 171.

[18] Bergman, Från Döudden,194ff.

[19] Thomas Wallerström, *Norrbotten, Sverige och medeltiden: Problem kring makt och bosättning i en europeisk periferi. Del 1 (Norrbotten, Sweden and the Middle Ages: Problems of power and settlement in a European periphery. Part 1.)* (Stockholm: Almqvist & Wiksell International, 1995).

[20] Inga-Maria Mulk,”Sirkas: ett samiskt fångstsamhälle i förändring Kr.f.-1600 e.Kr (Sirkas: a Sámi hunting community in change from the birth of Christ until 1600 AD)” (PhD diss., Umea university, Umea, Sweden, 1994); Lars Forsberg, “Site Variability and Settlement Patterns. An analysis of the hunter-gatherer settlement system in the Lule River Valley, 1500 B.C. - B.C./A.D.” (PhD diss., Umea university, Umea, Sweden, 1985).

[21] Jørgensen, *Production or trade?*; Bartolotta, Kim NA, et al. "Slag as evidence for early iron production in arctic Norway." *Acta Borealia* 5.1-2 (1988): 22-33.; Bartolotta, Kim NA, et al. “The Analysis of Bloomery Slag from Arctic Norway.” *Acta Archaeologica*, Vol. 61 (1990): 212-219.; Hood, Brian & Olsen, Björnar. Virdnejavre 112. A Late Stone Age – Early Metal Period site in interior Finnmark, North Norway. Acta Archaeologica 58 (1988):105-125; Sundquist, Traces of iron; Buchwald, Vagn Fabritius, *Iron and steel in ancient times* (Copenhagen, Royal Danish Society of Sciences, 2005); Annika Grälls, ”Något om slaggförekomster i Övre Norrland (Something about slag deposits in upper Norrland)” (Bachelor's thesis, Uppsala University, Uppsala, Sweden, 1986).

[22] Already at the time of publishing, interpretations of some of the analytical results were questioned, see Espelund, A. (1989). Comment on the paper: “Slag as evidence for early iron production in arctic Norway” by Kim NA. Bartolotta et al. (Acta Borealia 1988/1–2).

[23] Bennerhag et al, Hunter-gatherer metallurgy.

[24] Bennerhag et al, Hunter-gatherer metallurgy.

[25] Bennerhag et al, Towards a Broader.

[26] See, e.g., Nathaniel L. Erb-Satullo, “Towards a Spatial Archaeology of Crafting Landscapes,” *Cambridge Archaeological Journal* 32, No. 4 (2022): 567–583.

[27] E.g., Bennerhag et al, Hunter-gatherer metallurgy; Jørgensen, Production or Trade?; Forsberg, Assymetric twins?.

[28] The typological division of furnace constructions was first established in Radomir Pleiner, *Iron in Archaeology: The European bloomery smelters* (Prague, Archaeological Institute of Avér, 2000). For the Arctic European area see Jorgensen, Production or trade?; Kotivuori, Hannu. "Tidiga spår av järnhantering i norra Finland." *Ovnstypologi og ovnskronologi i den nordiske jernvinna. Portal: Kristiansand* (2013): 55-58.

[29] See e.g., David Dungworth,"Metals and Metalworking" in *The Oxford Handbook of Roman Britain*, eds Martin Millett, Louise Revell and Alison Jane Moore (Oxford: Oxford University Press, 2014): 532–554; Paul Rondelez, "The Irish bowl furnace: origin, history, and demise," *The Journal of Irish Archaeology* 26 (2017): 101–116; Eva Hjärthner-Holdar, Lena Grandin, Katarina Sköld and Andreas Svensson, "By who, for whom? Landscape, process, and economy in the bloomery iron production AD 400–1000," *Journal of Archaeology and Ancient History* 21 (2018): 1–50.

[30] Hjärthner-Holdar et al, By who, for whom?; Bennerhag et al, Hunter-gatherer metallurgy.

[31] For exception see

[32] Vincent Serneels and Sébastien Perret, "Quantification of smithing activities based on the investigation of slag and other material remains," in *Proceedings of the Archaeometallurgy in Europe conference,* Milan September 24-26, Vol. II (2003): 469-478.

[33] See discussion in Nathaniel L. Erb-Satullo and Joshua T. Walton, "Iron and copper production at Iron Age Ashkelon: Implications for the organization of Levantine metal production," *Journal of Archaeological Science: Reports* 15 (2017): 8-19.

[34] Prevailing organizational view of iron working in Europe (which is mainly based on materials from the Late Iron Age) is the primary forging of the raw iron was carried out at the smelting site and first thereafter distributed (in terms of iron bars) to various workshops. See, e.g., Sylvan Bauvais and Phillipe Fluzin, "Archaeological and archeometrical approaches of the *chaîne opératoire* in iron and steelmaking: methodology for a regional evolution study," in *Techniques and people: anthropological perspectives on technology in the archaeology of the proto-historic and early historic periods in the southern Levant*, eds Steven Rosen and Valentine Roux (Paris, De Boccard, 2009): 157–178.

[35] Mia Englund and Eva Hjärthner-Holdar, ”Smeden – en aktör i järnhanteringens långa kedja (The blacksmith – an actor in the long chain of ironworking)," in *At Upsalum – människor och landskapande. Utbyggnad av Ostkustbanan genom Gamla Uppsala*, eds Lena Beronius Jörpeland, Hants Göthberg, Anton Seiler and Jonas Wikborg (Stockholm, Statens historiska museer: Arkeologerna, 2017): 153–172.

[36] Roger Jørgensen, "The social and material context of the Iron Age blacksmith in north Norway," *Acta Borealia* 29, No. 1 (2012): 1–34.

[37] Sundquist, Traces of iron

[38] Stepanov, Ivan S., Lee Sauder, Jake Keen, Vanessa Workman and Adi Eliyahu-Behar. "By the hand of the smelter: tracing the impact of decision-making in bloomery iron smelting." *Archaeological and Anthropological Sciences* 14.5 (2022): 80.

[39] Marcos Martinón-Torres and Thilo Rehren, "Technical Ceramics," in *Archaeometallurgy in a Global Perspective*, eds Benjamin W Roberts and Christopher P Thornton (New York, Springer, 2014): 107–131; Stilborg, Ole. "The study of clay-built bloomery furnace shafts in Sweden–Ceramological analyses of an important part of iron production through 1500 years." *Journal of Archaeological Science: Reports* 47 (2023): 103808.

[40] Bennerhag et al, Hunter-gatherer metallurgy.

[41] Aschan, Joh:s. ”Om några förekomster af manganrik sjömalm i norra Savolax (On occurrences of enrichment in managanese in the lake ores of Savolax),” *Teknikern* 456 (1906): 78-80.

[42] Naumann, Einar. ”Södra och mellersta Sveriges sjö- och myrmalmer (Lake and bog ores of south and central Sweden),” Sveriges Geologiska Undersökningar, Serie C 297 (1922): 178–194.

[43] See, e.g., Bennerhag et al, Hunter-gatherer metallurgy; Hjärthner-Holdar et al, By who, for whom?; Peter Crew, Michael Charlton, Philippe Dillman, Philippe Fluzin, Chris Salter, Edmond Truffaut, ”Cast iron from a bloomery furnace,” in *The archaeometallurgy of iron: recent developments in archaeological and scientific research*, eds Jiří Hošek, Henry Cleere and Ľubomír Mihok (Prague, Institute of Archeology, Academy of Sciences of the Czech Republic, 2011): 239–316.

[44] Hjärthner-Holdar et al, By who, for whom?

[45] Crew et al, Cast iron from a bloomery.

[46] Gilmour, Brian. "The metallurgy, development, and purpose of pattern welding." *Historical Metallurgy* 51.2 (2017): 57-70.

[47] Güder, Ümit, Marie-Henriette Gates, and Ünsal Yalçın. "Early iron from Kinet Höyük, Turkey: analysis of objects and evidence for smithing." *Metalla, Deutsches Bergbau-Museum Bochum* 23 (2017): 51-65.

[48] Radomir Pleiner *Iron in archaeology: early European blacksmiths* (Prague, Institute of Archaeology of the Czech Academy of Sciences, 2006). This book is considered a central work in European ancient iron research, and in maps of the spread of the advanced smithing techniques in Europe, the arctic parts are not even on the map.

[49] Pleiner, *Iron in archaeology: early European*.

[50] Kelly, *The lifeways of hunter-gatherers*, 171.

[51] Evgeny V. Vodyasov, Ivan S. Stepanov, Timur R. Sadykov, Evgeniya M. Asochakova, Evgeniya S. Rabtsevich, Olga V. Zaitceva and Ivan A. Blinov, ”Iron metallurgy of the Xianbei period in Tuva (Southern Siberia),”

Journal of Archaeological Science: Reports 39 (2021): 103160.

[52] Brosseder, Ursula, Ernst Pohl, Damdinsüren Tseveendorzh, Lkhagvadorzh Munkhbayar, Alexandra Osinska and Sven Linzen. "The innovation of iron and the Xiongnu–a case study from Central Mongolia." *Asian Archaeology* (2023): 1-33.; Martin Winther Olesen, Astrid Skou Hansen, Peter Mohr Christensen and Torben Egeberg, “Iron Smelting in Central and Western Jutland in the Early Iron Age (500 BC – AD 200),” in *The coming of iron: the beginnings of iron smelting in Central Europe,* eds Markolf Brumlich, Enrico Lehnhardt & Michael Meyer (Rahden-Westf: VML, 2020): 61-80.; Markolf Brumlich, “The Teltow – an early Iron Smelting District of the Jastorf Culture,” in *The coming of iron: the beginnings of iron smelting in Central Europe,* eds Markolf Brumlich, Enrico Lehnhardt & Michael Meyer (Rahden-Westf: VML, 2020): 127-154.

[53] Lewis R. Binford, “Organization and formation processes: looking at curated technologies,” *Journal of Anthropological Research* 35, No. 3 (1979): 255–73.

[54] Bergman, Från Döudden.

[55] Naumann, Södra och mellersta Sveriges sjö-och myrmalmer.

[56] See references in: Liam Frink and Karen G. Harry, “An exploration of Arctic ceramic and soapstone cookware technologies and food preparation systems,” in *Ceramics in Circumpolar Prehistory: Technology, Lifeways and Cuisine*, eds Peter Jordan and Kevin Gibbs (Cambridge, Cambridge University Press, 2019).

[57] Bergman, Från Döudden.

[58] Eva Hjärthner-Holdar, "14C-analyser av kolprover från Röda Jordenområdet," *Riksantikvarieämbetet Analysrapport 23* (1998): 371–372.

[59] Binford, Organization.

[60] Peter Jordan and Marek Zvelebil (eds), *Ceramics before Farming: The dispersal of pottery among prehistoric Eurasian hunter-gatherers* (London/New York, Routledge, 2003).

[61] See discussion in Erb-Satullo, Towards a Spatial.

[62] Markolf Brumlich, “The Teltow – an Early Iron Smelting District of the Jastorf Culture,” in *The Coming of Iron. The Beginnings of Iron Smelting in Central Europe. Proceedings of the International Conference*, Freie Universität Berlin, Excellence Cluster Topoi, 19–21 October 2017 (2020): 127–154.

[63] Bennerhag et al, Hunter-gatherer metallurgy; Hjärthner-Holdar et al, By who, for whom?.

[64] Shadreck Chirikure, *Metals in past societies: A global perspective on indigenous African metallurgy* (New York, Springer, 2015).

[65] Peter Jordan and Kevin Gibbs, *Ceramics in Circumpolar Prehistory* (Cambridge, Cambridge University Press, 2019).

Appendix D

Paper IV

Reflections on an Arctic research process and the importance of the local place

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Reflections on an Arctic Research Process and the Importance of the Local Place

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Abstract

While reflecting over a defined research process, the place for our scholarly deed and focus area, Arctic Sweden, emerge as an influencing factor so strong it made us deviate in a major way from our planned research path at several times. It was partly about us having to relate to literature dealing with our place/region marked by persistent center/periphery perspectives, where our 2200-year-old findings of advanced iron technology in the hands of ancient arctic hunter-gatherers were totally at odds. The research process was also influenced by the place in terms of its legacies of (and partly continued) marginalization (in relation to the rest of Sweden) and large-scale and long-term national (to part also international) exploitation of its natural resources, which not least affect/ed the indigenous Sami and other minorities of the region. Today, the minorities' quest for recognition is expressed in strong ethnopolitical currents including, not least, ambitions to re-write history/fill the gaps in history writing, meaning challenging expectations can emerge of historians/archaeologists. Groups striving for recognition is a global postcolonial phenomenon, and we discuss consequences arising from this for the individual historian and for history writing. We also give examples of fruitful interdisciplinary ways out when literature has (too) little to contribute to the interpretation of your findings.

Keywords: Arctic Sweden; Place; Ancient hunter-gatherers; Research process; Iron and steel production; Postcolonialism; The Sami; Minorities; History writing; Center/periphery; Exploitation; Revitalization movements

Introduction

During research on ground-breaking findings of advanced iron and steel production in ancient Arctic (northernmost) Sweden[1], we (signed) to a high degree experienced the research process like a roller coaster, where we in addition to feelings of thrill experienced a loss of control over turns. It was a disruptive research process, continuously influenced by external features in ways we did not foresee. The experience made us pause and reflect on the paves chosen or not and why, and it is these (more or less free/conscious) choices and the reasons behind that we will address in the following. Over time our reflective process made us realize the place for our scholarly deed and focus area, Arctic Sweden, influenced our research process in a major way.

The research took place within a five-year research project (2016-2021) conducted in collaboration between Swedish archaeologists and historians of technology, with central elements of archaeometallurgy (the chemistry and microstructure of metallurgical remains) on 2200-year-old finds of advanced iron and steel production (i.e., contemporary with Roman steel production) in Arctic Sweden, pushing back the introduction of iron production 2,000 years to this today largest iron ore producing region in the EU, and into the hands of hunter-gatherers.[2] Hence, these are findings of a break-through character within the major historical narrative over the introduction of metals and its importance for the development of civilizations and nations.[3]

To start with, our research process was influenced by the fact we had to relate to literature dealing with the prehistory of our place/region (ancient Arctic Sweden) marked by persistent center/periphery perspectives where our findings are totally at odds, with all that entails in the form of a need to pave the way for our results/lack of previous research to interpret our findings through. The research process was also influenced by the place in terms of its legacies of (and partly continued) exploitation and marginalization, above all as encapsulated in the mindsets of large parts of the population. The concept of place is used in several disciplines – such as in sociology, human geography, and anthropology – often with focus on the perceptions of, and social meanings associated with places, where in turn conflicting perceptions of places can become sources of social division.[4] The local place which we refer to here is largely (but not only) related to a variety of old and newer perceptions of Arctic Sweden, more or less loudly articulated in literature or in the public debate, which we find have influenced our research process in a major way.[5]

In addition to perceptions, it is about legacies rooted in long-term (and continuing) large-scale national (to part also international) interests in the natural resources (minerals, forests, hydropower) of Arctic Sweden, interests which have resulted in many layers of institutions, footprints in landscape and painful memories, such as of the oppression of the indigenous Sami and other minorities of the region. And today there is a related strive for recognition taking

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[1] Bennerhag, Grandin, Hjärthner-Holdar, Stilborg and Söderholm, ”Hunter-gatherer metallurgy”.

[2] Bennerhag, Grandin, Hjärthner-Holdar, Stilborg and Söderholm, ”Hunter-gatherer metallurgy”.

[3] Metals and especially iron play the main role in both several national history narratives, such as the Swedish and the north American (Karlsson and Magnusson, *Iron and the Transformation of Society*; Misa, *A Nation of Steel*), and in the general global narrative on the development of nations/regions (Pleiner, *Iron in archaeology*), and particularly steel when it comes to the modern world (Diamond, *Guns, Germs, and Steel*). Even in the contemporary narrative on how to reach a climate-neutral society, (rare) metals play a leading role (Buchert, Schüler and Bleher, *Critical Metals*).

[4] For an overview, see; Beland Lindahl, Baker and Waldenström, "Place Perceptions and Controversies".

[5] The impact of the local place which we refer to is thus neither related to the methodology of ego-histoire – focusing on the connections between the context of a scholar's life and research and the content they produce, the situatedness of the scholar (Cole, "The History That Has Made You"; Berger and Ellis, "Composing Autoethnographic Stories") – nor to the various approaches to local or situated knowledge typically associated to either the long tradition of knowledge studies from the margins of society (Haraway, "Situated knowledges"; Harding, *Whose Science?*) or sustainability science (Lam, Hinz, Lang, Tengö, von Wehrden and Martín-López, "Indigenous and local knowledge").

place in terms of a rather loud multicultural ethno-politic debate and identity building in parallel to ongoing national reconciliation processes (we provide a fuller overview of the legacies and perceptions we intend for Arctic Sweden in the *Background* below).

In these rather typical (we find traces of them in many other places on earth[6]) postcolonial phenomena of recognition – often in the "periphery" (in relation to traditional "centers") – the expectations of the professional historian/archaeologist to contribute with particular history writing can be far-reaching. Hence, it is justified to, as we will do in the *Concluding discussion*, also reflect on what this means for the research process of the individual historian/archaeologist when she conducts research in and about such a place, and in extension to history writing. It is generally accepted that a fundamental task for scientific work is to contribute to a kind of infrastructure for organized knowledge and discussion that leaves an impression in the public debate and in people's norms and self-concept.[7] Our case is an example of when such expectations are pushed to the limit, i.e., when the individual professional historian/archaeologist continually met expectations (sometimes conflicting) and needs far beyond the basic scientific ones. Can we perhaps name it a "melting-pot" to do research in and about as historians/archaeologists?

In the following (after the Background) we will explore the paves chosen or not and why during our research process, where the local place for our scholarly deed and focus area emerges as a central impact factor. To reflect more deeply on the research process, what choices are made and why, are often close at hand for the critical historian.[8] However, it is not common for the historian, or indeed scholars in general to focus to a significant extent (i.e., in addition to a defined method section) on sharing such reflections within the framework of scholarly writings. Our case shows how such reflection on a deeper level, in addition to being enlightening to the individual researcher/research group, and for readers who want to evaluate the findings, also can generate important lessons for history writing in general. Hence, in the *Concluding discussion*, in addition to summarizing the main features of our chosen paves, at a general level we discuss the impact of the place (particularly "melting-pots" -locations) to individual historians/archaeologists and to history writing (we also discuss some related research policy aspects). We further reflect on the important openings we consider our interdisciplinary collaboration[9] offered – in this case between historians of technology and archaeologists, with central elements of archaeometallurgy – to our research process. We believe our experiences in this regard, of interdisciplinary/combined perspectives, can be useful to other historians/archaeologists focusing on the often-underexplored periphery. A sub-purpose of this article is to present the ground-breaking findings of advanced iron and steel production in ancient Arctic Sweden to a wider audience. Below follows first the Background to our place. We would like to point out that when we started the research project, we did not have the background to our place clear to us, and especially not in terms of the impact it exerted on our research process.

Background

Sweden is in the northern outskirts of Europe, and the northernmost outskirt of Sweden is in the Arctic. The region is geographically characterized by the Skanderna mountain range, large

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[6] Gilbert, *Indigenous Peoples' Land Rights*.
[7] Broström, *Forskningens uppgifter i samhället*, 5.
[8] Tosh, *The Pursuit of History*.
[9] Interdisciplinary collaboration is increasingly common in many sciences (including history and archaeology), not least in relation to climate change issues, where more effective solutions for various challenges often require crossing disciplinary boundaries. Hence, interdisciplinary study allows for a synthesis of ideas and characteristics from many disciplines, and it is often in the borders between multiple scientific fields where discoveries and advances in research and development are more likely to happen (Duerr and Herkommer, "Why does interdisciplinary research matter?").

forest areas and several large rivers. The area is sparsely populated. Most of Sweden's population (10 million) lives in the southern half of the country. Only about 11% live in the northern half, such as the majority of the Indigenous Sami living in Sweden (20,000-40,000 people is estimated to consider themselves Sami today[10]). In addition to the Sami (and the Swedish majority), there are also other groups, such as the Tornedalingar minority living in Arctic Sweden. Overall, the minorities seek recognition today, which we will return to below. However, for the melting-pot (as we perceive our place to represent to us) to emerge more clearly, we need to first draw a closer background to Arctic Sweden and its population. It is largely about riches in the form of natural resources and a multi-cultural population, where strong external interests through large-scale extraction (and related infrastructure) caused/causes wounds in local memories and landscape, alongside antagonisms. At the same time, it is about tenacious center-periphery views, where Arctic Sweden, as the outermost periphery of Sweden and Europe, is neglected in many contexts, alternatively, represents something to be conquered.

The prehistory of Arctic Sweden started already 10 000 years ago, when small hunter-gatherer groups arrived, after a 100,000-year-old vast inland ice sheet began to melt away. For millennia, a nomadic lifestyle based on hunting of reindeer, elk, seal, birds, and small-game mammals, together with fishing (both lake and sea) and the gathering of plants, featured the subsistence of the area. Due to the harsh climate, ancient cultivation and livestock keeping have generally been considered extremely difficult for the region. However, in recent years archaeological and palynological evidence (such as burnt bones and pollen from lake sediments) show the hunter-gatherer subsistence in the region varied widely from around 2000 BC and onwards, with several complementary economic forms in terms of both livestock keeping (indicated by sheep/goat bones and dairy fats on ceramics)[11] and the domestication of plants[12], alongside hunting, fishing, and gathering.

During Late Iron Age (from around AD 800), changes in the settlement pattern (from lake shores settlements to settlements by reindeer pastures) can be observed in Arctic Sweden, changes which have been interpreted as the consolidation of several hunter-gatherer groups alongside a transition from hunting and fishing to reindeer herding (and this, in turn, is generally interpreted as the emergence of the Sami as a group).[13] In parallel, there are indirect indications (from pollen records) of continuously developed cultivation and livestock keeping in the area.[14] Permanent cultivation (equaled with permanent settlement), is established around AD 1000-1100 in the lower part of Torne River/northernmost coast of The Gulf of Bothnia) based on both palynological and archaeological evidence.[15] In historical sources from the 9th century onwards (i.e., in the account of the North Norwegian “Norse“ chieftain Ohthere, and in the Icelandic medieval Egil's saga) there are several different groups of people mentioned living in the area, including the Sami[16] (at the time named Finns, however also applying to *Finnar*), and

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[10] The figure is estimated by the Sami Parliament (established in 1993), authority and at the same time popularly elected Sami parliament with the aim of improving the possibilities of the Swedish Sami as an indigenous people to preserve and develop their culture (www.sametinget.se).

[11] Palmbo, ”Bronsålder i Norrbottens kustland”; Pääkkönen, Bläuer, Olsen, Evershed and Asplund, ”Contrasting patterns”.

[12] Segerström, *The Post-Glacial History.*

[13] Hansen and Olsen, *Hunters in Transition*; Bergman, Zackrisson and Liedgren, “From hunting to herding”; Aronsson, “Pollen evidence of Saami settlement”; Hedman, *Boplatser och offerplatser*.

[14] Hörnberg, Josefsson, Bergman, Liedgren and Östlund,” Indications of shifting cultivation”; Segerström, *The Post-Glacial History*; Bergman and Hörnberg, “Early cereal cultivation”.

[15] Wallerström, *Norrbotten, Sverige och medeltiden;* Elenius, “Were the Kainulaiset”; Segerström, ”Vegetationshistoriska perspektiv”.

[16] Mentioned by Ohthere as hunter-gatherers with decoy reindeers.

the Kvens[17]. Yet, the meaning of these ethnonyms is not well described in the historical sources, and they have altered their meaning (dependent on context) through time.[18]

Overall, historical, archaeological and linguistical evidence show Arctic Sweden for long has been a multi-cultural arena inhabited by people with a linguistic diversity (evident through local place names in Finnish, Swedish and Sami) and with a multitude of overlapping economic strategies, mainly hunting and fishing but also cultivation, livestock farming and reindeer husbandry.[19] First in the sixteenth century, nation-state formation (and a related escalating extraction of the Arctic natural resources) led to the development of static ethnic identities making the region the contentious landscape it is today.[20] Today a decisive majority of the Swedish Arctic population consider themselves Swedes and have Swedish as their native language. Some of these identify themselves also as Sami, Tornedaling, Kvän or Lantalainen, where the three latter identities in different ways are partly based in geographic areas, partly in the languages Tornedal Finnish and Meänkieli, partly in the livelihood of agriculture and permanent setting (distinctive to the traditional nomadic Sami).

The prevailing view in archaeology/iron research is that the knowledge to produce iron and steel only came to the area when the ore-breaking mountain men from the south imported it here in the 17th century.[21] Ever since, and especially since the 19th century, the region is heavily characterized by natural resource extraction of great importance to Swedish national economy and politics, and overall for nation-building. It is about mineral-, forestry -and hydropower extractions which over the last few hundred years and still today strongly influence the development of the Arctic society. Especially the extraction and handling of metals (the region is by far the largest producer of iron in the EU) were central in the civilization process and the creation of the Swedish nation state.[22] Hence, this has strongly influenced national history writings, and still in recent publications iron production in terms of the establishment of the mining industry in the 17th -18th centuries is highlighted as *the* process creating preconditions for the building of the Swedish society.[23]

Because of the great national interest in the extraction of the arctic natural resources, the Swedish state recurrently, at least until the middle of the 20th century, identified Arctic Sweden as an area in need of modernization, civilization or "Swedishisation", for defense policy, nationalist and/or economic reasons. Iron and iron technology formed the basis for industrialization and was what finally, after long time and through southern immigration of miners made the arctic part of the country "civilized".[24] In parallel, the region adopted the image of the "Future Land", Sweden's own Frontier/Klondyke in the public debate, from where riches would spread across Sweden, people would settle, and business would flourish.[25] The image of the northern region as Future Land is still highly relevant. Hence, today there is a rather loud national public idea and debate that the green transition first should take place in Arctic Sweden, such as in terms of an expanded utilization of the region's hydropower resources in ore

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[17] Described by Ohthere as people residing in "the land of Cwenas" east of the Scandinavian mountain range and in Egils saga mentioned as a group of people living in the far east (Kvenland) (todays northern Sweden) with their king Faravid.
[18] Wallerström, *Vilka var först?*
[19] Bergman, "Finnar, lappar, renar och bönder"; Bergman and Ramqvist, "Farmer-fishermen"; Wallerström, *Norrbotten, Sverige och medeltiden*; Wallerström, "Were there really East Saami winter camps".
[20] Lindholm, Ersmark, Hennius, Lindgren, Loftsgarden and Svensson, "Contesting marginality"; Elenius, "The dissolution of ancient Kvenland".
[21] Pleiner, *Iron in archaeology*; Buchwald, *Iron and Steel*; Norberg, *Forna tiders järnbruk*; Hansson, *Från Nasafjäll till SSAB*.
[22] Hagström Yamamoto, *I gränslandet mellan svenskt och samiskt*.
[23] Karlsson and Magnusson, *Iron and the Transformation of Society*.
[24] Loeffler, *Contested Landscapes*; Ojala and Ojala, "Northern connections"; Ojala, *Sámi Prehistories*; Hagström Yamamoto, *I gränslandet mellan svenskt och samiskt*.
[25] Sörlin, *Framtidslandet*.

processing.[26] In parallel, something of a mining boom has been going on in the region since the 1990s, and according to the OECD, the region has the potential to become a world leader in mining.[27] Particularly the older version of the northern region as Future Land alongside the civilization ideas were anchored in tenacious center-periphery and social-evolutionary views in line with the World-system theory of social evolution.[28] Such old-world ideas are further, as we will show below, still strongly anchored in iron research.

The disparaging and discriminatory view of the region has included its population, and above all the indigenous Sami and other minorities who repeatedly throughout history have been subjected to state abuses in terms of land-confiscation and forced displacement and Christianizing of the Sami, and later (from the late 19th century), intense "Swedishisation" initiatives of both the Sami and of Finnish-speaking minorities (e.g., you were only allowed to speak Swedish in schools).[29] In the 1920s and -30s, discrimination also included biological racism in terms of, e.g., skull measurements.[30] Within a European and global context of internationally developed minority rights, the Sami were granted indigenous status in 1977 (prop. 1976/77:80, bit 1976/77:KrU43), but it is only in recent decades, within the framework of postmodern identity creation, that the voices of the indigenous Sami for once are really heard.[31] This is reflected, inter alia, in the emergence of Sami archeology as a new discipline aiming for (with focus on the Sami) counter forcing the often-derogatory view of the Arctic north in traditional Swedish as well as international history writings. The Finnish-speaking minorities of Arctic Sweden also strive for recognition and identity creation from claiming their own history/origin. The identity creation of the minorities overall comes to its strongest expression through protracted land use (including hunting and fishing rights) conflicts. Hence, when the Sami strive for land rights and the Swedish government through acts of reconciliation and based on the legal institute *Urminnes hävd* (Immemorial prescription[32]), grants exclusive tenure rights (of hunting and fishing) for areas of thousands of square kilometers (which were previously state-managed) to the Sami exclusively[33], this contributes to antagonisms between groups of the population (i.e., the nation-state's causation to the contentious landscape continues to this day). Hence, hunting and fishing is a central cultural (and also economic) activity for large parts of the Arctic population (regardless of which possible minority or majority you belong to).

The recent governmental application of *Urminnes hävd* alongside the general postmodern identity creation of the Arctic minorities overall contribute to the rather common question for archaeologists and historians of the region to face: Who were the first on this site? And often the questioner has quite definite ideas about whose/which group's cultural heritage a certain ancient relic should "belong to". [34] In parallel and as part of the general era of recognition, the Swedish state (2020/21) has appointed two Truth and Reconciliation Commissions, one for the Sami, and one for the Tornedaling, Kvän and Lantalainen.

Today, the long-term and large-scale natural resource extraction and historical layers of abuses and oppression of parts of the population have created partly wounded relations between the Arctic and the rest of Sweden in a broad sense. Memories and traces of the often-irreversible downsides of natural resource extraction in the local environment and economy are palpable in the regional public discourse, landscape, and population, alongside resonances of

[26] Lundmark, Carson and Eimermann, ”Spillover, sponge or something else?”.
[27] www.northsweden.eu.
[28] Wallerstein, ”The rise and future demise”.
[29] Persson, *Då var jag som en fånge*; Lundmark, *Stulet land*.
[30] Hagerman, *Käraste Herman*.
[31] Elenius, ”Nationella minoriteters symboliska nationsbyggande”.
[32] An ownership right acquired by using the land for a long time without anyone stopping you (Allard and Brännström, ”Girjas sameby mot staten”).
[33] Allard and Brännström, ”Girjas sameby mot staten”.
[34] Lundström, *Historisk rätt?*

discrimination and center-periphery views, and connected processes of recognition and reconciliation.

Concerning further the general archaeological situation of Arctic Sweden, it is a fact the region is poorly explored archaeologically, which is mainly due to a generally disparaging view of it's potential to produce archaeological finds of value, especially regarding iron technology.[35] These long held views have resulted in relatively few archaeological surveys in the region, and this is applicable to the entire Circumpolar area.[36] The topic of iron metallurgy in the Arctic Fennoscandian region (i.e., Arctic Sweden, Finland, and Norway) – as it is generally established (our findings will hopefully change this) – says the vast region, by and large up to modern times only came across iron through trade. And this although an abundance of metallurgical remains in the form of slag (a by-product that arises from various types of metallurgical processes) and even iron production sites have been recovered in the region over the years.[37] Slags were not least recovered during the first (and only) more extensive archaeological fieldwork taking place in northernmost Sweden, i.e., in the 1940s to the 1980s due to large-scale hydropower expansion and connected lake regulations. Still, these were virtually neglected in archaeological research.[38]

We see several and partly interdependent reasons for the neglection, with clear elements of a generally derogatory and discriminatory view of the region. Firstly, presumptions on the origin of iron technology are based on long-held models of Old World ferrous metallurgical developments, with early iron technologies used by hunter-gatherers totally at odds. Secondly, the chronological systematization of the metallurgical record has been considered almost impossible as the metallurgical finds were recovered alongside typical Stone Age finds, obviously not correlating to the chronology of the Three-Age system (the assumed evolutionary stages of Stone, Bronze, and Iron Age), which was the typical reference for dating. Additionally, using analytical methods such as radiocarbon dating was never considered although this was otherwise practiced for a long time in European iron research. Thirdly, slag has been considered waste material with limited information. If found in the same contexts as typical Stone Age finds, they were simply assumed to constitute evidence of a late use of stone tools rather than early knowledge of iron, meaning the Arctic hunter-gatherer communities still today are imposed with a "delayed stone age"/evidence of never fulfilling the expected stages of development.[39] The poor attitude has prevailed ever since. Hence, although there is a growing body from the 1980s onwards of evidence of local iron production sites from the Late Bronze Age and Early Iron Age in Arctic Finland and Norway[40], these finds (alongside other metallurgical finds) have been continuously dismissed as insignificant expressions of small-scale and simple/underdeveloped iron production, as anomalies and a mere result of imports via trade or exchange. No comprehensive attempts have yet (i.e., prior to our research) been made to analyze this material.[41]

Below we present the research process with a focus on the paves chosen or not and why. The layout is chronological to the extent we first deal with the period immediately before we

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[35] Bennerhag, Hagström-Yamamoto and Söderholm, "Towards a broader understanding".
[36] Cooper, Mason, Mair, Hoffecker and Speakman, "Evidence of Eurasian metal alloys"; Dyakonov, Pestereva, Stephanov and Mason, "The Spread of Metal".
[37] Bennerhag, Hagström-Yamamoto and Söderholm, "Towards a broader understanding".
[38] We know the lake-regulation archaeological material yield a relatively large amount of metallurgical remains since we (signed) went through parts of the material and found large amounts of slag that was not dated and usually not even catalogued, see also below in the main text.
[39] Serning, *Övre Norrlands järnålder*; Zachrisson, *Lapps and Scandinavians*; Hakamäki and Kuusela, "Examining the topography".
[40] Jørgensen, *Production or trade?*
[41] For an exception (in part), see; Jørgensen, *Production or trade?*

initiated the research project, and then the implementation of the research project (including an archaeological survey).

The research process

Archaeological survey of coast site Sangis and initiation of interdisciplinary collaboration

During the late 00s, when a major infrastructural public investment (albeit far from on par with the lake regulations in the 1940s-1980s) in the form of a new railway route along Sweden's northernmost coastline became relevant, Norrbotten County Museum carried out the required archaeological (rare) survey along the railway route. Uncovering an area of ca 7000 m^2 it constituted the largest archaeological excavations in northernmost Sweden over the last 50 years. At a site named Sangis, the examination resulted in finds of a breakthrough character, i.e., evidence that iron technology (including bloomery steel production and smithing) was an integrated part of the hunter-gatherer subsistence in Arctic Sweden already 2 200 years ago. Hence, it revealed a workshop area (containing metallurgical debris of predominantly smithing slags) at a hunter-gatherer habitation site, and less than 500m away, a bloomery furnace and debris from iron smelting (e.g., slags, technical ceramics, iron waste). Scattered habitation remains were also found in the furnace area. Radiocarbon analyses indicate that iron and steel production was initiated 200-50 BC (i.e., contemporary with the Romans), and maintained for at least 400 years.[42]

When the director of the archaeological excavation, Stone Age archaeologist Bennerhag, tried to find out the state of knowledge and slowly realized the breakthrough character of the metallurgical findings, she initiated a dialogue with the County Administrative Board to get further funding for more extensive analyses. Sweden’s northernmost County Administrative Board (in contrast to those further south) was not at all accustomed to such extensive archaeological efforts, or to burden developers with such expenses, and the case even returned to the developer (the national Traffic authority), with whom Bennerhag herself had to negotiate. In the end, far from granted, she managed to require the needed funding. Her archaeological unit at the County Museum had never analyzed metallurgical finds, but she sought out the leading player in metallurgical analyses in northern Europe, the Geoarchaeological Laboratory/Research Unit (GAL) in Uppsala, Sweden.

By integrating radiocarbon dating and integrated archaeometallurgical and ceramic analyses, GAL reconstructed central parts of the production process and revealed evidence of an elaborate craftsmanship including bloomery steel production and the mastering of advanced smithing techniques. Numerous finds of iron waste consisting of high-quality steel reflect the mastering of successful smelting processes, including high-temperature operations. Particularly the presence of cast iron indicates extreme temperature conditions in the furnace. This suggest the smelters both possessed extensive knowledge of different ore properties and were aware of the refractory properties of clays. Hence, one of the most critical passages while allowing high temperatures is to maintain structural stability of the furnace shaft throughout the process. The deliberate production of different steel qualities is confirmed from numerous steel objects found at the Sangis smithing site, showing several different steel alloys and combinations which in turn allowed very hard and tough edges to be produced. Several other types of iron were also used, including relatively soft ferritic iron and phosphoric iron with a higher ductility than carbon steel. The forged artefacts show an advanced craftsmanship, including skills in forge welding of composite constructions and heat treatments in several steps, traditionally associated with the Trans-Caucasian metallurgical center around 1200 BC and the Roman Empire in the

[42] Bennerhag, Grandin, Hjärthner-Holdar, Stilborg and Söderholm, ”Hunter-gatherer metallurgy”.

1st century BC (the latter thus contemporary with Sangis).[43] Overall, the findings show the smiths had thorough knowledge about the properties of each alloy, and which materials were suitable for different products.

Bennerhag continued to study the findings, and in the mid-10s, with encouragement from a new head of archaeology at the museum, Hagstrom-Yamamoto, it became relevant for Bennerhag to try initiate PhD studies on the topic. The nearest (local) university, Luleå University of Technology (LTU), did however not house archaeologists. Overall, LTU has rather small humanities- and social sciences departments as research (as well as education) mainly concerns technological aspects, and to a large extent the extraction and refinement of the region's natural resources. Hagstrom-Yamamoto and Bennerhag instead contacted archaeological institutions at two universities further south. The closest (300 km away) was not very interested, referring, among other things, to the fact that they were engaged in the younger Iron Age, and the findings in Sangis concerned the older Iron Age. At a larger and well-established older university 1100 km south, Bennerhag was welcome to initiate PhD studies if she brought full funding. Still, there was none.

At this stage, Bennerhag and Hagstrom-Yamamoto got in touch with the History of technology unit at LTU, and it was agreed to try to raise funding in collaboration. Was it perhaps possible to make it a partial history research project, such as searching for traces of the ancient iron handling in the Middle Ages? Unlike the archaeological institutions, the historians of technology found strong interest in the finds, and a couple of senior researchers were willing to try to write an application (for fundraising) together with the archaeologists. This was a multi-year process as the first applications did not generate funding. It was only when the group of archaeologists and historians of technology decided to try to make the research application more cross-disciplinary – instead of building-on a historical part on the archaeological – aiming at integrating the perspectives and trusting history perspectives would enrich the analysis of the archaeological finds, that funding was granted. This further meant Bennerhag become a PhD student in history of technology with professor (history of technology) Söderholm as main supervisor.

Why did scholars in history of technology choose to cross-disciplinary collaborate with local archaeologists? Söderholm is experienced in cross-disciplinary research with both social scientists and engineers. Still, she is normally a 20th century historian of technology, where the initiation of collaboration with stone-/iron Age archaeologists is a big step aside. Söderholm believes her thrill over the breakthrough-height of the finds in Sangis constituted a decisive reason for not considering the large time gap to be too great a hindrance. She further believes her local connection mattered, partly in terms of her feeling great thrill over the break-through findings in her backyard, partly in terms of her feeling satisfaction in the thought of contributing in spreading awareness of particularly these findings to the wider public in particularly this region, where iron muster such complex role and it should be meaningful for the population to find out iron- and steel production is a local knowledge with indeed long history. Söderholm furthermore believes the peripheral location of her university (in relation to other Swedish universities) mattered in terms of the high admissibility within her research unit (of historians) to enter unusual collaborations: it was already a highly cross-disciplinary research environment, typically due the secluded geographical location with hundreds of kilometers to other Swedish professional historians.

Overall, we can conclude that in this short analysis of the paves chosen or not and why in the years before we initiated the research-project, several aspects related to the place of our scholarly deed and focus area have been touched upon. Thus, the findings would probably not have been further scientifically explored had the place not even housed professional historians, which we believe is not a given at a technical university in the periphery. Those with experience

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[43] Pleiner, *Iron in archaeology*; Zavyalov and Terekhova, "Two iron technology diffusion routes".

from public universities at peripheral places around the world perhaps agree with us when we suggest these more often (than historians and archaeologists) house researchers of more “useful" disciplines (such as in the case of LTU, predominantly disciplines related to the extraction and refinement of the region's natural resources). At the same time, the local connection seems to have been of importance for the professional historians to choose to take on the project, and it may have been of importance they worked precisely at a university in the periphery, to be able to take such a broad step aside. So overall, the local place mattered in making the project happen, while the local in terms of the peripheral also came close to overturning the whole thing.

Archaeological survey of inland site Vivungi

In 2016, funds were received from the Swedish Research Council for a research project including an archaeological survey alongside integrated archaeometallurgical and ceramic analyses of new finds. Preparations immediately started for the archaeological survey of inland site Vivungi, where (undated) metallurgical remains in the form of slag and long settlement were established by previous surveys. The Vivungi site would turn out to muster evidence of an equally elaborate craftsmanship – including bloomery steel production – as in Sangis, thus further confirming the advanced technology of the ancient arctic hunter-gatherers. The Vivungi site revealed two bloomery furnaces about 30 m apart, including slag, technical ceramics, ore, and iron waste (of steel and even cast iron, usually related to a much later use of blast furnaces). Radiocarbon analyses indicate iron production started in Vivungi around 100 BC, and in each furnace area, scattered habitation remains were also found. Observed differences in curation strategies between the furnaces in Sangis and Vivungi further indicate the smelters were well acquainted with a variety of raw materials, and aware of their possibilities and limitations. Although the Vivungi site so far has not revealed evidence of a smithing site, the similarity in craftsmanship between the sites tells us it is reasonable to assume there was one. The scale of production is demonstrated from analyses of the furnaces in Sangis and Vivingi, showing each furnace was run several times. Based on the volume of slags, the estimated iron consumption of a Late Iron Age farm (2-5 kg/year)[44] and the calculated yield of Swedish limonite ore (5 kg iron metal from 10 kg ore)[45], the scale of production at each furnace (ranging from 9-80 kg iron) would have exceeded the consumption of a single household even if spread over several years.[46]

As parts of the advanced craftsmanship (such as the skills in forge welding and heat treatments in several steps) are contemporary(!) with the Roman Kingdom/Empire (800 BC–AD 500) – from where it according to literature is supposed to have spread like rings on water across Europe and eventually, at a much later date (17th century)[47], to the peripheral areas of Arctic Sweden – where did the knowledge/advanced craftsmanship originate (if we are now to go into that question)? Well, through Bronze Age finds, the hunter-gatherers of Arctic Fennoscandia are found connected with the Ananino Culture in north-western Russia as early as in the beginning of the second millennium BC[48], although these contacts are not yet particularly explored.[49] We suggest a far-reaching continuity in these contacts, which would have allowed for a rapid diffusion of iron metallurgy. Speaking for this are bronze finds at the Sangis smithing site with molding techniques and style with closest parallels in the Pyanobor culture (300 BC–AD 200), a direct heir of the Ananino culture. Also, the Pyanobor culture is characterized by

[44] Hjärthner-Holdar, Grandin, Sköld and Svensson, ”By who, for whom?”.
[45] Hjärthner-Holdar, Grandin, Sköld and Svensson, ”By who, for whom?”.
[46] Bennerhag, Grandin, Hjärthner-Holdar, Stilborg and Söderholm, ”Hunter-gatherer metallurgy”.
[47] Pleiner, *Iron in archaeology*; Buchwald, *Iron and Steel*.
[48] Forsberg, Asymmetrical twins?
[49] Ojala and Ojala, “Northern connections”.

specialized knowledge in iron handling, including both steel production and advanced forging techniques.[50]

We perceive it was of decisive importance for our broader interpretation and understanding of the archaeological findings (which we will tell you more about in the *Concluding discussion* below) that we collaborated interdisciplinary, historians of technology with archaeologists, and with central elements of archaeometallurgists. Our collective competence was further crucial for us arriving at the important insight about the tenacity of the traditional narratives of Old World ferrous metallurgical developments and its devastating impact on iron research in Arctic Fennoscandia along with other peripheral regions. Not least did history perspectives enrich the analysis by taking interest in the traditional narrative regarding other peripheral regions, regardless of how far away, geographically, they are located relative to our own. In parallel to the realization of the uphill battle in literature regarding the tenacity of the traditional narratives, which would cause us to seriously deviate from our planned path of research, we further became increasingly aware of the strong ethnopolitical forces wanting to influence our research.

The tenacity of traditional narratives alongside strong ethno-political forces

In line with traditional narratives, the origin of iron technology and its subsequent dispersal through time and space is recurrently the key theme in European iron research, as are the strong bias for evolutionary theories.[51] At the core of the origin discussion is the Single invention model, in which theories on diffusionism constitute a central framework. Based on an understanding that fundamental and complex innovations like metallurgy can only be invented once, the diffusion of iron technology from the origin/the center to other areas/the periphery is typically explained in a unilineal and one-directional sequence, reminiscent of a ripple diffusion model. The civilization concept is at the core of this line of reasoning, i.e., innovation diffusion presupposes civilizations. Historical overviews on the diffusion of iron technology across Europe typically focus on the civilizations of the Near East, Greece, and the Roman Empire, considered succeeding centers, innovators, and donors of iron technology crucial to the development of ferrous metallurgy in Europe.[52]

Other features of prevailing interpretations of the traditional narratives involve evolutionary perspectives on technological change, such as linking the emergence of iron technology to increasing social complexity and a sedentary agricultural lifestyle, and the Three-Age system resting on the idea iron technology was guided by a pre-existing understanding and knowledge of bronze and copper technology.[53] These evolutionary perspectives are continuously heavily influential and a non-questionable departure in much literature. Still, in our ancient Arctic case it is about hunter-gatherer communities without prominent sedentary elements and signs of an existing (before iron) bronze and copper knowledge. Such explanatory models consistently place perceived peripheral areas as the ancient Arctic at a great disadvantage, and the predominant scholarly opinion is the ancient arctic hunter-gatherers did not have any noteworthy role in metal technology on a broader European scale. We faced this continuously in meetings with international as well as some Swedish researchers, such as at conferences, where in dialogues between two researchers studying our posters we could overhear “do you really believe in this”, and sometimes in review-situations, where our findings/sources tend to be neglected.

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[50] Koryakova and Epimachov, *The Urals and western Siberia*.

[51] See Bennerhag, Hagström-Yamamoto and Söderholm, ”Towards a broader understanding”, for an overview.

[52] Childe, “Archaeological ages”; Wertime, “The beginnings of metallurgy”; Pleiner, *Iron in archaeology*; Buchwald, *Iron and Steel*.

[53] Kanjanajuntorne, ”The three-age system”; Eliyahu-Behar, Yahalom-Mack, Gadot and Finkelstein, “Iron smelting and smithing”.

The tenacity of the traditional narratives affects not only the Arctic region/the outermost periphery, but also even earlier iron finds (1st millennia BC) in central Sweden.[54] Hence, these are typically not acknowledged within European iron research, but considered imports or simply dismissed as evidence, and the radiocarbon datings are rationalized as contaminated.[55] Similar views apply also to the emergence of iron technology on the African continent and in the New World.[56] Hence, the center-periphery paradigm is a global phenomenon that influences peripheral areas of nations/regions/continents world-wide, not least in the broadest way that archaeological finds are less researched in these areas.[57] At the same time, these geographical areas have often in recent years experienced growing postcolonial, ethnopolitical and revitalization movements, with increasing criticism and deconstruction of national history writings alongside a critical debate on the construction of cultures and ethnicity. Often it manifests itself in an aspiration for restoration in the literature on pre-historic societies defined as less stratified or highly mobile. This is what we now are experiencing in Arctic Sweden in terms of the indigenous Sami and other minorities. Still, although the Arctic Fennoscandian revitalization movement of recent years strives to challenge the nationalist and socio-evolutionary ideas including the notion of the area as having a retarded and inferior cultural development[58], we find the ideas reverberates even in much post-1980s archeological research of the region. Hence, at the same time as this research often challenge traditional top-down models, the new explanatory models typically uphold the dichotomy between hunter-gatherers and farmers and interpret/organize the archaeometallurgical record within traditional frameworks, where Arctic Fennoscandia lack any noteworthy role.[59] This research further often openly strives to place the Sami ethnicity as far back in the past as possible, and therefore typically refers to the ancient hunter-gatherers in all of northern Fennoscandia, although wrongly according to us, as proto-Sami.

Our over time increasingly deepened understanding of the tenacity of the traditional narratives in literature, even in newer Sami literature, made us compelled to seriously deviate from our established research path (which was basically about deepening the understanding of the early iron production in the Swedish Arctic) to write an article that for once would make the tenacity clear, to make it stop.[60] On the one hand it was frustrating to see how the revitalization literature was still trapped, on the other hand it was about paving the way for our results, so they would have a chance of being better received by the scientific community than previous "premature" iron findings. What concerns in turn the rather strong ethno-political forces we face in our daily work (outside of literature) as historians/archaeologists with breakthrough results on ancient Arctic Sweden, these required a lot of reasoning in the research group, and the process was closely connected with the insights described above, on the tenacity of the traditional narratives also in newer Sami literature.

We have faced strong interest from representatives of the minorities of Arctic Sweden throughout our research proces. To some extent, this took place in our daily research environment, the History unit at LTU, which – even though we are only about 15 individuals – by and large reflected our region in terms of the division of the population into different minorities/majority, and likewise the ethno-political forces were found in our environment. It

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[54] Hjärthner-Holdar, *Järnets och järnmetallurgins introduktion*.
[55] Pleiner, *Iron in archaeology*; Bebermeier, Brumlich and Cordani, "The coming of iron"; Gassmann and Schäfer," Doubting radiocarbon dating".
[56] Killick and Fenn, " Archaeometallurgy".
[57] Killick and Fenn, " Archaeometallurgy"; White and Hamilton, *Ban Chiang*.
[58] Loeffler, *Contested Landscapes*; Ojala, *Sámi Prehistories*; Hagström Yamamoto, *I gränslandet mellan svenskt och samiskt*.
[59] Forsberg, *Forskningslinjer inom samisk förhistoria*; for examples, see: Hansen and Olsen, *Hunters in Transition*; Ramqvist, "Fem Norrland"; Kuusela, Nurmi and Hakamäki, "Unhierarchical and hierarchical core-periphery relations".
[60] See Bennerhag, Hagström-Yamamoto and Söderholm, "Towards a broader understanding".

differed how political we choose to be in our research work, still, one of our colleague researchers continuously encouraged us to establish it was proto-Sami groups producing steel in Sangis and Vivungi. Several colleague researchers further have/had assignments in the Truth and Reconciliation Commissions/alternatively in relation to the application of Immemorial prescription in court cases.

When we faced the ethno-political forces in the process of contributing new research, we felt a strong need to halt our research process and try to get an overview of the situation. This is when we realized the interest minority representatives typically show new archaeological finds have the same features as conventional narratives, i.e., with the greatest interest directed towards the very oldest finds (origin) and towards metal finds. Accordingly, the public showed particularly strong interest for Sangis once early iron production was established there, as well as later for Vivungi, when it was established also there. Metals are further typically attributed a central role in the Sami literature, i.e., what ultimately drives social development forward.[61] Also, the problems with an ethnic point of departure in history writing became increasingly clear to us. Like in previous national history writing, this is essentially about highlighting specific archaeological finds and prehistoric remains that suit the ruling historical narrative – typically based on the categorization of human societies into different types, attributed certain cultural traits etc. – and suppress anomalous finds, telling another/different story. Thus, it is basically about overshadowing/downplaying variations.[62] It is further about placing today's collective identities in prehistoric cultural landscapes, even without actual archaeological record supporting or identifying this.[63] In addition to contributing to a distorted history, such history writing contributes to exclude *other* groups, preventing them from feeling a sense of belonging with the finds/the history writing.

For us to assign any ethnic labels to our ancient finds would be to go against the scientific and "rational approach to history" that is the foundation of our education. Also, the exclusion aspect suits us poorly. Hence, the satisfaction in the thought of spreading awareness (iron and steel was a local ancient knowledge) among the Arctic population in a broad sense (beyond minorities/the majority), has all through been an important inherent drive to us (not least since this today is the largest iron ore producing region in the EU). We further experienced such collective feelings at the excavation site in Vivungi in 2019 when we arranged a combined popular communication activity/community based participatory research strategy.[64] As many as 350 visitors (representing both majority and minorities) attended from all over the region (there is only 10 permanent residents in Vivungi), and it was strikingly clear the visitors found great value in participating.

Regarding our professional responsibility and the coherent importance of our writings and statements for society's use of history, it was however still important to us not to try to isolate our research from the current movements.[65] Hence, in order to increase our readiness for the

[61] Forsberg, ”Forskningslinjer inom samisk förhistoria”.

[62] For example, see Hedman, who mention there are prehistoric remains (cocking pits) not fitting the forest Sami settlement pattern (emerging around AD 700), still, without referring to it further as an indicator of other subsistence/settlement patterns (Hedman, *Boplatser och offerplatser*).

[63] See for example Hansen and Olsen, suggesting the appearance of a Sami ethnicity in the last millennium BC as a process without any tangible material traces (Hansen and Olsen, *Hunters in Transition*); and Bergman and Hörnberg, claiming Saami cultivation around AD 500 based solely on pollen evidence and a geographically defined setting (Sápmi) without any links to the archaeological material/social context of Sami (a connection to the Sami environment/context is a possible explanation, but not the only one) (Bergman and Hörnberg, "Early Cereal Cultivation").

[64] This not only informed locals of Vivungi about the pioneering discoveries and advanced knowledge of their ancestors, but also generally expanded our understanding of the archaeological material, such as regarding the local availability of pivotal raw materials (Haywood, "A ´Sense of Place´ in Public Participation").

[65] Rüsen, ”Berättande och förnuft”.

political dimensions[66] of our writings and archaeological finds, we tried to deepen our knowledge of the broader ancient history of the Arctic, and particularly what literature said regarding the rise of the various population groups (minorities and majority). Still, this proved close to impossible since, overall, there is very little literature on the subject, and what still exists, this mostly focus on one *minority* only, often the Sami[67]. The few first paragraphs of the Background on this theme is an attempt from our side to contribute to more balance in literature. Overall, the ethno-political dimensions of “our” place has taken up a lot of our time, and it is especially the experiences of this aspect of the local place-impact that form the basis of the present article, which then constitutes article number two which deviate from our established research path.

Concluding Discussion

The analysis of the research process shows it was disruptive, not least in the sense we, at two (!) times, felt urged to deviate heavily from our established research path (to deepening our understanding of the early iron production in the Swedish Arctic) in terms of writing unplanned scientific journal articles, of which the present article is one (in the spring of 2023, we have in total published/submitted 4 journal articles related to the project). The analysis further shows how this in a broad sense can be explained by the place for our scholarly deed and focus area, Arctic Sweden. In part it has to do with the step-motherly treatment in literature of our place, where there is very little to draw upon for the understanding of iron technologies in the hands of ancient Arctic hunter-gatherers, why we felt urged, in order to pave the way for our results, to point this out in a scientific article.[68] We feel we have our fruitful collaboration (historian of technology/archaeologist) to thank for this insight, as well as possibly the peripheral location of LTU, for the collaboration to even come about.

In part it has to do with the legacies of our place in terms of long-term and continuing Swedish national (to part also international) natural resource interests in the Arctic and a related marginalization, exploitation and (to part) oppression of the Arctic population (especially its minorities), over time evolving into postcolonial ethnopolitical recognition processes. Our increasing insight of the problems with the ethno-politically colored history writing – which (overall) was the only recent literature we had to relate to regarding ancient arctic Sweden – together with our experiences of ethnopolitical forces as historian and archaeologist with an ancient focus, urged us to again deviate heavily from our established research path to write the present article. Hence, it is worrying, especially when there is not yet a considerable amount research at all about a region´s early history (as is the case for Arctic Sweden compared to the rest of Sweden), when the neglect of certain finds alongside interpretations made on weak empirical grounds, create a distorted history/false model of reality, which further downplay variations in human societies and their interactions. It is furthermore worrying (not least in a place like ours, with several minorities alongside a majority, and partly hurtful relations) when ethnic prefixes of archaeological finds and history writing contribute to exclude *other* groups, preventing them from feeling a sense of belonging with the finds/the history writing.

Here we can testify that although we strongly strived not to contribute in our writings to either a continued stepmotherly treatment of the Swedish Arctic, or ethno-politically colored history writing, it has been a great challenge not to slip there, because pretty much all the literature we relate to have either (or both) tendencies. Here we see a danger for history writing in general, as historian/archaeologist with your entire surrounding (both literature and colleagues) politically colored, are you even aware you follow that path yourself?

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[66] Lundström, *Historisk rätt?*
[67] Elenius, “Were the ´Kainulaiset´”; Bergman and Hörnberg, “Early cereal cultivation”; Hedman, *Boplatser och offerplatser*; Ojala, “Contested colonial history”.
[68] Bennerhag, Hagström-Yamamoto and Söderholm, ”Towards a broader understanding”.

Concerning our experiences of ethnopolitical forces as historian and archaeologist with an ancient focus, it has taken a lot of time to increase our readiness for the political dimensions of our writings and archaeological finds. Add to that the time to prepare for (and carry out) meetings with representatives of minorities trying to claim their history, and (from time to time) strong expectations (due to your, as researcher, local situatedness and area of focus) to muster research results and specialist knowledge in government investigations and court trials with a central place in the public debate, then we should be able to talk about a "melting-pot" to work in and focus research on as historians and archaeologists. In addition to the vulnerability it may mean for the individual researcher to act in a "melting-pot" -region, it can also be a heavy burden for the small (few individuals) historical and archaeological institutions generally operating at universities (and perhaps especially so in peripheral areas such as the Swedish Arctic?) to bear expectations and needs linked to both revitalization and reconciliation movements, land use conflicts and a generally crying-need for extended archaeological excavations and new history writings. This, in turn, has bearing on the literature and public debate about the regional importance and benefit of universities, which we believe would be enriched by including central cultural values, such as those we see expected from local historians and archaeologists in the Swedish Arctic to contribute with, to the otherwise rather one-sided focus on triple/quadruple-helix (university–industry–government/society interactions[69]) effects in terms of innovation and entrepreneurship.

Overall, our lessons about the impact of the place should be important for historians/archaeologists in many other places on earth, and perhaps especially so in peripheries experiencing post-colonial revitalization movements. Although the place meant a lot of uphill for our research process, we want to emphasize the legacies of the place also contributed a central drive throughout the research process, a strong desire to spread knowledge of the findings to the population of our region. We also found a strong drive (yes, even a feeling of having found the very key away from outdated explanatory frameworks and ethnic bias) through our combination of perspectives and methods from archaeology, history of technology, and archaeometallurgy. Hence, not only did we find tools to empirically reconstruct the different (technical) steps in the production process, but also the social context in terms of choices, needs and rules where production took place. Through theoretical and methodological approaches (on chaîne opératoire[70], cultural transmission[71], and communities of practice[72]) we further increased our understanding of the dynamics of the transmission of the knowledge to produce iron in ancient times, beyond traditional simplified explanations in terms of power relations and trade/exchange.[73] Hence, the various stages of the iron production – collection and preparation of the ore, charcoal production, smelting and smithing processes – all required more or less specialist skills, in turn indicating the existence of an apprenticeship system to maintain and pass on the knowledge. Furthermore, each process stage alone, but not least aggregated, required extensive work efforts, especially considering the small-sized communities in question (25-50 people[74]). Add to this the arctic climate, which made it a challenge only to survive, and where it was necessary to carefully plan the collection and preparation throughout the year, of food, firewood, clothing, and other necessities. Overall, we can assume the large and reasonably collective work efforts meant there was a common agreement in the ancient Arctic communities to produce iron, flanked by a common need/desire for iron. In a forthcoming article[75] we suggest labor was freed up by the localization by fish-rich lakes (there is an abundance of settlement-finds in terms of fish bones). We suggest the

[69] For overviews, see: Etzkowitz and Zhou, *The Triple Helix*, and; González-Martinez, García-Pérez-De-Lema, Castillo-Vergara and Bent Hansen, "Systematic review of the literature on the concept of civil society".
[70] Leroi-Gourhan, *Gesture and Speech*.
[71] Jordan and Zvelebil, *Ceramics before Farming*.
[72] Lave and Wenger, *Situated learning: legitimate peripheral participation.*
[73] White and Hamilton, *Ban Chiang.*
[74] Kelly, *The lifeways of hunter-gatherers.*
[75] Bennerhag and Söderholm, "Ancient Arctic Fennoscandian".

communities were located at these sites and had the potential to free labor *before* the introduction of iron, thus, there is a complete lack of signs of reorganization after iron handling was taken up.

In sum, by studying metals (and with a combined perspective) in addition to updating the historical narrative over the introduction of metals (geographically *and* socially), we broaden the perspectives on the ancient arctic hunter-gatherers in terms of specialization and organization, and overall reshape the otherwise rather passive and single-track view of hunter-gatherers. We believe the combined/interdisciplinary perspective would be useful also to other historians/archaeologists focusing on the often-underexplored peripheries.

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Appendix E

Table 2

Analysed sites

Table 2. *Analysed sites*

No	Country	Site	Site Id	Context	Production step	Material
1	Norway	Hemmestad Nedre	No number	Production site	Smelting	Slag, furnace wall
2	Norway	Flakstadvåg	No number	Production site	Smelting	Slag, furnace wall
3	Norway	Øvreværet	No number	Dwelling site	Smelting/primary smithing	Slag with metal inclusions
4	Norway	Røsnesvalen	26980	Hut	Smelting/smithing	Hearth lining or furnace wall, slag?
5	Norway	Slettnes	No number	Hut	Secondary smithing	Slag, iron fragment, iron object
6	Norway	Fjære	No number	Dwelling site	Secondary smithing	Slag, hearth lining
7	Norway	Makkholla	150901	Dwelling site	Secondary smithing	Hearth lining, slag
8	Norway	Virdnejavre 112	No number	Dwelling site	Smithing?	Sandstone with slag layer
9	Norway	Hellervikjä	46967	Hut	Finished object	Fragment of iron object (knife?)
10	Norway	Mestersanden[1]	56557	Dwelling site	Finished/semifinished objects	Iron fragment, bone with metallic iron
11	Finland	Kemijärvi, Neitilä	320010104	Dwelling site	Smelting	Slag, furnace wall, iron waste
12	Finland	Kajani, Äkälänniemi	205010002	Dwelling site	Smelting	Slag, furnace wall, iron waste
13	Finland	Rovaniemi, Riitakanranta	699010474	Dwelling site	Smelting	Slag, furnace wall, iron waste
14	Finland	Rovaniemi, Kotijänkä[2]	699010469	Dwelling site	Smelting	Slag
15	Finland	Mikkeli, Kitulansuo, Ristiina	696010026	Dwelling site	Smelting	Slag, lining (slag pit), iron waste
16	Finland	Lahti, Kilpisaari	532010021	Dwelling site	Smelting	Slag, lining (slag pit)
17	Sweden	Vivungi, Jukkasjärvi 723	L1994:8821	Production site	Smelting	Ancient ore
18	Sweden	Sangis, Nederkalix 842	L1992:9207	Production site	Smelting	White metal, clips
19	Sweden	Nåttiholmen, SMA 4006	L1995:364	Dwelling site	Smelting, smithing	Slag, lining
20	Sweden	Revi, SMA 929	L1995:53	Dwelling site	Smithing	Slag, lining
21	Sweden	Revi, SMA 3319	L1996:9978	Dwelling site	Smelting	Slag
22	Sweden	Revi, SMA 4131	No number	Dwelling site	Smithing	Slag, lining
23	Sweden	Hoppot, NA 36	L1996:9593	Dwelling site	Smelting/primary smithing	Metallic iron
24	Sweden	Sangis, Nederkalix 730	L1992:6497	Dwelling site	Primary, secondary smithing	Slag, lining
25	Sweden	Sangis, Nederkalix 797	L1992:8588	Dwelling site	Primary/secondary smithing	Slag, lining, metallic iron
26	Sweden	Rappasundet	L1996:9944	Dwelling site	Smithing	Slag, lining
27	Sweden	Revi Saxplats	No number	Dwelling site	Smithing	Slag, lining
28	Sweden	Sandudden, NA 53	L1996:9040	Dwelling site	Smithing	Hearth lining, lining
29	Sweden	Sandudden, NA 54	L1996:8099	Dwelling site	Primary, secondary smithing	Slag, lining, metallic iron, stone
30	Sweden	Sandudden, Ö Gottjärn, NA 55	L1996:8103	Dwelling site	Smithing	Slag, lining, stone
31	Sweden	Sandudden, NA 80	L1996:7942	Dwelling site	Smithing	Slag
32	Sweden	Sandudden, NA 82	L1996:8958	Dwelling site	Primary/secondary smithing	Slag, lining, metallic iron
33	Sweden	Sandudden, NA 83	L1995:4248	Dwelling site	Smithing	Slag
34	Sweden	Vallen, Nederluleå 90	L1992:5168	Hut	Primary/secondary smithing	Slag, metallic iron, stone
35	Sweden	Måttsund, Nederluleå 134	L1992:918	Dwelling site	Smithing	Slag
36	Sweden	S Holmnäs, NA 303	L1995:2336	Dwelling site	Smithing?	Lining
37	Sweden	Gottjärnmynnet, NA 69	L1996:8638	Dwelling site	Smithing?	Slag, lining
38	Sweden	Snotterholmen, NA 71A	L1996:8026	Dwelling site	Smithing?	Lining
39	Sweden	Sandudden, NA 79	L1996:7938	Dwelling site	Smithing?	Lining, fresh ore
40	Sweden	Räktjärv, Töre 50	L1992:3598	Grave	Finished object	Knife, iron
41	Sweden	Bergnäsudden, NA 16	L1996:9129	Dwelling site	?	Slag?
42	Sweden	Kosjärv, Töre 510	L1992:5683	Dwelling site	Semifinished/finished objects	Slag?, metallic iron, needle
43	Sweden	Månsträsk, NA 2145	L1995:3887			Fresh ore
44	Sweden	Notvik, NA2153	L1995:3875			Fresh ore
45	Sweden	Tellek	No number			Fresh ore
46	Sweden	Masseviken, NA 357	L1995:3605			Fresh ore

47	Sweden	Nåludden, NA 397	L1995:2182		Fresh ore
48	Sweden	Vivungi, ore survey	No number		Fresh ore
49	Sweden	Vuolgamjaur, NA 202	L1995:2480		Fresh ore
50	Sweden	Abraur, NA1738	L1995:6070		Fresh ore
51	Sweden	Abraur, Åmynne, NA 36, Apl	No number		Fresh ore
52	Sweden	Skidträsk, NA 2179	L1995:6955		Fresh ore
53	Sweden	Ö Sguegesuolo, NA 48	L1996:9549		Fresh ore
54	Sweden	Vivungi, experiment	No number	Experimental smelting	Slag, metallic iron

[1]From the Mestersanden site in Norway, only one find was available during our research visit.

[2]From the Kotijänkä site in Finland only a minor part of the find material was available during our research visit, with the result that only one find was sampled. This find had previously been interpreted as part of a ceramic bellow tube, however, new analyses indicate that this is slag formed in connection to the air inlet.

Appendix F

Table 3
Analysed finds, Finland

Table 4
Analysed finds, Norway

Table 5
Analysed finds, Sweden

Table 3. Analysed finds, Finland

No	Site	Find No	Material I	Material II	Ocular examination	Metallographic analysis	Petrographic analysis	Chemical analysis	Ceramic analysis (Ts)	Ceramic analysis (Thermal analysis)	Radiocarbon dating
11	Kemijärvi, Neitilä	KM 15671:320	Slag		x						
11	Kemijärvi, Neitilä	KM 15671:354	Slag		x						
11	Kemijärvi, Neitilä	KM 15671:592	Furnace wall		x				x		
11	Kemijärvi, Neitilä	KM 15671:1319	Furnace wall		x				x		
11	Kemijärvi, Neitilä	KM 16145:68	Slag		x		x	x			x
11	Kemijärvi, Neitilä	KM 16145:609	Slag		x						
11	Kemijärvi, Neitilä	KM 16145:1678	Iron waste		x	x					x
11	Kemijärvi, Neitilä	KM 16553:20	Furnace wall		x						
11	Kemijärvi, Neitilä	KM 16553:124	Furnace wall		x						
11	Kemijärvi, Neitilä	KM 16553:124	Slag		x		x	x			
11	Kemijärvi, Neitilä	KM 16553:124	Iron fragment		x						
11	Kemijärvi, Neitilä	KM 16553:142	Lining (slag pit/hearth?)		x				x		
11	Kemijärvi, Neitilä	KM 16553:216	Slag		x						
12	Kajani, Äkälänniemi	KM 21213:47	Furnace wall		x				x	x	
12	Kajani, Äkälänniemi	KM 21213:55_1, 2	Iron waste		x	x (2)					x
12	Kajani, Äkälänniemi	KM 21213:55	Slag		x		x	x			x
12	Kajani, Äkälänniemi	KM 21213:55	Furnace wall		x				x		
12	Kajani, Äkälänniemi	KM 21213:64	Furnace wall		x				x	x (2)	
12	Kajani, Äkälänniemi	KM 21213:64	Slag		x						
12	Kajani, Äkälänniemi	KM 21213:64	Slag		x						
12	Kajani, Äkälänniemi	KM 21213:64	Slag		x						
12	Kajani, Äkälänniemi	KM 21213:64	Slag		x						
12	Kajani, Äkälänniemi	KM 21213:64	Iron waste		x						
12	Kajani, Äkälänniemi	KM 21213:64	Furnace wall		x						
12	Kajani, Äkälänniemi	KM 21213:64	Slag		x						
12	Kajani, Äkälänniemi	KM 21213:72	Iron waste		x	x					
13	Rovaniemi, Riitakanranta	KM 25374:58	Iron waste	Slag	x	x					
13	Rovaniemi, Riitakanranta	KM 25374:59	Slag		x		x	x			
13	Rovaniemi, Riitakanranta	KM 25374:69	Slag		x		x	x			
13	Rovaniemi, Riitakanranta	KM 25374:92	Slag		x						
13	Rovaniemi, Riitakanranta	KM 25374:107_1	Slag		x		x	x			
13	Rovaniemi, Riitakanranta	KM 25374:107_2	Iron waste		x	x (2)					x
13	Rovaniemi, Riitakanranta	KM 25374:139	Furnace wall		x				x		
13	Rovaniemi, Riitakanranta	KM 25374:145	Furnace wall		x						
13	Rovaniemi, Riitakanranta	KM 25374:173	Furnace wall		x						
13	Rovaniemi, Riitakanranta	KM 25374:195	Slag		x						
13	Rovaniemi, Riitakanranta	KM 25374:197	Furnace wall		x						
13	Rovaniemi, Riitakanranta	KM 25374:214	Furnace wall		x				x	x	
13	Rovaniemi, Riitakanranta	KM 25374:234-241	Furnace wall, air-inlet hole?		x						
13	Rovaniemi, Riitakanranta	KM 26172:109	Iron waste		x						
13	Rovaniemi, Riitakanranta	KM 26172:212	Slag		x						

No	Site	Find No	Material I	Material II	Ocular examination	Metallographic analysis	Petrographic analysis	Chemical analysis	Ceramic analysis (Ts)	Ceramic analysis (Thermal analysis)	Radiocarbon dating
13	Rovaniemi, Riitakanranta	KM 26172:229	Slag with iron		x						
13	Rovaniemi, Riitakanranta	KM 26172:236	Iron waste		x	x					
13	Rovaniemi, Riitakanranta	KM 26172:282	Iron waste		x						
13	Rovaniemi, Riitakanranta	KM 26172:391	Iron waste		x	x					x
13	Rovaniemi, Riitakanranta	KM 26172:670	Iron waste		x						
13	Rovaniemi, Riitakanranta	KM 26172:675	Slag		x						
13	Rovaniemi, Riitakanranta	KM 26172:676	inlet hole		x				x		
13	Rovaniemi, Riitakanranta	KM 26172:727B	Furnace wall	Slag	x				x	x	
14	Rovaniemi, Kotijänkä	KM 26780:34	Slag		x						
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:1499	Iron waste		x						
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:1539	Iron waste		x						
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:1618	Lining (slag pit/hearth?)		x				x		
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:1698	Slag		x		x	x			
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:1746	Slag		x						
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:1749	Iron waste		x	x (2)					x
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:1751	Lining (slag pit/hearth?)		x						
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:1779	Iron waste		x						
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:1996	Slag		x						
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:2224	Iron waste		x	x					x
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:2401	Slag		x		x	x			
16	Lahti, Kilpisaari	KM 32180:66	Lining (slag pit)		x				x		
16	Lahti, Kilpisaari	KM 32180:105	Slag		x						
16	Lahti, Kilpisaari	KM 32180:325	Slag		x						
16	Lahti, Kilpisaari	KM 32180:326	Slag		x		x	x			

Table 4. *Analysed finds, Norway*

No	Site	Find No	Material I	Material II	Ocular examination	Metallographic analysis	Petrographic analysis	Chemical analysis	Ceramic analysis (Ts)	Ceramic analysis (Thermal analysis)	Ceramic analysis (P-ED-XRF)	Radiocarbon dating
1	Hemmestad Nedre	Ts 11225C	Slag, reduction		x		x	x				
1	Hemmestad Nedre	Ts 11225C	Furnace wall		x							
1	Hemmestad Nedre	Ts 11225C	Slag, reduction		x							
1	Hemmestad Nedre	Ts 11225C	Charcoal		x							x
1	Hemmestad Nedre	Ts 11225A	Furnace wall		x				x	x		
1	Hemmestad Nedre	Ts 11225A	Furnace wall (air-inlet hole)		x							
1	Hemmestad Nedre	Ts 11225A	Furnace wall		x							
1	Hemmestad Nedre	Ts 11225A	Slag, reduction	Iron?	x	x	x	x				
1	Hemmestad Nedre	Ts 11225C	Slag, reduction	Furnace wall	x							
1	Hemmestad Nedre	Ts 11225C	Slag, reduction	Furnace wall	x							
1	Hemmestad Nedre	Ts 11225C	Slag, reduction		x	x						
1	Hemmestad Nedre	Ts 11225B	Furnace wall		x							
1	Hemmestad Nedre	Ts 11225B	Slag, reduction		x	x						
1	Hemmestad Nedre	Ts 11225B	Slag, reduction		x		x	x				x
1	Hemmestad Nedre	Ts 11225B	Furnace wall		x				x		x	
2	Flakstadvåg	Ts11209:80	Furnace wall		x							
2	Flakstadvåg	Ts11209:102	Furnace wall		x				x			
2	Flakstadvåg	Ts11209:129	Furnace wall	Slag, reduction	x		x		x			
2	Flakstadvåg	Ts11209	Slag, reduction		x		x	x				
3	Övreväret	Ts 11297.2	Slag, reduction or primary smithing	Metal inclusions	x	x	x					x
4	Rösnevalen	Ts4190d	Lining/furnace wall?	Slag (?)	x		x		x			
5	Slettnes	Ts 9433m	Slag, smithing		x		x	x				
5	Slettnes	Ts 9433e	Metallic iron		x	x						x
5	Slettnes	Ts 9433l	object		x	x						
6	Fjäre	Ts 8363u	Slag, smithing	Hearth lining	x		x	x	x			
7	Makkholla	Ts10911qm	Soapstone, heat affected		x							
7	Makkholla	Ts10911qj	Hearth lining		x							
7	Makkholla	Ts10911qn	Hearth lining	Slag, smithing	x		x		x			
7	Makkholla	Ts10911qp	Conglomeration of clay, asbestos, bone, charcoal		x							
8	Virdnejavre 112	Ts8406caa	Sandstone	Slag, smithing (?)	x		x		x			
9	Hellervikjä, House 1	Ts 4179d	Iron object, fragment (knife?)		x	x						
10	Mestersanden	C21105/65	Iron fragment		x							
10	Mestersanden	C21105/253	Bone artefact	Iron fragment	x							

Table 5. *Analysed finds, Sweden*

No	Site	Find No	Material I	Material II	Ocular examination	Polished sample	Test roasting	Metallographic analysis	Petrographic analysis (Ts)	Chemical analysis	Ceramic analysis (Ts)	Radiocarbon dating
17	Vivungi, Jukkasjärvi 723	F397	Ancient ore		x							
17	Vivungi, Jukkasjärvi 723	F406	Ancient ore		x	x				x		
17	Vivungi, Jukkasjärvi 723	F409	Ancient ore		x							
17	Vivungi, Jukkasjärvi 723	F425	Ancient ore		x							
18	Sangis, Nederkalix 842	F766	White metal clips		x							
19	Nåttiholmen	SMA?	Slag, reduction?		x							
19	Nåttiholmen	SMA 4006	Slag, smithing		x							
19	Nåttiholmen	138	Slag, smithing	Lining	x				x	x		
20	Revi, SMA 929		Slag, smithing, reduction?	Lining	x							
21	Revi, SMA 3319		Slag, reduction		x				x	x		x
22	Revi, SMA 4131		Linings	Slag, reduction	x							
23	Hoppot, NA 36	Sample 10	Iron		x			x				
24	Sangis, Nederkalix 730	F31	Slag, smithing		x							
24	Sangis, Nederkalix 730	F7120	Slag, smithing	Cu?	x			x				
24	Sangis, Nederkalix 730	2502	Lining		x						x	
24	Sangis, Nederkalix 730	3618	Lining		x						x	
24	Sangis, Nederkalix 730	3636	Lining		x						x	
24	Sangis, Nederkalix 730	748	Lining		x							
24	Sangis, Nederkalix 730	787	Lining		x							
24	Sangis, Nederkalix 730	815	Lining		x							
24	Sangis, Nederkalix 730	819	Lining		x							
24	Sangis, Nederkalix 730	1306	Lining		x							
24	Sangis, Nederkalix 730	1340	Lining		x							
24	Sangis, Nederkalix 730	1592	Lining		x							
24	Sangis, Nederkalix 730	1612	Lining		x							
24	Sangis, Nederkalix 730	1689	Lining		x							
24	Sangis, Nederkalix 730	1696	Lining		x							
24	Sangis, Nederkalix 730	1704	Lining		x							
24	Sangis, Nederkalix 730	2506	Lining		x							
24	Sangis, Nederkalix 730	3790	Lining		x							
24	Sangis, Nederkalix 730	3792	Lining		x							
24	Sangis, Nederkalix 730	3821	Lining		x							
24	Sangis, Nederkalix 730	4706	Lining		x							
24	Sangis, Nederkalix 730	7040	Lining		x							
24	Sangis, Nederkalix 730	7073	Lining		x							
24	Sangis, Nederkalix 730	7090	Lining		x							
24	Sangis, Nederkalix 730	7091	Lining		x							
24	Sangis, Nederkalix 730	7092	Lining		x							
24	Sangis, Nederkalix 730	7094	Lining		x							
24	Sangis, Nederkalix 730	7124	Lining		x							
24	Sangis, Nederkalix 730	7126	Lining		x							

No	Site	Find No	Material I	Material II	Ocular examination	Polished sample	Test roasting	Metallographic analysis	Petrographic analysis (Ts)	Chemical analysis	Ceramic analysis (Ts)	Radiocarbon dating
24	Sangis, Nederkalix 730	7127	Lining		x							
24	Sangis, Nederkalix 730	3419	Lining		x							
24	Sangis, Nederkalix 730	3482	Lining		x							
24	Sangis, Nederkalix 730	3485	Lining		x							
24	Sangis, Nederkalix 730	3617	Lining		x							
24	Sangis, Nederkalix 730	3619	Lining		x							
24	Sangis, Nederkalix 730	3623	Lining		x							
24	Sangis, Nederkalix 730	7129	Lining		x							
24	Sangis, Nederkalix 730	3204	Lining		x							
24	Sangis, Nederkalix 730	3271	Lining		x							
24	Sangis, Nederkalix 730	3272	Lining		x							
24	Sangis, Nederkalix 730	7033	Lining		x							
25	Sangis, Nederkalix 797		Metallic iron included in slag		x			x				
25	Sangis, Nederkalix 797		Slag, smithing	Lining	x				x	x		x
26	Rappasundet		Slag, smithing		x							
27	Revi Saxplats	SMA?	Linings		x							
27	Revi Saxplats	SMA?	Slag, smithing		x				x	x		
28	Sandudden, NA 53	1/1b	Hearth lining		x						x	
28	Sandudden, NA 53	No 2	Hearth lining		x							
28	Sandudden, NA 53	No 4-6	Linings?		x							
28	Sandudden, NA 53	No 7	Hearth lining		x							
28	Sandudden, NA 53	No 8	Lining?		x							
28	Sandudden, NA 53	No 9	Hearth lining		x							
28	Sandudden, NA 53	No 10	Lining?		x							
29	Sandudden, NA 54	1	Lining	Slag?	x							
29	Sandudden, NA 54	2	Lining		x				x			
29	Sandudden, NA 54	3	Stone		x							
29	Sandudden, NA 54	4	Stone		x							
29	Sandudden, NA 54	9	Lining	Slag	x							
29	Sandudden, NA 54	12	Slag, smithing	Lining	x				x	x		
29	Sandudden, NA 54	No 46-48	Linings		x							
29	Sandudden, NA 54	No 68	Metallic iron		x			x				
29	Sandudden, NA 54	No 68	Slag, smithing	Lining	x				x	x		
29	Sandudden, NA 54	No 155	Lining		x							
29	Sandudden, NA 54	No 156-158	Slag?		x							
29	Sandudden, NA 54	Sample 192, 193	Slag?		x							
29	Sandudden, NA 54	Strayfind 1971	Slag, smithing (part of find no 12)	Lining	x							
29	Sandudden, NA 54	Strayfind no 3	Lining		x							
29	Sandudden, NA 54	No 71-76	Linings		x							

No	Site	Find No	Material I	Material II	*Ocular examination*	*Polished sample*	*Test roasting*	*Metallographic analysis*	*Petrographic analysis (Ts)*	*Chemical analysis*	*Ceramic analysis (Ts)*	*Radiocarbon dating*
29	Sandudden, NA 54	No 89	Sintered sand, slag, smithing		x							
29	Sandudden, NA 54	No 88	Slag, smithing		x							
29	Sandudden, NA 54	No 114-120, 174, 205	Linings		x							
29	Sandudden, NA 54	No 69, 70	Sintered sand, metallic drops?		x							
29	Sandudden, NA 54	No 103	Lining?	Slag?	x							
29	Sandudden, NA 54	No 104	Lining?		x							
29	Sandudden, NA 54	No 133	Slag, PCB		x							
29	Sandudden, NA 54	No 134-142	Linings?/Slag?		x							
29	Sandudden, NA 54	No 189	Iron		x			(x)				
30	Sandudden, NA 55	Strayfind A	Lining	Slag?	x							
30	Sandudden, NA 55	No 33	Slag, PCB		x							
30	Sandudden, NA 55	No 31-35 (sample 31, 32, 34)	Slag, smithing	Lining	x							
30	Sandudden, NA 55	No 34	Stone	Slag	x							
30	Sandudden, NA 55	No 35	Stone		x							
30	Sandudden, NA 55	No 32	Lining	Slag	x				x	x	x	
30	Sandudden, NA 55	No 31	Slag, smithing		x				x		x	
31	Sandudden, NA 80	No 8-10	?		x							
31	Sandudden, NA 80	No 5	Slag, smithing		x							
32	Sandudden, NA 82	No 30	Iron		x			x				
32	Sandudden, NA 82	No 30	Lining	Slag	x				x		x	
32	Sandudden, NA 82	No 30	Slag		x				x	x		x
33	Sandudden, NA 83	No 42-45	Slag, smithing		x							
34	Vallen, Nederluleå 90		Iron		x			x				
34	Vallen, Nederluleå 90	97	Slag (hamering scales)		x							
34	Vallen, Nederluleå 90	89	Slag (hamering scales)		x							
34	Vallen, Nederluleå 90	94	Slag (hamering scales)		x	x						
34	Vallen, Nederluleå 90	99	Slag (spray slag)		x	x						
34	Vallen, Nederluleå 90	95	Slag, smithing?		x				x	x		
34	Vallen, Nederluleå 90	100	Stone	Slag	x				x			
35	134		Slag, smithing		x							
36	S Holmnäs, NA 303	7	Lining		x							
36	S Holmnäs, NA 303	8	Lining	Slag?	x							
37	Gottjärnmynnet, NA 69	No 22-27	Lining	Slag, smithing	x							
38	Snotterholmen, NA 71A	No 7	Lining		x						x	
39	Sandudden, NA 79		Fresh ore		x	x	x			x		
39	Sandudden, NA 79	No 64	Lining		x							

No	*Site*	*Find No*	*Material I*	*Material II*	*Ocular examination*	*Polished sample*	*Test roasting*	*Metallographic analysis*	*Petrographic analysis (Ts)*	*Chemical analysis*	*Ceramic analysis (Ts)*	*Radiocarbon dating*
40	Räktjärv, Töre 50		Knife, iron		x							
41	Bergnäsudden, NA 16	Sample 1	Slag?		x							
42	Kosjärv, Töre 510	35	Metallic iron?		x							
42	Kosjärv, Töre 510	219	Metallic iron?		x							
42	Kosjärv, Töre 510	245	Iron needle, bar?		x							
42	Kosjärv, Töre 510	21	Sintered material		x							
42	Kosjärv, Töre 510	69	Sintered material		x							
42	Kosjärv, Töre 510	77	Sintered material		x							
42	Kosjärv, Töre 510	105	Slag?		x							
43	Månsträsk, NA 2145		Fresh ore		x		x		x	x		
44	Notvik, NA 2153		Fresh ore		x		x					
45	Tellek		Fresh ore		x		x					
46	Masseviken, NA 357	Nr 25	Fresh ore		x		x					
47	Nåludden, NA 397	Nr 2	Fresh ore		x		x					
48	Vivungi, ore survey		Fresh ore		x	x			x	x		
49	Vuolgamjaur, NA 202		Fresh ore		x		x					
50	Abraur, NA 1738		Fresh ore		x		x		x	x		
51	Abraur, NA 36, Apl		Fresh ore		x		x					
52	Skidträsk, NA 2179		Fresh ore		x		x					
53	Ö Sguegesuolo, NA 48	7	Fresh ore		x		x					
53	Ö Sguegesuolo, NA 48	8	Fresh ore		x		x					
54	Vivungi, experiment	F1-3	Metallic iron		x			x				
54	Vivungi, experiment		Slag, reduction		x				x	x		

Appendix G

Table 6

Radiocarbon dating, Finland

Table 7

Radiocarbon dating, Norway

Table 8

Radiocarbon dating, Sweden

Table 6. *Radiocarbon dating, Finland*

No	Site	Sample	Context	Material	14C-age (BP)	Lab id
11	Kemijärvi, Neitilä	KM 16145:68	1.5 m outside the furnace	Charcoal in slag	2074 ± 33 BP	Ua-64344[1]
11	Kemijärvi, Neitilä	KM 16145:1678	1 m outside the furnace	Carbon extracted from steel	1968 ± 31 BP	Ua-66062[1]
12	Kajani, Äkälänniemi	KM 21213:55_1	Furnace, slagheap	Charcoal in slag	2195 ± 31 BP	Ua-64343[1]
12	Kajani, Äkälänniemi	KM 21213:55_2	Furnace, slagheap	Carbon extracted from steel	1970 ± 28 BP	Ua-67778[1]
12	Kajani, Äkälänniemi			Charcoal	2220 ± 100 BP	Hel-2098[2]
12	Kajani, Äkälänniemi			Charcoal	2180 ± 90 BP	Hel-2101[2]
13	Rovaniemi, Riitakanranta	KM 26172:391	3.5 m outside the furnace	Carbon extracted from steel	2048 ± 28 BP	Ua-66063[1]
13	Rovaniemi, Riitakanranta	KM 25374:107_2	Furnace	Carbon extracted from steel		Undatable[1]
13	Rovaniemi, Riitakanranta		Furnace	Charcoal	2090 ± 100 BP	Hel-2955[3]
13	Rovaniemi, Riitakanranta		Furnace	Charcoal	1820 ± 110 BP	Hel-2965[3]
14	Rovaniemi, Kotijänkä			Charcoal	1560 ± 90	Tku-034[3]
14	Rovaniemi, Kotijänkä			Charcoal	1750 ± 90	Tku-035[3]
14	Rovaniemi, Kotijänkä		Furnace	Charcoal	1880 ± 110	Hel-3173[3]
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:1749_2	Furnace	Carbon extracted from steel	1722 ± 42 BP	Ua-67779[1]
15	Mikkeli, Kitulansuo, Ristiina	KM 28960:2224	Furnace, slagheap	Carbon extracted from steel		Undatable[1]
15	Mikkeli, Kitulansuo, Ristiina		Furnace	Charcoal	1530 ± 80 BP	Hel-3837[4]
16	Lahti, Kilpisaari I		In connection to the furnace	Charcoal	AD 550	Unpublished[5]

[1]This study; [2]Schulz, E-L. (1986). Ein Eisenverhiittungsplatz aus der alteren Eisenzeit in Kajaani, *Iskos* 6, 169-173; [3]Kotivuori, H. (1996). Pyytiijistli kaskenraivaajiksi, in M. Saamisto et al. (eds.). *Rovaniemen historia vuoteen 1721: kotatulilta savupirtin suojaan*, Jyviiskylii, 34-125; [4]Lavento, M. (1999). An iron furnace from the Early Metal period at Kitulansuo in Ristiina, in the southern part of the Lake Saimaa water system, *Fennoscandia archaeologica* 16, 75-80; [5]Saipio, J. (2015). Nastola Kilpisaari 2 – Esihistoriallisen röykkiön elämänkaari, *Muinaistutkija* 1 (2015), 2–18.

Table 7. *Radiocarbon dating, Norway*

No	Site	Sample	Context	Material	14C-age (BP)	Lab id
1	Hemmestad Nedre	11225C	Structure I (furnace)	Charcoal (pine)	2300 ± 30	Ua-67109[1]
1	Hemmestad Nedre	11225B	Furnace II	Charcoal in slag (coniferus tree)		Undatable[1]
1	Hemmestad Nedre		Furnace I	Charcoal (pine/birch)	2344 ± 69	T-14761[2]
1	Hemmestad Nedre		Furnace I, slagheap	Charcoal (pine/birch)	2360 ± 89	T-14762[2]
1	Hemmestad Nedre		Furnace II	Charcoal (birch)	2351 ± 67	Tua-2662[2]
1	Hemmestad Nedre		Furnace II, below furnace (slag pit?)	Charcoal (pine/birch)	2255 ± 68	Tua-2663[2]
1	Hemmestad Nedre		Charcoal kiln	Charcoal (foliferous trees)	2247 ± 70	T-14763[2]
2	Flakstadvåg		1 m outside the furnace	Charcoal (pine)	1747 ± 37	T-13126[2]
2	Flakstadvåg		Furnace	Charcoal in slag (pine)	1793 ± 34	Wk-20639[2]
3	Øvreværet	11297:2	Smelting/primary smithing	Carbon extracted from steel inside slag	281 ± 26	Ua-67777[1]
3	Øvreværet			Charcoal	2296 ± 70	T-4296[3]
3	Øvreværet		Tilv. 1981/43, F56	Organic material adhered to ceramics	2380 ± 55	T-2448[4]
5	Slettnes	9433e	Smithing	Charcoal on iron (deciduous tree/birch?)	1189 ± 29	Ua-67108[1]
5	Slettnes		Tuft F204	Charcoal	1160 ± 70	Beta-52220[5]
5	Slettnes		Tuft F204	Charcoal	1250 ± 80	Beta-52219[5]
6	Fjære			Ceramics	2860 ± 110	T-6151[6]
7	Makkholla		Felt II, rute 42x, -3y, lag 2	Reindeer antler	2280 ± 100	T-4815[7]
7	Makkholla		Felt III, rute 5x, -1y, lag 3	Charcoal (birch)	2400 ± 110	T-4814[7]
10	Mestersanden		Cultural layer, area 3	Fishbone	1650 ± 90	T-1728[8]
10	Mestersanden		Cultural layer, area 3	Fishbone	1700 ± 90	T-1729[8]
10	Mestersanden		Cultural layer, area 4	Reindeer antler	1770 ± 90	T-2743[8]
10	Mestersanden			Ceramics	2550 ± 100	T-6147[6]
10	Mestersanden			Ceramics	2170 ± 90	T-6472[6]
10	Mestersanden			Ceramics	2450 ± 120	T-6474[6]

[1]This study; [2]Jørgensen, R. (2010). *Production or trade?: the supply of iron to North Norway during the Iron Age,* PhD thesis, Tromsø University; [3]Jørgensen, R. (1986). The early metal age in Nordland and Troms, *Acta Borealia* 3 (2), 61-87; [4]Andreassen, D. (2002). *Risvikkeramikk. En analyse av teknologisk stil på Nordkalotten i sein steinbrukende tid*, MSc thesis, Tromsø University; [5]Hesjedal, A., Damm, C., Olsen, B. and Storli, I. (1996). *Arkeologi på Slettnes: dokumentasjon av 11.000 års bosetning*. Tromsø museum; [6]Jørgensen, R. and Olsen, B. (1988). *Asbestkeramiske grupper i Nord-Norge: 2100 f. Kr.-100 e. Kr.* Tromura, Kulturhistorie nr. 13, Universitet i Tromsø.; [7]Olsen, B. (1984). S*tabiliet og endring: produksjon og samfunn i Varanger 800 f. Kr-1700 e. Kr*, PhD thesis, Tromsø university; [8]Helskog, K. (1980). The chronology of the younger stone age in Varanger, North Norway. Revisited, Norwegian Archaeological Review 13 (1), 47-54.

Table 8. *Radiocarbon dating, Sweden*

No	Site	Sample	Context	Material	14C-age (BP)	Lab id
17	Vivungi 723		Furnace 2, slag pit	Charcoal (pine)	2076±32	Ua-57488[1]
17	Vivungi 723		Furnace 2, slag heap	Charcoal (pine, twig/branch)	1962±31	Ua-57487[1]
17	Vivungi 723	Id 392	Furnace 2, slag heap	Carbon extracted from steel (iron waste)	1899±32	Ua-57788[1]
17	Vivungi 723		Furnace 2, slag heap	Charcoal (pine)	1820±32	Ua-57491[1]
17	Vivungi 723		Furnace 3, slag heap	Charcoal (pine)	2124±32	Ua-57489[1]
17	Vivungi 723		Furnace 3, slag pit	Charcoal (pine, twig/branch)	2035±32	Ua-57490[1]
17	Vivungi 723	Id 1759	Furnace 3, slag heap	Carbon extracted from steel (iron waste)	1998±31	Ua-57789[1]
17	Vivungi 723		Single find within site	Charcoal in slag (birch)	2097±29	Ua-51279[1]
18	Sangis 842	F13:1	Furnace, slag heap	Charcoal in slag (pine)	2295 ± 35	Ua-38706[1]
18	Sangis 842		Furnace, slag heap	Charcoal (birch)	2025 ± 30	Ua-40588[1]
18	Sangis 842	F759	Furnace, slag heap	Carbon extracted from steel (iron waste)	1994 ± 31	Ua-57787[1]
18	Sangis 842		Furnace, slag pit	Charcoal (birch)	1950 ± 32	Ua-40589[1]
19	Nåttiholmen	128	Dwelling site	Organic material adhered to ceramics	2 286 ± 30	Ua-72702[2]
19	Nåttiholmen	131	Dwelling site	Organic material adhered to ceramics	2 177 ± 30	Ua-72703[2]
19	Nåttiholmen	237	Dwelling site	Organic material adhered to ceramics	2 413 ± 31	Ua-72704[2]
19	Nåttiholmen	304	Dwelling site	Organic material adhered to ceramics	2 321 ± 30	Ua-72705[2]
19	Nåttiholmen	308	Dwelling site	Organic material adhered to ceramics	2 313 ± 30	Ua-72706[2]
21	Revi	SMA 3319	Smelting	Charcoal in slag (pine)	1955 ± 30	Ua-69701[1]
24	Sangis 730	F1112	Smithing hearth A4	Charcoal in slag (pine)	2980 ± 100	Ua-36293[1]
24	Sangis 730	F7045	Smithing hearth A4	Carbon extracted from steel (iron waste)	2186 ± 29	Ua-59598[1]
24	Sangis 730		Smithing hearth A4	Charcoal (pine)	2125 ± 30	Ua-33335[1]
24	Sangis 730	F925	Smithing hearth A4	Carbon extracted from steel (iron waste)	1981 ± 77	Ua-59595[1]
24	Sangis 730	F2768	Structure A27	Pottery	2740 ± 30	Poz-23960[1]
24	Sangis 730		Structure A27	Burnt bone	2720 ± 110	Poz-23611[1]
24	Sangis 730	F1784	Structure A27	Charcoal (organic residue next to bronze buckle)	1990 ± 30	Poz-23733[1]
24	Sangis 730	F2771	Structure A27	Carbon extracted from steel (unidentified object)	1966 ± 34	Ua- 59597[1]
24	Sangis 730	F3010	Structure A27	Carbon extracted from steel (iron waste)	1895 ± 30	Ua-36296[1]
24	Sangis 730		Structure A29	Charcoal (crowberry, small twigs)	1885 ± 30	Poz-23737[1]
24	Sangis 730		Structure A29	Burnt bone	1850 ± 50	Poz-23610[1]
24	Sangis 730	F3763	Smithing hearth, A45	Charcoal in slag (pine)	2430 ± 75	Ua-36294[1]
24	Sangis 730		Smithing hearth A45	Burnt bone	2115 ± 35	Poz-23608[1]
24	Sangis 730	F1840	Smithing hearth A53	Carbon extracted from steel (iron waste)	2150 ± 30	Ua-59596[1]
24	Sangis 730	F913	Smithing hearth A53	Charcoal in slag (pine)	1915 ± 35	Ua-36292[1]
24	Sangis 730	F2684	Single find within site	Carbon extracted from steel (socketed axe)	2115 ± 30	Ua-36295[1]
24	Sangis 730	F878	Single find within site	Carbon extracted from steel (knife)	1831 ± 41	Ua-59594[1]
25	Sangis 797		Smithing	Charcoal in slag (pine)	1676 ± 36	Ua-69700[1]
32	Sandudden, NA 82	No 30	Smithing	Charcoal in slag (pine)	1747 ± 30	Ua-69699[1]
34	Nederluleå 90	Kp 6	Dwelling site, house	Charcoal	2000 ± 35	Ua-36800[3]
34	Nederluleå 90	Kp 16	Dwelling site, house	Organic material adhered to ceramics	2035 ± 30	Ua-36801[3]
34	Nederluleå 90	Kp 13	Dwelling site, house	Charcoal	2060 ± 35	Ua-36802[3]
40	Töre 50		Grave	Chremated human bones	1761 ± 39	Ua-51569[4]
42	Kosjärv		Dwellingsite	Burnt bone	2280 ± 40	Ua-33179[5]

[1]This study; [2]Nils Harnesk, Norrbottens museum, E-mail to author, March 23, 2023; [3]Bennerhag, C. (2012). *En boplatsvall från förromersk/romersk järnålder. Delundersökning av Raä 90, Nederluleå socken, Norrbottens län*, Norrbottens museum rapport 2012:6. Luleå; [4]Bennerhag, C. (2015). *En brandgrav från romersk järnålder. Arkeologisk räddningsundersökning av Raä Töre 50:1, grav- och boplatsområde*, Norrbottens museum rapport 2015:16. Luleå; [5]Östlund, O., Palmbo, F. and Jonsson, M. *Mötesstation Kosjärv, Bondersbyn 2:2, Töre sn, Norrbottens län, Västerbotten*, Norrbottens museum dnr 384-2006. Luleå.

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