A brief history of scientific artefact studies at the University of helsinki

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Abstract

This article provides an overview of archaeological science applications in artefact studies at the University of Helsinki. Since the first metal artefact analysis published in the 1860s, University of Helsinki researchers have carried out numerous nationally pioneering scientific artefact studies, developed new analytical procedures, and embraced the international trends of integrating chemical, microscopic, and isotopic analyses in archaeological artefact studies. Here, the focus is on inorganic archaeological artefacts, objects made of metals, ceramics, glass, and lithics. Scientific methods can help us to understand where, how, for what purpose, and when objects were made, certain raw materials were selected, specific technologies developed, and finished products distributed. In this way, scientific artefact data can help us to recognise and contextualise the different roles, values, and functions the objects had in the lives of the people who made and used them, and interpret the artefact evidence in the wider societal, inter-communal, and inter-cultural settings.

Keywords: archaeological science, scientific artefact analysis, inorganic artefacts, chemistry, microscopy, isotope analysis, metals, ceramics, lithics, glass, University of Helsinki

Introduction

The history of the scientific analysis of archaeological artefacts in Helsinki reaches back almost 160 years. The first study was published in the 1860s, when the University was still called the Imperial Alexander University in Finland (henceforth University of Helsinki, or abbrev. Helsinki), 60 years prior the establishment of the Archaeology chair at the newly renamed University of Helsinki in 1923. This article offers on overview of the most significant steps in the development of the scientific studies of archaeological objects at the University of Helsinki, i.e., research conducted by Helsinki-based scholars (in various fields, e.g., chemistry, physics, history, and archaeology) who were either affiliated with or studied at the University.

University of Helsinki archaeologists have largely followed the international trends in adopting scientific methods of artefacts analysis. Most of the new analytical methods introduced in archaeological artefact studies in the Western World in the 20th century were, after minor delay, also applied in Helsinki-based studies (Figure 1). Keeping on track with global developments is itself a considerable accomplishment for the small research community of archaeologists at Helsinki. For instance, neutron activation analysis (NAA) emerged in Finnish archaeology in the 1980s, after its use in archaeology peaked in the States already in the 1960s and 1970s (see Speakman & Glascock 2007). Similarly, scanning electron microscopy (SEM) has been applied in artefacts studies in Helsinki since the 1990s, after its archaeological applications were developed in international research institutions in the 1980s (e.g., Freestone & Middleton 1987). Today, in the early 2020s, both worldwide and in Helsinki archaeological artefact analysis has moved forward from classical typo-chronological categorisations, and the application of scientific methods, chemical, microscopic, and isotopic analysis, has become more of a standard in modern artefact studies. There is a thriving ambition to develop new archaeological science applications to better understand the past, to ask more complex research questions, and to provide more detailed and more accurate science-based interpretations. Over the decades, there has also been a lively international debate on the relationships between science, archaeological science, and archaeology (see, e.g., Snow 1959; Hawkes 1968; Isaac 1971; Daniel 1981; De Atley & Bishop 1991; Jones 2004; Gosden 2005; Martinón-Torres & Killick 2016, and references therein), but Finnish scholars have not actively participated in this discussion, probably because science applications in Finnish archaeology have been rather sporadic until the very recent decades.

This chapter focusses on the archaeological science of inorganic artefacts: objects made of metals, ceramics, lithics, and glass. The key case studies are presented for each material group, along with a discussion on the evolution of the science applications and research questions asked in relation to the particular material group. Scientific artefact analyses are applied in archaeology to investigate the material composition, technologies, source areas, and mobility of artefacts and their raw materials. Scientific artefact studies go beyond the traditional, typo-chronological approaches, and allow us to propose new research questions such as where, how, for what purpose, and when the objects were made, certain raw materials selected, specific technologies developed, and finished products exchanged and distributed? Many of the analytical methods discussed here are applicable to all of the inorganic materials, but each material group also presents its own, material related analytical challenges. On the other hand, each material group can also offer a unique contribution to archaeological research, its own perspective on the past.

Metals

Helsinki-based researchers were national pioneers in archaeological science and scientific artefact analysis in Finland. The earliest published scientific analysis of archaeological artefacts in the Finnish context is the chemical analysis of copper-based metal objects – including a brooch (Figure 2) found during roadwork at Vanaantausta in Janakkala (in the Häme region) in the 1860s and donated to the University's ethnographic collection by the landowner. This pioneering chemical analysis was carried out by chemists J.J. Chydenius (later appointed as a Chemistry professor in Helsinki) and F.W. Westerlund, and published by Yrjö Koskinen and K.E.F. Ignatius in 1866.

The early archaeometallurgical analysis already aimed to answer the questions of where, of which materials, and how the artefact was produced. The methods available back then were ap-

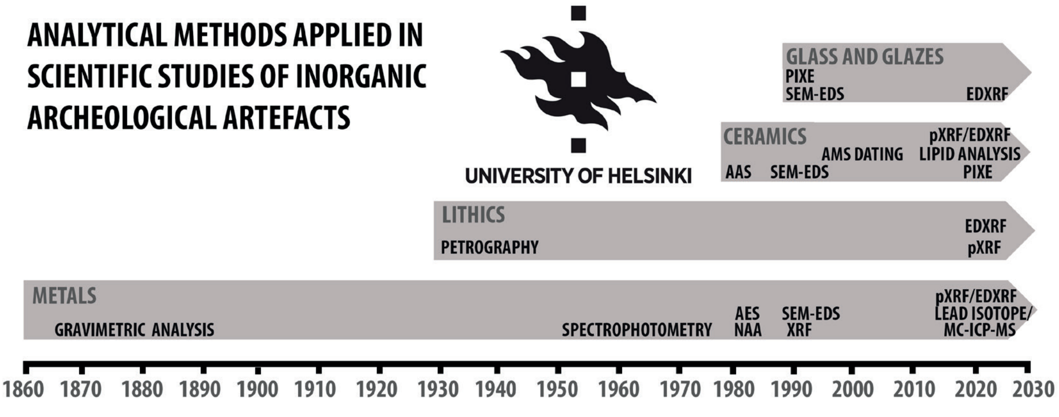

Figure 1. A timeline of scientific analyses of inorganic archaeological objects published by University of Helsinki affiliated scholars (E. Holmqvist).

plied to determine the chemical composition of the alloy, with the aim to discriminate objects from different sources based on different metal concentrations in the alloy – isotopic analysis methods to link the metals used in archaeological artefacts to source metal ores were developed more than a century later (see, e.g., Gale & Stos-Gale 2000; Gale *et al.* 2003; Radivojevic *et al.* 2018).

In their description of the late Iron Age objects from the Vanaantausta site (at the time a suspected burial site), Koskinen and Ignatius (1866, 68–69) note that the rounded bronze brooches (Figure 2) in particular looked different from their oval Scandinavian counterparts. In fact, the research questions formulated by Koskinen & Ignatius almost 160 years ago sound astonishingly familiar (1866, 68–69):

> '*It at least appears doubtless that the discovered objects are Finnish, not Scandinavian, and the following matter seems to confirm this. To obtain more detailed knowledge about the bronze components and their relations, we submitted some of the bronze fragments found to Mr. Docent Dr. J.J. Chydenius, under whose supervision Mr. F.W. Westerlund performed a chemical inspection. Some of the convex-brooches, Nrs 19–21 in this study, showed component concentrations in the following manner: copper (Cu)=87,15%, lead (Pb)=7,8%, tin (Sn)=2,55%, zinc (Zn)=2,25%, lost=0,97%.*'[1]

In a strikingly modern manner, they continue to discuss typological comparanda and even comparative chemical data derived from international publications, stating, for example, that 'the concentrations offer no similarity with the oldest bronzes from Scandinavia.' (Koskinen & Ignatius 1866, 69). The method used by Chydenius in this analysis almost certainly was gravimetric analysis,[2] although the method is not named or described in the publication. It also appears that the brooch from Vanaantausta did not survive the analysis (Ikäheimo 2010, 33).

The same methodology, gravimetric analysis, was applied again some decades later, when J.E. Ax (later Ailio) published a study titled *Bronze analysis* in 1896, for which he had carried out the chemical analysis himself.[3] Ax reported chemical data on 'bronze objects' found in various locations (Vöyri, Orismala, Äimälä, Noormarkku, Sodankylä), an arm-ring (2440:2; Cu=90%, Sn=9%), an axe (Cu=70%, Sn=10%, Pb=0.1%, Fe=0.2%, Zn=1%), a sword-handle (Cu=88%, Sn=10%, Pb=0.3%, Fe=2.8%), a chain fragment (no. 68; Cu=75%, Sn=1.8%, Pb= 0.3%, Fe=1.8%, Zn=15%), and a neck-ring fragment (no. 2001:4; Cu=70%, Sn=0.7%, Pb=0.1%, Fe=traces, Zn=27%)

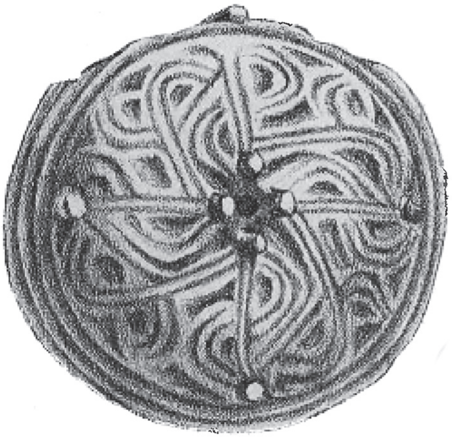

Figure 2. A drawing of an Iron Age copper-based brooch from Vanaantausta in Häme, one of the first archaeological artefacts in Finland to be subjected to chemical analysis (after Koskinen & Ignatius 1866).

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[1] Translated from Finnish by the author; in the original publication, Koskinen & Ignatius use the traditional Finnish term *vaski* for copper (1866, 69): '*Epäilemätöntä ainakin lienee, että löydetyt kalut ovat Suomalaisia, eikä Skandinavilaisia; sitäpä myöskin seuraava seikka näyttää vahvistavan. Saadaksemme pronssin seos-aineista ja niiden suhteista tarkemman tiedon, olemme jättäneet muutamia löydetyistä pronssi-kappaleista herra Docentille Tohtori J. J. Chydenius'elle, jonka johdon alla herra F. W. Westerlund on niista tehnyt kemiallisen tutkinnon. Muutama kupura soljista N.o 19–21, näin tutkittuna, osoitti seos-aineiden määrät seuraavalla tavalla: Vaskea (Cu)=87,15 prosenttia; Lyijyä (Pb)=7,8 prosenttia, Tinaa (Sn)=2,55 prosenttia, Sinkkiä (Zn)=2,25 prosenttia, Hukkaan mennyt 0,97 prosenttia.*'

[2] Pers. comm. S. Hornytzkyj.

[3] I wish to thank Seppo Hornytzkyj for bringing this information to my attention.

– although based on the reported concentrations, the latter two appear to be made of brass, an alloy of copper and zinc, rather than bronze. Ax also analysed one 'silver-find', which he identified as silver-coated bronze (Ax 1896, 38).

The gravimetric method was probably also applied in the studies conducted between the late 1910s and 1930s, focusing on finds from Finland as well as foreign artefacts: bronze axes from Siberia and East-Russia (Tomula 1917, Kampman, later Kenttämaa, 1928; 1934; see also Ikäheimo 2010, 33). In the 1928 study, Kampman reports the alloy compositions and weights of seven Viking Age metal weights, the majority of which he identifies as made of zinc and lead alloyed copper (Cu=67–84%, Pb=5–17%, Zn=2–16%, Fe<1%), and suggests that the Finnish region had adopted international scaling standards in the late Iron Age (Kampman 1928).

In the 1950s, new methodology was introduced in the analysis of copper-based alloys in Finnish archaeology, when Salmo (1953) and Meinander (1954, 61–62) probably used the spectrophotometry services of the Oy Keskuslaboratorio – Central laboratorium Ab (Ikäheimo 2010, 44). Meinander found that the axes he studied were made of bronze (Cu=88–96%) and copper alloyed with tin, except for one Laukaa Seima-type axe, made of copper (Cu=99.5%; Meinander 1954, 61–62; see also Huurre 1982). Salmo (1953, 11) also published the concentrations identified for a ca. 10th century CE copper-based bar found in Köyliö, Pajula, reporting a brass-like composition (Cu=79.2%, Zn=13%, Pb=7%, with traces of Ag and Bi).

By the 1980s, atomic emission and neutron activation methods also reached Finnish archaeology, having peaked internationally already during the earlier decades (e.g., Speakman & Glascock 2007). Matti Huurre (1982, 20, 30)[4] published an elemental analysis of a copper-based gouge (KM20850, ca. 200 BCE) found in Kukkosaari in Suomussalmi, showing that the artefact was made of copper (Cu=99.9%). A few years later, Hölttä and Rosenberg (1987; the latter being a Helsinki physics alumnus) reported on neutron activation analysis (NAA) procedures applied to copper-based axes and a chisel, but the archaeological value is limited by the lack of information on the objects, apart from a list of find locations. A similarly strong emphasis on methodological reporting can be seen in Rosenberg's analysis of historic silver coins from the National Museum collections (1985).

In the collaboration by Rosenberg and then University of Helsinki archaeology professor Ari Siiriäinen on the NAA analysis of two prehistoric bronze artefacts (a dagger and a sword from Bromarv and Luopioinen, respectively) (Siiriäinen 1984, appended by Rosenberg's report), both archaeological and methodological issues are covered, but are poorly integrated, probably because having only two analysed artefacts limited the archaeological interpretive value of the chemical data. From the late 1980s onwards, Leena Tomanterä (University of Helsinki alumna) developed research methods for archaeological metal artefacts at the National Museum artefact conservation laboratory, including X-ray fluorescence spectrometry (XRF), SEM-EDS analysis, and X-ray imaging of objects, focusing especially on Iron Age bronze and silver finds (e.g., Tomanterä 1990; 1991; Tomanterä 2008; Hornytzkyj & Tomanterä 2008; see also Moilanen 2010).

The first lead isotope (LI) analysis of copper-based archaeological artefacts in the Finnish context was published in 2019 in connection with the Levänluhta research project, which studied the Iron Age water burial in Isokyrö, in western Finland (Wessman *et al.* 2017; Holmqvist *et al.* 2019). In this study, the artefacts, mainly Merovingian period jewellery (Figure 3a), were sampled for multi-collector inductively coupled plasma mass spectrometry (ICP-MS) for geochemical and lead isotope (^{204}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb) characterisation. As traditionally in Finnish archaeology, it had been thought that the copper used in Bronze and Iron Age artefacts recov-

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[4] Huurre does not report the analytical method used at the Outokumpu Oy analytical laboratory, but according to Janne Ikäheimo's inquiries, atomic emission spectroscopy, AES, was used; see Huurre (1982, 30) and Ikäheimo (2010, 43) for the original data report.

ered in the Finnish region originated from ores located in the Scandinavian region. However, the results of the LI analysis clearly showed that neither domestic nor Scandinavian metals were used, but instead the copper was extracted from ores located in southern Europe (Holmqvist *et al.* 2019, Figure 3b–c). These findings are in line with recent results elsewhere in Scandinavia (Ling *et al.* 2013; 2014; Melheim *et al.* 2018) pointing towards the use of imported copper, linking northern Europe, and by extension the Finnish region, to the long-distance, pan-European copper transport network. It is possible that the foreign metals used in workshops in the Finnish region, for the manufacture of jewellery of domestic designs, were recycled metals that had arrived here already in the Bronze Age (Holmqvist *et al.* 2019; see also Bray *et al.* 2015).

The Levänluhta metal object analyses (Wessman *et al.* 2017; Holmqvist *et al.* 2019) also highlighted the issues related to non-invasive geochemical characterisation of archaeological, copper-based metals. Elemental concentrations acquired non-invasively from the object surfaces by portable XRF were compared to those measured from samples that were micro-drilled from the object cores and analysed via ICP-MS. Although the artefact surfaces appeared clean and relatively corrosion free in macroscopic inspection, there were, in some cases, drastic disparities between the non-invasive pXRF and invasive ICP-MS datasets, likely resulting from surface issues, e.g., patina-related enrichment of iron and lead values, that affected the pXRF data reliability, sometimes even preventing the alloy identification (Holmqvist *et al.* 2019).

Certain data issues introduced by the portable XRF instrumentation, e.g., in-air analysis and the spot-size (typically 8 mm for the current generation of instruments, see Holmqvist 2017), can be overcome by using a laboratory-based XRF equipped with a vacuumed sample chamber and adjustable spot-size to focus on corrosion-free spots on the artefact surface. This kind of laboratory instrumentation was applied non-invasively to investigate the chemical concentrations of the metal and gilding materials of a Viking period pendant found during the University of Helsinki archaeology field-school in Bartsgårda in 2020 (Holmqvist & Ilves 2022; Figure 4a). The pendant was made of brass, an alloy of copper and zinc, probably deliberately chosen for a gilded artefact for its golden hue, whereas the elevated mercury values in the gilding result from the amalgamation process, which used mercury to melt the gold on the brass surface (Holmqvist & Ilves 2022).

Although the case studies are not numerous, the University of Helsinki has an impressive research history of 160 years in archaeometallurgy, and Helsinki-affiliated scholars have been the leading national pioneers in adopting new scientific methods in the study of archaeological metal artefacts. We can see in the Finnish case studies that they followed and adopted the international developments in methodological applications. In the early cases, the studies are affected by reduced data accuracy and vastly invasive methodologies, sometimes even at the expense of the studied artefacts. The more recent case studies highlight how nowadays even non-invasive methods can be successfully applied to determine material characteristics of archaeological metals, and on the other hand very detailed provenance data can be attained via extremely small samples sizes, causing minimal damage to the archaeological finds (Figure 4b).

Ceramics

Similarly to archaeological metals, the most common research questions related to ceramics that are approached by scientific methods deal with the provenance and technology of the artefacts: where and how the ceramics were produced. However, organic residues, such as food remains sometimes surviving on ceramic surfaces, offer possibilities to also ask when the pots were made and used, and for what purpose - how were they used, and what was stored or prepared in them?
To my knowledge, the earliest techno-compositional trials of archaeological ceramic finds in Finland link to the Vanaantausta case discussed above (Koskinen & Ignatius 1866). Ceramic sherds found at the same site were subjected to (unspecified) heat-tests by J.J. Chydenius, who stated in his report that the pots were ‘dark-coloured, porous

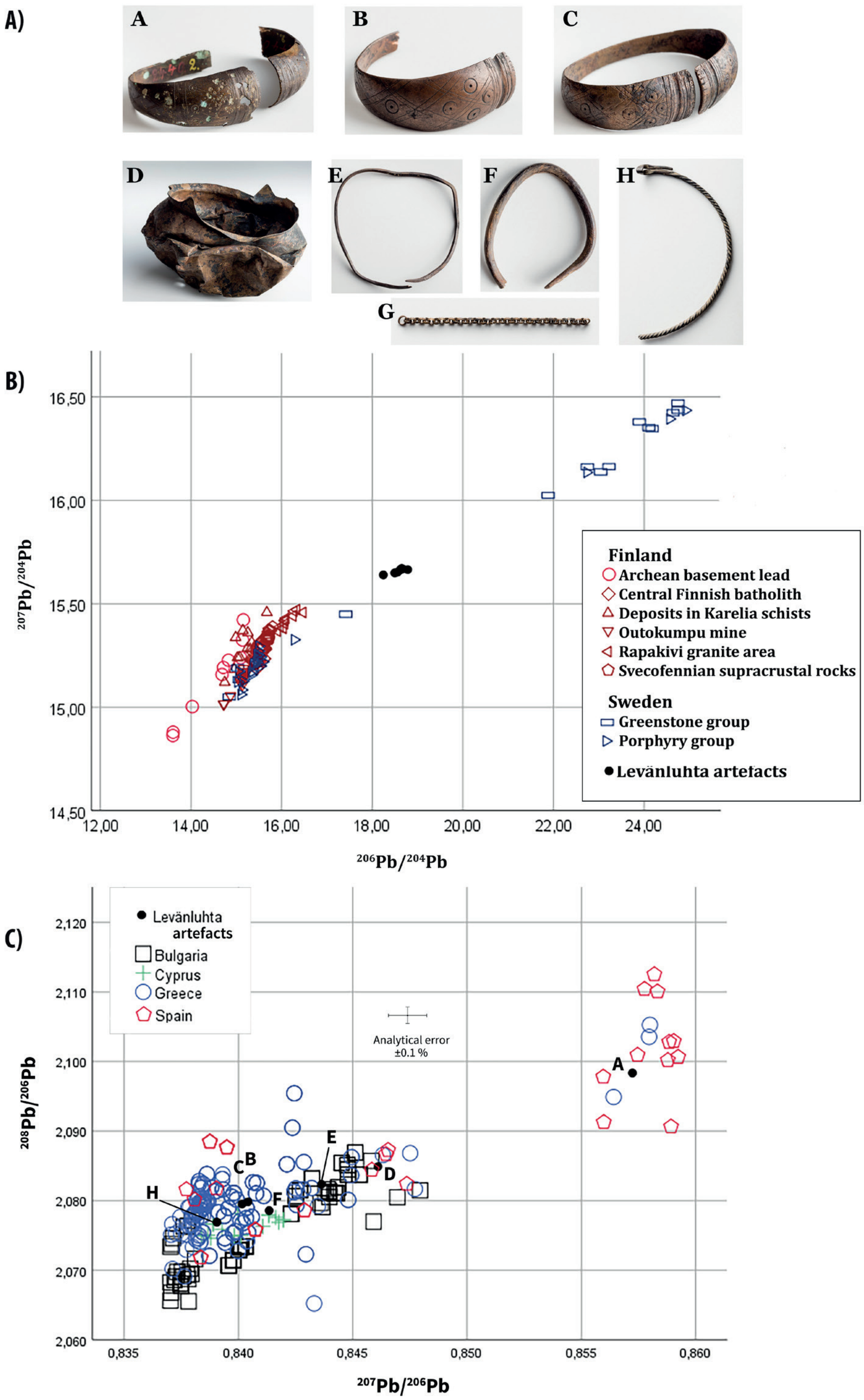

Figure 3. a) Copper-based artefacts, included in the first lead-isotope analysis of Finnish archaeological artefacts; b) lead-isotope ratios of the Levänluhta artefacts plotted together with ore data from Finland and Sweden and c) from southern Europe, indicating that the metal was extracted from southern European copper ores (after Holmqvist *et al.* 2019).

Figure 4 a) Decorative details of a gilded Viking Age brass pendant from the Åland Islands (after Holmqvist & Ilves 2022); b) after sampling a sword with a micro-drill to acquire pristine, corrosion-free metal for provenance analysis, the hole was not visible to the naked eye after conservation (E. Holmqvist).

and large grained', and that 'during heating, vapours deriving from an organic matter appeared, spreading a weird smell'. Further exposure to fire led the sherds to develop 'a light dark colour throughout, which undoubtedly derived from iron-oxidation' leading to the conclusion that 'the vessels were unfired, and not even exposed to fire' (Koskinen & Ignatius 1866, 124).[5]

After these early experiments, there were no significant tests on the ceramic analysis front before the late 1970s, when a team led by a University of Helsinki based geologist, Pentti Alhonen, conducted pioneering diatom and atomic absorption spectrometry (AAS) analyses on Comb Ware and Pit Ware sherds found near Kotka on the Finnish coast and on the Åland islands (Alhonen *et al.* 1980; Alhonen & Väkeväinen 1981; Figure 1). Alhonen *et al.* were able to identify the species of the diatoms (single celled algae, see Wilkinson *et al.* 2017, 269) in the archaeological ceramic material and found that the majority were freshwater species. Thus, they concluded that the clay used in the ceramic manufacture was formed in the Ancylus Lake (a fresh water phase of the Baltic, ca. 9500–8000 BP) – an admirable research achievement, although perhaps of more geological and methodological than archaeological value. The authors note themselves that these clay characteristics probably held no significance to the ancient potters, as 'it is quite evident that raw material for clay vessels most readily available in the environment of the stone age dwelling sites was taken' (Alhonen *et al.* 1980, 203). As for the determination of the geochemical properties of the clay vessels via AAS, they note that results were affected by the added tempers in the ceramic matrices (Alhonen *et al.* 1980, 203), an issue that today is commonly mitigated by integrating microstructural, mineralogical, and geochemical analysis in ceramic provenance studies (Bishop *et al.* 1982; Tite 1999; Arnold *et al.* 2001; Wilson & Pollard 2001).

Further advances in material sourcing were made in the 1990s, when Mika Lavento and Seppo Hornytzkyj (1995; 1996) succeeded in identifying and provenancing anthophyllite asbestos used as temper in Typical Comb Ware and Subneolithic Asbestos Tempered Ware in the

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[5] Translated by the author from the original, Koskinen & Ignatius (1866, 124): '*Aine on havaittu olevan tummanväristä, haperaa ja isorakeista. Kuumennettaessa, nousi siitä ensin jonkun eloperäisen aineen höyryjä, jotka syttyivät ja levittivät omituisen hajun. Kun kuumuutta lisättiin, saivat astian pirstat vähitellen läpitsensä heleän ruskean värin, joka epäilemättä tuli rauta-happeumasta. Nämä seikat osittavat, että astiat eivät ole olleet ollenkaan poltettuja, eikä edes tulen vaikutuksen alaisina.*'

Ancient Lake Saimaa region (in eastern Finland). Lavento and Hornytzkyj used a scanning electron microscope fitted with an energy dispersive spectrometer (SEM-EDS) to carry out geochemical analysis of the asbestos-fibres used as temper in the pots, and compared their composition to geological anthophyllite samples collected near the archaeological sites. The archaeological and geological samples showed a very similar composition, indicating that the archaeological communities in the Ancient Lake Saimaa region acquired asbestos from the regional deposits in metamorphosed ultramafic rocks throughout prehistory (Lavento & Hornytzkyj 1995; 1996). A more recent SEM-EDS study that examined prehistoric ceramic fabrics manufactured in the same region also confirmed the longevity and regionality in raw clay source exploitation (Oinonen *et al.* 2014; Pesonen 2021).

In the 2010s, major advances were made in the analysis of Finnish archaeological ceramics, when Cramp *et al.* (2014) published the first-ever lipid-analysis of archaeological ceramics found in the Finnish region. Cramp *et al.* investigated food residues in Neolithic Comb Ware (3900–3300 BCE) and Corded Ware Culture ceramics recovered on the Finnish coast, and found, based on diagnostic biomarker lipids and preserved fatty acid values (ϱ^{13}C), that there was a transition from aquatic resources to ruminant products that took place ca. 2500 BCE. These findings of milk residues on the Corded Ware pots confirmed Neolithic farming at the Finnish latitudes for the first time (Cramp *et al.* 2014).

It can be valuable to integrate provenance and food residue analyses, in order to determine whether the ceramics sampled for the lipid analyses are locally made or imports, and accordingly, whether the biomarkers identified in the food remains and the associated subsistence modes link to the find-location of the artefact, and not to the artefact's previous life somewhere else (Holmqvist *et al.* 2018; Pääkkönen *et al.* 2020). Archaeologists often assume that mundane ceramics are local products, and consumed locally, although artefact exchange was probably quite common in prehistoric times. People transported their personal ceramic items, and pots were probably also transported and exchanged for their social meanings (see Holmqvist 2021 and references). The exchange of Corded Ware pots was examined by sampling archaeological ceramics from 24 sites in today's Finland, Estonia, and Sweden, for geochemical provenance determination (Holmqvist *et al.* 2018; Holmqvist 2021). The geochemical comparison of the pottery samples was carried out by SEM-EDS and proton induced X-ray emission (PIXE), at the Inorganic Chemistry Laboratory and the Accelerator Laboratory at the University of Helsinki, respectively.

The results showed that the majority of the analysed pots geochemically grouped with other artefacts recovered from the same region, indicating regional pottery groups – pots produced in the areas in question – but there were also indications of pottery transport across the Baltic Sea, and 7.4 % of the finds were imported to their 'site of abandonment' (Figure 5). The real portion of imported pottery used by the studied communities was, however, probably higher, as imported ceramic material was also recycled as grog-temper in the manufacture of new pots (Holmqvist *et al.* 2018). The crushing of pots in the prehistoric recycling process reduces the archaeological visibility of these imports, as the majority of the material is only present as temper in the other artefacts of the assemblage (Holmqvist 2021).

Corded Ware ceramics were transported to the Finnish region especially from Estonia (Holmqvist *et al.* 2018), where agriculture was notably also adopted earlier than in the area of Finland (e.g., Kriiska 2009). The practice of recycling crushed pottery to temper new ones appears for the first-time in Finnish pottery manufacturing during the Corded Ware phase (Holmqvist *et al.* 2018 and references). In ethnographic studies, grog-temper often conveys different social meanings; pottery and grog can be associated with the owner's persona, soul, identity, kinship, and ancestry, issues that may explain why this temper-material was favoured by the migrating Corded Ware potters, to maintain material ties with their previous generations and homelands (see Holmqvist *et al.* 2018; Holmqvist 2021; and references therein).

It is important to understand the chronological context of the pottery related phenomena. Helsinki-based researchers have played a key role

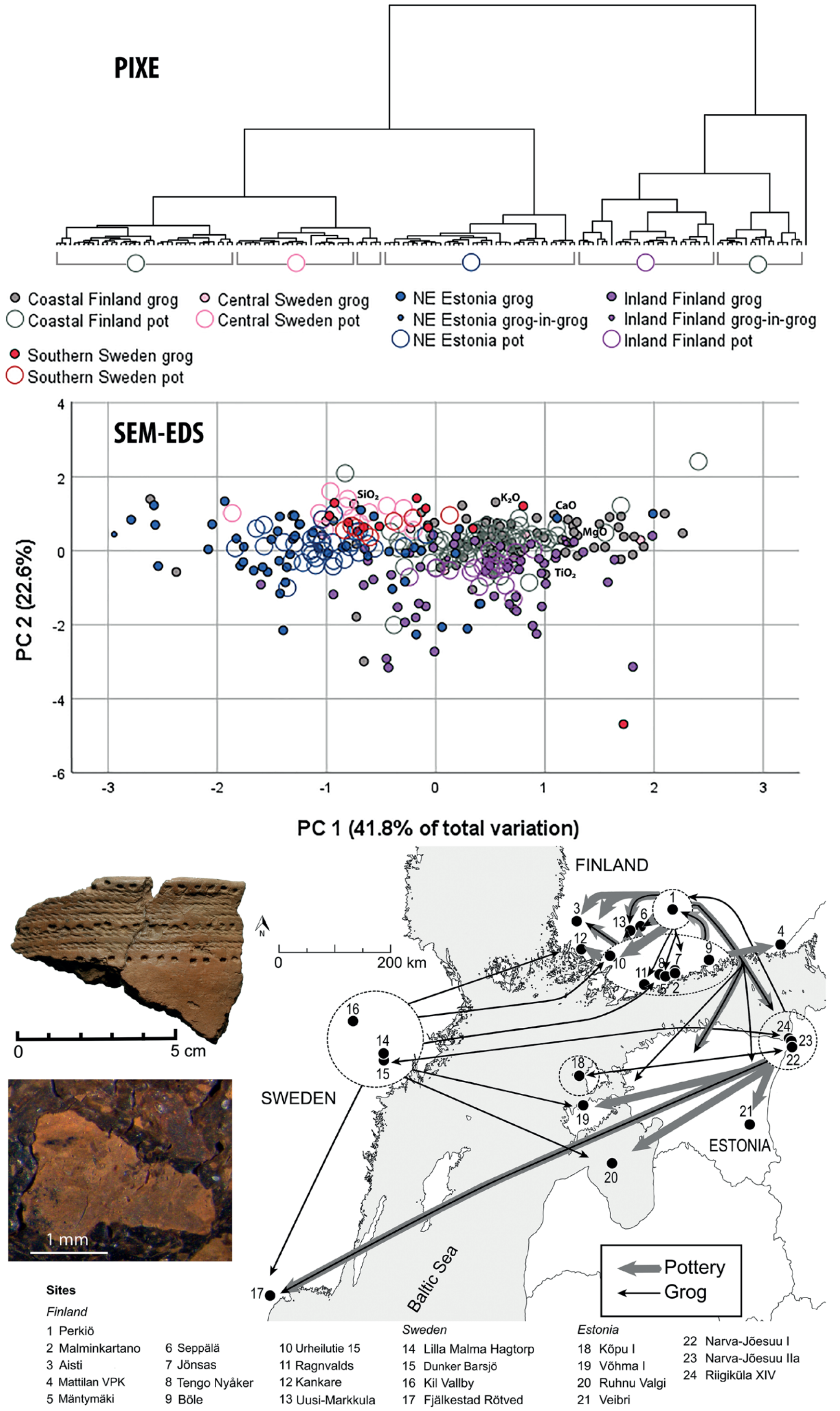

Figure 5. Exchange networks of Late Neolithic Corded Ware based on geochemical data of ceramic fabrics and grog-temper (after Holmqvist 2021).

in introducing the scientific dating of archaeological ceramics in Finnish archaeology, namely applying radiocarbon (^{14}C) dating (by accelerator mass spectrometry, AMS) of organic food crust or other use-phase related organic material found on the artefact surfaces (Lavento & Hornytzkyj 1995; Lavento 2001, 88–107; Piličiauskas *et al.* 2011; Cramp *et al.* 2014; Oinonen *et al.* 2014; Lavento & Patrushev 2015; Mökkönen & Nordqvist 2017; Holmqvist *et al.* 2018; Pesonen *et al.* 2019; Pääkkönen *et al.* 2020; Pesonen 2021). The Laboratory of Chronology, at the Department of Physics, the University of Helsinki, has been an important collaborator in advancing the scientific dating of archaeological materials in Finland.

After developments in portable instrument design in the early 2000s, non-invasive methods, especially portable X-ray fluorescence spectrometry (pXRF), have become very popular in the geochemical characterisation of archaeological materials, particularly obsidian (see, e.g., Tykot 2017; Kuzmin *et al.* 2020 and references), but also ceramics. Non-invasive methods such as pXRF can be useful when sampling for destructive analysis is not an option, for instance, when dealing with delicate fragments or intact objects. However, analytical results acquired via surface analysis of non-homogenised ceramic materials can be affected by surface irregularities, matrix effects (mineralogical composition, added tempers, porosity), surface layering (slip, paint, glaze), and contamination, factors that can seriously affect the reliability of the results (Holmqvist 2017 and references).

Over the past 40 years and more, the analysis of archaeological ceramics carried out at the University of Helsinki has demonstrated an ambitious adoption of new scientific methods. Helsinki affiliated scholars have welcomed international research developments and sought new ways to integrate novel methods into Finnish archaeology, either via developing research facilities at the University or in collaboration with other national and international research institutions. The case studies highlight the research potential of archaeological ceramics, going far beyond using pot sherds as tools for typology-based relative chronologies. Ceramics carry a plethora of evidence on past resources, technologies, diets, beliefs, contacts, and mobility, to name just a few possibilities.

Glass and glazes

In the Helsinki-based studies of archaeological glass and glazes, a major emphasis has been placed on methodological experiments, and especially the application of multi-method data to approach archaeological research aims: grouping archaeological finds based on their geochemical characteristics (how, or of what materials the glass was made), potentially indicative of different places of production.

Following methodological developments at the University of Helsinki science campuses in Kumpula and Viikki in the late 1980s and 1990s, Pirkko Kuisma-Kursula and her colleagues conducted chemical analysis on late medieval and early modern period archaeological glass artefacts, by combining data acquired by proton induced X-ray emission method (PIXE) and scanning electron microscope with energy dispersive spectrometry (SEM-EDS) (e.g., Kuisma-Kursula 1997; 2000; Kuisma-Kursula *et al.* 1997; Kuisma-Kursula & Räisänen 1999). In their numerous case studies, Kuisma-Kursula *et al.* found that integrating trace element data of the high-sensitivity PIXE method (for sourcing) with micro-imaging and light element measurements by SEM-EDS (for glass component identification) worked well for discriminating glass from different production areas, although pinpointing the actual source areas proved difficult.

For instance, over 50 glass vessel fragments from the Aboa Vetus museum were identified as a compositionally homogeneous corpus of potash-lime-silica glass, probably originating from a single source (Kuisma-Kursula 1997). Another case study compared 13th–14th century ecclesiastical window glass (the earliest in Finland) from Koroinen to glass vessels: the window glasses were lead-silica and wood ash-lead-silica glasses, and the vessels were made of potash-lime-silica, mixed alkali, soda-lime-silica and lead glass, all likely imports from central Europe (Kuisma-Kursula & Räisänen 1999). Furthermore, Kuisma-Kursula *et al.* (1997) tested statistical analysis on combined PIXE and SEM-EDS datasets of one hundred (13th–18th century) glass finds, collected from several central European sites, to discriminate mixed-alkali, potash-lime-silica and soda-lime-silica glass from different sources.

More recently, early glazing technologies applied on late medieval (c. 14th–17th century) redware pottery in the Gulf of Finland region (five sites in the Helsinki, Turku, and Tallinn areas) were examined together in a geochemical assessment of ceramic fabrics produced in those regions (Holmqvist *et al.* 2020). In this study, a compositional and micro-structural analysis of the glaze recipes was carried out by SEM-EDS, and on the ceramic fabrics by SEM-EDS and ED-XRF (Holmqvist *et al.* 2020). The results indicated that at least Tallinn and Turku served as manufacturing centres for the redware pots, and that the high-lead (PbO <67%, sometimes tin-opacified) glazes were applied on the pots (made of non-calcareous ceramic recipes) before firing, either as lead-oxide-plus-sand mixture or as lead-oxide itself. Cracks, bubbles, and undiffused mineral grains in the glaze microstructures also demonstrate that the early glazing technologies sometimes suffered from insufficient firing times and temperatures (Holmqvist *et al.* 2020; Figure 6).

The case studies demonstrate that there has been research interest, methodological know-how, and research instruments available for the study of archaeological glass finds in Helsinki already for decades. The published datasets offer valuable comparable data for future studies, especially considering the extensive geographical (from Finland to central Europe) and chronological (several centuries) coverage of the analysed glass finds. As it stands, new glass analysis projects are emerging in Helsinki. New endeavours are aided by the development of less invasive methods, better facilitating the analysis of small-sized glass fragments in the Finnish archaeological collections. Methodological developments will probably also lead to more precise source determinations of archaeological glass in the future.

Lithics

Although there has been a strong research interest in prehistoric lithic artefact technologies among University of Helsinki affiliated scholars (see, e.g., Rankama 2011; Tallavaara *et al.* 2010; Manninen 2016; and references), the studies that have actually conducted scientific (e.g., petrographic or geochemical) material characterisation of archaeological lithic artefacts or the potential parent rock materials are not numerous.

However, we can see a research history expanding over the past 100 years, with the earliest studies dating to the late 1920s. Geologist Aarne Laitakari published his work (in collaboration with Prof. Aarne Eskola) on late Neolithic battle axes (and the potential source rocks) in the National Museum collections in 1928, using

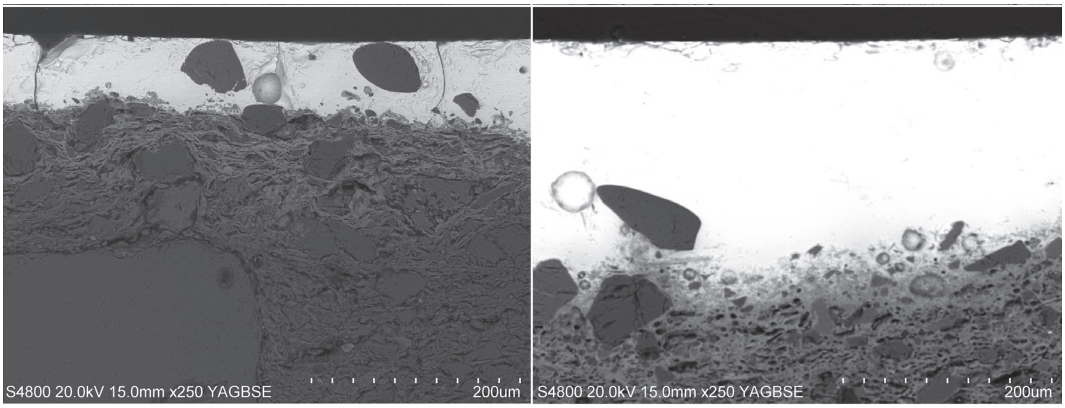

Figure 6. Manufacture faults (bubbles, cracks, and undiffused mineral grains) in medieval redware glazes under a scanning electron microscope (after Holmqvist *et al.* 2020).

microscopic (petrographic thin section) analysis combined with macroscopic inspections (via magnifying glass) (Laitakari 1928, see also Soikkeli 1912). Laitakari macroscopically determined the raw material of ca. 500 objects, and some of the axes were sampled for thin-section analysis; he also examined the correlation between the lithic material and the different battle-axe types defined by Europaeus (1922; later Äyräpää). As a result, Laitakari concluded that most of the 'Finnish'-type axes were made of olivine diabase, which probably originated from the Satakunta diabase outcrop in western Finland (Laitakari 1928).

Laitakari's provenance hypothesis still lives on, although it has not been confirmed by direct archaeological evidence of a quarry or manufacture site in Satakunta. However, recent research developments, after a gap of almost a century in Finnish battle-axe research, may provide further light on this matter (Holmqvist & Nordqvist 2021). In Finland, the Corded Ware Culture battle-axes are often found intact, which makes application of invasive methods in the study of their material characteristics difficult. Modern non-invasive methods allow fast analysis of large numbers of artefacts, and portable instruments can be taken to foreign museum collections to acquire data on comparative materials, offering research possibilities that have not been available earlier (Holmqvist & Nordqvist 2021; Figure 7a).

In addition to the persistent questions of where and how artefacts were produced – the most frequently asked questions in scientific artefact studies in Helsinki and worldwide – there is also a great value in inquiring for what purpose. The questions of how lithic artefacts were used also links to the social meaning of their exchange and circulation. In a recent study by Ahola *et al.* (2022), geochemical provenance determinations and microscopic use-ware analysis of slate-rings were combined to examine the gift-giving systems of the 4th millennium BCE hunter-gatherer groups, and intentional fragmentation and the ways the artefacts were worn as personal ornaments (Figure 7b). The study also confirmed that the raw material source of the slate-rings found in the Finnish region is located hundreds of kilometres away in the Lake Onega metatuff region

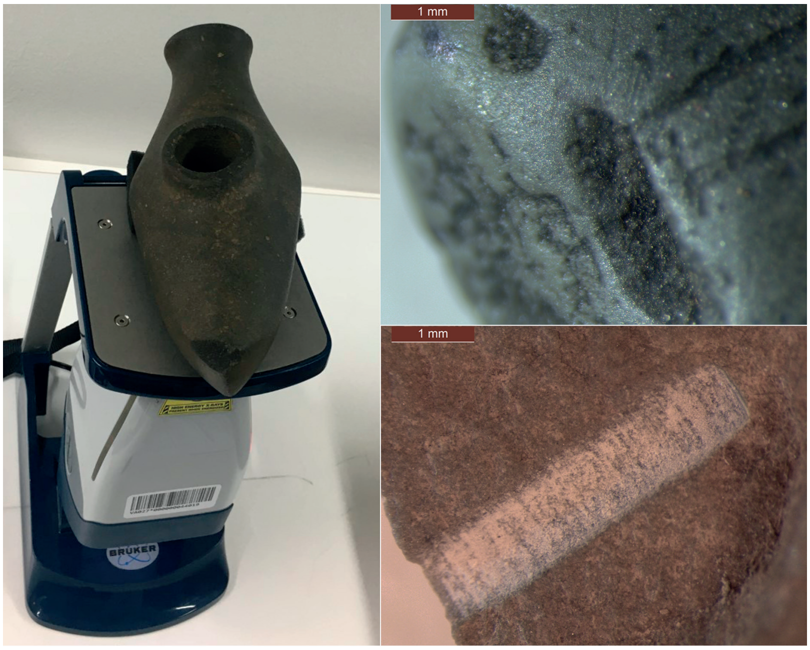

Figure 7. a) Non-invasive geochemical analysis of a Neolithic battle-axe using a portable XRF at the Finnish Heritage Agency premises (E. Holmqvist); b) manufacture-marks on slate-rings under a stereomicroscope (after Ahola *et al.* 2022).

(Ahola *et al*. 2022). Future studies of archaeological lithics will hopefully further extend the research questions from the traditional material identification focus and source-narrative to also consider the social and societal meanings of the artefacts and the circulation of materials.

Concluding remarks

Over the past century and more, the archaeological community at the University of Helsinki has followed the global trends of archaeological artefact studies and introduced inter-disciplinary methodologies in their research. Today, user-friendly, cost-efficient, and increasingly artefact-preserving analytical instruments (e.g., microscopes, portable XRFs) are available to researchers and students. As a result, archaeological artefact studies have irreversibly transformed from typo-chronological classifications into ambitiously cross-disciplinary endeavours, asking more complex research questions and formulating new interpretive narratives.

Archaeological science (= archaeology + science) is based on collaboration by definition. Thus, research that builds on data and knowledge-sharing between scholars from different backgrounds and expertise leads to the best research outcomes, as is demonstrated by the examples discussed above. We have access to research facilities equipped with versatile, state-of-the-art methodological arsenals in the Archaeology Laboratory, other University of Helsinki departments and campuses, and external and international research institutes. During the preparation of this article in 2023, the University of Helsinki Archaeological Laboratory has just moved to its brand-new premises – archaeological science in Helsinki is prospering and finding new ways to increase our understanding of the past. The Archaeology curriculum at the University of Helsinki offers specialist courses on applying scientific methods not only to artefacts, but also to the full range of archaeological materials and remains, both during fieldwork and in the laboratory.

Still, in practice, the pursuit of the archaeological science of objects can be crippled by analytical costs and difficulty in accessing methods and materials. Invasive sampling is still today often inevitable in order to attain the best analytical results, for example to access pristine metal below the surface corrosion on a metal artefact. In addition, numerous artefacts need to be sampled to secure representable sampling. Furthermore, gaining access to foreign collections for sampling can be crucial to solving archaeological questions of material phenomena such as mobility – modern political borders did not apply in prehistory – but securing permits to sample foreign materials can be very difficult. These issues can impact the research design, limit the numbers of analysed artefacts, and impose restrictions on the regional coverage of comparative studies. However, there are ways to mitigate these challenges, primarily through sampling strategy design, developing minimized sampling, increasing the application of non-invasive methods, and most importantly by building national and international research collaboration to facilitate access to research materials and laboratories.

It is our collective responsibility as a research community to commit to responsible research of archaeological artefacts. We need to plan our research and sampling in a manner that preserves materials for future generations to study. However, we also need to continue to experiment in our analytical work, advance method development, challenge existing perceptions, and seek to reach the research potential that we cannot even imagine today – that is how we can secure another 160 years, and hopefully much more, of archaeological science in Helsinki and worldwide.

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